

III

The Interdependence of Water and Energy in the U.S.-Mexican Border Region

David A. Rohy

ABSTRACT

Water and energy are two extremely important resources for the personal, economic, and environmental well-being of U.S.-Mexican border region residents. Neither resource is abundant nor independent of the other in this region. Continued economic growth requires both resources to be readily available and affordably priced with minimal environmental impact. Strong links exist between the two. For example, new technologies exist that greatly enhance potable water quality but require large inputs of electricity. In a similar manner, new highly efficient power plants can consume vast quantities of water in their cooling towers.

Wastewater is a disposal problem, a potential potable water resource, and an energy sink. New technologies to reclaim wastewater are based on electrotechnologies. This chapter focuses on the California-Mexico border region and includes recommendations for employment of new technologies throughout the border region.

La Interdependencia del Agua y de la Energía en la Región Fronteriza de México-Estados Unidos

David A. Rohy

El agua y la energía son dos recursos extremadamente críticos para el bienestar personal, económico y ambiental de los habitantes de la región fronteriza de México-Estados Unidos. Ninguno de estos recursos es abundante o independiente del otro en esta región. El crecimiento económico continuo requiere que ambos recursos sean de fácil disponibilidad y a precios accesibles con un impacto ambiental mínimo. Existen fuertes vínculos entre ambos recursos. Por ejemplo, existen nuevas tecnologías que aumentan considerablemente la calidad del agua potable, pero que requieren de una gran provisión de electricidad. De manera similar, las plantas nuevas de energía altamente eficientes pueden consumir vastas cantidades de agua en las torres de enfriamiento. Las aguas residuales presentan un problema de disposición, son una fuente potencial de agua potable y son un pozo de energía. Las nuevas tecnologías para sanear las aguas residuales están basadas en electrotecnologías. El autor se enfoca en la región de la frontera California-México e incluye recomendaciones para el empleo de las nuevas tecnologías a lo largo de la región fronteriza.

CRITICAL ISSUES

Some 6% of all of the electricity used in California supplies potable water and processes wastewater (Anderson 1999). This is twice the United States' national average. Most of the border region would be uninhabitable desert without the energy-intensive and costly water systems put into place over the past century. And without modern technology the wastewater generated by the large populations in the

border region would create an environmental disaster. Growth in population and economic activity requires additional water, wastewater, and energy facilities. The interdependence of these infrastructure needs cannot be ignored.

More stringent human water standards and more stringent environmental standards demand that both potable water and wastewater streams have higher purity and at the same time minimize or eliminate the use of chemical disinfectants and flocculants. Proper disposal of the greater quantity of impurities removed from the water is an additional problem. The technologies to achieve these goals are becoming available but require significantly more electrical energy than current practice. Similarly, high-efficiency power plants require large quantities of water to achieve maximum efficiency. The water is primarily used to condense spent steam used in the steam (Rankine) bottoming cycle. This water evaporates into the environment absorbing its latent heat of vaporization from the condenser and is lost to the cycle. Because of the strong links, some have anticipated the convergence of energy and water utility companies (Duque 1999). The public sector should also consider the convergence of the regulation and permitting activities of these two essential resources.

On top of it all, the population in the border region has seen high rates of growth, which are expected to continue throughout the border region.

Potable Water Use

In 1996, the San Diego-Tijuana region consumed 683,000 acre-feet (af) of water for residential, commercial, industrial, and agricultural uses (Ganster 2000). (An acre-foot is equal to 842 million cubic meters, or approximately 326,000 gallons. One acre-foot of water covers one acre of land in water one foot deep). Much of this water was imported into the region from the Colorado River and northern California. Tijuana and Rosarito Beach received additional water from the Guadalupe River. In 1996, 90% of the regional water was used in the San Diego area and 10% in the Tijuana area. In 2000 San Diego County consumed 695,000af of water. Experts project the use of 848,000af of water in the border region in the year 2010.

With more than 1 million new residents anticipated to arrive in the county, San Diego alone expects to use 813,000af of water in the year 2020. Few new sources have been identified to supply additional water.

Potable Water Supply for the Border Region

The Colorado River is the major source of water for the California-Mexico border region. Seven western states in the United States—including Arizona and New Mexico—and Mexico share that water under a 1922 agreement. Historically, California has been allowed to exceed its limit. But as the neighboring states grow and require more water, California's "take" of Colorado River water will be reduced to 4.4 million acre-feet (MAF) from 5.25MAF by 2015 (Conaughton 2001). This is a 16% reduction, some of which will be borne by the San Diego region. Possible new sources of water are the purchase of "excess" agricultural water from the Imperial Valley and the increased use of desalinated brackish groundwater, treated wastewater, and seawater desalination. Incidentally, energy requirements increase as one moves from the treatment of brackish water to the treatment of wastewater to seawater desalination.

The San Diego County Water Authority has reached an agreement with the Imperial Irrigation District that will allow annual transfers of up to 100,000af of water conserved by agricultural users in the Imperial Valley for up to 75 years. The water authority has been investigating methods of transporting this water to the San Diego area.

Mexico is entitled to between 1.5MAF and 1.7MAF of Colorado River water per year. Mexican officials (San Diego County Water Authority web site 1999) have estimated that the need for water in the Tecate-Tijuana-Rosarito area will increase 70% between 1998 and 2020.

The existing Acueducto Río Colorado Tijuana is too small to deliver the water needed by the growing Tijuana and Rosarito areas. In October 1999 Mexican and American authorities at the International Boundary and Water Commission (IBWC) signed an agreement to collaborate on a \$3 million feasibility study of potential binational aqueduct options that could bring Colorado River

water to the Tijuana-Rosarito Beach and San Diego areas (San Diego County Water Authority press release 1999). The San Diego County Water Authority and the Comisión Nacional del Agua (CNA) are the lead agencies in the United States and Mexico, respectively. The study was completed in 2002. Each country would transport water it owns in the future aqueduct.

Should a new aqueduct be built, it will require several pumping stations, each requiring significant electrical service. The electrical load can be reduced with the use of recently developed high-efficiency motors. Variable speed electric motors are also being incorporated into water systems to lower the energy requirements when full flow is not required. The use of energy recovery generators on the downward sections of the water route will produce additional energy to use or sell.

There are many other critical issues surrounding potable water:

- The San Diego-Tijuana region is growing rapidly and will require 24% more water by 2010 than it used in 1996
- The sources of and delivery aqueducts for the new water have not been fully identified and existing supplies may be scaled back
- Pumping existing water requires considerable electrical energy, and that may require additional pumping and treatment facilities by 2010
- New electrical generating facilities may be needed for new pumping and treatment facilities
- Natural gas for generating facilities currently is limited
- Prices for natural gas are increasing
- Colorado River water is becoming increasingly saline, and it will require an energy-intensive desalination process to bring river water into compliance with United States' water standards in the future

Wastewater Issues in the Border Region

A large fraction of the used water in the region is disposed of in sewer and wastewater systems. These streams of wastewater must be pumped to treatment facilities; processed to remove solids, bacteria, and other substances; and then pumped again to the point of release

or reuse. This water purification process—which involves aerating, stirring, processing for solids, and pumping—uses large amounts of energy, to the tune of 1,400 kilowatt hours (kWh) to 1,800kWh per million gallons. About 50% of that energy is used for aeration, 30% for solids processing, and 15% for pumping. Other processes consume the remaining 5%. New technologies such as ultraviolet (UV) radiation, ozone treatment, improved filtration, and low-pressure reverse osmosis will increase the energy use per gallon of wastewater treated.

Several new electrotechnologies are being developed and applied to treat water. Electrotechnologies are desirable because they lessen or eliminate the need to add chemicals like chlorine to the water. As these new technologies are applied, the environment will be healthier but the treatment of potable and wastewater will use more electrical energy. With the increases in the price of electricity in California and throughout the west, wastewater plant operators cannot ignore the cost of energy. In at least one wastewater facility in the border region, the electricity bill has more than doubled to \$250,000 per month from the \$110,000 per month it paid before California's energy crisis began.

Critical wastewater issues mirror those of potable water: The region is growing, flows of wastewater will increase with population and economic growth, considerable electrical energy is used to process the wastewater, new water treatment technologies require more electric energy, new power plants may need to be constructed to provide power to move and treat the waste, and bills for electricity at wastewater treatment facilities are escalating rapidly.

Economic Growth in the Region

The San Diego-Tijuana border region has seen high economic growth rates for the past decade. The confluence of trained human resources in this region and its presence in the Pacific Rim market area promise continued economic growth. But the two limiting factors for economic growth are water and power. There is no large-scale, indigenous fresh water resource in the border region. Except for a small amount of renewable energy, almost all energy products are imported. Economic growth cannot continue without adequate

water and energy. Current limited supplies of both resources are close to stalling growth.

A healthy economy is associated with people who care about their environment. Reasonably affluent people have the resources to protect the environment and to restore that which has been abused. A limited or stagnant economy often leads to a lower quality of life with less attention paid to the environment.

Most engineering and financial organizations require only small amounts of water and power. Manufacturing activities associated with the engineering functions are more water- and energy-intensive. Certain high-tech industries consume large amounts of power for their computer systems, while others use water to cool manufacturing equipment. All these activities occur throughout the border region. In addition, each employee has a residence that consumes both water and power. These are all components of economic growth for the border region.

Air conditioning is an important aspect of economic growth. Due to earlier development along the ocean, most new construction is in hot, dry, inland areas. Occupants of these buildings demand air conditioning. There are two basic methods of providing this: evaporation of water or vapor-compression cycle machines. Evaporating water removes heat from an area and provides useful and economic cooling in the dry climate typical of the border. Since the water used in this cooling scheme must be relatively free of minerals, potable water is the best source for this purpose. Unfortunately, this technology, if widely deployed, would further strain the region's potable water supply. Electrically driven vapor compression cooling is the primary alternative to evaporative cooling. The vapor compression refrigeration device is driven by electricity but consumes no water. However, most electric power generating plants used to power the vapor compression machines do consume large quantities of water. Including the water used in generating electricity, vapor compression refrigeration uses less water than evaporative cooling.

Water Resources in the Region

The San Diego-Tijuana region has a highly diverse geography, numerous species of plants and animals, abundant sunshine, abun-

dant seawater, but almost no indigenous sources of fresh water. The average rainfall at San Diego International Airport is less than 10 inches (25cm) per year. Mountainous regions to the east receive greater amounts of rain, while areas south, such as Tijuana, typically receive less rainfall.

The San Diego-Tijuana region has numerous water storage reservoirs. However, these man-made lakes are used for water system balancing, not to capture significant amounts of runoff from rains. Tijuana's water is stored in Rodríguez Reservoir. Water in that reservoir comes from the Colorado River and some winter flow from the Rio de Las Palmas. San Diego has numerous small reservoirs including Sweetwater, Barrett, Morena, Lake Murray, among others. To prepare for future water shortages caused by drought, earthquakes or other disasters, the San Diego County Water Authority is constructing the Olivenhain Emergency Storage Project. The dam is about 300 feet high and the reservoir will store more than 90,100af of water. The reservoir is scheduled to be complete in 2003 but it will take several years to fill to capacity. It is likely that other facilities of this type will be required to protect the growing population and business base of the border region.

Under California law, water districts like San Diego's can produce power for their own use or for sale to local governmental agencies and electricity can be produced by hydro facilities or by combustion turbines. Water agencies can produce electricity needed for water purification in their own facilities.

These facilities, if built in the proper terrain, can also be used as "pumped storage" for the electrical system. Pumped storage is a method of balancing the electrical system during a 24-hour period by "storing" electricity produced during the night and "replaying" it during the daytime. In this scheme, water is pumped from a lower reservoir to a higher reservoir during the night hours when electrical power is both plentiful and inexpensive. The water is released to the lower reservoir through generators during the high demand hours of the day, producing additional electricity for the region. No water is consumed in this process, no additional fuel is consumed for generation, no new electricity is produced, although some energy is lost due to inefficiencies in pumping and generating equipment. Pumped storage facilities have been built and are currently

operating in other parts of the world. While pumped storage facilities have been proposed for the San Diego mountain region, none have proceeded into the licensing phase. This confluence of water storage and electrical energy balancing can be beneficial to a region. A drawback of such a system is the extensive use of land.

Orange County, California, currently relies on a local aquifer for part of its water balancing system. Maintaining the aquifer requires the addition of 300,000af per year. By 2020 the water authority will have to add an additional 150,000af per year into the aquifer both to meet demands for the water and to maintain a supply for drought years. To accomplish this mission, authorities have proposed an ambitious project—the Groundwater Replenishment System—that will produce a reliable supply of high-quality, low-salinity water (Mills 1999). By 2020 this system will reclaim 100,000af of wastewater per year. The reclaimed water will be pumped upstream to settling basins where it will re-enter the aquifer. The project will use the latest membrane processes, including microfiltration and reverse osmosis, and will be applied after conventional water treatment. Orange County estimates water produced by this process will require 1,470kWh/af. This is a marked reduction from the 3,200kWh required to import northern California water or the 2,200kWh required for Colorado River water. Other border municipalities could implement similar technology to increase their supplies of potable water.

Energy Resources in the Region

The border region has few traditional energy resources. While oil, natural gas, and coal have been developed within a reasonable distance, there is little commercial development in or near the region. Few electrical generating facilities were located in or near the region until recently. Recent changes in the western border region include the repowering of the Rosarito power station with modern gas-fired, combined-cycle equipment. This change alone will significantly improve the air quality in Northern Baja California, especially in Rosarito. Several other new power plants are being proposed including one in Otay Mesa (500 megawatts [MW]) near San Diego. Two plants are under construction in Mexicali (750MW and 300MW). A

new natural gas transmission pipe to supply the fuel to these plants is being built.

Non-traditional or renewable resources are relatively abundant in the border region, although they are thinly deployed at this time. For example, the entire border region has abundant sunlight. Due to generally cloudless skies, photovoltaic and solar water heating systems have greater economic payback in this region than in almost any area of the United States. As well, geothermal resources are abundant in the California-Mexico border region. While the quality of the resource (temperature and mineral content) is not as high as some would like, it can be economically developed and managed. Additional geothermal generators with the combined capacity of several hundred megawatts can be added without imperiling the vitality of the resource. Wind generators, which produce electricity at a competitive price of between \$0.04 and \$0.05 per kilowatt-hour, can be installed in selected areas of the border. However, some people object to the noise and visual "pollution" of wind generators.

Manufacturing facilities and offices along the border generate significant quantities of waste paper and wood. While most is recycled into new paper and cardboard, some of the waste can be used as fuel in electrical generating plants. Combustible waste from border agriculture and industry, called biomass, can be burned to produce electricity, if properly sorted. Collection and preparation costs of the fuel result in relatively high-priced electricity.

Methane from wastewater treatment plants is burned as fuel in limited instances in the border region. Greater use of this relatively clean fuel should be encouraged. Used automotive tires, shipping pallets, and other waste is often used as fuel in small facilities today, but should be discouraged until new technologies are developed to reduce the extensive amounts of air pollutants generated.

PRESERVING NATURAL RESOURCES IN THE REGION

The border region has one of the more fragile ecosystems in the world. Abundant flora and fauna exist in a delicate balance with nature due to high summer temperatures, cold winter temperatures in some areas, and generally dry conditions. The low rainfall creates

conditions in which the soil often lacks nutrients and materials needed to retain moisture. While plants and animals have adapted to these conditions, human intervention can quickly upset the balance. The impact of water development on the environment is well-documented. Energy development can have similar effects on the natural resources of the border region.

While every human action has an effect on the environment, some are more significant. Geothermal power production, with proper controls, can be beneficial. However if the brine is not re-injected into the ground and is instead spilled onto the ground, the ground and water resources are fouled. This results in catastrophic loss of plant and animal life. In a like manner, the development of coal bed methane can result in the loss of water supplies and the pollution of groundwater. Overall, the development of any water or energy resources must balance the needs of humans with those of the environment.

Electrotechnologies for Water Purification

The California Energy Commission (CEC) has estimated that total energy used to pump and treat water in California exceeds 15,000 gigawatt hours (GWh) per year, or at least 6.5% of the total electricity used in the state per year.

Potable Water Transportation and Treatment

Extensive canals and pumping facilities transport potable water to the California-Mexico border region. Pumping water from the Colorado River through pipes and canals is energy intensive. The Orange County Water District estimates 2,240kWh of electricity is required to move one acre-foot of water from the Colorado River to the Los Angeles Basin, and 3,240kWh is required to move the same quantity of water from northern California via the State Water Project (SWP) to Los Angeles.

The SWP delivers approximately 3MAF of water per year. Some 70% of this water is destined for cities and 30% for agricultural purposes. The SWP generates, buys, and sells electricity to balance

its energy needs throughout the state. In 1996 the SWP paid \$192 million for its net energy needs. It has a Capacity Exchange Agreement with Southern California Edison (SCE) under which the SWP supplies up to 412,500 megawatt hours (MWh) of energy to SCE during peak hours and Edison returns 110% of the energy received during mid- and off-peak hours.

Combining the energy load of the SWP (5.7 million MWh) with that of the California Department of Water Resources (4.6 million MWh) results in a total electricity load of 10.3 million MWh for delivering water (California Department of Water Resources 2001).

Approximately 1,100MW of installed electrical generating capacity is currently needed to move water from its source to California towns. For perspective, that is about the output of one large nuclear reactor. Pumping the additional water required in the San Diego-Tijuana border region by 2010 will require another 50MW of capacity. This additional requirement for power can be met with one medium-sized gas-turbine power generator burning natural gas. Unfortunately the region has extremely limited natural gas pipeline capacity and the price for natural gas has escalated recently.

Potable Water Technology

Potable water is treated with various processes, including flocculation and chlorine. These conventional processes consume about 30kWh/af. It is likely that the use of chlorine for water purification will be either limited or eliminated entirely in the future. To replace this method of purification, water scientists are developing the use of UV light radiation and ozone gas to eliminate harmful bacteria in water. Each of these two methods has had successful tests and is in the deployment stage. Each method is considerably more energy intensive than the use of chlorine. Other new processes are reverse osmosis and microfiltration. There are also two advanced filtration technologies: nanofiltration and ultrafiltration.

UV light is used to inactivate viruses and bacteria by causing a photochemical breakdown of the cellular nucleic acids within the target organism. This prevents the DNA within that organism from replicating. UV treatment is especially effective against *Giardia* and *Cryptosporidium*. This technology is used for the treatment of both

potable and wastewater. Several facilities employing this technology are in routine operation. However, UV systems use an additional 5kWh/af of water treated. Considerable research is underway to apply UV light in the most complete and economical manner. Energy reduction and longer lamp life are two goals of that research.

Ozone treatment of water improves disinfection, reduces or eliminates the formation of harmful byproducts of chlorine, enhances the coagulation process, and improves the color, taste, and odor of water. There are about 100 ozone treatment facilities in use in the United States and about 50 more are scheduled for construction. These facilities typically use 72kWh/af. Most of the electricity is used for the ozone generator. All ozone treatment devices include a subsystem to destroy excess ozone to prevent release into the air.

Reverse osmosis is a water purification technique that forces water through thin membranes. Until recently this process employed energy-intensive high pressure, but new membrane technology has reduced the pressure required. Nonetheless, energy costs are still high, ranging from \$0.55 to \$0.65 per 1,000 gallons. Some have estimated the cost to treat wastewater is as high as \$3.75 per 1,000 gallons. Cost numbers vary greatly due to plant capital costs and use factors. This great variation in numbers is also indicative of a changing technology base.

In a 1995 test, the city of El Paso, Texas, demonstrated reverse osmosis that reduced the salinity of groundwater and Rio Grande water to less than 100 milligrams per liter (mg/l) from levels as high as 2,700mg/l. Reverse osmosis can be an effective method of reducing total dissolved solids common in high concentrations in aquifers in this region. The city of Harlingen, Texas, treats its wastewater for solids and then runs it through a reverse osmosis unit before selling the water to a cotton washing and dyeing facility. The facility has been expanded to a capacity of 4 million gallons of water per day.

Other membrane systems have been developed for desalinization. Torray Engineering Co. of Japan is working on a multiple-filter reverse osmosis arrangement for seawater desalinization (*Nikkei Weekly* 1997). The system uses pressures of up to 990 atmospheres to recover up to 60% of the original seawater as fresh water. The estimated cost is \$6.50 per 1,000 gallons. However, one of the problems associated with seawater desalinization is the disposal of the concentrated brine that remains after the fresh water has been extract-

ed. In many cases it is too concentrated to be returned safely to its source.

Wastewater Transportation and Treatment Technology

Wastewater treatment plants using modern technologies are producing relatively high-quality water that can be used for many purposes, including landscaping, industrial cooling, and power plant cooling. Wastewater facilities use many of the technologies discussed above. The international wastewater treatment plant at San Ysidro, California, is producing 26 million gallons of treated water per day. A Mexican plant in the border region treats 20 million gallons of wastewater per day. San Diego has built a modern wastewater reclamation facility that can handle 25 million gallons per day. However, according to a recent report, it was only selling 3% of the water it produced (Baliant 1999); 7% went to facility operations and landscaping and the remaining 90% was returned to the wastewater system to be retreated by another wastewater treatment plant before being dumped into the ocean. The cost to produce the reclaimed water in the San Diego facility is estimated to be between \$310 and \$990 per acre-foot depending on how grant and incentive monies are allocated. The cost of Colorado River water in 1999 was \$434/af. Obviously, governments must find more buyers for high-quality reclaimed water.

ELECTRIC GENERATION WATER NEEDS AND IMPACTS BY GENERATION TECHNOLOGY

Water is a constraining factor for energy development. The Electric Power Research Institute projects inadequate water supplies will limit energy development nationally by 2038. Specific areas could realize that limit sooner.

Gas Turbine Combined-Cycle Generators

Electricity generation can consume large quantities of water. Most new electricity generation plants use gas turbine, combined-cycle (GTCC) technology. This technology combines a modern gas turbine engine with a conventional steam generator. The exhaust heat from the gas turbine provides the thermal energy to create steam for the steam generator. In some applications, additional fuel is burned in the gas turbine exhaust stream to further increase the steam temperature, thereby increasing power output and efficiency. The gas turbine engine itself requires essentially no water to operate as all major components are air-cooled. Almost all the unused energy (waste heat) exits the engine in the exhaust stream. This unused energy flows through a tube bundle called a "heat recovery steam generator" (HRSG). The steam produced by the HRSG turns a steam turbine that in turn drives an electrical generator. Steam turbines require highly purified water to make steam. Therefore, the steam used in the expansion process must be recovered and reused. The steam is returned to the liquid state in another heat exchanger called a condenser. Most often the condenser is cooled with another stream of less purified water, called "cooling water," with characteristics similar to ordinary tap water. As the cooling water condenses and cools the steam used in the turbine, it vaporizes and is released into the atmosphere. Almost all of the cooling water is lost. The small amount of water remaining contains a highly concentrated blend of the minerals that were in the original cooling water stream.

There are two major water/energy issues in this form of electricity production. First, the cooling water required by a modern GTCC is 1,000af of water per 100MW of power. More than 20,000MW of new power plants could be built in California to meet demand in the next 10 to 15 years. Perhaps as many as 5,000MW of new power could be generated in plants built in Baja California in the same period. If all this power were generated using GTCC technology with water-cooled condensers, California and Baja California would have to supply 200,000af and 50,000af of water, respectively, to these facilities. The new power plants alone would consume enough water to supply a city of 2 million people.

The second issue raised by new power plants is the disposal of the

small amount of water that remains after the condensing process. The remaining water contains high concentrations of minerals found in normal tap water, but the concentrations are high enough to cause a disposal problem. SWP water contains magnesium at levels of 7 parts per million (ppm) to 15ppm. In most cases, power plant owners have applied for EPA permits to dispose of this brine in a dry well.

There is an option for the operator of a water-cooled GTCC to avoid disposing of the concentrated cooling brine. Technologies exist that could extract all the water from the brine. The result is water that can be reused in the cooling process and a "dry cake" of minerals that can safely be disposed of in approved landfills. But this option is expensive. To reduce the cost, operators can extract valuable minerals from the dry cake. For example, at the La Paloma power plant project the projected dry cake contained 5% magnesium by weight. The magnesium in the dry cake is a valuable resource and was valued at nearly \$1.50 per pound in early 2001. The auto industry is planning to incorporate hundreds of pounds of magnesium into each vehicle in the near future to reduce vehicle weight and thereby increase fuel economy. Recovery of this metal might more than offset the cost of using the dry cake technology. To be cost effective, large metal recovery plants need to be built and several power plants in one region need to supply the dry cake to the one recovery plant. Several builders of new power plants would have to agree to use this process to make it economical.

Both of the aforementioned issues can be resolved by using forced air to cool the spent steam in the combined cycle plant. Air cooling is a proven technology. It requires no water and therefore has no wastewater with high mineral concentrations for disposal. Unfortunately there is a price to pay: Water is a very efficient coolant while air is not, thus air condensers must be considerably larger than water condensers. This is both an initial cost problem and a visual pollution problem. For a major power plant, the air condenser is comparable in size to a large aircraft hangar. In addition, air condensers require relatively large quantities of electricity to power the air blowers. Because of these factors, the air-cooled GTCC is 3% to 4% less efficient than a water-cooled GTCC. This is equivalent to a 6% to 8% drop in total plant efficiency. The com-

bination of high initial cost and higher operating cost results in higher priced electricity.

The large water-cooled GTCC power plants use large amounts of water. In California, power plant operators are required to use processed wastewater where available. However, some citizens object to the use of wastewater in condensers because they fear the possibility of the spread of a virus or bacteria that could be released during evaporation. Most experts find this fear unfounded. While use of treated wastewater is highly desirable for power plant cooling, that water could find other uses displacing the use of potable water. At one power plant in the high desert region of Southern California, the applicant proposed using treated wastewater only to find that all such water had been committed to enhancing the wetlands of the area. Subsequently the applicant chose to buy potable water for condenser cooling, which added considerable operating cost to the project. However, in most areas there is excess treated wastewater suitable for industrial and landscaping uses.

The use of water in modern power generation plants creates many issues and possible solutions. Every potential site for a power plant has a different water infrastructure. Community planning should promote power plants being sited near sources of treated wastewater.

Nuclear Power Generation

While no new nuclear power generating facilities are currently being proposed, nuclear power is likely to gain increased popularity and there are several reasons why. First, the U.S. Department of Energy is likely to approve a high-level nuclear waste facility, an action that must be taken before any new nuclear facility can be built in the near future. Second, requirements to reduce atmospheric carbon dioxide (CO₂) are being raised. Fossil-fueled power plants are a major contributor to atmospheric CO₂. Nuclear power plants contribute to the CO₂ problem only during construction when large quantities of concrete are cured. Third, there is a need for greater fuel diversity. Fourth, while capital costs for nuclear plants are high, operating costs are below \$0.02 per kilowatt-hour. This is a lower cost than the cost of electricity produced by coal.

If nuclear power plants are built in the border region, local water

resources may be heavily taxed. Nuclear power generators have very large cooling requirements. While the GTCC technology is about 55% efficient, today's nuclear power plants are only 33% efficient. The higher the efficiency, the less waste heat is rejected in the condenser. Nuclear power plants reject 67% of the heat produced by the fission process. While it is technically feasible to use air cooling, California's nuclear power plants rely solely on ocean water cooling since most areas do not have sufficient fresh water for reactor cooling. Air cooling for nuclear reactors requires extremely massive structures with large parasitic power losses. Ocean water cooling heats the ocean in the immediate area of the cooling water return pipe, increasing turbidity and changing the local ecology. In addition, fish and mammals can be harmed by the water intake system if it is not properly engineered to prevent ingestion.

Hydroelectric Power Generation

Damming rivers to create reservoirs for hydroelectric generators can have both positive and negative social and ecological effects. Because of the lack of significant surface water resources along the U.S.-Mexican border, the possibility of dealing directly with such effects is rather remote. However, California receives about 23% of its electricity from large and small hydroelectric facilities located elsewhere. Any change in hydroelectric facilities in California could impact the electricity or water situations along the border. Some environmentalists advocate the removal of hydroelectric facilities to enable the restoration of salmon and other fish to their natural habitats. Removing these facilities could reduce the amount of electricity and potable water available for use elsewhere.

Increasing the use of wild-river hydroelectric power could also have deleterious effects on water and electric power. Over-dependence on hydroelectric power causes severe shortages of electricity when there is a dry weather cycle such as the severe spring 2001 drought in the Pacific Northwest and the northern Sierra. Power plant operators had to reduce electricity output to manage the available water for environmental protection and potable water. Power that would have been transmitted to California was not available. This puts additional stress on other power generation plants.

Renewable Energy

Renewable energy sources have varying needs for water. Solar photovoltaic and wind generators require no water to operate and have no impact on water availability or quality. Biomass power plants can have a significant effect on water availability and quality. Biomass power plants most often use the Rankine or steam cycle for power production. The water internal to the process is recycled. However water is needed for the steam condenser. In this way biomass power plants are similar to GTCC power plants. Both biomass and GTCC power plants have the same problems of water requirements and residual water disposal. Air-cooled condensers can be used on biomass power plants, but the cost of the fuel combined with the cost of the air-cooled condenser makes this combination prohibitively expensive.

Geothermal resources are abundant on both sides of the California-Mexico border. Power plants using geothermal energy employ the Rankine or steam cycle and require water-cooling of the condenser. Some of the cooling water can come from the spent geothermal steam. The major water quality issue with geothermal energy development is the disposal of the spent resource. In the border region the resource consists primarily of superheated brine, a hot liquid containing high concentrations of salts and minerals. In a geothermal power plant, the brine is “flashed,” producing the relatively pure steam used to drive turbines. In some cases, multiple flash steps are employed to maximize the energy recovered from the brine. Large quantities of brine remain after flashing. The best method of disposal is to return the spent brine to the underground areas where the brine originated, as is done in the California’s Imperial Valley. But it requires large amounts of energy to pump the brine back into the ground. If the brine is not returned to an underground reservoir, large amounts of salts from the brine accumulate on the surface. These deposits pose a possible risk to surface water supplies and surface soil quality. Recent advances in geothermal technology allow operators to “mine” the spent brine for economically valuable minerals. Zinc is being removed from the brine in the Imperial Valley at a cost competitive to a conventional zinc mine. Other valuable substances can also be removed from the brine to

increase power plant revenue. Some of the increased revenue can be applied to proper disposal of the spent brine.

Fuel Diversity

Almost all power plants proposed in California and the western end of the U.S.-Mexican border region are fueled by natural gas. The increased use of natural gas in power plants throughout North America is causing major changes in the supply and price of this fuel. The Gas Technology Institute predicts the United States will import natural gas from outside North America by the year 2010. This gas will arrive at U.S. or Mexican ports as liquid natural gas (LNG). El Paso Natural Gas and others have announced their intention to locate LNG facilities in Baja California, possibly in Ensenada. Importing natural gas in this manner reduces energy security and can increase fuel costs. While LNG has been delivered safely to other countries for decades, many fear the possibility of a catastrophic explosion of a supply ship while in the harbor. These fears will drive considerable policy debate in both the United States and Mexico. Experts estimate that a sustained price of \$3.50 (in 2000 dollars) or more per million British thermal unit (Btu) is required to import LNG.

Natural gas supplies will be a critical issue by 2010. Energy security and the safety issues associated with LNG are likely to drive the public debate toward a more balanced and diverse energy supply. It is likely many future power plants will use renewable or nuclear resources as fuel. At this point it is not clear that renewable energy resources alone can supply the quantity of power needed by 2010.

Non-traditional methods of securing natural gas supplies are now being used in the United States. About 6% of U.S. natural gas is being produced from underground coal beds where the gas is trapped in the coal formation by an overburden of water. Developers drill wells and draw down the water level to increase the flow of gas from the coal strata. There are several associated effects of this extraction method. First, the ground water level recedes, causing many wells in the area to go dry. The local aquifers may be permanently damaged, eliminating farming and ranching in those areas. Second, the water produced by this method is often laden with

undesirable minerals. Usually that water is disposed of in nearby creeks and rivers, causing damage to local fish and wildlife populations. Until adequate research is undertaken to fully assess the impact of this form of energy development on water supplies and other parts of the environment, development of coal bed methane should be avoided in the water-short border region. Damage to any aquifer would have long-term effects on border residents' quality of life. Coal bed methane has been identified as a resource in the eastern end of the Texas-Mexican border region.

EFFECTS OF NATURAL GAS AND OIL SHIPMENT AND USE ON WATER

Natural gas is supplied to the border area by long-distance pipelines. Except for small amounts of landfill gas, no natural gas is locally produced. The major impact of natural gas on water resources is the disruption of the surface environment when the pipes are installed.

Natural gas does contain measurable amounts of sulfur oxides. When natural gas is consumed in power plants, home heaters, industry, and the like, sulfuric acid can be produced in the atmosphere and subsequently dropped into fresh water rivers, reservoirs, and watersheds. This has not been a significant problem in the border region to date.

Due to increased demand for natural gas in the western region of North America, some companies are now proposing to build docking facilities for ships importing LNG. The docking facilities would include heat exchangers to gasify the liquid and pressurizing equipment for pipeline transportation. The gasification process absorbs large quantities of heat and thus could produce low-cost air conditioning or refrigeration. The equipment to pressurize the gas for pipeline transportation requires large quantities of energy. An alternate transportation system would have heavy trucks take the LNG to the user.

Petroleum is widely used in the border region for transportation. Almost all petroleum products are produced elsewhere and supplied to the area via ocean-going tankers, pipelines, or truck transport. The use of petroleum can lead to degradation of local aquifers, watersheds, and ocean habitats. Oil dripped on pavement by vehi-

cles is the primary cause of seawater fouling from petroleum. Rain or irrigation water carries the oil from the streets into storm drains; from there the oil travels with the water into the ocean. Leaking petroleum storage tanks are another mechanism for fouling groundwater.

Oxygenating additives to gasoline, specifically MTBE, are particularly troublesome when they penetrate groundwater supplies. The human nose can detect extremely small quantities (parts per billion) of MTBE in drinking water. In addition, it is difficult to remove this chemical additive from groundwater supplies. If developers were to start to drill for oil and gas in the coastal waters off the border there would be a potential for water pollution from drilling mud and petroleum liquids. However, technology is now in place to control those fluids during seabed drilling. One company, Newpark Resources, accepts and processes about 10,000 barrels of such waste per day (Lyon 2000).

Overall, storage, transportation, development, and use of petroleum and natural gas can have detrimental effects on border water resources if not properly handled.

POTENTIAL OUTCOMES AND SOLUTIONS

Potential Outcomes

Water and energy are two major requirements for a healthy environment and economy. If local and regional governments do not take aggressive action to improve the use of water and energy in the border region, economic development and growth will be halted and residents' quality of life will be impaired.

There is no question that large sums of time and money will be required to resolve the limitations on water and energy in the border region. New water purification technologies can be energy-intensive. Fortunately technology and clever engineering are being developed that, if intelligently employed, could provide solutions. For example, in the new Olivenhain water storage reservoir in northern San Diego County, static water head pressure provides all the energy necessary to operate new microfiltration devices. No electricity is used for this purpose.

Each community in the border region must be creative and adapt general solutions to the local water and energy problems. The requirements of time and money can be reduced when knowledge and experience are shared.

Potential Solutions

- GTCC power plants can use large quantities of water to cool the condenser, so as the need for power grows, power plant operators may have to find other sources for cooling than potable water
- Use treated wastewater wherever possible to cool condensers and other industrial equipment
- Reduce the condenser effluent to dry cake to recover and reuse as much water as possible
- Develop technology to recover cooling water from the exhaust stream of gas turbine generators
- Use dry cooling technologies if no other water source is available
- Implement renewable power sources such as photovoltaics and wind generators that require no water for operation

Water treatment technologies are becoming more energy-intensive. On balance, the use of these new technologies will provide higher quality potable water and will reclaim more wastewater for reuse. This beneficial use of electricity must be figured into future power demands.

Potable Water Solutions

- New water sources must be found to serve the growing needs of the border region. In the San Diego-Tijuana border region there are no obvious conventional sources of water that have not been developed. Conservation measures should be deployed first to reduce the need to pump potable water and wastewater. In that way, the region will also save electrical energy.
- A water resources conservation plan must be developed. A con-

servation program should focus on locating and stopping leaks and continuing to install low-flow water appliances. These elements alone can drastically reduce domestic water consumption. In some regions leaks in the water transmission and distribution systems and in users' facilities can account for 50% of all consumption. "Mexico City's leaks could supply a city the size of Rome" (Gleick 2001). Controlling leaks is not glamorous science, but it makes excellent economic sense.

- Agricultural activity varies greatly within the border region. Where agriculture and dairy industries are intense, the availability of good quality water is a major issue. Planting crops that require less water should be investigated in every farming area. Once these crops are selected, farmers should install modern drip or micro-sprayer irrigation systems. Technicians have demonstrated a 40% reduction in water use on tomato crops using drip irrigation (Gleick 2001). While most farmers use gravity-feed irrigation systems, farmers as a group spent \$1.2 billion on various forms of energy in 1995 to pump water from its source to crops (U.S. Bureau of Census, Agriculture and Financial Statistics Division 1996).
- The people in the border region must find a means of using highly treated waste water to replace all uses of potable water that do not compromise human health. The remaining treated water should be used to recharge the local aquifers. A method to increase the quality of processed wastewater before returning it to aquifers has been developed for Orange County. Scientists estimate the returned water will remain in the ground for at least two years before being pumped out. Currently this water resource is being disposed of in the ocean.
- Communities should develop power plants and water processing plants in close proximity. They should install technology to reclaim the water and heat energy in the exhaust of generating plants. When natural gas (methane) burns in those facilities the by-products in the exhaust are carbon dioxide and water. Over two pounds of water are produced for every pound of fuel. As the efficiency of the power plants increases, the exhaust temperature decreases, making it easier to condense the water in the exhaust. While this may not be a large source of water, it may

- be enough to supply the needs of the power plant itself. The unused heat in the exhaust of a power plant can be used to accelerate water evaporation in evaporative desalinization of brackish water or sea water. Alternately, the unused heat could be used in other water purification processes.
- “Distributed water-processing technology” should be developed for use in the border region. Potable water and wastewater services should be coordinated. Coordination of water and wastewater services through decentralized treatment and reclamation facilities can significantly reduce energy costs and can provide reclaimed water where needed for green areas and natural areas. The core of this concept is to reclaim the water at the site of its first use. Local processing not only reduces the total consumption of water, it also reduces the electricity needed to pump the water to a recycling center and back to end users.
 - So-called “gray” water effluent—water that has been used in showers, basins, and washing machines—produced by residences should be recovered and re-used. In small villages or neighborhoods one could recover and upgrade this water to potable water standards in a community processing center. Very small users in remote areas could use solar-powered passive stills to reclaim brackish or gray water. Stills of this type are commercially available at a relatively low cost. With the appropriate technology, large office buildings or industrial facilities could have an onsite water processing facility. At least one building that housing 60 workers has such a facility (*Business Week* 2001) where approximately 900 gallons of wastewater per day are treated in a 2,800 square foot courtyard next to the office. The reclaimed water is used for outside landscaping and toilets in the building. The water is treated in a garden setting in which plants and organisms work together to break down noxious substances. Other plants consume any remaining nutrients before the water is reused. Using water several times before disposing of it can greatly reduce the need for new sources, allow economic expansion to continue in the border region, and consume less electricity overall. The displaced electricity can then be used for economic expansion.
 - Wastewater processing plants produce off-gases that are pre-

dominately composed of methane. These combustible gases are used to produce electricity at many processing facilities.

Distributed wastewater treatment facilities could provide some of their electricity needs by using this source of energy.

- Desalination technology has advanced significantly in the past decade. The amount of energy needed in desalination processes is no longer as high as it once was. The technologies employed now are low-pressure, reverse osmosis and micro-, ultra-, and nanofiltration. Capacitive deionization is a promising new technology. The salinity of Colorado River water delivered to the border region currently exceeds the standards for human consumption. To reduce salinity, the Metropolitan Water District in Los Angeles mixes Colorado River water with water from the State Water Project. In the foreseeable future the water districts may have to employ desalination technology to “fresh” water supplies to meet minimum standards. Low energy, desalination technologies also could be used to upgrade other sources of brackish water. Farmers often reuse water until the water leaches enough salts from the soil to be unusable for irrigation. That water could also be processed for additional uses in the fields.
- Public funding for water-related research and development should be increased. Research and development should emphasize reducing energy input to water purification processes. Other areas of emphasis should include methods to increase the use of reclaimed water, especially at decentralized water treatment facilities. Some thought should be given to the convergence of distributed energy systems with distributed water treatment.

CONCLUSIONS

Water and energy have a strong interdependence. Both resources are vital to the growth and well-being of the border region, and both are in limited supply. Communities must be proactive in the selection, design, and placement of capital assets used to provide these resources. New technologies must be carefully evaluated and selected on the potential benefits and negative effects in the affected com-

munity. No community should plan the expansion of facilities for one resource without first evaluating the effects on the provision of the other resource.

REFERENCES

- Anderson, Carie. 1999. "Energy Use in the Supply, Use and Disposal of Water in California." California Energy Commission internal report. 25 January.
- Baliant, Kathryn. 1999. "Down the Drain." *San Diego Union-Tribune* 10 October.
- Business Week*. 2001. "A Water-Treatment Plant for Every Office Building?" 22 January.
- California Department of Water Resources. 2001. <http://www.dwr.water.ca.gov>.
- Conaughton, Gig. 2001. "Water Agencies Turn Their Eyes to the Sea." *San Diego Union-Tribune* 28 January.
- Duque, Henry M. 1999. "Utility Convergence: Perspective from the Water Industry." Paper presented at Current Issues Challenging the Regulatory Process Center for Public Utilities conference, New Mexico State University. 10 March, Santa Fe, New Mexico.
- Ganster, Paul. 2000. *The San Diego-Tijuana International Border Area Planning Atlas*. San Diego: San Diego State University Press, Institute for Regional Studies of the Californias.
- Gleick, Peter H. 2001. "Making Every Drop Count." *Scientific American* 284(2).
- Lyon, Frank. 2000. Personal email communication with author. 1 December.
- Mills, William R., Jr., *et al.* 1999. "Advances in Membrane Technology to Provide Cost Effective Water in the 21st Century." Orange County Water District. Unpublished report.
- Nikkei Weekly*. 1997. "New Desalinizing System Raises Fresh Flow." 13 October.
- Pasternak, Judy. 2001. "Coal-Bed Methane Puts Basic Needs of Water, Energy at Odds." *The Los Angeles Times* 27 March: San Diego County Water Authority. 1999. <http://www.sdcwa.org>.

San Diego County Water Authority. 1999. Press Release. 14 October.
U.S. Bureau of Census, Agriculture and Financial Statistics
Division. 1996. "Agricultural Irrigation in the United States."
Journal of Applied Irrigation Science 31(2).