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Articles

Urban sanitation programs on Mexico's northern border and the circular economy approach

Programas de saneamiento urbano en la frontera norte de México y el enfoque de economía circular

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Abstract

This study looks at the Northern border sanitation program gran vision study and the Northern border strategic sanitation program, both programs were formulated after introducing the environmental chapter of the USMCA in 2020. The study examines three relevant cases of border cities: Tijuana, Baja California; Nogales, Sonora; and, Nuevo Laredo, Tamaulipas. The research is based on a documentary review and interviews with key informants. The study found that the proposed solutions were mainly based on conventional infrastructure projects, with limited incorporation of reuse, recycling and recovery strategies for materials, energy and water. The study emphasizes the importance of holistic planning that incorporates circular economy principles and green infrastructure to improve the sustainability of sanitation projects in the region.

Keywords: urban sanitation, Mexican northern border, circular economy strategies, green infrastructure, USMCA.

Resumen

En este artículo se analizan el Programa de saneamiento de la frontera norte estudio gran visión y el Programa estratégico de saneamiento de la frontera norte, ambos se formularon luego de la introducción del capítulo ambiental del T-MEC en 2020. Se examinan tres casos relevantes de ciudades fronterizas: Tijuana, Baja California; Nogales, Sonora; y, Nuevo Laredo, Tamaulipas. La investigación se basa en una revisión documental y entrevistas a informantes clave. Se encontró que las soluciones propuestas se apoyan principalmente en el desarrollo de infraestructura convencional, con una incorporación limitada de estrategias de reutilización, reciclaje y recuperación de materiales, energía y agua. El estudio enfatiza la importancia de una planeación que

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incorpore principios de economía circular y formas de infraestructura verde para mejorar la sostenibilidad de los proyectos de saneamiento en la región.

Palabras clave: saneamiento urbano, frontera norte de México, estrategias de economía circular, infraestructura verde, T-MEC.

Introduction

The border sanitation issue and USMCA

Transboundary flows of untreated wastewater, or those that do not comply with the regulations established in binational agreements, generate significant environmental and health impacts on border populations and consequently on United States-Mexico diplomatic relations (Allen, 2020; Hargrove et al., 2018; Mumme, 2021). In the early 1990s, communities on both sides of the border were predominantly discharging raw sewage, which constituted a high risk to their populations, who experienced high rates of gastrointestinal illnesses and hepatitis (Allen, 2020; Giner et al., 2022; Hargrove et al., 2018).

In the middle of that decade and with the intention of signing the North American Free Trade Agreement (NAFTA), environmental issues, mainly water management and wastewater treatment on the border, became priority issues for the relationship between the two countries. The Border Environment Cooperation Commission and the North American Development Bank (NADB)[1] were founded in 1994 to address these issues. By 2019, NADB had partially funded 133 sanitation infrastructure projects on both sides of the border through grants and loans that provided nearly USD 760 million of a total cost of USD 1.9 billion (Allen, 2020).

According to some authors, high investments in infrastructure—conventional wastewater collection, conveyance and treatment systems—have significantly improved water sanitation in U.S. border cities (Giner et al., 2017, 2022). On the Mexican side, health benefits have also been reported for the region's inhabitants derived from a reduction in exposure to open-air wastewater discharges (García Ochoa et al., 2023; Giner et al., 2017).

Although time-series data on environmental conditions are unavailable for the region, water quality in the water bodies shows some tangible improvements due to investment in sanitation infrastructure (Allen, 2020). Nevertheless, non-compliant transboundary water flows are still observed between Tijuana-San Diego, Mexicali-Calexico, Nogales, Sonora, and Nogales, Arizona, and along the Rio Bravo-Rio Grande (Allen, 2020; Comisión Internacional de Límites y Aguas [CILA], 2024; Dougherty, 2018; Mumme, 2021).

In 2020, the signing of the United States-Mexico-Canada Agreement (USMCA) to follow up on NAFTA generated expectations in the Mexican government regarding the need to comply with the commitments on sanitation mainly due to the inclusion of

[1] In November 2017, the Border Environment Cooperation Commission and the NADB merged and the NADB continues to support the development and financing of environmental infrastructure in the border region.

an environmental chapter. This concern about the environmental implications of the USMCA was one of the main reasons for the formulation of two sanitation programs: the Grand Vision Northern Border Sanitation Program also known as the Grand Vision Study (EGV, Spanish acronym for *Estudio de gran visión*) published by the International Boundary and Water Commission (IBWC) in 2021, and the Strategic Sanitation Program for the Northern Border (PESFN, Spanish acronym for *Programa estratégico de saneamiento para la frontera norte*) formulated by the National Water Commission (Conagua, Spanish acronym for *Comisión Nacional del Agua*), based on the EGV.

Although Chapter 24 of the USMCA does not explicitly include water and sanitation issues, it does establish some specific commitments on environmental issues, including obligations under multilateral environmental agreements on three topics:

a) the prevention, reduction or control of a leakage, discharge or emission of environmental contaminants

b) the control of chemicals, substances, materials or wastes that are hazardous or toxic to the environment

c) the protection or conservation of wild flora or fauna, including endangered species, their habitat, and natural areas under special protection (Article 24.1: Definitions).

A legal analysis of Chapter 24 of the USMCA, reported in the EGV, states that penalty mechanisms for non-compliance are now active and include everything from technical consultations to dispute settlement panels and may even include trade sanctions (CILA, 2021a, Annex 4). Article 24.27 provides a direct procedure for non-compliance with obligations: "Any person of a Party may submit a petition asserting that a Party is failing to enforce its environmental laws effectively". Such petitions shall be filed with the Secretariat of the Commission for Environmental Cooperation.

In parallel, the Mexican and U.S. governments have tried to develop new opportunities for environmental financing and cooperation. For example, in December 2021, the NADB Board of Directors agreed to extend its lending conditions to allow investments in a wider range of infrastructure projects to address climate change and promote a green economy (BDAN, 2021). It is particularly important that the joint statement of the second meeting of the USMCA environmental committee (September 2023) refers to the fact that potential areas of collaboration regarding the circular economy (CE) approach were presented at that meeting.

The recent context of the USMCA presents, on the one hand, challenges on environmental issues that may result in potential trade sanctions for non-compliance with binational commitments on border sanitation. On the other hand, it presents opportunities to expand investments beyond conventional sanitation infrastructure with recent approaches such as the CE framework.

This study reviews the projects proposed in the EGV and the PESFN to assess whether the strategies proposed in these programs comply with some of the principles of the CE in the planning of border urban sanitation infrastructure. Sanitation problems and infrastructure project proposals are specifically analyzed as solutions for three border cities: Tijuana, Baja California; Nogales, Sonora; and Nuevo Laredo, Tamaulipas. This analysis aims to explore the possibilities of implementing CE strategies and forms of green infrastructure.

The paper is structured as follows: this introduction is followed by a conceptual review of the CE approach and strategies proposed in urban water and sanitation. Afterwards, a methodological section is presented. The fourth section reviews the border sanitation problem and the types of infrastructure projects formulated to solve it, followed by a review of the three border city cases. Finally, the conclusions of this study are presented.

Circular economy approach and strategies in water and sanitation

From a purely functional perspective, the natural resources of the territory where cities are located constitute the physical base that provides inputs for their functions and processes. In this approach, urban systems are usually linear in their processes, also called the take-make-waste arrangement.

Water for cities is obtained from natural sources at long distances or from great depths. It is used for industrial or commercial activities and in housing and is disposed of by being released into the environment. Alternatively, a vision of cities as complex systems that receive, transform and reduce inputs that generate products and emit waste leads to a concept of resource use that differs from the linear one (Novotny, 2011). Derived from this vision, the CE approach has been proposed. A CE can be defined as:

> Circular economy is an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow. This is done by using cyclical materials flows, renewable energy sources and cascading-type energy flows. (Korhonen et al., 2018, p. 39)

A central principle in the CE approach is the restorative use of resources, according to which unprocessed materials should not become waste (Geisendorf & Pietrulla, 2018). This also implies limiting the production flow to a level that nature supports and using ecosystem cycles in economic cycles while respecting their natural reproduction rates (Korhonen et al., 2018).

The paradigm shift from a linear to a circular model is particularly relevant in urban sanitation, where wastewater is often seen as a problem rather than a valuable resource. Given that a linear conception sanitation processes do not include resource recovery, there is a leakage of matter and energy, as well as environmental pollution flows arising from treatment processes and intensive use of non-renewable energy (Daigger, 2009; Programa mundial de evaluación de los recursos hídricos, 2017).

One of the key aspects of CE in sanitation is the recognition of wastewater as a resource for nutrient recovery. The CE approach emphasizes that wastewaters and their sludge are properly treated, they can be transformed into fertilizers, thus contributing to nutrient cycling within agricultural systems. This approach could not only reduce reliance on synthetic fertilizers but can also mitigate the environmental impacts associated with their production and use (Moya et al., 2019).

Other key CE strategies include water reuse, recycling, reclamation, energy production and recovery, and restoration of natural water sources (Guerra-Rodríguez et al., 2020; Smol et al., 2020; Furness et al., 2023). Specifically, implementing CE strategies in wastewater treatment plants can extend equipment lifetime, optimize maintenance and reduce environmental impact (Castellet-Viciano et al., 2022). Artificial wetlands also play a crucial role in this new paradigm, as they offer economically viable treatment solutions and, at the same time, generate marketable products such as fertilizers and biofuels (Masi et al., 2018).

Innovations in wastewater treatment, such as anaerobic digestion and bioelectrochemical systems, can be essential for improving resource recovery and energy efficiency (Ghimire et al., 2021). These technologies not only improve the sustainability of sanitation systems but also contribute to the CE by generating valuable by-products that can be reintegrated into local economies.

Implementing CE strategies can also reduce the carbon footprint of wastewater treatment plants, aligning with broader climate change mitigation efforts (McKenna et al., 2022). Wastewater energy extraction technologies can transform wastewater treatment plants into significant energy producers, thus contributing to zero carbon goals (Rani et al., 2022).

Nonetheless, the transition to a circular economy in the sanitation sector requires strong governance frameworks that facilitate the implementation of resource-oriented waste management and sanitation systems. This underscores the need for collaborative efforts between governments, private sector actors, and civil society to create enabling environments for circular sanitation initiatives (Ddiba et al., 2020).

Based on a review of specialized literature, Morseletto et al. (2022) have proposed eight strategies for managing water in a circular way while identifying some policy, governance, and implementation challenges that must be addressed to facilitate the transition to a circular water economy. The strategies proposed due to their relevance and applicability to water are organized into three categories: decrease (avoid, reduce, replace), optimize (reuse, recycle, cascade use) and preserve (store and recover).

Whereas avoiding the use of water means not using it in certain activities, reducing its use consists in using a smaller volume than usual. Replacing, on the other hand, means substituting water for some other substance in some process, which might be feasible in uses such as industry. Morseletto et al. distinguish between reuse and recycle and propose that while reuse can be understood as using water again for the same or a different purpose without any treatment—that is, with the same quality or with a level of alteration that does not prevent further use—recycling implies using a volume of water again after treatment to obtain a level of quality required for that further use.

In Morseletto's categorization of strategies, cascading use consists in a sequence of consecutive water uses, for example, in an industrial plant for cooling first, then in cleaning, and finally in toilets. This strategy requires both the physical proximity of the uses and technologies that work in synergy.

Preserving water involves two strategies: to store water for future use, which may or may not involve pre- or post-storage treatment, and to recover materials and energy. Adopting such a strategy is straightforward in sanitation by recovering treated water and by-products of treatment such as sludge, in which water, nutrients and energy can be recovered (Programa mundial de evaluación de los recursos hídricos, 2017). The sludge resulting from sanitation processes has a high organic content, and it is feasible to directly use anaerobic treatment for gas recovery to enable electric power generation (Aguilar-Benítez & Blanco, 2018).

Green infrastructure can also be a mechanism for implementing CE strategies. Green water infrastructure generally refers to natural or semi-natural systems that involve a deliberate and conscious effort to use ecosystem services to provide benefits for sustainable water management (Programa mundial de evaluación de los recursos hídricos, 2018).

Some forms of green infrastructure include constructed wetlands, green roofs, or rain gardens. Creating green infrastructure is a strategy that can be implemented in support of conventional rainwater drainage infrastructure to divert runoff flow and control sediment flushing into the sanitary sewer system. Stream re-naturalization and riparian habitat restoration can also be associated with treated water polishing while improving aquatic habitat and ecological flow.

Sanitation can even favor access to drinking water if the potential for water recycling is implemented adequately for indirect human use, thus substituting significant volumes of first-use water in activities that require lower quality, such as industry and agriculture.

Nonetheless, it is necessary to identify optimal ways to implement CE practices and strategies to take full advantage of its potential in wastewater management (Guerra-Rodríguez et al., 2020; Kundu et al., 2022). It is important to recognize that the CE approach may encounter several challenges for its implementation, the most important of which are the regulatory framework, costs, technology, and the perception of potential users (Frijns et al., 2024; Kakwani & Kalbar, 2020).

In Mexico, several regulations, such as the Mexican Official Standard (NOM, Spanish acronym for *Norma Oficial Mexicana*), must be complied with before implementing CE strategies in water. Among the most important, NOM003-Semarnat-1997 establishes maximum permissible limits for the use of treated water in public services for direct, indirect, or occasional contact implemented by public bodies. This standard limits, for example, recreational use with direct physical contact with treated water.

NOM-001-Ecol-1996 establishes standards for water recycling in natural and artificial reservoirs used for agricultural irrigation. NOM-001-Semarnat-2021 establishes standards for treated water for irrigation of green areas. NOM-014-Conagua regulates the artificial recharge of aquifers with treated wastewater. NOM-127-SSA1-2021, Water for human use and consumption, establishes in Article 1.3 that this standard does not apply to treated wastewater and specifies in Article 5.1 that: "Water from supply systems should not have treated wastewater as a source of supply". Therefore, direct human use is very restricted.

A constraint to promoting the industrial use of treated water is the difference in tariffs. The tariff for treated water is lower than that for drinking water, while investment costs are high, for example, in purple pipe systems for distribution (R. Laborín, personal communication, June 7, 2022).

Treated water tariffs lower than those for drinking water are used to attract industry to replace its use of first-use water at lower costs. Nevertheless, transporting treated water in plants generally located far from city centers and industrial parks requires large investments for constructing purple pipes and pumping with the consequent electricity costs.

On the other hand, there is also competition in the treated water market with the industry that owns water rights, and the costs of those rights may be lower than the cost per treated water tariff. This situation can often make it financially unviable to replace first-use water with treated water for industrial use.

Some technical aspects that may limit water recycling are that it requires regularity in the flow of treated water and constant quality, which implies an efficient operation of wastewater treatment plants (WWTP). The main limitations of water recycling for drinking water use are the risks to public health and its rejection by potential users due to the repugnance factor, with a psychological basis (Rozin et al., 2015).

Treated waters may still contain hazardous contaminants such as pathogens, micropollutants and antibiotic-resistant genes, posing challenges for safe reuse (Guerra-Rodríguez et al., 2020).

Informing about the recycling process, water quality, benefits to the source and the fact that recycling is practiced elsewhere may improve confidence and acceptance of recycled water for direct human use (Fielding et al., 2019). One proposal that has emerged recently is to rename treated water as recovered water or regenerated water, which could incentivize public acceptance. Notwithstanding these limitations, adopting CE principles in wastewater management can contribute to sustainable development and resource security.

The following section presents the research methodology used in this study.

Methodology

This work applied a qualitative methodological approach comprising two components: the first consisted of a general documentary review of the two sanitation programs under study and complementary materials; the second was the analysis of three selected case studies, complemented by interviews with key informants.

The documentary review focused on identifying in the academic literature and in official documents and gray literature the status of the sanitation problem in the border region, as well as the infrastructure planning formulated and implemented to address it. The documentation of two programs was reviewed: the EGV and the PESFN, both formulated between 2021 and 2022, as well as related official documents (IBWC minutes, expenditure budget, among others).

The EGV includes extensive documentation with one general report and 15 specific reports, one for each of the thirteen border cities and two regions. On the other hand, the PESFN projects were registered in the regional water programs of the three hydrological-administrative regions covering the six border states, published by Conagua:

Hydrological-Administrative Region I Baja California Peninsula (Conagua, 2021a), Hydrological-Administrative Region II Northwest (Conagua, 2021b), and Hydrological-Administrative Region VI Rio Bravo (Conagua, 2021c).

The main criteria for the selection of the three cases were the presence of wastewater flows between neighboring urban areas on the border, the binational impacts on the border sanitation problem recorded with the signing of agreements in IBWC minutes, and the presence of an international wastewater treatment plant (IWTP) as an indicator of a sanitation system with a high degree of interdependence. Other important indicators analyzed were the size and growth rate of the population.

To identify the possibilities for implementing circular economy strategies in each case, the proposal of categories by Morseletto et al. (2022) and the forms of green infrastructure identified by the World Water Assessment Program were adopted (Programa mundial de evaluación de los recursos hídricos, 2018). Regarding CE strategies, each of the three project-specific reports sought to identify measures to avoid, reduce and replace volumes of first-use water; mechanisms to reuse and/or recycle volumes of water and/or materials; actions to promote cascading water use; and initiatives to store water for future uses and recover materials and energy from wastewater. Regarding green infrastructure, it was sought to identify its main forms: the construction of wetlands, the establishment of green spaces for bioretention and percolation, green roofs and the use of permeable pavements.

To complement the documentary information on these three cases, interviews were conducted with key informants—officials, former officials and leaders of civil organizations who are experts in border sanitation issues—in at least one of the three cities selected as case studies. Interviews were conducted with seven informants through videoconferences and telephone calls in the period June-July 2022.[2]

Each interview included three main topics, posed with open-ended questions: first, the border sanitation issues in each city (Tijuana, Nogales and Nuevo Laredo); second, the priority in each case for binational investment in sanitation projects; and third, interviewees were asked to identify project alternatives that can be implemented with the CE or green infrastructure approach.

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[2] The key informants interviewed for this work were: Hernando Durán Cabrera, former Director of the Comisión Estatal de Servicios Públicos de Tijuana (CESPT) and member of the Board of Directors of Tijuana Innovadora (civil society organization); Carlos de la Parra, member of the Board of Directors of the North American Development Bank (NADB) and Chair of the Board of Directors of Restauremos el Colorado, A. C.; Rigoberto Laborín Valdéz, former Director of CESPT, former Technical Undersecretary of Sanitation of the Secretaría para el Manejo, Saneamiento y Protección del Agua (Seproa) of the Government of the State of Baja California; Óscar Ibañez, representative of the governor of Chihuahua in Ciudad Juárez and former director of the Central Water and Sanitation Board of Chihuahua; David Negrete Arroyos, who has been a representative of the IBWC for more than 25 years in Nuevo Laredo, Ciudad Juárez and Reynosa; Claudia Gil, former general director of the Municipal Institute of Research and Planning of Nogales, environmental science specialist at the Arizona Department of Environmental Quality; and Joaquín Marruffo, former NADB project manager, manager of the border programs unit at the Arizona Department of Environmental Quality. The author would like to acknowledge their important contributions to this work.

Four interviews were conducted by videoconference, with a transcript of the recording. However, in the remaining three cases, the interviewees preferred to conduct the interview by telephone. The texts of transcripts and interview notes were analyzed, and the relevant information for each topic was categorized using two main dimensions: the CE and green infrastructure approach, and the strategies proposed by Morseletto et al. (2022) and the forms of implementation of green infrastructure as categories.

Subsequently, this information was contrasted thematically with that contained in specific reports and secondary sources (publications of binational agencies, mainly the Environmental Protection Agency (EPA), IBWC and NADB, and newspapers, among others).

Sanitation programs at the northern border

The main organizations involved in water and sanitation management on the United States-Mexico border are, on the Mexican side, the Secretaría de Relaciones Exteriores, the Comisión Nacional del Agua (Conagua), and the Comisión Internacional de Límites y Aguas (CILA). Their counterparts on the U.S. side are the IBWC, as well as the EPA. These agencies intend to address the border problem through collaborative actions and commitments recorded in "Minutes", a mechanism established in the International Water Treaty of 1944.[3]

By 2024, out of a total of 330 signed minutes, 47 (14%) had established agreements on sanitation issues. One of the most important is Minute 261, signed in 1979, entitled "Recommendations for the solution of border sanitation problems". In this document, sanitation problems on the border are defined as:

> … each case in which the waters that cross the boundary, including coastal waters, or that flow in the limitrophe reaches of the Rio Grande and the Colorado River, have sanitary conditions that present a hazard to the health and wellbeing of the inhabitants of either side of the border or impair the beneficial uses of these waters. (Minute 261, signed September 24, 1979, in El Paso, Texas)

In 1995, Minute 294 was signed, entitled "Facilities planning program for the solution of border sanitation problems" under which funds were provided both by Mexico, through the then Secretariat of the Environment, Natural Resources, and Fisheries (Semarnap, Spanish acronym for *Secretaría de Medio Ambiente, Recursos Naturales y Pesca*), and by the United States through the EPA, for the construction of infrastructure projects (International Boundary and Water Commission, 1995). In 1997, the Border Environmental Infrastructure Fund (BEIF), administered by the NADB, was created to channel non-repayable resources.

[3] Referred to as IBWC Minutes, hereafter referred to as Minutes. The Minutes can be consulted at: https://www.ibwc.gov/minutes/

Three international wastewater treatment plants (IWTPs) have been constructed along the border to prevent untreated discharges into the Rio Grande/Rio Bravo river: two located in the United States that receive raw sewage from Mexico (IWTP Rio Rico, Arizona, 1972; IWTP IBWC/South Bay in San Diego, 1999) and one located in Mexico (IWTP Nuevo Laredo, 1996). The operation of these plants implies different responsibilities for the Mexican border cities. While in Tijuana and Nogales the commitment is not to exceed the agreed-upon volumes of wastewater crossing the border for treatment, in the case of Nuevo Laredo, its responsibility is to operate the IWTP and maintain it adequately to treat the water on the Mexican side. The IBWC Mexican section oversees the operation, costs and maintenance of the Nuevo Laredo IWTP.

In 2000, the Joint Investment Program for drinking water and sanitation infrastructure projects for populations along the United States-Mexico border was created. Minute 304 established that funds provided by the EPA for project funding through the NADB could be applied to projects in either Mexico or the United States and that those funds should match grants provided by Mexico. In contrast, the funds provided by Mexico only apply to projects on the Mexican side.

In 2003, the environmental program Frontera 2012 (PAF 2012, Spanish acronym for *Programa Ambiental Frontera*) was formed. The main objective of this program was to reduce water pollution in the region. In the PAF 2012 report, it was declared that more than 500 000 homes were connected to wastewater collection and treatment services. Subsequently, the environmental program Frontera 2020 (PAF 2020) was signed in mid-2012. Goal 2 of PAF 2020 proposed improving access to clean and safe water, and a target was set for 2015 to promote access to adequate sewerage and sanitation services for at least 42 000 households.

PAF 2020 was followed up with the environmental program Frontera 2025 (PAF 2025). An important aspect of this program is that, under Objective 4, specific actions are proposed to promote the recycling of treated wastewater and the conservation of first-use water and energy. It is proposed that 100% of the Joint Investment Program projects for drinking water and sanitation infrastructure projects for populations in the United States-Mexico border region selected for development include an evaluation of water recycling opportunities.

Given the possible implications of the environmental chapter 24 of the USMCA, in 2021, the IBWC commissioned the formulation of the Northern Border Sanitation Program, a Grand Vision Study (EGV).[4] The Conagua took up this study and in 2022 formulated the Strategic Sanitation Program for the Northern Border. The general objective of the EGV was to "Identify the actions and alternatives that Mexico requires to comprehensively address border sanitation problems, their impacts on public health by 2050, and to promote environmental care" (CILA, 2024). The EGV was intended to become the programming and budgeting instrument to maximize investments in border sanitation issues.

[4] This study was assigned to FG y Asociados through national public bidding in the call for bids No. IBWC-JUA-LPN-6-2020.

The EGV characterizes the sanitation problems of thirteen individual border cities and two regions in which several suburban and small rural localities are grouped (the Valle de Juarez and Frontera Chica in Tamaulipas, see Figure 1).[5] In general, the projects identified in the EGV and taken up in the PESFN can be classified as the construction, expansion and rehabilitation of sewerage networks, pumping stations and treatment plants, as well as the preparation of diagnoses and executive projects.

The EGV identifies some existing water recycling initiatives in four cities: Tijuana, Tecate, Ciudad Juarez and Nuevo Laredo. The projects proposed to promote recycling are extending purple pipe systems and improving water pumping. Generally, a low percentage (less than 10%) of treated water is reused in each city, except Acuña and Piedras Negras, Coahuila, where all of it is used to generate electricity.

Some general sustainability criteria defined for evaluating sanitation infrastructure projects in the EGV are: location of facilities in safe areas; redundancy in the system, for example, with treatment processes that can tolerate variations in organic loads and are easy to operate; and preference for gravity systems over electromechanical systems (CILA, 2021a, p. 149).

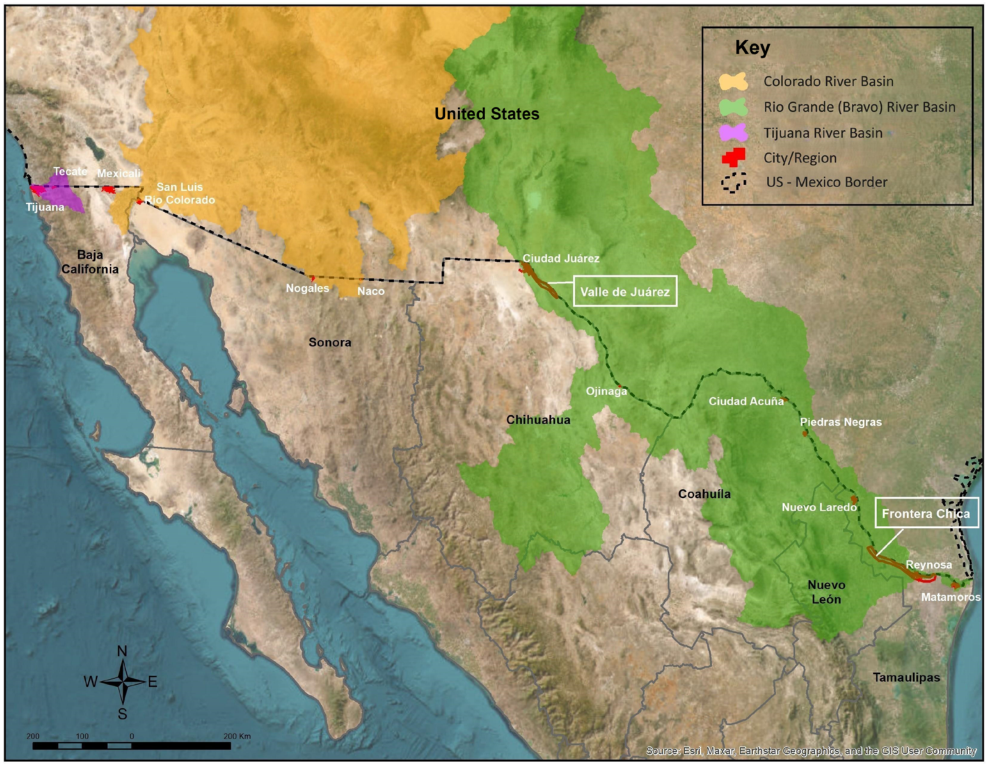
Furthermore, in its general report, the EGV considered four resilience criteria in the sizing of conventional infrastructure project alternatives (catchment, treatment and conveyance processes): robustness, redundancy, resources for adaptation and speed of recovery of service levels. Notwithstanding, it is mentioned that implementing resilience can be extremely costly and can trigger social conflicts, which is why they are generally not evaluated as preferred options (CILA, 2021a).

Table 1 presents information on population, drainage coverage, sanitation and estimated investment for infrastructure projects in the thirteen cities and two border regions analyzed in the EGV. The total estimated investment for a portfolio of 868 infrastructure projects with a time horizon of 2050 is MXN 44.61 billion. The EGV assumes that a percentage of these investments (30%) will come from EPA funds through the NADB. Even though inadequate operation and poor maintenance are two of the main causes of transboundary wastewater flows, the NADB does not allocate a budget to those items, which can be explained because the U.S. Congress does not authorize it to the EPA (Elmer, 2021).

An important fact is that, on average in border cities, 99% of the population—except for some rural communities in the Juárez Valley—is connected to sewer services. These data indicate that the main sanitation problem in Mexican border cities is not sewerage coverage but the growing volumes of wastewater treatment required by the ever-increasing population. In some border cities, such as Reynosa, up to 50% of wastewater is not treated (Leija McDonald et al., 2022).

[5] The region known as Valle de Juárez includes the following border towns in Chihuahua: San Isidro-Loma Blanca, El Millón-San Agustín-Jesús Carranza-Tres Jacales, Porfirio Parra-Barreales-Juárez and Reforma, Guadalupe, Praxedis G. Guerrero, Colonia Esperanza and El Porvenir. The Frontera Chica region includes seven cities in Tamaulipas: Nueva Ciudad Guerrero, Mier, Miguel Alemán, Ciudad Camargo, G. Díaz Ordaz, Río Bravo and Nuevo Progreso.

Figure 1. Mexican border cities and their location in three transboundary river basins



Source: created by the author

Regarding population, Tijuana is the largest and fastest-growing border city. By 2020, the city of Tijuana had already surpassed the projection estimated for 2030 by the *Consejo Nacional de Población* (Conapo). As is evident, population growth is reflected in the need for greater investment in infrastructure. 32.6% of the projected investment is concentrated in Tijuana.

The Conagua took up several of the projects identified in the EGV and incorporated them into the PESFN. The objective of the PESFN is "To promote, with the support of the three levels of government of the Mexican Republic and international actors, necessary actions in sanitation in the municipalities that influence the Mexican borderline" (Conagua, 2021a, p. 234). The PESFN identified 516 actions and an estimated investment amount of MXN 23 823.85 million. Of these actions, 126 are located within the EPA-Conagua Joint Investment Program with an investment of MXN 8.9 billion; of this amount to be invested, Conagua expects the EPA to contribute with MXN 3.7 billion. There is a notable difference in the number of actions and estimated funding between the two programs.

Table 1. Population, growth rates and sanitation investment projections for border cities to 2030

Municipality/ locality	Population 2020	Growth rate 2010-2020	Population 2030 (projected by Conapo)	Housing without sewerage (%)	Required volume of sanitation (l/s)	Estimated investment EGV (millions of pesos)
Tijuana, B. C.	1 922 523	23%	1 910 948	0.16	2 990	14 555
Tecate, B. C.	108 440	7%	119 223	0.34	170	894
Mexicali, B. C.	1 049 792	12%	1 245 707	0.16	1 943	6 049
Nogales, Sonora	264 782	20%	268 419	0.17	713	1 740
San Luís Río Colorado, Sonora	199 021	11.6	226 017	0.25	327	1 333
Naco, Sonora	5 774	-10%	6 987	0.46	19	231
Ciudad Juárez, Chihuahua	1 512 450	13%	1 517 811	0.09	4 555	11 590
Valle de Juárez, Chihuahua	22 197	—	9 348	.65-.92	76	85.3
Ojinaga, Chihuahua	24 534	-7%	33 756	0.09	95	218
Nuevo Laredo, Tamaulipas	425 058	11%	434 412	0.08	1 283	1 218
Piedras Negras, Coahuila	176 327	15%	228 121	0.11	635	1 949
Acuña, Coahuila	163 058	19%	168 952	0.17	456	1 225
Reynosa, Tamaulipas	704 767	15%	916 924	0.06	2 143	2 006
Matamoros, Tamaulipas	541 979	11%	569 325	0.18	1 687	869
Frontera Chica, Tamaulipas	201 132	—	222 907	0.24	121	648

Source: created by the author with data from IBWC (CILA, 2021a), Instituto Nacional de Estadística y Geografía (n. d.) and Conapo (2021)

The registration of projects requiring joint investment in Conagua's hydrological-administrative basin programs can be considered a first step for their certification and financing within the EPA-Conagua Joint Investment Program. In this regard, on December 14, 2021, derived from the proposal of a senator for Chihuahua on a strategy to face the drought in the north of the country, the Mexican Senate approved an agreement requesting the Conagua to update a comprehensive strategy for the management of national waters, with a greater emphasis on the states and municipalities of the northern border.[6]

In January 2022, the Ministry of the Environment and Natural Resources responded with an official letter requesting the creation of a special budget program: sanitation of the northern border to finance sanitation projects and to prepare diagnostics and

[6] Technical data sheet of the approved resolution available at: https://www.senado.gob.mx/65/gaceta_del_senado/ficha/proposicion/20377. Response from Conagua available on the web page of the Legislative Information System: https://infosen.senado.gob.mx/infosen/CCTP/RESPUESTAS/2023-09-05/DGPL_1P1A_3827_MEDIO_AMBIENTE_SEQUIA.pdf

executive projects for the PESFN. Nevertheless, this program was not included in the 2023 or 2024 federal budgets. The only project with a budget allocated for 2024 on the northern border was rehabilitating the La Amistad international dam in Coahuila (MXN $188 686 241).

Sanitation issues and circular economy strategies in three border cities: Tijuana, Nogales and Nuevo Laredo

This section reviews the sanitation issues of three Mexican border cities (Tijuana, Baja California, Nogales, Sonora, and Nuevo Laredo, Tamaulipas) based primarily on the specific EGV reports for each of the three cases, supplemented by secondary sources and key informant interviews. For each city, possibilities for implementing circular water economy strategies such as water recycling, use of treated water, implementation of green infrastructure (for example, constructed wetlands), and elements of energy sustainability were identified.

Sanitation issues in Tijuana, Baja California

In 2020, the population in Tijuana, Baja California, was 1 922 523 inhabitants, with the highest growth rate for Mexican border cities (23.2%) from 2010-2020. Tijuana is highly relevant to border sanitation issues given its proximity to San Diego, California. Both urban areas share water flows through rivers that cross the border from south to north (see Figure 2). Tijuana's sanitation system has 18 treatment plants, the four main ones being IWTP South Bay, WWTP San Antonio de los Buenos (SAB, also known as Punta Banderas), WWTP Arturo Herrera, and WWTP La Morita. The total installed treatment capacity is approximately 3 000 l/s (CILA, 2021b).

The sanitation system operation is based on concentrating wastewater flows in the South Bay IWTP and the WWTP SAB. The IWTP treats about 30% of the volume collected (H. Durán, personal communication, June 9, 2022). The SAB plant, built in 1987, was rehabilitated in 2003 to increase its capacity from 750 l/s to 1 100 l/s. However, it has not been operating adequately, at least since 2004 (C. de la Parra, personal communication, June 15, 2022; R. Laborín, personal communication, June 7, 2022).

WWTP SAB discharges to the ocean and the Tijuana River are the two main sources of transboundary flows of raw sewage, causing a persistent binational environmental problem. The SAB pipeline to the ocean discharges wastewater carried by currents northward, primarily during the summer months, which impacts Imperial Beach. Tijuana's sanitation system has more than 3 800 km of sewer mains, 57% of which are failing due to wear and tear that can result in runoff into the Tijuana River (CILA, 2021b).

In the Tijuana-Arroyo Alamar River area, surface runoff from sewage generated by irregular human settlements in neighboring areas, which lack sanitary sewers, discharges into the river. The proliferation of vegetation and garbage on the Tijuana River, channeled to prevent flooding, results in the recurrent dragging of solid material, which is added to sediments that flow into the Pacific Ocean and thus becomes a channel of mixed water and silt that leads to the sea and an estuary that is an ecological reserve (C. de la Parra, personal communication, June 15, 2022).

The PB-IBWC pumping plant, built in 1991, pumps treated and untreated water during low water periods due to the increased flows that run off from the Tijuana River, usually confined to the lined channel, so it does not cross the border. This system pumps water from the Tijuana River that carries a mixture of treated water from the Arturo Herrera and La Morita WWTPs, as well as water from Tecate and runoff from the dam, to prevent this water from crossing the U.S. border, although its capacity is often exceeded and its cost is very high (H. Durán, personal communication, June 9, 2022; R. Laborín, personal communication, June 7, 2022). Cross-border flows occur when there are operational failures at the PB-IBWC or flows greater than its operational capacity.

The border sanitation issue in Tijuana has led to the signing of several IBWC minutes (270, 283, 298, and 320). In 2017, due to severe rains in December 2016 and January 2017, rainwater entered the wastewater collection system and caused a sanitary sewer to rupture, resulting in discharges into the Tijuana River that crossed the international border.[7]

The Conagua recorded that from 2019 to 2021, the three levels of government invested USD 46 million in projects to clean up the Tijuana River. One of the most important projects was the expansion and modernization of the PB-IBWC pumping plant. By the end of 2021, the EPA reported plans to invest USD 300 million to reduce transboundary wastewater flows.

An issue under discussion was the destination of this investment. The options were: *1*) reduce flows on the Mexican side even with a proposal to recycle water through natural filtration to a dam; or *2*) improve treatment capacity on the U.S. side (R. Laborín, personal communication, June 7, 2022; Elmer & Calderón, 2021). Nevertheless, the problem persisted. In June 2023, a spill of untreated water was reported due to the rupture of a pipe in the outfall sump, which affected up to 40 km of ocean for several months, causing the closure of beaches on both sides of the border (KSDY50 San Diego, 2023).

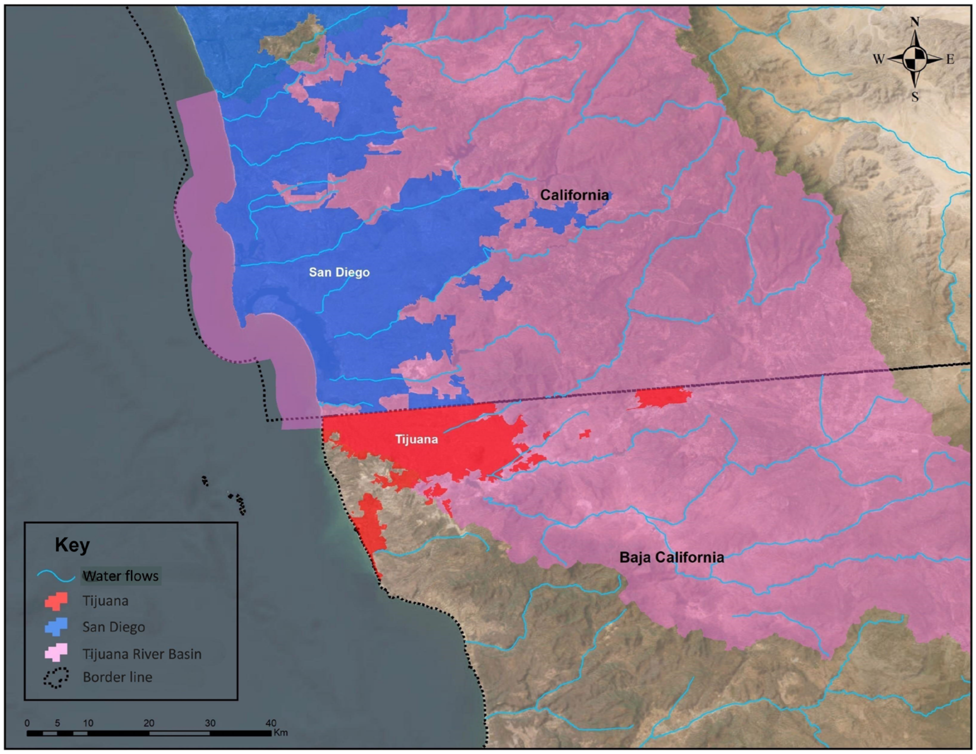
The EGV report for Tijuana generally proposed rehabilitating and expanding the sewerage and sanitation systems. Some specific projects proposed were the construction of a pumping sump to collect wastewater generated in the Sainz Canyon river basin and the construction of a pipeline with a new intake from the Tijuana River to minimize the possibility of transboundary water crossings. No projects related to the recovery of materials, sludge or gases for electric power generation were included, nor was the use of constructed wetlands for wastewater polishing or any form of green infrastructure proposed.

In July 2022, the Conagua and the EPA signed a declaration of intent for the implementation of the following projects: doubling the capacity of the IWTP, the rehabilitation and retrofitting of the WWTP SAB, and the rehabilitation of primary sewer lines and pumping plants. In August 2022, Minute 328, "Sanitation infrastructure projects in Tijuana, Baja California-San Diego, California, for immediate implementation and

[7] The Minute 320 Binational Technical Group and the Water Quality Task Group conducted an investigation of this event, and a spill volume of 143 million gallons was estimated: http://www.cila.gob.mx/syca/idarrt0417.pdf

for future development", came into effect, through which the construction of 17 sanitation projects in Tijuana and San Diego was agreed upon, with an approximate cost of USD 474 million over five years (Conagua, 2023). This means that Tijuana accounts for the largest recent binational investment in sanitation infrastructure on the United States-Mexico border.

Figure 2. Tijuana, Baja California-San Diego, California



Source: created by the author

The Conagua-EPA Joint Investment Program establishes that the Conagua will finance projects to remove and recycle effluents from the Arturo Herrera and La Morita WWTPs, the rehabilitation of the international collector and the rehabilitation of the PB-1, Laureles1 and 2, and Matadero pumping plants (Secretaría de Relaciones Exteriores, 2023). Nonetheless, in 2024, no budget was allocated in Ramo 16, corresponding to Semarnat, for any sanitation project in Tijuana.

Potential CE strategies for the water sanitation system in Tijuana, Baja California

It is estimated that only 6% of the water is recycled in Tijuana. The treated water reuse infrastructure consists of a line that starts at the Arturo Herrera WWTP and sends treated wastewater to Morelos Park, Monte de los Olivos Cemetery and Campestre

Golf Club (CILA, 2021b). On the WWTP SAB grounds, treated water is used to irrigate a garden center. In 2019, treated water began to be supplied to the Samsung plant.

In 2015, the Comisión Estatal de Servicios Públicos de Tijuana (CESPT) prepared a study in which three alternatives for using treated water for aquifer recharge were identified: *1*) recycle all water from the Tijuana and Alamar river basin, including water from the IWTP; *2*) similar to the first, but without including water from the IWTP; *3*) the use of two dams: a new dam on the Tecate River and the Abelardo L. Rodriguez Dam (BDAN et al., 2015). The third alternative was concluded to be attractive because it incorporates a new dam that would capture about 400 l/s based on a preliminary hydrologic analysis. The first two options would require negotiations with the United States to return treated water and conveyance works that would be accommodated within the branch roads to the Tijuana River channelization.

Another alternative whose feasibility needs to be evaluated is the use of treated water for aquifer recharge through the construction of an infiltration system in Valle de Las Palmas. Recently, the pumping of treated wastewater from WWTP Arturo Herrera and La Morita to Valle de Guadalupe has also been contemplated. Reusing treated water from these plants would reduce the volume discharged to the river and the pumping load of the PB-IBWC for the "distancing" (H. Durán, personal communication, June 9, 2022). Potential demand is estimated at 2 400 l/s in agricultural irrigation for the Guadalupe and Las Palmas valleys, 480 l/s for public-urban services, and 58 l/s for industrial, commercial and service use (RL Construcciones y Proyectos, 2017). However, the approximate distance to Valle de Guadalupe is 94 kilometers; consequently, this option involves pumping with high energy costs and environmental impacts.

A sectorization strategy in wastewater treatment, based on the 27 micro-watersheds defined in the urban area of Tijuana, could expand the possibilities of reuse with greater effect in substituting first-use water and be less vulnerable to impacts, for example, climate change. This strategy can be implemented in at least two ways: *1*) if sectorized wastewater management and treatment are adopted, or *2*) if advanced treatment or polishing modules are added for certain volumes of WWTPs in strategic areas (H. Durán, personal communication, June 9, 2022; Stip et al., 2019).

Sanitation issues in Nogales, Sonora

Nogales, Sonora, and Nogales, Arizona, form a cross-border urban area known as Ambos Nogales (see Figure 3). In 2020, the population in Mexican Nogales was 264 782 inhabitants, with a growth in 2010-2020 of 20.2%. Due to the topographic characteristics of this border area, with high slopes toward Arizona, the waters flow by gravity to the U.S. side, and this phenomenon has been recorded as a long-standing problem (IBWC Minute 206, 1958).

The sanitation problems in the city of Nogales, Sonora, result from the fact that much of the sanitation infrastructure has reached the end of its useful life; most pipes are 30 or even 50 years old (CILA, 2021c). Throughout the city, sanitary sewerage has high levels of percolation of rainwater and sand since the rainwater infrastructure in the city is inadequate. This affects the pumping equipment's operation and the outfalls' useful life.

The infrastructure to address the sanitation problem in Nogales includes five plants, the main one being the IWTP Rio Rico, built in 1972 in Arizona, and the second in importance is the WWTP Los Alisos, built in 2012, with a capacity of 220 l/s that discharges to the Bambuto River, although it is estimated that in 2019 it operated with an average flow of 179.29 l/s.

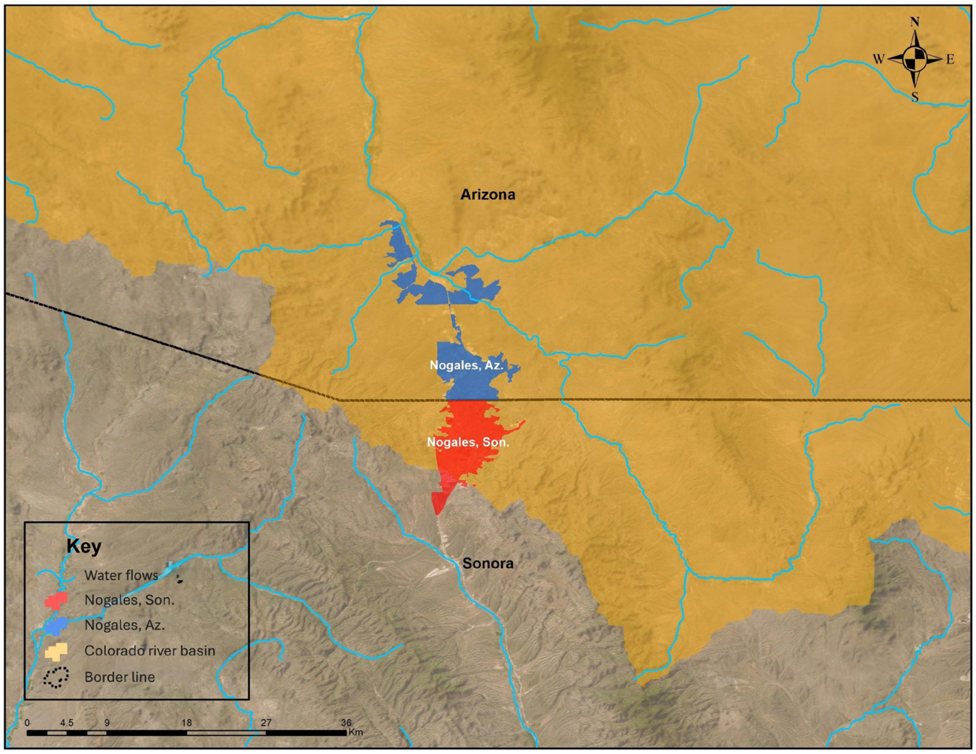
The developers have constructed three WWTPs that have been turned over to the Organismo Operador Municipal de Agua Potable, Alcantarillado y Saneamiento of Nogales for operation: Puerta de Anza, Lomas del Sol and La Mesa (the latter of which is no longer in operation). In 1988, under IBWC Minute 276, the Mexican and U.S. governments agreed that a flow of 434 l/s would be treated at the IWTP. This IWTP was expanded in 2000, and the collection system was renewed in the same year. Other smaller capacity WWTPs are Lomas del Sol and Puerta de Anza, both in the city's eastern sector. The sewerage system was rehabilitated in 2004.

Although the Los Alisos WWTP has five pumping units, it generally operates with only one of these units, as four of them are not functioning due to poor operation. This exceeds the treatment volume allocated to Mexico at the Rio Rico IWTP. The IBWC covers the costs of treating the agreed volume based on the costs of doing so in its territory. In addition, the Organismo Operador Municipal de Agua Potable, Alcantarillado y Saneamiento of Nogales must cover the cost of the actual treatment for the volume exceeding the agreed-upon flow. In 2019, the IWTP treated 573 l/s, which exceeded the agreed volume by 139 l/s.

In 2020, projects were carried out to expand the sewerage system to the southwestern neighborhoods of Nogales. In 2021 it was agreed, through the signing of Minute 326, to rehabilitate the international collector in the face of various malfunctions. Establishing mechanisms to ensure efficient operation and continuous maintenance of the existing binational infrastructure is also an important issue to be addressed (C. Gil, personal communication, June 15, 2022).

Conventional infrastructure projects are proposed in the specific EGV report for Nogales. The main projects are the expansion of the combined capacity of the Los Alisos WWTP from 240 l/s to 440 l/s capacity, the replacement of approximately 5.8 km of deteriorated sewers and collectors in the downtown area, and rehabilitation in several neighborhoods. Other projects contemplated are the rehabilitation of the Los Alisos outfall maintenance wells, the rehabilitation and expansion of the La Mesa plant from 30 l/s to 70 l/s, and the expansion of the Puerta de Anza treatment plant from 45 l/s to 60 l/s (CILA, 2021c). The estimated budget for the identified projects is MXN 1.740 billion (CILA, 2021a).

Figure 3. Nogales, Sonora-Nogales, Arizona



Source: created by the author

Potential CE strategies for the Nogales, Sonora, sanitation system

A first important point to note is that the possibilities for water recycling in Nogales, Sonora, are limited because up to 90% of the wastewater is treated at the Rio Rico IWTP. Nevertheless, the specific report for Nogales states that there is a potential for the reuse of almost 24 million cubic meters of treated water in the WWTP Los Alisos, with a purple line to the industrial zone, new growth areas for irrigation of parks and gardens, car washing, etcetera.

Another possibility is to derive treated wastewater from the WWTPs Lomas del Sol and Puerta de Anza, both in the city's eastern sector, which could provide water for various uses in parks, parkways, commercial and sports areas, and up to two industrial zones. This would require constructing a 12.1 km purple line (CILA, 2021c). In 2022, a project was implemented with EPA and NADB support to identify potential uses of treated industrial water for Nogales (C. Gil, personal communication, June 15, 2022).

There is also an initiative for a binational corridor of green infrastructure to capture water for aquifer recharge and mitigate the impact of stormwater (Giner et al., 2019; Schwartz et al., 2023). Specifically, the creation of rain gardens has been encouraged; these consist of depressions with native vegetation to reduce runoff and, at the same time, filter rainwater and thus contribute to aquifer recharge. Nevertheless, this project is not integrated into the sanitation plans managed by IBWC (EGV) or Conagua (PESFN). These proposals could be integrated into a master stormwater and treated water management plan.

A financial problem facing the city of Nogales, Sonora, is the high electricity cost of pumping raw sewage. Nonetheless, no energy generation alternatives, such as photovoltaic cells, are being considered for pumping water at sites where pumping is feasible.

Paradoxically, the main environmental benefits of sanitation in Nogales, Sonora, are received in downstream locations north of the Rico River, primarily in the communities of Tumacacori and Tubac. Water treated at the Rio Rico IWTP is discharged into the Santa Cruz River. From the treated water discharge site, the Santa Cruz River carries an estimated volume of water between 500 l/s and 950 l/s, of which 90% is water coming from Mexico (García Ochoa et al., 2023).

It is important to consider that the treated water at the Rio Rico IWTP is still Mexican property and could be planned for reuse on the Mexican side (J. Marruffo, personal communication, June 15, 2022). Nonetheless, this would require not only infrastructure for its conveyance and pumping to the Mexican side but also a binational negotiation and an adequate regulatory framework that guarantees public health and water quality while allowing the feasibility of reusing treated water for indirect agricultural, urban, industrial and environmental reuses, such as artificial recharge of aquifers.

Sanitation issues in Nuevo Laredo, Tamaulipas

Nuevo Laredo, Tamaulipas, and Laredo, Texas, also known as the two Laredos, are located within the Rio Bravo/Grande river basin (see Figure 4). In 2020, the population in Nuevo Laredo was 425 058 inhabitants. Compared to 2010, the population grew 10.7%. Nuevo Laredo's sanitation system can treat 1 617 l/s of wastewater through five WWTPs.

The sewer network was built in 1900-1920 and consists of approximately 781 km of pipes. The concrete pipes (77.3%) have reached the end of their useful life, estimated at 15 to 30 years, mainly in the center of the city, which causes land subsidence commonly called "sagging" (CILA, 2021d).

In 1989, a sanitation project was initiated with six main components: a river connector, the Coyotes connector, the rehabilitation and subsequent network expansion, a pumping plant and a treatment plant. This project was completed in 1996 at a cost of USD 60 million. Although it was not possible to disconnect the sanitary system from the rainwater system, discharges to the Rio Bravo were reduced from 1 100 l/s to 160 l/s (D. Negrete, personal communication, June 7, 2022).

The Nuevo Laredo IWTP is the largest plant, with an installed capacity of 1 360 l/s using a secondary treatment system. It began operations in 1996 and is expected to reach the end of its useful life by 2036 (D. Negrete, personal communication, June 7, 2022).

The effluent quality of the IWTP meets the mandatory parameters established by the IBWC because it discharges into the flood zone of the Rio Grande, an international body of water. It operates at about 70% (950 l/s) of its capacity, generating an average of 10 tons of sludge per day.

The disadvantages of the current way of handling sludge at the IWTP are the insufficient space—both in the drying beds and in the storage space within the IWTP prior to final disposal in the landfill—and the potential environmental impacts it has because it is considered waste. Sludge management at the IWTP represents the plant's biggest operational and economic problem due to the saturation of the drying and storage space and the need to transport it for final disposal in landfills with the consequent transportation costs.

The WWTP Norponiente discharges its effluent, with a quality that meets the conditions for human contact, to the El Coyote stream, where it forms a small backwater called El Laguito, which is used for recreation (CILA, 2021d).

Nuevo Laredo has sanitation responsibilities established in two IBWC minutes. The first was signed in 1989, Minute 279, "Joint measures to improve the quality of the waters of the Rio Grande in Nuevo Laredo Tamaulipas-Laredo Texas". In 1997, Minute 297, "Operations and maintenance program and distribution of its costs for the international project to improve the quality of the waters of the Rio Grande at Laredo, Texas-Nuevo Laredo, Tamaulipas" was signed.

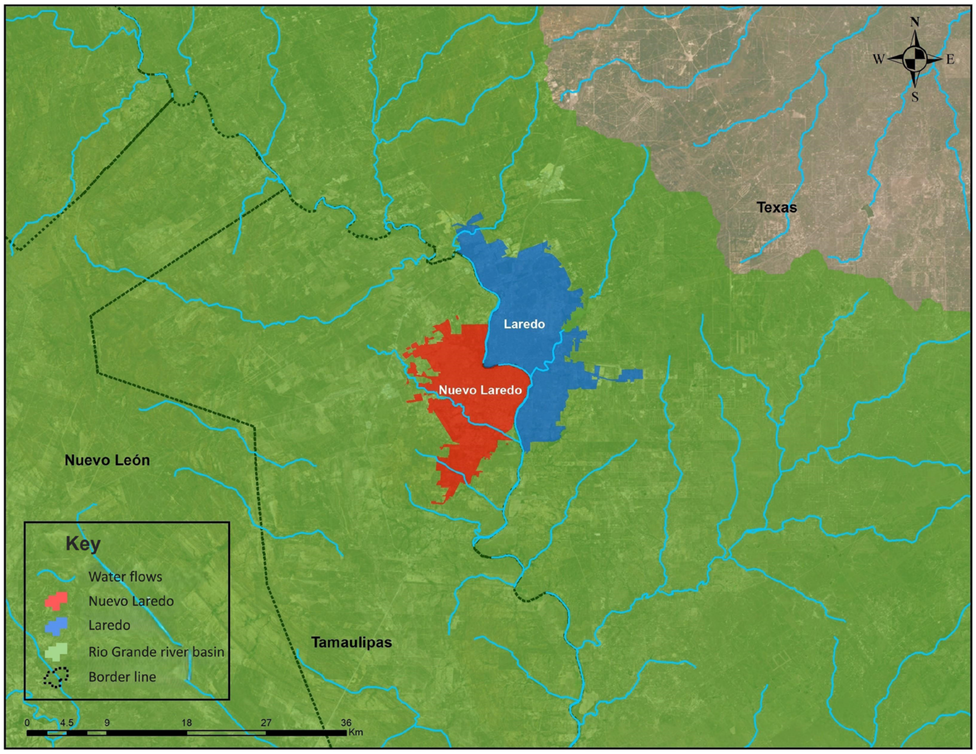
In 2013, it was estimated that at least 19 million liters of wastewater from Nuevo Laredo were discharged into the Rio Bravo/Grande (Satija, 2013). For 2023, it was estimated that 47 million liters of untreated water per day would be discharged into the Rio Grande. That year, discharges occurred in both the sanitation and rainwater systems (D. Negrete, personal communication, June 7, 2022).

To address the sanitation problem in Nuevo Laredo, the EGV proposes a program similar to that of 1996: rehabilitate the river collector, rehabilitate the Coyotes collector, increase the diameter, expand the network in some neighborhoods that do not have sewerage, and the rehabilitation, which is the core of the center of the city, of the fallen, sinking and collapsed sewerage systems.

In June 2023, one of the main projects is expanding the WWTP Norponiente's (200 l/s) capacity to its full design capacity of 600 l/s. Approximately 25% of the total sanitation expenditures correspond to electrical energy expenses. In this regard, the EGV proposes reengineering the pumping stations and acquiring emergency plants in priority facilities in the event of an eventual lack of electrical energy.

Concerning sludge management, the EGV mentions an intention to develop a large-scale composting project to use the 10 tons of sludge and produce more than 10 tons of organic fertilizer per day. Nevertheless, the actions identified do not include this project, only a budget for external sludge disposal.

Figure 4. Nuevo Laredo, Tamaulipas-Laredo, Texas



Source: created by the author

Potential CE strategies for the Laredo, Tamaulipas sanitation system

In Nuevo Laredo, only 6% of the water treated at the IWTP—more than 2 300 000 m^3—is recycled (CILA, 2021a). Treated water is used to cool the electromechanical equipment at the IWTP itself and to irrigate some municipal green areas, such as Viveros Park and the Paseo Colón walkway through a treated water line. Treated water from the Las Torres WWTP is used to irrigate Silao Park, Las Torres Boulevard and Las Palapas.

The EGV proposes a reuse study and executive project to expand water recycling. Some future recycling options are: in the agricultural sector, for the compaction of land for urban development, and the delivery of wastewater to the industries of Nuevo Laredo and surrounding municipalities that do not require first-use water for their processes, which would free up the first-use water that is destined for this activity.

No forms of green infrastructure have been implemented in any WWTP in Nuevo Laredo, such as constructed wetlands associated with wastewater treatment. Nonetheless, given the good quality of the sludge produced by the IWTP, small-scale composting has been initiated as an option for recycling nutrients to make fertilizers. In addition to large-scale composting, projects for electricity-generating plants using some percentage of the sludge could be considered to reduce the volume of sludge and the cost of electricity (Aguilar-Benítez & Blanco, 2018).

For a possible decentralization process of sanitation in Nuevo Laredo, the city can be sectorized into five main drainage river basins: Puente III, Alazanas, Coyote, Ribereño and Las Animas. These drainage basins represent geographically distinguishable areas in which decentralized treatment systems could be implemented.

An important project planned to be built in the flood zone of the Rio Grande is the Dos Laredos Binational Park: "mirror parks" on both sides of the border, with a total extension of ten kilometers along the river. This project, presented in February 2022, is an initiative of the mayors of Laredo and Nuevo Laredo and the Chamber of Commerce and was supported by the United States Ambassador and promoted by the Rio Grande International Studies Center (Creciendo con Nuestro México, 2022).

This project is inspired by the San Antonio River Walk and includes parks, sports and cultural facilities and sanctuaries (D. Negrete, personal communication, June 7, 2022; Oliveras González, 2024). This project requires the restoration of the river, rehabilitating the sanitation and storm drainage systems to eliminate untreated water discharges and eliminating invasive and highly water-consuming vegetation; treated water would be used to irrigate green areas.

Conclusions

Continued binational investments in conventional sanitation infrastructure since the 1970s have achieved nearly complete coverage of household connections to the sanitary sewer system in northern Mexican border cities. Nonetheless, sanitation systems deteriorating due to the end of their useful life or inadequate maintenance or operation result in volumes of untreated water and spills of treated and untreated wastewater crossing the United States-Mexico border.

In general, sanitation programs are oriented toward increasing investments to try to cover sanitation system failures due to natural deterioration, deficient operation and maintenance, or new needs derived from strong and continuous population growth. This type of planning prioritizes the renovation, rehabilitation and expansion of conventional infrastructure.

A key aspect is that this planning approach, in a context that implies environmental commitments with potential sanctions by the environmental chapter of the USMCA and possibilities of financing environmental infrastructure with broad scopes, has not been adjusted to new approaches such as CE and forms of green infrastructure.

This paper shows that the EGV and PESFN programs prioritize conventional infrastructure and insufficiently incorporate CE strategies or forms of green infrastructure despite proposals made by the NADB to finance infrastructure to address climate change and promote a green economy and the proposal in the PAF 2025 that 100% of Border Environment Infrastructure Fund projects should include an assessment of water recycling opportunities.

Unfortunately, the conventional approach has been insufficient to solve the cross-border sanitation problems that have persisted for several decades, as observed in the three cases reviewed and to a greater degree in Tijuana, with persistent leakage and spillage of wastewater across the border.

Although sanitation systems will continue to rely significantly on conventional infrastructure, given that it is unfeasible to replace it completely, it is necessary to identify a viable balance between an approach based on conventional infrastructure and CE strategies, including green infrastructure. Several important aspects were identified for achieving greater sustainability and resilience in sanitation systems:

1) The possibility of replacing the scale and degree of centralization of these systems (for example, large plants that concentrate treatment in the peripheries or outside the cities) with a sectorized system (considering the micro-watersheds in a city). A sectorized system may offer better possibilities for resilience to phenomena such as climate change.

2) The need for sufficient local operational and financial capacity to operate and maintain infrastructure (new or rehabilitated) that is resilient to change.

There is also a need to develop master plans for integrated stormwater and treated water management in each city, including green infrastructure to promote filtration and aquifer recharge. Binational cross-border projects with an environmental focus—for example, the green infrastructure network in Ambos Nogales and the Dos Laredos Binational Park—should be integrated into the master plans because they are interdependent with integrated stormwater and sanitary drainage and depend on effective wastewater sanitation.

In particular, the Ambos Nogales green infrastructure network proposal offers a model for merging CE solutions to restore ecosystem services with a strategic and binational planning approach (Lara-Valencia et al., 2022). An integrated approach also requires that water and sanitation and environmental agencies at the municipal and state levels coordinate and establish programs that consider how water and sanitation management affects or benefits the environment of border cities.

In urban planning, it is necessary to consider that new housing developments that comply with an adequate scale include CE strategies to take advantage of water through the retention, treatment, reuse, and recycling of water supplied by municipal systems and the environment (rainwater capture, rain gardens, decentralized treatment, among other strategies). This would require adapting local regulations and identifying and promoting economic incentives.

As the literature review suggests, transitioning to a circular economy in the sanitation sector requires governance frameworks that promote collaborative efforts between governments, private sectors and civil society (Ddiba et al., 2020). It is necessary to recognize that, given the binational nature of the border sanitation issue addressed in this paper, further analysis is required that includes aspects such as management structures and the changes needed to incorporate the principles of CE and green infrastructure approaches in sanitation planning, financing, regulation and implementation.

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