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Water Without Borders: A Look at Water Sharing in the San Diego-Tijuana Region

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ABSTRACT

Given the aridity and growing population of the U.S.-Mexican border region, few leaders miss the fundamental connection between adequate water supply and quality of life in border communities. As dominant factors, aridity and population growth cause persistent controversies of political, economic, and environmental natures, affecting the evolution of water supplies and infrastructure. Water-related infrastructure refers to infrastructure used to manage water sources, including potable water, wastewater, and storm water. Like most infrastructure along the border, water infrastructure is physically divided into two portions, each separately serving each country.

Conventional water sources are rainfall, snowmelt, groundwater, and surface waters such as lakes and rivers. Non-conventional water sources include desalinated water and recycled water. Regardless of where they are located, many factors define the envelope of constraints for providing water infrastructure, including: demographics and land uses, water sources, land form, and the capacity of existing infrastructure. To explore the paradigm of Water Without Borders—

the transboundary sharing of water resources—each of the above constraints must be addressed to define the technically feasible options. The San Diego-Tijuana region provides an example to illustrate the engineering issues that must be answered to create physical conditions conducive to sharing water across the U.S.-Mexican border.

Despite existing constraints, two types of regional opportunities may exist for water sharing: transboundary water transfers or jointly owned and operated water infrastructure. The options for water sharing include a binational aqueduct, a binational desalination plant, transfers of recycled water, and a jointly owned and operated groundwater recharge and extraction system. A constraints analysis suggests shared aquifer storage and recycled water reuse are feasible and cost-effective opportunities for water sharing that would benefit Tijuana, Rosarito, and San Diego. By means of injection into aquifers accessible from both sides of the border, recycled water overcomes the barriers to transport caused by urban development.

Since three existing plants and four future plants could become sources of recycled water, several alternatives may emerge for large-scale aquifer storage and reuse in the San Diego-Tijuana region. One possible scenario would combine two potential projects into one conjunctive use project resulting in transboundary water sharing and multiple benefits. The first project would restore the riparian habitat along the Río Alamar in Tijuana; however, no surplus of surface waters is available for the restoration. The second proposed project would bring recycled water from across the border to the vicinity of the river where it could be discharged into infiltration basins constructed along the riverbed. Using the riverbed for recharge would simultaneously act to restore the habitat value of the riparian corridor and recharge the aquifer.

Agua Sin Fronteras: Una Mirada a la Repartición del Agua en la Región San Diego-Tijuana

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RESUMEN

Con la aridez y el crecimiento de la población de la frontera Estados Unidos-México, pocos líderes desconocen la conexión fundamental entre el suministro del agua y la calidad de la vida en comunidades fronterizas. Los factores dominantes—la aridez y el crecimiento de la población—causan controversias persistentes de tipo político, económico y ambiental, las cuales afectan la evolución de los suministros del agua y infraestructura. Infraestructura relacionada con agua se refiere a la infraestructura que se usa para el manejo de fuentes de agua, agua potable, aguas negras y aguas pluviales. Como la mayoría de la infraestructura fronteriza, la infraestructura del agua está dividida físicamente en dos porciones, cada una sirviendo a cada país.

Fuentes convencionales incluyen aguas pluviales, provenientes de la nieve derretida, de las superficies acuáticas como los lagos y los ríos y agua subterránea. Fuentes no convencionales incluyen agua desalinada y reciclada. Aparte de la ubicación, los factores siguientes definen las restricciones para proveer infraestructura acuífera: usos demográficos y agrícolas, fuentes acuíferas, la topografía y la capacidad de la infraestructura en existencia. Para explorar el paradigma de agua sin fronteras, es decir el uso compartido de los recursos del agua de la frontera, hay que tratar con las restricciones susodichas para definir las opciones técnicamente posibles. La región San Diego-Tijuana provee un ejemplo para ilustrar los retos de ingeniería que tienen que ser resueltos para crear las condiciones conducentes para compartir el agua en la frontera.

A pesar de restricciones existentes, dos tipos de oportunidades regionales puedan existir para el compartimiento del agua: transfe-

rencias del agua entre la frontera o infraestructura acuífera que sea poseída y dirigida conjuntamente. Las opciones del compartimiento del agua incluyen un acueducto binacional, una planta de desalinación binacional, transferencias del agua reciclada, y una recarga de los mantos subterráneos y un sistema de extracción poseída y dirigida conjuntamente. Un análisis de restricciones sugiere una oportunidad factible y efectiva del compartimiento del agua para beneficio de Tijuana, Rosarito y San Diego—un almacenaje acuífero compartido y el reuso del agua reciclada. El inyectar agua reciclada en los acuíferos accesibles por los dos lados de la frontera, permitirá que el agua reciclada supere los obstáculos de transporte causado por el desarrollo urbano.

Con tres plantas en existencia y cuatro potenciales como fuentes de agua reciclada, varias alternativas para almacenaje acuífero en larga escala y el reuso del agua residual en la región San Diego-Tijuana. Un escenario posible combinaría dos proyectos potenciales en un proyecto conjunto con el resultado del aprovechamiento compartido del agua fronteriza y beneficios múltiples. El primer proyecto restituiría el hábitat ripario por el Río Alamar, sin embargo, no habría excedente de aguas superficiales para la restauración. El segundo proyecto propuesto traería agua reciclada del otro lado de la frontera a la vecindad del río donde se podría recargar hacia las cuencas infiltradas construidas por el lecho. Usando el lecho para la recarga simultáneamente servirá para restaurar el valor del hábitat del corredor ripario y la recarga del acuífero.

INTRODUCTION

Given the aridity and growing population of the U.S.-Mexican border region, few political leaders miss the fundamental connection between adequate water supply and quality of life in border communities. The strong, influential voices of leaders need to be anchored by the reality of what is physically and technically feasible if border communities are to meet demands for adequate potable water quantity and quality cost-effectively.

If population increases mean water resources and infrastructure are becoming a greater constraint to social and economic well-being,

then social strife, economic hardship, and local friction between nations will be inevitable. To circumvent constraints from water shortages, new sources and infrastructure are needed now. The transboundary sharing of water resources and infrastructure merits further examination given the complex and intertwined social and economic relationship between U.S. and Mexican border communities. Where traditional water supplies cross the border—and several watersheds do—the physical conditions seem to support the possibility of transboundary water sharing in new ways. Transboundary water sharing requires binational collaboration and funding. Funding will probably be successful only if benefits exist for both parties.

The concept of Water Without Borders, proposed in this chapter, means overcoming the political boundaries that are seen as physical barriers so that water sources and/or water infrastructure can be shared efficiently for the benefit of both countries. This approach keeps with the trend toward watersheds as a planning region. The watershed approach recognizes that surface water flows, groundwater aquifers, ecosystems, and biodiversity do not conform to political boundaries. Using watersheds as natural regions allows for the joint management of water supplies, water quality, flooding, and environmental health.

Binational water management is not a new concept, although transboundary water management is. This chapter offers an engineering approach that results in identification of a physically and technically feasible model within a moderately short timeframe for achievement. The San Diego-Tijuana region is used as the case study for this analysis. Engineering constraints are examined through demographics, land use, water sources, land form, and the capacity of existing infrastructure. Possible sources of water and scenarios for water sharing are discussed, as are the engineering issues that apply to each option. Although political, social, and environmental constraints exist, they are not addressed here. Finally, a scenario is examined for one of the most feasible options—aquifer storage and reuse of recycled wastewater.

Wastewater recycling is an important opportunity for water sharing. In an arid region with limited water sources, using water more than once is a common-sense method of extending water resources

and increasing the socio-economic benefits from each gallon of water. The source of water is reliable and can be used to meet demands that require lesser water quality. Like all new infrastructure, recycled water distribution could be cost-prohibitive due to interferences caused by existing infrastructure in urban areas. Alternatively, injecting recycled water into underground aquifers makes it possible to store large quantities and achieve long-distance transport through natural flow paths. By spreading the recycled water under a large region, both the United States and Mexico could access the water, producing a shared benefit and incentive for such a program. In streambeds where aquifer recharge is known to occur, stream restoration may enhance aquifer storage.

WATER INFRASTRUCTURE

Water-related infrastructure refers to methods used to manage water sources, potable water, wastewater, and storm water. Conventional water sources include rainfall, snowmelt, groundwater, and surface waters such as lakes and rivers. Non-conventional water sources include desalinated water and recycled water. Recycled water is water used for human purposes that is then treated to remove pollutants, enabling its safe reuse. Potable water refers to water of safe and acceptable quality in accordance with defined national standards for human drinking. Storm water is actually rain water, but once the rain lands, it is called “storm water” when managed for health and safety purposes, including flood control. Hereafter, water infrastructure refers to methods used for collection, distribution, treatment, and storage of (non-storm) water and wastewater.

Like most infrastructure along the border, water infrastructure is physically divided into two parts: the Mexican portion serving Mexico and the U.S. portion serving the United States. In the San Diego-Tijuana region, water infrastructure follows this pattern with few exceptions. Figure 1 shows the San Diego-Tijuana region with potable water infrastructure. Note how infrastructure is divided by the border. Only one pipeline—an emergency water connection initially installed to provide water to Tijuana during a period of severe drought—crosses the border. The network for wastewater collection is similarly divided although not shown in this figure. The only

infrastructure crossing the border is a wastewater interceptor from Pump Station No. 1 in Tijuana to the International Wastewater Treatment Plant (IWTP) in San Diego. At the IWTP, a connection exists to send treated water back to Tijuana, but this is non-operational as no receiving pipeline is installed.

Regardless of where they are located, the following factors define the constraints for engineering water infrastructure:

Demographics and Land Uses

- Existing and future population
- Existing and planned land uses, including how they produce water demands and how they hinder construction of water infrastructure
- Existing and future water demands based on population and land uses

Water Sources

- Natural sources and limits of water
- New sources of water

Land Form

- Distance between sources, demands, and existing water infrastructure
- Topography and relative elevation of sources, demands, and existing water infrastructure

Capacity of Existing Infrastructure

- Hydraulic capacity of existing conveyance, storage, and treatment facilities
- Water quality of natural sources, potable water after treatment, and water discharged from wastewater treatment plants

In addition to these constraints, cost and environmental protections steer engineering decisions for the provision of water infrastructure. To explore the paradigm of Water Without Borders, each of the above constraints must be addressed to define the technically feasible options. The San Diego-Tijuana region provides an example to illustrate the engineering issues that must be answered to create

the physical conditions for water to be shared. Scenarios for realistic water sharing are suggested with an emphasis on use of recycled water, particularly by way of groundwater recharge and extraction. The conditions for water sharing along other sections of the border may be different, but the same questions must be answered about the physical and qualitative conditions of the infrastructure and the water itself.

DEMOGRAPHICS AND LAND USES

A high population and a relatively rapid population growth characterize both Tijuana and San Diego. Tijuana's population is much smaller than San Diego's, but it is growing considerably faster. Table 1 shows population growth statistics for Tijuana and San Diego over the last decade.

Table 1. Population Growth Trends in the San Diego-Tijuana Area

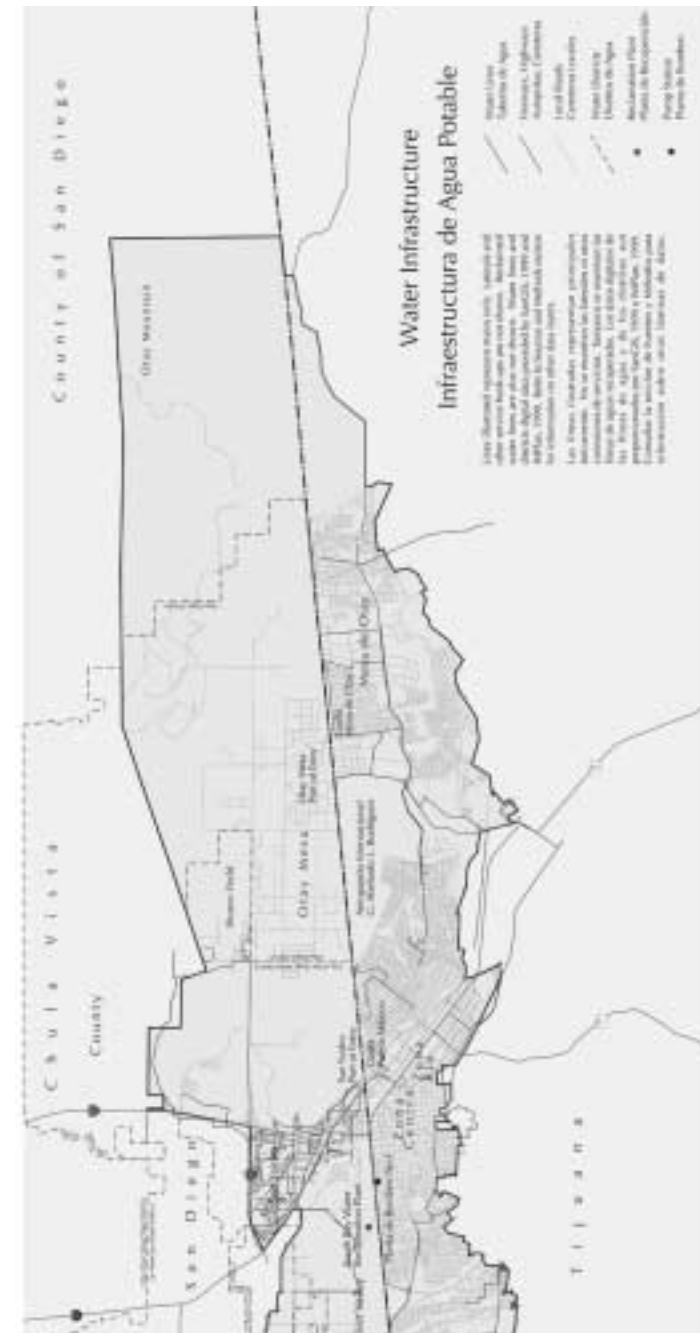
City	1990	1995	2000	Increase 1990-2000
San Diego	2,498,000	2,626,700	2,813,800	11.3%
Tijuana	747,400	991,600	1,210,820	62.0%

Source: Ganster

In 2010, the population of this binational region will increase from 3.70 million to 5.45 million people with 60% living in San Diego and 40% in Tijuana. The population projection for 2020 is about 7 million people (Ganster et al. 2000).

Existing and planned land uses affect water demand. Figure 2 shows land uses in the San Diego-Tijuana area. Urban land uses make the expansion of infrastructure difficult and expensive, particularly for pipelines. For example, construction of a recycled water network in a developed urban area must accommodate existing buildings, pavement, and underground utilities, as well as social impacts such as traffic delays and loss of business in construction zones. The additional cost of constructing infrastructure in developed urban areas is, in fact, the major physical barrier to recycling

Figure 1. San Diego-Tijuana Potable Water Infrastructure



Source: Ganster

water on a municipal scale. By contrast, recycling water to agricultural lands is commonly practiced and less expensive to implement. This suggests that trading fresh water for recycled water could result in increases to fresh water supplied for urban uses. The feasibility of this opportunity for the San Diego-Tijuana area is examined below.

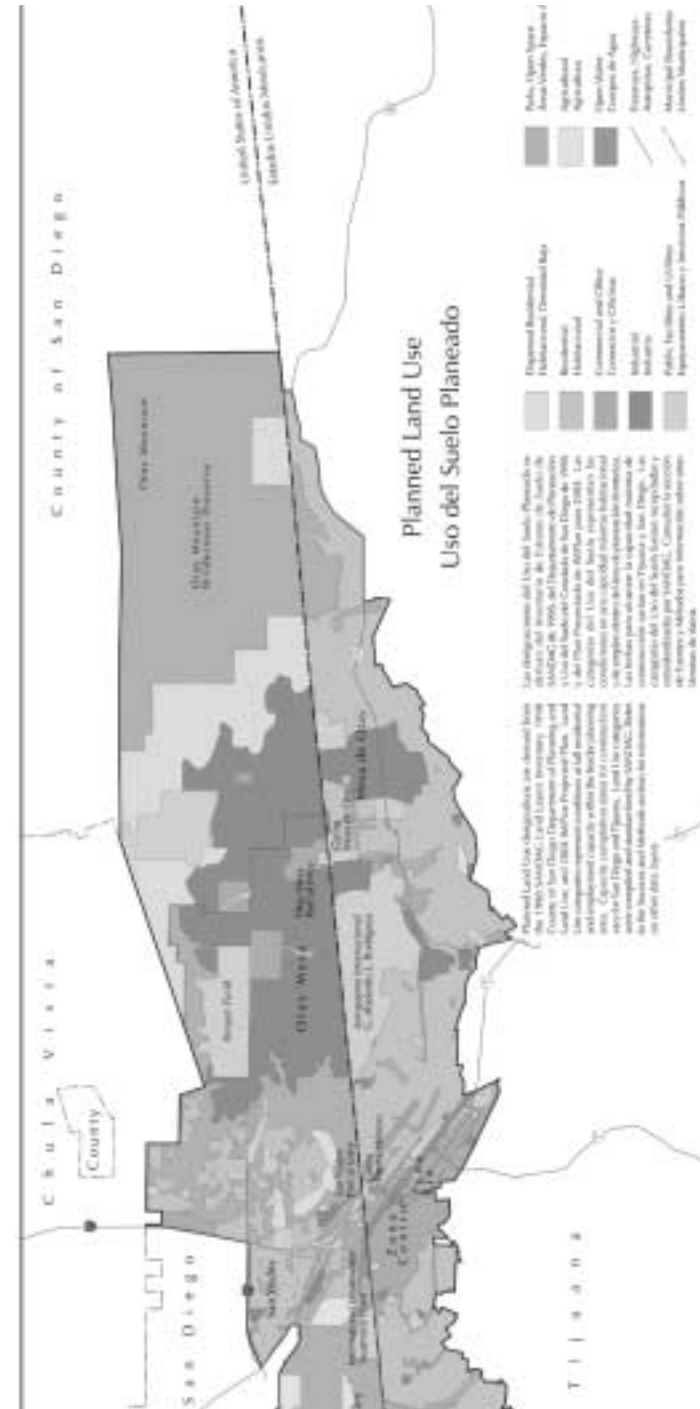
In a typical year, San Diego County imports 90% of its water while Tijuana imports about 95%. By 2010, San Diego will consume about 87% of the water in this area while Tijuana will consume 13%—if the infrastructure capacity keeps up with the growing water demand (Ganster et al. 2000). Without an increased supply of water and adequate water infrastructure, the demand will exceed capacity quickly, as shown in Figure 3. From this review of the demographic conditions, the highest unmet demand is currently, and will continue to be, in the Tijuana-Rosarito area.

For this reason, the Tijuana-Rosarito area should be the focus of increased water supply and sanitation services with serious examination of all potential sources. Conversely, per capita water consumption is so high in the San Diego area that water infrastructure needs should focus on reduction of demand for fresh water supplies through water conservation, extensive water recycling, and provision of new facilities for emergency water storage.

If agricultural land uses remain in proximity to urban areas, the cost of trading water might be feasible within the short term. For example, water from the IWTP could be transferred to farmers along the coast south of Rosarito who traditionally used raw wastewater before the conveyance canal was replaced by a pipeline. With additional treatment, this water might be acceptable for additional purposes, such as landscape and golf course irrigation at resorts developing on the coast, or for agricultural uses in the U.S. portion of the Tijuana River Valley. Agricultural users in the United States would likely prefer recycled water from the South Bay Water Reclamation Plant (SBWRP) because of the potential for industrial compounds in the effluent from the IWTP.

Long-distance water trading, such as between San Diego-Tijuana and the Imperial-Mexicali Valleys, could become feasible if the cost of fresh water were to increase substantially or the transfer and sale of recycled water were subsidized. With either scenario the cost increases for the general public, driving development of water recy-

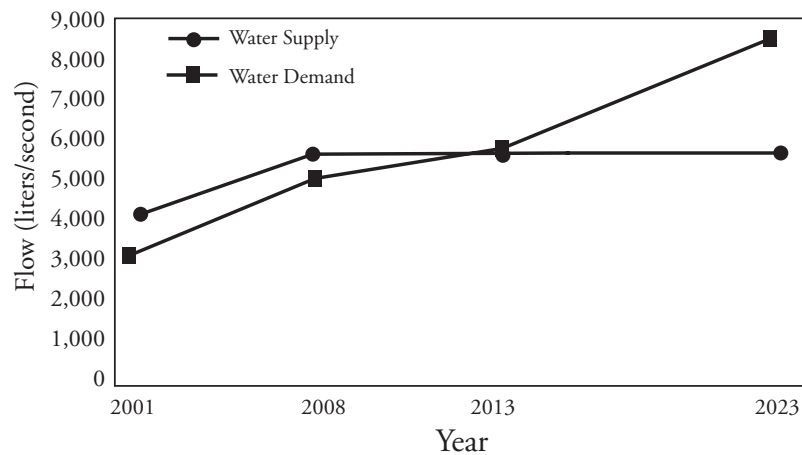
Figure 2. San Diego-Tijuana Land Use



Source: Ganster

cling infrastructure. Water quality issues would have to be addressed to protect agricultural soil quality from salts and protect consumers from biological or industrial pollutants.

Figure 3. Projection of Water Supply and Water Demand for the Tijuana-Rosarito Area 2001-2023



Source: Comisión Estatal de Servicios Públicos de Tijuana (CESPT)

WATER SOURCES

Natural Sources and Limits of Water

In the San Diego-Tijuana region, the Colorado River, rainfall, and groundwater are the natural sources that serve both municipalities. Surface water from Northern California also supplies water to San Diego and other regions of California. Natural limits, water rights, and environmental protections require the sharing of these waters with other populations and species. These sources as allocated are not adequate for sustained or improved quality of life in the San Diego-Tijuana region. With the exception of obtaining fresh water supplies from agricultural lands, there is probably little reason to expect or justify additional importation of water to the region.

The Colorado River is the main source of shared water for San Diego-Tijuana. Water is conveyed through open channels on each side of the border. It may be possible to transfer additional Colorado River water from agricultural uses to urban uses, such as from the Imperial and Mexicali Valleys and Baja California. Ongoing plans and studies to increase the hydraulic capacity of the channels include a plan for a shared channel. This would be a form of transboundary water sharing for mutual benefit. Depending on the route taken, the channel could be located in either country or cross back and forth between the two. An advantage for locating a shared channel in the United States includes the rigorous bidding and construction practices required there. An advantage to locating the channel in Mexico is the lower cost of labor for construction.

Rainfall in natural watersheds is collected in reservoirs in the San Diego-Tijuana region. Given the low amount of rainfall in the region, the percentage of water demand met by rainfall is in decline as demand increases with population growth. Varied rainfall frequently results in below-normal water levels in reservoirs. Rodríguez Reservoir, the only reservoir for rain water catchment in Tijuana, periodically nears empty (CESPT 2002). The use of reservoirs for capturing rainfall is extensive in San Diego, resulting from several decades of water infrastructure construction. Most recently, construction has focused on emergency storage reservoirs. Opportunities for shared emergency storage could mitigate the effects of long-term drought on the San Diego-Tijuana region.

Groundwater is extracted to meet a portion of current water demands. Local aquifers offer many possibilities for shared water storage, transport, and extraction. A particularly attractive feature is the potential for transporting water underground through natural aquifers without the interferences and costs associated with transporting water through urban areas. Stream restoration can enhance groundwater supplies with storm water not captured by existing reservoirs (Dallman and Piechota 2000). Sources of water for recharge include rainfall during abundant years, recycled water, desalinated water, and, under certain circumstances, Colorado River water.

Without additional infrastructure to take advantage of the possibilities described here, groundwater levels will continue to drop and

degrade in quality. The paradox associated with the use of aquifers without stream restoration is that water from other sources will have to supplement natural groundwater resources.

New Sources of Water

Currently, the three most technically feasible sources of water are demand reduction, desalination, and recycled water. Demands are water “losses” due to agricultural, industrial, commercial, residential, and landscape uses or other leakages resulting in lost use of water. Demand reduction is simply the reduction in water demand that results in water becoming available for other uses or demands. Demand reduction is sometimes referred to as “found water,” and occurs through conservation, such as using water-saving consumer devices like low-flow flush toilets and timed drip irrigation. Demand reduction also occurs through reduction in water losses in the public water distribution system. These “system losses” can be significant. In Tijuana, system losses from leaking water distribution lines have varied from 25% to 41%. These losses are the major reason why the total water quantity sent into the distribution network outstrips the total quantity recorded for billing purposes (Caloca 1997). Conservation and reduction of water losses should be a key element of any water supply program.

Desalination is an effective technology although it is rarely considered unless other sources of water are inadequate. The cost of desalinated water is often greater than 10 times the cost of water from existing sources. The cost of construction and energy for operations will continue to limit its use, despite the stability of this source, because ocean water provides a year-round source of water at a predictable flow. Desalination can also take advantage of brackish groundwater and can be used to remove salts from recycled water. Within the context of transboundary water sharing, desalination will not likely provide a significant source of water supply unless water shortages increase further or emergency conditions, such as a drought, occur. In the San Diego-Tijuana area, desalination is currently used for water supply only in Oceanside, California. The City of Oceanside extracts and desalts 8 million gallons per day (MGD) of brackish groundwater. The groundwater is combined with water

from other sources and distributed throughout the city. The San Diego County Water Authority is proceeding with plans to construct a much larger plant to desalinate ocean water in the neighboring city of Carlsbad.

Like desalination of ocean water, recycling provides a constant source of water. Recycled water is wastewater that has been treated to standards that make it safe for reuse. The level of treatment dictates the type of use. Elevated salts in recycled water may render the water unsuitable for some uses unless diluted with other water. For example, this type of water can be used to irrigate vegetation with a low salt tolerance. Most recycled water in the San Diego area is used for landscape irrigation, industrial purposes, and groundwater recharge in areas like Santee Lakes. Conjunctive management of surface, recycled, and groundwater has the potential to increase the use of recycled water and to extend surface and groundwater quantities.

Recognizing that public resistance to the use of recycled water will probably limit the number of uses for this water, the primary issue from an engineering perspective is reduced to finding adequate numbers of users in clusters to make the cost feasible for construction of a completely separate water distribution system used solely for recycled water. The cost of recycled water is high—anywhere from 1.3 times to 10 times higher than the cost of existing sources, not including the cost of the distribution system. Where opportunities for aquifer storage and recovery exist, the feasibility of using recycled water increases substantially by replenishing groundwater sources. This is because the wholesale cost of groundwater is low—about \$20 per acre-foot. By contrast, the cost of imported water is about \$150 per acre-foot, depending on the source (Bradley 2002).

LANDFORM

Landform is a fundamental constraint dictating the feasibility of water infrastructure and water sharing. (Technically speaking, almost any infrastructure option is feasible, but many are not affordable. Therefore, technical feasibility actually refers to the ability or willingness of the consumers to pay for the infrastructure.) Ideally, engineering common sense dictates: gravity-moved water from areas of higher elevation to areas of lower elevations should be

considered, water demands should be met by local water sources, and water should be exposed to sunlight to allow disinfection to occur through natural ultraviolet light irradiation. In reality, the opportunities to conform with nature are often overruled by the need to speed up treatment, the location of water supplies in far-away places or deep below the ground surface, and by other unnatural conditions. Thus the engineer's challenge is to cost-efficiently provide pipelines, pumps, chemicals, mechanical treatment equipment, concrete storage structures, electrical supply, process instrumentation, electronic controls, and a host of other means to meet society's demands for water and sanitation.

The land form of the San Diego-Tijuana region is characterized by hilly terrain, requiring extensive water pumping to route water to its intended destinations (Figure 4). Tijuana's elevation is much higher than San Diego's, so by following the flow of gravity, water sharing across the border favors the flow of water from Tijuana to San Diego. But, given the higher water use and greater availability of water in San Diego than Tijuana, this probably does not make sense, except possibly for the limited agricultural uses found in the Tijuana River Valley. The difference in elevation and the hilly terrain also suggest challenges and cost increases associated with transferring water from San Diego to Tijuana.

As a political barrier, the border acts as an artificial constraint imposed on natural conditions and infrastructure options. One needs only to look at the existing wastewater infrastructure in Tijuana to understand how land form and political boundaries have conspired to exacerbate transboundary health and environmental impacts caused by raw wastewater spills in Tijuana. Historically, a large portion of the wastewater collected in Tijuana was routed to the Tijuana River where it flowed downhill to the north, into the United States, through the Tijuana Estuary, and into the Pacific Ocean without treatment. To intercept the gravity flow of renegade wastewater flows, CESPT constructed pipelines, a pump station, and a canal to keep the water at a high elevation and redirect the flow to a treatment plant to the west. Because of construction deficiencies, deferred maintenance on the conveyance structures, and the cost of continuous operation of the pump station, raw wastewater spills remained common. The sewage flows downhill into the

United States through the now-protected Tijuana River National Estuarine Research Reserve and into the Pacific Ocean on the U.S. side of the border. If transboundary sharing of water infrastructure had been envisioned when the original wastewater infrastructure was conceived, it is possible that more reliable and less-costly infrastructure could have been constructed with some facilities at the higher elevation in Tijuana, a pipeline crossing the border and paralleling the river, a treatment plant at a low elevation in the United States, and discharge of treated effluent through an ocean outfall like those typically used in the United States. Instead, decades of unpleasant, publicly criticized, and expensive efforts focused on how to make further improvements to a system that fights gravity because a political constraint opposes natural land form and common sense. Eventually, this condition of siting infrastructure contrary to nature was partially overcome through construction of the IWTP and the South Bay Ocean Outfall (SBOO). Located in the United States below and north of Pump Station No. 1, the IWTP and SBOO treat and discharge about half of the collected wastewater from Tijuana.

CAPACITY OF EXISTING INFRASTRUCTURE

Examination of water infrastructure in the San Diego-Tijuana region is instructive. The infrastructure components are usually separated as a result of political boundaries rather than natural boundaries, particularly within the San Diego area, where many political jurisdictions exist. Figure 5 shows the wastewater agency boundaries, which also represent infrastructure boundaries. Clearly illustrated are the main wastewater pipelines and pump stations of the San Diego Metropolitan Wastewater Department, which is the largest district. Infrastructure systems that separately serve numerous cities, sometimes by separate water and wastewater services, produce challenges for sharing water services within the region. This is particularly true with regard to recycled water. For example, the recycled water facilities located at the North City Water Reclamation Plant (North City) and at the SBWRP are not connected. This means water cannot be transferred between the two for flexibility of operation or to optimize the customer base. The cost to

connect the plants would be very high and only considered if there were a compelling benefit.

The distribution of effluent water quality is also instructive. While all water treatment plants appear to provide adequate treatment for potable uses, the quality of treated wastewater varies considerably. The lowest effluent quality from wastewater plants discharges from the San Antonio de los Buenos treatment plant while the highest quality discharges come from North City and SBWRP. The latter two plants produce high-quality water suitable for many agricultural and urban uses. Yet, only a small portion of the water is used because the cost of redistribution cannot be covered by the market price for the water. Between these two water quality extremes lie the effluents from the Point Loma treatment plant and the IWTP. The Point Loma plant lies on the coast far from most users while the IWTP lies close to many users, particularly urban consumers in Tijuana. Of concern for the use of this water are the large number of industrial compounds present in the wastewater stream that flows into the plant. Without significant additional treatment, the water will not likely be safe for most uses. However, the flow is large, making the opportunity for water recycling worthwhile.

Viewing the infrastructure as a whole, the only transboundary water sharing operations using existing infrastructure have occurred through the Otay emergency water connection from San Diego to Tijuana, the emergency wastewater disposal connection from Tijuana to Point Loma (also no longer in use but available), and the IWTP, which treats Tijuana wastewater in San Diego with the option of returning treated effluent to Tijuana.

Figure 4. Topography and Hydrography



Source: Ganster

Figure 5. Wastewater Jurisdictions in San Diego



Source: San Diego Metropolitan Wastewater Department

SCENARIOS FOR WATER SHARING

Given the constraints provided in the preceding sections, the following conditions shape the opportunities for water sharing across the border:

1. Two types of opportunities exist for water sharing: transboundary water transfers and jointly owned and operated infrastructure. The options for water sharing in the San Diego-Tijuana area include a binational aqueduct, binational desalination plant, transfers of recycled water, and a jointly owned and operated groundwater recharge

and extraction system. Additionally, joint management of the Tijuana River watershed could lead to improved use of existing water sources, particularly if stream restoration is included.

2. Water sharing should focus on sustainability, characterized as meeting minimal standards for basic water needs and quality of life while preserving the environment. The needs of the Tijuana-Rosarito area exceed the needs of the San Diego area and therefore should be the initial focus for water sharing. However, water sharing without benefit to the San Diego area leaves little incentive for investment.

3. Additional water from the Colorado River is unlikely to arrive in the San Diego-Tijuana area for quite some time, if at all. However, a jointly owned and operated water aqueduct would strengthen the reliability of water transferred directly to the San Diego-Tijuana region; yet, the institutional and political challenges associated with this option are significant.

4. Groundwater is a shared resource of the region. Within the Tijuana River Valley, groundwater overdraft for agricultural uses has caused such degradation in water quality that it currently has limited use. In Tijuana, the groundwater wells produce water with a relatively high salt content. The continued production of the wells is unknown (CESPT 2002). Groundwater can be recharged to preserve the water-bearing capacity of the aquifer as well as the quality and quantity of the water yield. Injection of water from other sources could extend the life of the aquifers indefinitely and allow sub-surface transport of water to users.

5. Desalination offers the opportunity for unlimited water supply, but equipment and energy remain costly. It is plausible that desalination could become an avenue for water sharing in the near future. One desalination plant currently exists in the region, serving only one U.S. municipality.

6. Recycled water offers a steady supply of water but public opinion hinders the optimization of this resource. Recycled water is costly

when a separate distribution network is required and the quality limits its uses.

7. Theoretically, trading agricultural water for recycled water could provide more surface water for urban uses. Large distances and urban land uses between sources and users affect the cost and technical feasibility of trading, making the cost of pipeline installation infeasible.

8. Several potential sources of recycled water are located in the San Diego-Tijuana region. Some, such as the North City plant, are not hydraulically connected nor feasible sources for transboundary water sharing.

9. Elevation differences and urban land uses make water transfers from the San Diego area to the Tijuana-Rosarito area both challenging and costly. The IWTP and the SBWRP represent the best water quality from existing plants. The plants are well-located for this purpose.

The described engineering constraints and summary of shared water options point to many challenges for technically feasible and cost-effective water sharing benefiting both Tijuana-Rosarito and San Diego. It is possible that one option—shared aquifer storage and reuse of recycled water—could be implemented in the near future because of the relatively small amount of new infrastructure needed to transport the water. Recycled water injected into an aquifer that straddles both sides of the border and is accessible from both sides offers advantages by overcoming the cost of long-distance conveyance through highly developed urban areas. Recycled water is a reliable stream of water and injection into aquifers may meet with less public resistance than other routes for reuse.

POSSIBLE SOURCES OF RECYCLED WATER

By focusing on water sharing for urban uses, three existing plants and four future plants could become sources of recycled water: the IWTP, SBWRP, San Antonio de los Buenos Water Treatment Plant, and the four water reclamation plants to be built by the Comisión Estatal del Agua (CEA) as part of a large infrastructure project financed in part through a loan from the Japan Bank for International Cooperation.

International Wastewater Treatment Plant

The IWTP was built on the U.S. side of the international border by agreement between the United States and Mexico (International Boundary and Water Commission [IBWC] Minute No. 283) to end decades of pollution in the Tijuana River estuary caused by spills from Tijuana's sanitary sewer system. Although the agreement specifies that secondary treatment will be provided at the IWTP, the first phase of this facility provides only advanced (i.e. chemically assisted) primary treatment. Effluent that has not been disinfected is discharged into the Pacific Ocean through the SBOO. The plant has difficulty meeting U.S. discharge standards for toxicity for aquatic organisms. The first phase of the international plant treats an average dry weather flow (ADWF) of 25MGD and a peak wet weather flow (PWWF) of 50MGD.

Under the terms of IBWC Minute No. 283, Mexico is entitled to the treated effluent from the IWTP for the uses it deems appropriate; thus, provisions have been made in the plant's effluent structure to connect to a future pump station and pipeline that would return the flow to Tijuana should Mexico request it. However, until additional treatment is provided, the toxicity of the effluent may deter recycling efforts.

South Bay Water Reclamation Plant

The SBWRP, located adjacent to the IWTP, is part of the City of San Diego water reclamation system and was designed to provide 15MGD of tertiary treated effluent, complying with the require-

ments of Title 22 of the California Code of Regulations, making it suitable for unrestricted landscape irrigation. Plant effluent not used for irrigation or other purposes is discharged through the South Bay Ocean Outfall.

The plant capacity was expanded from 7.5MGD to 15MGD during construction with the expectation of selling the additional flow of recycled water to Mexico. The potential market would be identified through a survey of possible industrial, commercial, and institutional users. This survey was not conducted and thus the potential demand for recycled water in Tijuana is not quantified.

San Antonio de los Buenos Water Treatment Plant

This treatment plant began service in 1989 to treat wastewater transported from Tijuana Pump Station No.1 and is designed for 17MGD ADWF and 25MGD PWWF. (Before the IWTP was built, flows exceeding these maxima routinely bypassed the treatment plant and were combined with treated effluent prior to discharge.) Effluent is discharged at the shoreline—there is no outfall into the Pacific Ocean to allow for dilution of the effluent in deep water. A construction contract was recently awarded to expand the capacity of the plant from 17MGD ADWF to 25MGD ADWF and to correct deficiencies of the existing treatment units. There are no current plans to construct an outfall and the effluent would continue to discharge into the ocean at the shore. Some of the effluent from the San Antonio de los Buenos Water Treatment Plant is used to irrigate a golf course and other landscapes at a nearby resort. The resort provides additional treatment in aerated lagoons prior to use.

Planned Reclamation Plants in Tijuana–Rosarito

The CEA will construct four wastewater treatment and reclamation plants under its Infrastructure Project for Environmental Sanitation and Potable Water Supply in Baja California. The plants are Monte Olivos (340 liters per second [l/s]), La Morita (150l/s), La Gloria (100l/s), and Lomas Rosarito (75l/s). These plants will be located in the vicinity of industries that consume large volumes of water. The approach taken by the CEA in siting these facilities is to provide

industrial users with recycled water to replace an equivalent volume of potable water.

POTENTIAL USES OF RECYCLED WATER

Fresh water supplies can be extended with the use of recycled water. Potential uses for recycled water from these plants include landscape and agricultural irrigation, industrial water use, and groundwater recharge. The current status of these reuse options are examined later. Toilet flushing is also an excellent use of recycled water but is slower to gain public acceptance. Historical uses of recycled water for toilet flushing were not identified for the Tijuana-Rosarito area.

Landscape Irrigation

Tijuana–Rosarito is a high-density urban region with few parks, golf courses, cemeteries, or other green areas, limiting opportunities for using recycled water for landscape irrigation. Thus, construction of a separate water distribution system cannot be justified on the basis of providing landscape irrigation water. However, this is not to say that this application should be ignored. Currently, there are several “single-user” irrigation projects in Tijuana. These water reuse projects individually serve two golf courses, a public park (the EcoParque Project), and several hotels or resorts along the Tijuana-Ensenada tourist corridor. These are simple, low-cost water reclamation projects that could be replicated in a relatively short time to provide irrigation water to nearby soccer fields, institutional facilities, and the like. Consequently, projects like these have the potential to make small but cumulatively significant contributions to alleviating the region’s serious water shortage problem.

Agricultural Irrigation

The agricultural reuse situation is similar to that of landscape irrigation: There are limited opportunities in the Tijuana–Rosarito region where urbanization has displaced most agricultural land uses. Interestingly, the only well-known case of agricultural irrigation of this type took place along the open conveyance canal between Pump

Station No. 1 and the San Antonio de los Buenos Water Treatment Plant. The irrigation practice consisted of illegal diversions of raw wastewater by farmers along the canal alignment. Since the original conveyance system was recently replaced by a pipeline, this use no longer exists.

Industrial Water Use

The large number of maquiladoras located in Tijuana both prior to and since the North American Free Trade Agreement (NAFTA) may provide a significant potential demand for recycled water. As previously mentioned, CEA has sited four planned water reclamation plants near concentrations of industrial facilities that could use the effluent from these plants; however, the cost of making this water available is undetermined. The potential demand by Tijuana's industry has not been established and thus the financial feasibility of this type of use cannot be assessed. Perhaps more importantly, industrial facilities within the city are widely dispersed. Thus, the cost of distributing recycled water to those facilities interested in using it is likely to be so high that it would render such a project infeasible.

Using Recycled Water for Groundwater Recharge

Groundwater recharge involves the use of water from other sources to supplement natural recharge where groundwater extraction creates an overdraft condition. An aquifer storage and reuse system consists of recharge and extraction wells and distribution facilities where the water is extracted. Treatment before injection and after extraction may be necessary.

Of all the possible uses of recycled water described, aquifer recharge has the greatest potential for using significant volumes of treated wastewater effluent, such as the 25MGD currently being treated at the IWTP or the 15MGD flow from the SBWRP. Tijuana's original water supply consisted of wells in the unconfined aquifer of the Tijuana and Alamar rivers. Rosarito's water was supplied from wells from La Misión aquifer near Ensenada. Groundwater supplied by 22 wells located within the Tijuana-Rosarito area and four wells from La Misión field accounted for approximately half the total

water supplied to the two cities until the 1980s (Boyle Engineering Corporation 2002). Due to water level variations in this shallow aquifer, low yields, water quality problems, and poor well conditions, water pumped from the existing wells currently comprises only a small portion of Tijuana's water supply. To raise this percentage, CESPT is implementing a phased program to rehabilitate several wells (CESPT 2000).

A parallel recharge program could aid CESPT's efforts to preserve groundwater production. Groundwater recharge using recycled water would increase well yield and improve water quality by mixing high-salinity natural groundwater with lower-salinity recycled water. Particularly noteworthy, the aquifer would serve as the conveyance medium, thus avoiding the need to build a separate recycled water distribution system. Some users (including agricultural and industrial) with access to the aquifer would simply drill wells to tap into it.

Several alternatives may emerge for large-scale aquifer storage and reuse of recycled water. The following scenario describes one approach that combines two potential projects into one conjunctive use project resulting in transboundary water sharing and multiple benefits. The scenario illustrates the value of adopting a watershed approach where several issues can be addressed holistically.

The first project, proposed by the Instituto Municipal de Planeación, the planning agency of the Municipality of Tijuana, would restore the riparian habitat along the Río Alamar (Michel and Graizbord 2002). The Río Alamar is considered an outstanding natural resource and vital recharge zone for the large aquifer that lies beneath the Alamar and Tijuana rivers (Michel 2001).

Since a surplus of surface waters is not readily or reliably available for restoration, additional projects, such as storm water retention basins or wetlands restoration, would have to be implemented before the river restoration project could proceed. The second proposed project would bring recycled water to the vicinity of the river where it could be discharged into infiltration basins constructed along the riverbed. The Río Alamar is a natural zone of recharge for an aquifer where the majority of Tijuana's existing wells are located, so the value of this second project is obvious. Using the riverbed for recharge would simultaneously restore the habitat value of the ripar-

ian corridor and recharge the aquifer. At this time, recycled water is the only logical source for this purpose because of its year-round availability.

Recycled water for a Río Alamar restoration project could be provided either by the IWTP or the SBWRP. In the case of the IWTP, at least secondary treatment is needed. Secondary treatment units could be built either adjacent to the existing facility or at a location in Tijuana. An aerated lagoon-based system was proposed to upgrade the IWTP to secondary treatment. Under this alternative, an average of 25MGD of treatment capacity could be accommodated at the existing site. This limitation does not exist in Mexico since ample land is available at several locations along the Río Alamar. Construction costs and the opportunity for tertiary treatment facilities would seem to favor building additional treatment plants in Tijuana. The actual treatment level needed will depend on Mexican water quality regulations and the quality of secondary effluent (discharges). Until secondary treatment is installed, uncertainty remains regarding the quality of the secondary effluent and its suitability for reuse. The uncertainty stems from an unenforced program requiring pretreatment of industrial waste streams before discharging into the sewer. This condition could necessitate tertiary treatment for safe reuse.

There is currently a proposal from the private sector to build the IWTP secondary treatment facilities at a site adjacent to the Río Alamar. To make this proposal work, a pump station, conveyance pipeline, and return pipeline would have to be built. The return pipeline would allow discharge of excess effluent through the South Bay Ocean Outfall if reuse does not consume all of the effluent.

This proposal prompted the U.S. Congress to pass legislation (Public Law 106-457) to provide a revenue stream to pay for construction, operation, and maintenance of a secondary treatment facility in Mexico. To implement this type of project, IBWC Minute No. 283 would have to be amended since the original document stipulates that all treatment is to be provided in the United States. At this time, both countries have agreed to enter into negotiations to amend Minute No. 283.

In the case of the other source of reclaimed water, the SBWRP will discharge tertiary-treated effluent suitable for reuse. A pump

station and conveyance pipeline would still be needed but not a return pipeline because of the SBWRP's location in San Diego. The SBWRP effluent will be more uniform in quality. However, there are still issues to be resolved, including the cost of purchasing the recyclable water, the need for a binational agreement for such a transfer, and the perceived social issue of exporting U.S. "wastewater." By contrast and per binational agreement, water treated at the IWTP is owned by Mexico, which retains sovereign rights to the water.

Aside from the clear environmental benefits of a Río Alamar recharge project, there is a social and humanitarian component that makes the project unique. Portions of the riverbed are currently occupied by unauthorized dwellings. The Río Alamar extends into the United States, where it is called Cottonwood Creek, and terminates at Barrett Reservoir. Should the volume of this reservoir be exceeded due to unusually heavy rains (such as during an El Niño event) and/or large flows of surface runoff produced in the watershed, a considerable flow could swell in Cottonwood Creek/Río Alamar with potentially disastrous consequences for the dwellings and their occupants in the riverbed (a more tragic scenario would occur if Barrett Dam were to fail during a strong earthquake). Thus, clearing the riverbed to make room for a restoration project through groundwater recharge would ultimately protect the inhabitants of these dwellings from potential harm.

From the U.S. side of the border, this option offers several benefits. The area of the aquifer that underlies the Tijuana River Valley has limited value given the decades of overdraft and increased salinity of groundwater. As recycled water presses into this area, brackish water will recede toward the coast. Groundwater levels may rise. Valley agriculture would be able to expand and plant fewer salt-tolerant crops.

Obstacles to the implementation of the conjunctive use project include:

- The use of groundwater for Tijuana-Rosarito's and San Diego's needs must be secured to ensure long-term cooperation and benefit
- The use of water from the IWTP would require improvements from primary to tertiary treatment to make the water safe (the construction of additional treatment facilities could occur adja-

cent to the SDIWTP or in the Tijuana area); alternatively or additionally, recycled water from the SBWRP, once completed, could augment water for recharge

- The removal of the existing dwellings from the Río Alamar river bed—a daunting task for both social and political reasons

Either of the treatment options and the issue of binational benefit would require approvals from the Mexican government through negotiations—a traditionally slow and sometimes difficult process—between the IBWC and its Mexican counterpart, Comisión Internacional de Límites y Aguas (CILA). The Comisión Nacional del Agua (CNA), the federal regulatory agency having jurisdiction over all groundwater in Mexico, has not yet developed standards for groundwater recharge using recycled water. Finally, the studies to determine important characteristics of the Río Alamar aquifer, such as infiltration and storage capacity, have yet to be conducted.

CONCLUSIONS

This chapter addressed the practical feasibility of Water Without Borders, a concept of transboundary water sharing that would benefit both the United States and Mexico. The San Diego-Tijuana region is an example that illustrates the value of a holistic watershed approach. Challenges include the need for higher treatment levels to recycle water, the lack of integrated infrastructure for efficient water sharing, hilly topography creating obstacles, the high cost of piping water through dense urban areas, large distances to agricultural users (often separated by dense urban areas), as well as the non-engineering challenges of public perception and the political boundary creating an institutional barrier.

While a few options exist for producing new sources of water for this arid region, recycled water is one source that can be readily shared, thanks to topographic, hydrogeologic, and infrastructure conditions. The most suitable sources of recycled water would be the SBWRP and IWTP, given the current water quality, proximity to the border, and/or status of binational agreements on water from these plants. By injecting recycled water at higher elevations of the Río Alamar, the water would become available to consumers in Tijuana

and downstream in the Tijuana River Valley in the United States. Both communities would benefit and avoid the high cost of piping the water through dense urban areas. Were stream restoration a part of the project, the cost of aquifer storage could be reduced while restoring valuable habitat and open space and mitigating flood disaster.

The constraints, challenges, and opportunities for water sharing may be similar along other portions of the border. This example illustrates some of the tough realities and shows how transboundary collaboration and engineering can reduce water deficiencies, providing improved quality of life and security for border residents.

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