13 Treatment Plant Effects on Wastewater Irrigation Benefits: Revisiting a Case Study in the Guanajuato River Basin, Mexico

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Abstract

In 1999 field research was carried out to explore the advantages and risks of urban wastewater use for 140 ha of crop production in the Guanajuato River basin. It was found that wastewater which was freely available to the farmers represented an important additional source of irrigation water, with secondary benefits including nutrients and the foregone cost of wastewater treatment. In 2002, the urban water supply and sanitation utility, a financially autonomous public utility, began to operate an activated sludge wastewater treatment plant in response to the imposition of legally mandated fines for the release of untreated wastewater to open water bodies. As follow-up to the 1999 study, this chapter is based on field visits and interviews and sets out to qualitatively answer the following research question: Does the introduction of wastewater treatment influence the crop production benefits of wastewater irrigation? The study found that because wastewater treatment was oriented to comply with environmental regulations, little attention was paid to the links with the land irrigated by wastewater. The presence of the treatment plant provides the utility with the option of selling treated wastewater, thus increasing its own economic benefits. Industrial users appear to be the most suitable potential customers; the utility would stand to receive US$0.43/m^3 in estimated sale price plus saving the US$0.25/m^3 fine. This transfer of water would introduce competition among water-use sectors, a process that is already leading to wastewater farmers' uncertainty about their future share of irrigation water. However, to date no commercial transaction to transfer treated wastewater to non-agricultural users has taken place. For this reason the expected changes in impacts on wastewater farmers have been minimal. If this happens, however, the wastewater farmers stand to lose because only about 30% of the wastewater-irrigated land has a water concession title (linked to the land) issued by federal authorities.

Introduction

In 1999 field research was carried out by Scott *et al.* (2000) to explore the advantages and risks of urban wastewater use for crop production in the water-short Guanajuato River basin in west-central Mexico where at least 140 ha of land were irrigated with raw wastewater downstream of the city of Guanajuato[1] in two peri-urban communities: San José de Cervera

[1] Guanajuato is the name of the state as well as its capital city (and the river that runs through it). Unless otherwise indicated, Guanajuato here refers to the state not the city.

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and Santa Catarina. Findings showed that wastewater represented an important additional source of irrigation water, with secondary benefits including nutrients and the foregone cost of wastewater treatment. It was stated that 'wastewater irrigation is a critical component of intensive water recycling in the Guanajuato River basin, based primarily on the value of the water resource and the nutrients it transports. The land irrigated with raw wastewater downstream of the city serves as *de facto* water treatment with significant retention of contaminants' (Scott *et al.*, 2000). The study did not measure the environmental costs and risks associated with untreated wastewater irrigation, which if adequately quantified would reduce the overall benefits. The study did address health risks but was unable to draw firm conclusions based on: a. the difficulty in establishing clear causal links between wastewater quality and health, and b. insufficient data on diarrhoea incidence.

Wastewater irrigation and discharge to open water bodies – in Mexico all rivers, lakes, wetlands, and groundwater are considered public property under federal jurisdiction – are subject to the maximum allowable contaminant limits established in the environmental regulation NOM-001-1996.[2] This regulation also establishes a fine of US$0.25/m^3 of untreated wastewater discharge that exceeds the permitted limits. In accordance with this national policy, urban water supply and sanitation utilities across the country constructed wastewater treatment plants using a timeframe based on the population size of the city. In June 2000 the Guanajuato city utility called the Sistema de Agua Potable y Alcantarillado de Guanajuato (SIMAPAG) (in English, the Guanajuato Water Supply and Sanitation Board) undertook the construction of an activated sludge plant to treat all the wastewater discharge from the city centre. The treatment plant started operating in June 2002. This chapter addresses the changes in wastewater irrigation in the Guanajuato River basin that are occurring as a result of the treatment plant. It attempts to provide qualitative answers to the research question: 'Does the introduction of wastewater treatment influence the crop production benefits of wastewater irrigation?'

The need to assess the effects of the introduction of wastewater treatment on downstream irrigation is essential due to the rapid implementation of wastewater treatment in Mexico, a country where unregulated wastewater irrigation is prevalent. In addition, the experience of a middle-income country in converting from untreated to treated wastewater use provides important lessons for low-income countries that are considering wastewater treatment. Backed by the national environmental laws and state policies, treated wastewater volumes will increase in Mexico and as a consequence, the use and management of wastewater irrigation will change. For instance, in Guanajuato 87% of its wastewater should be treated by 2005 compared to the current 57% (CEAG, 1999). In this state alone, approximately 20,000 ha (5% of the 416,690 ha irrigated in the state) could be irrigated using the 207 million m^3 of wastewater currently generated annually in the state's 46 municipalities.

The first part of the chapter consists of a general overview of the Guanajuato River followed by a brief description of the salient characteristics of SIMAPAG and its wastewater treatment plant. In the second part the use of wastewater in agriculture and its consequences in the state of Guanajuato are reviewed, followed by a discussion of the treatment plant's impact on urban wastewater use for crop production. Finally, lessons learned and policy recommendations are presented.

The Guanajuato River Basin

The Guanajuato River constitutes a sub-basin to the Lerma–Chapala Basin. It encompasses the municipalities[3] of Guanajuato, Silao, Irapuato

[2] Having followed the procedures established in the Federal Law on Methodology and Regulations to formulate Mexican Official Regulations, the National Consultative Committee on Environmental Protection Regulations, on 30 October 1996, passed the Mexican Official Regulation (in Spanish, Norma Oficial Mexicana, NOM) NOM-001-ECOL-1996.

[3] In Mexico, the municipality is the next political and administrative level below the state and encompasses both the urban or town centre and the surrounding rural areas.

and Romita. The wastewater produced in these cities, estimated at 1 m^3/s, receives varying levels of treatment – from secondary treatment in Irapuato to none at all in smaller urban centres like Romita. As a result, the 12-km reach of the Guanajuato River from the city to La Purisima reservoir is highly contaminated with organic loads, bacteria and inorganic pollutants. In this reach, untreated wastewater is diverted for irrigation purposes. During the field work of 1999, the irrigation diversions for the two peri-urban communities, San José de Cervera and Santa Catarina, were studied in depth (Scott *et al.*, 2000). One important characteristic of this relatively small sub-basin is the presence of multiple water and nutrient recycling loops. Based on flow measurements of the total river discharge of 0.305 m^3/s flowing out of the study reach over half (0.162 m^3/s) was comprised of return flows. This means that the sub-basin's limited water resources could be managed to satisfy multiple demands.

National Water Commission (CNA) data show that from 1992 to 1999, water quality in the Guanajuato River further downstream of the larger city of Irapuato, but above its confluence with the Lerma River, deteriorated significantly (CNA, 2000). According to these data, the Guanajuato River is considered contaminated for agricultural uses.

SIMAPAG and the Wastewater Treatment Plant

In order to better understand options for wastewater management it is critical to review the basic features of the water supply and sanitation utility. One of a total of 31 water supply utilities in the state of Guanajuato, SIMAPAG supplies municipal water and manages sewerage in the city of Guanajuato (total population around 106,000). SIMAPAG is a financially autonomous public utility with an independent administration that is subject to regulatory oversight by a governing council of municipal representatives and citizens who are appointed by the elected municipal government. The SIMAPAG governing council appoints the utility's general manager and approves the budget including water and sanitation fees.

At the state level, water supply coverage is over 95% of the urban population and 75% of the rural population. In recent years, the growth in number of connections has consistently exceeded population growth (Fig. 13.1) indicating that urban water supply coverage will soon reach 100%. The relevance of these data is that wastewater volumes will continue to grow at rates faster than urban population growth. Many of the federal programmes to support municipal water utilities are not expressly oriented to increase water supply and sanitation coverage, but instead to rehabilitate infrastructure. This only permits increased coverage indirectly.

In 2001, Guanajuato city's potable water supply level was 95% and the sewerage coverage level was 82%. Domestic connections represented almost 94% of the total water connections. Meters (some 25,000 in total) are installed on all connections allowing the utility to estimate wastewater discharge by household. The average monthly consumption per connection was 27.7 m^3 at an average fee of US\$0.59/m^3 (Scott *et al.*, 2000). Sewerage and other non-water supply fees represent 8.3% of the billed amount; this will increase to 10%. SIMAPAG pays the federal government approximately US\$200,000 in water use fees; however, as an incentive federal authorities waived these fees during the period of wastewater treatment plant construction just as they do for other urban water utilities in the process of wastewater treatment implementation.

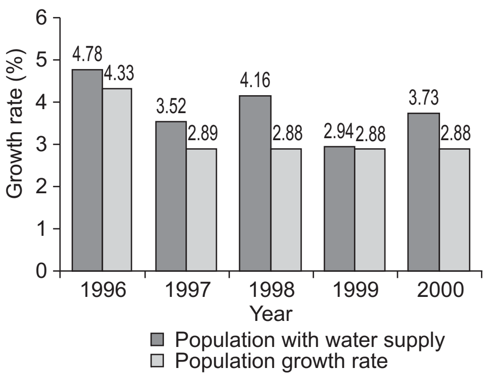

Fig. 13.1. Comparison between population growth rate and increase in water supply coverage in Guanajuato state, Mexico (CEAG, 2001).

In 2002, a financial surplus of US$158,000, or 25% of expenditure, was generated. Subject to the approval of the governing board, surpluses are used for infrastructure improvement and other capital investment. Despite significant outlays to cover SIMAPAG's share of the wastewater treatment plant construction in 2001 and 2002, the accumulated reserves totalled US$1,182,000 at the end of 2002 (Marco Antonio Ortíz, SIMAPAG general manager, personal communication, 2003). Additionally, the overall efficiency (including the physical, commercial and billing efficiency) has varied between 55.8% and 61.2% in the past 4 years. SIMAPAG aims to increase this to a consistent 60%, the benchmark set for receiving performance- based federal support programmes including wastewater treatment.

The total annual wastewater volume generated in Guanajuato's 46 municipalities is 207.13 million m^3. If this water could be used directly for agricultural purposes, around 20,000 ha of grain crops could be irrigated, equivalent to almost 5% of the actual irrigated land in the state (416,690 ha). At the end of 1998, only 25 million m^3/year were treated; however, in the first quarter of 1999, this increased to 34.46 million m^3/year. There are 16 urban wastewater treatment plants and another 26 plants in rural areas. Of the urban plants, at least four are officially recognised as having agricultural use (Irapuato, San Francisco del Rincón, Coroneo and Tierra Blanca). Eleven small rural plants, each with a design discharge of 2–10 l/s, generate treated wastewater used for irrigation. However, there is a declared lack of technical and administrative capacity on the part of many utilities to implement wastewater treatment and cost recovery.

SIMAPAG constructed an activated sludge[4] with chlorine disinfection treatment plant for a total investment cost of US$3.6 million (see Fig. 13.2 and Table 13.1). The federal government contributed 24%, the municipal government 40%, and SIMAPAG the remaining 36% derived from the operating budget surpluses carried forward from past years. According to the average consumption per connection the expected sewage

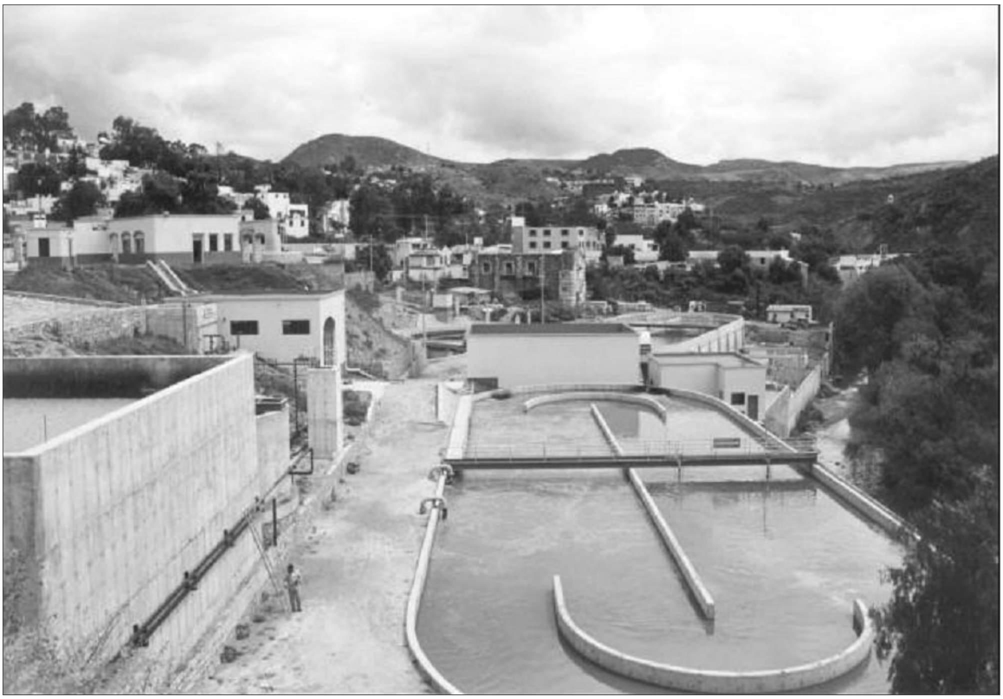

Fig. 13.2. The Guanajuato city wastewater treatment plant

[4]The 1,100 kg of sludge generated daily is landfilled.

Table 13.1. Plant treatment design parameters.

Parameter	Unit	Influent	Effluent
Design discharge	lps	140	140
Total suspended solids (TSS)	mg/l	217	< 60
Total biochemical oxygen demand (BOD_5)	mg/l	337	< 60
Total nitrogen (Kjeldahl)	mg/l	82	< 35
Faecal coliforms	MPN /100 ml	6.2×10^6	< 1000
Total phosphorus	mg/l	11	< 20

discharge[5] from Guanajuato city is 0.14 m^3/s or 12.1 million l/day. Before the wastewater treatment plant started operation, this effluent flowed directly down the Guanajuato River where it was diverted for irrigation. Currently 70% of the total wastewater discharge is treated – the wastewater collector pipe for the treatment plant inlet only covers the main part of the city and does not collect sewage from the neighbouring peri-urban community of Marfil that represents the remaining 30% of wastewater. The wastewater generated in this area continues to flow downstream untreated. SIMAPAG will have to pay some US$470,000 annually in discharge fines unless it makes satisfactory progress in treating this wastewater.

SIMAPAG had four principal motives behind the implementation of wastewater treatment, it aims to:

- Meet the maximum allowable contaminant limits according the National Water Law and comply with discharge regulations or face fines
- Assume responsibility for water quality preservation
- Improve the public health and ecology
- Benefit directly the 81,000 inhabitants who are provided with sewerage coverage.

Urban Wastewater Use for Crop Production and its Consequences

Irrigation with wastewater is a common practice in Guanajuato. According to official records, there are 3,200.4 ha irrigated with wastewater, with a water volume of 19.1 million m^3 (Sánchez, 1995), but there are numerous wastewater irrigation areas that have not been accounted for. One of the most important areas for this kind of irrigation is the area surrounding León, Guanajuato's largest city with a population of approximately 1 million. Starting at least 40 years ago, irrigation with wastewater began in a small area to the south-west of the city and spread southwards with the expansion of the urban area and the consequent greater availability of wastewater (Sánchez, 1995). A considerable volume of wastewater is used in agriculture, with or without federally approved water use rights.[6]

Health and environmental risks have been identified particularly because of the prevalence of chromium derived from Leon's important leather and tanning industries. The risks to exposed populations are dependent mainly on water management and the irrigation methods used (Blumenthal *et al.*, 2000). In León, wastewater is used in furrow irrigation of maize and alfalfa. Similarly, in the Guanajuato city study area only furrow irrigation is used for maize and alfalfa.

Treatment Plant Effects on Wastewater Irrigation Benefits

Benefits of untreated wastewater use

Before the construction of the wastewater treatment plant, a number of wastewater irrigation benefits in the study area were identified.

[5] This figure was estimated based on the 2000 SIMAPAG records of 27.7 m^3/month average consumption and 22,347 connections, and assuming that 70% of the total consumed water per outlet will return as sewage.

[6] All irrigation water users in Mexico are supposed to be listed in the Public Register of Water Rights (Registro Público de Derechos de Agua). Failure to register can entail that water use may be summarily curtailed.

According to Scott *et al.* (2000), the benefits from wastewater irrigation are as follows:

1. The water used for irrigation represents a recycling of urban wastewater in a basin context. Related studies found that irrigation output per hectare is approximately US$1,800, and per cubic metre of water is US$0.16 (1994 dollars) (Kloezen and Garcés-Restrepo, 1998). Therefore, the water value of wastewater used for irrigation represents a significant monetary benefit to both society and the water users.
2. The waste stream has a nutrient value that represents an input that reduces the agriculture production costs. For the case study, the annual gross values of the wastewater and wasteload to farmers in San José de Cervera were estimated at US$252,000 and US$18,900 in Santa Catarina.
3. The continued application of the wastewater to the land would be a more economical form of wastewater treatment than activated sludge treatment and subsequent discharge to the open river where treated water is mixed with untreated discharge further downstream.

These benefits were reassessed in light of the implementation and operation of the new wastewater treatment plant, based on field visits and discussions with the treatment plant manager and the SIMAPAG general manager as well as with farmers from San José de Cervera and Santa Catarina communities.

Impact on water value

The presence of a treatment plant provides SIMAPAG with the option of selling the treated water to whichever sector can afford it; however, no commercial transaction has taken place yet. Various plans to sell water for tourism development, a golf course, an expansion of the University of Guanajuato campus, etc. continue to be considered. This would definitely add value to the water but would also result in greater competition among water users, some of whom have existing rights over the wastewater flow. Findings showed that the operational cost of one m^3 of treated wastewater is US$0.11. By means of a sanitation service charge equivalent to 10% of the billed amount for water supplied, SIMAPAG recovers US$0.04/$m^3$ from domestic users and US$0.08/$m^3$ from industrial and commercial users. Therefore, in order to be profitable the sale price for treated water should be at least US$0.07/$m^3$. Industrial customers could afford to pay up to US$0.50/$m^3$ giving an estimated surplus of US$0.43/$m^3$. Small-scale agriculture could scarcely afford to pay for treatment or for the fine, confirming that the polluters should not expect existing users to pay for treatment. The productivity of small-scale irrigation systems in the area however (around US$0.15/$m^3$ according to Silva Ochoa *et al.*, 2000) is lower than the cost of the untreated wastewater discharge fine (US$0.25/$m^3$) and approximately in the same range as the operational cost of treatment (US$0.11/$m^3$). Higher productivity – up to US$0.50/$m^3$ – could be reached if more profitable crops like vegetables were cultivated, but vegetables and greens consumed raw are not permitted to be irrigated with wastewater in Mexico. From the above analysis it is clear that the treatment plant is not a benefit to the farmers.

Impact on nutrient value

The existing concentrations of total nitrogen (N) and total phosphorus (P) in the effluent are sufficient to meet the nutrient requirements for alfalfa. Considering a 1 m irrigation depth to satisfy the alfalfa nutrient demand, which is equivalent to 88 kg N/ha and 115 kg P/ha, the required concentrations are 9 mg/l for N and 12 mg/l for P, both significantly lower than the design quality of the effluent (Table 13.1). These results concur with what was observed during the field visits; farmers showed very little concern for the reduction of nutrients due to wastewater treatment upstream. Actually, farmers appeared to have little evidence of any treatment taking place because treated and untreated discharges mix in the river downstream of the plant. Improved water quality can only be visually appreciated 4 km downstream of the plant. Further down, a slaughterhouse dumps significant quantities of contaminants in the river. Moreover, in most cases the treated wastewater still has high nutrient concentrations ranging from 20–40 mg

N/l, 20–35 mg P_2O_5/l, and 40–50 mg K_2O/l. As a result, water users' primary concern is that volumes will reduce.

The sludge represents an important source of nutrients; the treatment plant produces 1.1 tonnes of waste solids daily. The storage and elimination of this material is one of the major operational problems faced by the plant. According to the recommended application rate of sludge for agricultural soils (15 t/ha per year), the total area that would benefit from the wastewater treatment is 30–50 ha, which is only around 20–30% of the total wastewater use area. Unfortunately, the solid waste is taken to a landfill. Because Guanajuato has no major industry, heavy metals are not a problem (the 1999 study found that heavy metals were within US and European norms).

Impact on foregone treatment costs

It appears obvious that wastewater irrigation was not considered as an alternative method for wastewater disposal. The definitive guideline for the selection of the wastewater treatment process was the environmental regulations described in NOM-001-1996. The possibility of using wastewater irrigation as a complementary process for wastewater treatment was not considered. However to make this a viable option the total land area required for this purpose should have water rights, which is not the case at present (most of the land currently irrigated with wastewater does not hold an officially recognised right). Annually, there are 300,000–500,000 m^3 of water that is legally granted, which represents just 30–50 ha of irrigated land.

From SIMAPAG's perspective, the wastewater treatment plant should be oriented to the use of treated wastewater in various types of landscape irrigation, i.e. golf courses and parks, where the maximum allowable limits are higher than those for agriculture. At present there is no concern to treat wastewater specifically for the requirements of the pre-existing use, which is irrigation. SIMAPAG seeks to treat water to the level required to avoid the fine and to sell treated water in order to recuperate the capital investment. The cost and difficulty in operating and maintaining a conventional treatment plant to produce effluent that meets the limits for irrigation are too high for agriculture to bear. This represents a clear case for the 'polluter pays' principle.

Conclusions and Recommendations

Wastewater treatment in Guanajuato city has been implemented despite the lack of an integrated framework for its use or for wastewater management in a larger basin context. The ideal outcome of wastewater treatment would be to increase the benefits of municipal water users and the utility as well as those of agricultural and other (potential) wastewater users. Nevertheless, Guanajuato's wastewater treatment project was oriented to meet environmental regulations and little attention was paid to the links with existing wastewater use for irrigation. As a result, the immediate benefit from the implementation of wastewater treatment is simply to avoid the pollution fine. Strictly from the financial perspective, this is cause enough to treat the city's wastewater.

The major impact of treatment for the users of wastewater is the possible reduction in the water discharge in the river if the treated water is sold to non-agricultural customers either inside or outside the Guanajuato River sub-basin. While there has been speculation that the General Motors automobile assembly plant in the adjoining Silao River sub-basin is looking for additional sources of water, at present the purchase and piping of water appear to be prohibitively expensive. Farmers are in a weak position to defend their access to the wastewater flows given that only 30–50 ha have a water entitlement.

There is little or no expected impact on the nutrient value resulting from treatment, given that the nutrient requirements of the principal crop, alfalfa, would continue to be met even after treatment. Additionally, other sources of untreated urban wastewater enter the river downstream of the treatment plant, entailing sufficiently high nutrient loads that little effect of treatment was perceptible to the farmers. The benefits from the waste solid sludge are being lost because these go directly to a landfill instead of being spread on agricultural land.

Further research is needed to identify conditions under which the substantial benefits of wastewater irrigation can be captured while financial sustainability of the water supply and sanitation utilities is maintained. The following issues need to be addressed in further detail:

- The conditions required for wastewater markets to function, specifically commercial feasibility for irrigation use of treated vs. untreated wastewater, pricing and supply mechanisms, etc.
- Water rights conflicts
- Hydrological impact of selling the treated water outside the sub-basin
- Water quality assessment of the final use, e.g. at the farm level for irrigation
- Accounting for the nutrients lost in the treatment process.

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