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Research Paper

Consolidating the use of reclaimed water for irrigation and infiltration in a semi-arid agricultural valley in Mexico: water management experiences and results

L. G. Mendoza-Espinosa and L. W. Daesslé

ABSTRACT

The city of Ensenada (Baja California, Mexico) experiences severe water restrictions for urban and agriculture use, and reclaimed water (RW) for crop irrigation and aquifer infiltration has been identified as a promising water management option. This paper presents the path followed to consolidate the reclamation scheme that included monitoring programs on RW, groundwater, and agricultural soil. Seventy-nine percent of the RW samples complied with the particular discharge permit for El Naranjo wastewater treatment plant (WWTP), yet the local water utility has to have a better control of its wastewater treatment plant to avoid spikes of fecal coliforms. The presence of fecal coliforms in soil samples at surface and 30–60 cm depths indicates that farm workers could be at risk during the handling of the product, so it is highly recommended that workers be provided with clothes that will protect them from direct contact with water and soil. Results from monitoring wells adjacent to Las Ánimas and San Carlos creeks showed, on some occasions, the presence of fecal and total coliforms that could indicate infiltration of RW. In conclusion, technical aspects can be monitored and controlled yet the most challenging aspects that remain are social and political which require extensive negotiation and institutional arrangements.

Key words | crop irrigation, Ensenada, Mexico, water reclamation

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INTRODUCTION

Developing operational water reuse programs around the world can be very challenging. There are a series of factors that have to be considered, many dealing with cultural issues. In Mexico, even though in certain parts of the country wastewater reuse is common, even for the cultivation of crops for human consumption (Jimenez 2005), in other parts it has been very difficult to implement. Such is the case of Ensenada, the only city in Baja California that relies mainly on local aquifers and not on the Colorado River for water supply. One such aquifer is located in the Maneadero agricultural valley, an important producer and exporter of vegetables and the main water source for the city of Ensenada (250 liters per second (lps), equivalent to 7.9 million cubic meters (Mm^3) per year). Conversely, Ensenada produces approximately 600 lps (19.5 $Mm^3\,y^{-1}$) of disinfected secondary effluent from four wastewater treatment plants. Mendoza-Espinosa *et al.* (2004) determined that this reclaimed water (RW) met quality standards for the irrigation of crops not suitable for human consumption, and for aquifer infiltration.

In 2009, a pipe to supply Maneadero with Ensenada's reclamation water was built, but was not used for years due to a disagreement on the cost of the RW for farmers. With the help of academics from UABC, and after many years of negotiation between the state water authority

doi: 10.2166/washdev.2018.021

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called CESPE (acronym in Spanish for Comisión Estatal de Servicios Públicos de Ensenada) and the local farmers, it was agreed that the water would be supplied free of charge, and in June 2,014 CESPE started to send 200 lps (6.3 $Mm^3\ y^{-1}$) of RW to Maneadero Valley for the irrigation of fodder and flowers and discharge into the dry San Carlos and Las Ánimas creeks.

A water quality monitoring program was established to ensure that risk to health and the environment was kept to a minimum where crops are irrigated. In addition, the groundwater was analyzed to determine the possible impact of RW on the aquifer. The current investigation explains the steps taken along the way to reach consensus on the benefits of water reuse in Maneadero and the results obtained so far in the 2015–2016 period.

MATERIALS AND METHODS

First, a description and an explanation of the processes undertaken to reach consensus are presented. A brief description of the research undertaken in each step is provided. Second, once RW was being sent to Maneadero, the monitoring program was initiated. The program ran from February 2015 to November 2015. RW has been discharged in three zones of the valley (Figure 1).

RW was sampled directly from the pipes that discharged into the distribution tanks and the creeks. Groundwater was sampled directly from wells near the irrigated fields and the creeks. In addition, samples for microbiological quality of the soil were taken before and after the harvest in six locations of one of the fields irrigated with RW at 0–30 and 30–60 cm depth intervals. RW and groundwater were analyzed for pH, temperature, BOD_5, total suspended solids (TSS), turbidity, total dissolved solids (TDS), ammonia, nitrates, phosphates, and fecal and total coliforms. Soil samples were analyzed for fecal and total coliforms, all according to APHA (2005). The total number of samples was 18 for RW, 42 for groundwater, and 20 for soil. The sampling dates are shown in the corresponding tables.

RESULTS AND DISCUSSION

In order to consolidate water reuse in Maneadero a series of steps were necessary which were divided into five stages: (1) RW quality; (2) groundwater quality; (3) water management

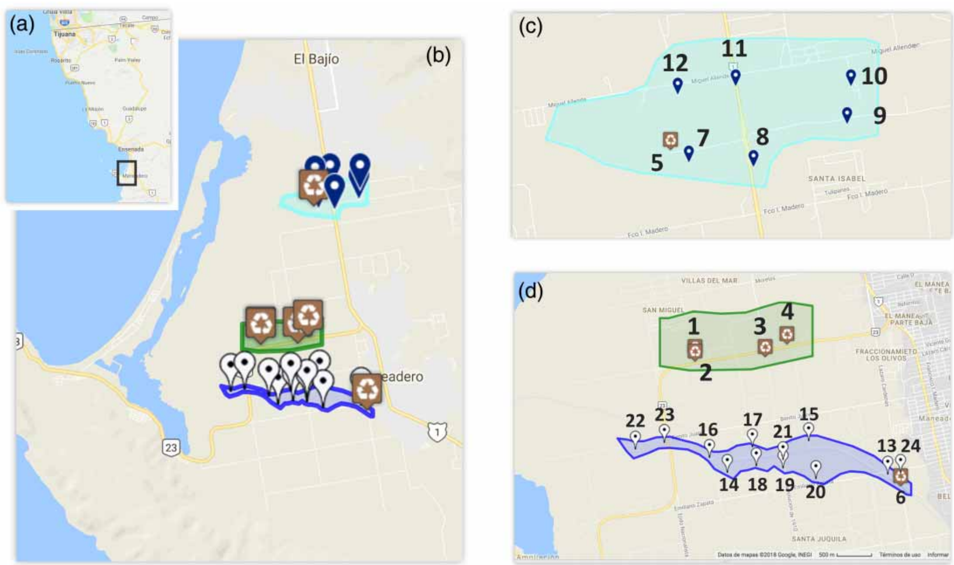

Figure 1 | General map showing the location of Ensenada (a), the sampling sites (b) with San Carlos in the north, irrigation sites at the center and Las Ánimas creek in the south, details of the San Carlos creek sampling site (c) and the irrigation site and Las Ánimas site (d). (For reclaimed water sites and wells ID please refer to Tables 1–3.)

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options; (4) stakeholders negotiation and institutional arrangements; and (5) monitoring and impact on the environment.

Reclaimed water quality

Mendoza-Espinosa *et al.* (2004) established that the quality of the effluent from El Naranjo wastewater treatment plant (WWTP) was good enough to be used for the irrigation of crops and had the potential for aquifer recharge. At that time, there was no Mexican legislation for aquifer recharge, so it was argued that this was a limiting factor. When the recharge norm was published in 2009, it was plausible that Ensenada's RW could meet it (with the exception of TDS) following the example of another northern Mexican City, San Luis Río Colorado, where approximately 0.03 $Mm^3\ d^{-1}$ of RW are infiltrated into vast fluvial-sand deposits (Sol-Uribe *et al.* 2008). The Mexican norm established that any water used for aquifer infiltration (including RW) must comply with quality guidelines of water for human consumption (NOM-127-SSA1-1994) and, if it does not, the aquifer capacity to remove potential contaminants above such norm must be demonstrated (Daesslé *et al.* 2014).

Groundwater quality

Seawater intrusion has severely contaminated the Maneadero aquifer and the soil irrigated by these waters close to the coast, producing salinized wells and abandoned farmlands (Daesslé *et al.* 2005). Moreover, a high concentration of nitrates in groundwater is caused by anthropogenic pollution derived from the lack of sewage systems in the Maneadero town and valley (Daesslé *et al.* 2009, 2014).

Daesslé *et al.* (2005, 2014) concluded that seawater intrusion, as evidenced by high TDS, progressed faster in the central and southern coastal sections of the aquifer, reaching 9.46 $g\ l^{-1}$ in 2002, and up to 25.6 $g\ l^{-1}$ in 2011. It also affected the sites along the San Carlos creek, where the 'high quality' (TDS 1.5 $g\ l^{-1}$) concentration isohaline line has retreated westward, leaving (already in 2002) at least three wells used for urban supply above the 1.0 $g\ l^{-1}$ official limit for human use. Except for the sites along the riverbeds, it appears that TDS concentrations had reached an historic maximum in several sites in this aquifer. Hence, people in Ensenada rely on bottled water for drinking and cooking purposes.

Water management options

The need for an integral project for sustainable management of the Maneadero aquifer has been evident for decades. Collaboration and close participation between all the users is required in order to succeed in a management program. Waller-Barrera *et al.* (2009) used an optimization model to determine the best economic-engineering option for water management for the city of Ensenada. Results highlighted that in order to guarantee an efficient water supply for the city, water reuse represented the best option from an economic point of view, followed by the construction of the Colorado River aqueduct and finally by desalination. Despite this, in 2013 a desalination plant with a capacity of 250 lps (7.9 $Mm^3\ y^{-1}$) was authorized and began construction in Ensenada. To date (2017), the construction of the desalination plant continues and it has been calculated that its capacity will not be enough to meet the city's current water deficit. Another measure since 2014 has been the supply of c. 2 $Mm^3\ y^{-1}$ from the Colorado River (via Tijuana) to Ensenada but this has not been enough to completely eliminate water scarcity.

Stakeholders' negotiation and institutional arrangements

In spite of the need for reuse, the Baja California state water authority was reluctant to invest in the construction of the aqueduct that would carry RW from El Naranjo WWTP to Maneadero unless written consent by farmers to accept RW for crops' irrigation was provided. Such an agreement was reached in 2009 and the State Government built a 20-km-long pipeline from El Naranjo WWTP to the south of the Maneadero Valley, which ended at a 2,000 m^3 distribution tank (Daesslé *et al.* 2014). These facilities, however, were never used, as farmers were expected to pay for each m^3 of RW supplied and invest in their own infrastructure to connect to the distribution tank to receive RW for irrigation. Finally, after five years of drought, in 2013, local politicians and the local water management committee decided to invest in the water infrastructure to deliver RW

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to Maneadero. More importantly, there was a verbal agreement between the local farmers and CESPE that the RW would be delivered free of charge in order to encourage farmers to accept it and promote awareness of its importance to other farmers that were hesitant. To date, there is no written agreement between water authorities and farmers about the length of this deal to provide RW for free. It is expected that the farmers will, eventually, agree to pay the RW tariff established by the State Government ($4 pesos per cubic meter equivalent to $0.20 US dollars per m^3). On June 29, 2014, approximately 200 lps (6.3 $Mm^3\,y^{-1}$) of disinfected secondary effluent from CESPE's wastewater treatment plants started to be delivered continuously to Maneadero Valley. Of these, 80 lps (2.6 $Mm^3\,y^{-1}$) are used to reactivate agriculture production of 200 ha (thus increasing the total irrigation surface area from 2,530 ha to 2,730 and representing 7.3% of the valley's total agricultural area) in areas that were mostly abandoned for agriculture and 120 lps (3.9 $Mm^3\,y^{-1}$) directly to Las Ánimas creek and to a lesser extent to San Carlos creek, where part of the RW is naturally infiltrating the aquifer. Only 80 lps (2.6 $Mm^3\,y^{-1}$) are used for agriculture irrigation due to infrastructure limitations (pipe size delivering RW to irrigation zone and limited surface area prepared for RW irrigation). As mentioned earlier, the success of this initial scheme has already produced interest from more farmers to use more RW for irrigation, resulting in the need to invest in more piping to increase the amount of RW used for irrigation, calculated in an increase to 130 lps (4.1 $Mm^3\,y^{-1}$) for the irrigation of 500 ha (unpublished data supplied by Mr Alejandro Guzmán, Chief Operating Officer COTAS Maneadero) (COTAS Maneadero) (equivalent to 15.5% of the resulting total valley agricultural area).

Monitoring and impact on the environment

Reclaimed water

Table 1 presents all results at the point of discharge of the RW. On 21% of the occasions, the maximum levels for total suspended solids by Mexican legislation were exceeded, which could be troublesome for farmers by causing clogging to their drip irrigation systems. In 22% of the cases, the maximum level for fecal and total coliforms were exceeded which indicated that disinfection of the RW was deficient. More importantly, the average TDS concentration was 3.1 $g\,L^{-1}$, indicating that the RW has a very high salinity and its use for irrigation is very limited and must be used with caution.

A comparison between RW quality in the current study and that by the USEPA (2012) is presented in Table 2. Although the RW in Maneadero was usually below the maximum threshold, it was clear that the WWTP had problems that caused high levels of TSS, BOD_5, and fecal coliforms some of the time. Other parameters that could be of concern are nitrates and helminth eggs. Nitrates are not considered a problem by Mexican legislation and are not included in legislation for RW. However, helminth eggs are considered a problem and should be below 1 egg per liter, according to Mexican legislation for treated wastewater. In Ensenada, previous studies by Mendoza-Espinosa *et al.* (2004) established that they were not present in treated wastewater from 2000 to 2003. Moreover, since starting operation of El Naranjo WWTP in 1999, CESPE monitors helminth eggs bimonthly and they have never been detected (unpublished data).

In order to have reliable treatment, and despite stating the obvious, CESPE must have enough funding for a solid operation and maintenance program. Unfortunately, this has not always been the case, as many municipal and state water agencies in Mexico have financial limitations. Thus, CESPE needs to be clearly aware that the success of the RW scheme depends entirely on its capacity to provide a consistent and high quality effluent and have in place a protocol to inform the farmers whenever they have problems with water quality compliance. From these observations, it is crucial that CESPE and the farmers stay in close communication, to have a permanent working group that would meet periodically in order to evaluate results and discuss solutions for possible problems. It is also recommended to have a third party involved in the monitoring of the RW, preferably an academic institution with no commercial interest but with the moral authority to issue alarms and recommendations as soon as water quality problems are detected.

Groundwater

All groundwater samples had high TDS concentrations (Table 3). In those wells near the San Carlos creek, the high concentrations of nitrates in well Sofia Calderon and

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Table 1 | Results for RW from the three study zones

Site	Site name	Date (2015)	T °C	pH	BOD (mg L^{-1})	TSS (mg L^{-1})	Oils and grease (mg L^{-1})	Turbidity (NTU)	NO_3–N (mg L^{-1})	NH_4–N (mg L^{-1})	PO_4–P (mg L^{-1})	TDS (mg L^{-1})	FC (org/100 mL)	TC (org/100 mL)
1	Irrigation discharge 1 (93)	27 Apr			9	2	<2	4	4.9	4.6	1.4	2.670		
		19 May	24.0	7.19	17	11	<2	7	6	4	1	2.670	46	70
		08 Oct			11	**49**	11	195	1.3	24	11.5	3.360	**160.000**	**160.000**
2	Irrigation discharge 2 (94)	04 Jun	24.6	7.21		5	<2	4	2.8	23.1	10.9	2.910	33	33
		13 Jul	27.8	7.27	19	27	<2	21	3	38,1	3	3.100	**>1.600**	**>1.600**
		03 Aug	27.7	7.45	16	14	<2	11.8	2,2	30	1	3.300	23	240
		22 Sep			<2	2	<2	4	2	3.5	1	3.480	50	80
		03 Nov			<2	2	<2	4.7	1	1	1	2.300	2	2
		19 Nov	23.1	6.98	<2	2	<2	2	2.8	1	13.3	3.280	2	4
3	Irrigation discharge 3 (Benjamín)	18 Aug	29.4	7.16	11,4	14	5	2	2.2	1	12.6	3.460	33	33
4	Irrigation discharge 4 (97)	07 Sep	28.1	7.17	10	2	<2	5	2.5	3.4	9.5	3.530	50	50
5	San Carlos creek discharge	19 May	24.0	7.50	20	15	<2	11	4.2	9.5	1.6	2.740	<2	<2
		13 Jul	27.7	7.49	<2	**109**	<2	24	2.4	32.8	10.7	3.050	**>1.600**	**>1.600**
		03 Nov	25.2	6.57	9	**127**	<2	61	2.1	2.8	12.8	3.140	50	130
		19 Nov	23.7	7.04	<2	2	<2	2.2	1	1	12.3	3.280	<2	<2
		03 Dec	20.3	7.21	6	2	<2		2.1	1	8.1	3.390	<2	<2
6	Las Ánimas creek discharge	27 Apr			20	3	<2	5	4.7	4.7	1,5	2.650		
		18 Aug	29.1	7.16	14.9	14	<2	2	2.4	1	12	3.430	23	23
		08 Oct			9	**168**	8	64	1.3	23.9	14.3	3.480	**160.000**	**160.000**

Results in bold and underlined exceed the Mexican norm NOM-001-SEMARNAT-1996 and the particular discharge permit for El Naranjo WWTP (which is 30 mg L^{-1} of BOD_5 and 30 mg L^{-1} for TSS).

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Table 2 | Compliance of RW used for irrigation and discharge in Maneadero and US EPA for restricted and non-restricted irrigation (USEPA 2012)

	Non-restricted irrigation (USEPA 2012)	Restricted irrigation (USEPA 2012)	RW CESPE	Compliance
Types of treatment	Secondary, followed by sand filtration and disinfection	Secondary, followed by disinfection	Secondary, followed by sand filtration and disinfection	Yes
Reuse activities	Irrigation of crops suitable for human consumption, even raw	Irrigation of crops suitable for human consumption after being processed Irrigation of crops not suitable for human consumption	Irrigation of crops non suitable for human consumption	Yes, restricted
Water quality parameters	pH = 6.0–9.0; BOD ≤ 10 mg L^{-1}; Turbidity ≤ 2; FC = not detectable; Cl_2 residual ≥ 1 mg L^{-1}	pH = 6.0–9.0; BOD_5 ≤ 30 mg L^{-1}; TSS ≤ 30 mg L^{-1}; FC ≤ 200 MPN/100 mL; Cl_2 residual ≥ 1 mg L^{-1}	pH = 7.1; BOD_5 = 10 ± 6 mg L^{-1}; TSS 12 ± 15 mg L^{-1}; FC ≤ 1.000 MPN/100 mL; Cl_2 = 1 mg L^{-1}	Yes, partially (spikes need to be controlled)

fecal and total coliforms in wells Mario Barron and Ernesto Avalos are worrying.

However, it was not possible to establish if these wells were already contaminated by cattle activity (manure) and/or leaching from Maneadero town's latrines (as suggested for nitrate pollution by Daesslé *et al.* (2014)), before RW was used for irrigation and infiltration. Adjacent to Las Ánimas creek, fecal and total coliforms were detected in five wells. In three of them, the levels were relatively high which could be due to the impact of RW on Las Ánimas creek or due to other yet undefined sources in the area. In two wells (Ernesto Murillo and Jose Jimenez), high levels of nitrates were detected in accordance with previous studies by Daesslé *et al.* (2009, 2014).

In terms of water conservation as a result of RW for irrigation, groundwater is the only source of water for agriculture. Hence, it can be calculated that the irrigation of 2,530 ha demands approximately 19.5 Mm^3 per year. Thus, the current application of 80 l/s would represent an extra 2.6 Mm^3 per year of water used for irrigation and plans to employ 130 l/s would mean an increase to 4.1 Mm^3 per year. The total amount of groundwater used for agriculture irrigation would not decrease as RW would be used for 'new' agricultural areas and no substitution between 'white' water and RW would take place.

Microbial indicators in soil

Table 4 shows the results for fecal and total coliforms in soil. In samples previous to the application of RW for irrigation (August 17, 2015), the soil did not present fecal coliforms. In the samples taken during irrigation (October 21, 2015) high levels of fecal indicators were detected in four sites, matching the places where sunflower crops were still being watered and the soil had a high moisture content and was protected from sun by foliage. After irrigation (December 14, 2015), fecal coliforms were only detected in one site at a depth of 30–60 cm and total coliforms in three sites, although irrigation had stopped for at least a couple of weeks.

In terms of fecal contamination, the soil samples did not present contamination before the use of RW for irrigation, yet contamination was evident during irrigation and fecal coliforms were detected in some samples even four months after irrigation. This could have been caused by operational problems at the El Naranjo WWTP, which can only stress the fact that the treatment plant must be reliable. With the exception of a single sample, soil samples taken 3 weeks after irrigation did not present fecal coliforms, in line with Lazarova & Bahri (2005), who mention that fecal coliforms have a survival rate of a maximum of 20 days in soils. In addition, the presence of fecal coliforms in soil samples at the surface and 30–60 cm depths can indicate that farm workers could be at risk during the handling of the product. Therefore, it is highly recommended that workers be provided with clothes and shoes that will protect them from direct contact between their skin, and water and soil. Moreover, basic hygiene measures such as washing their hands thoroughly after work must be enforced. Immunization for all workers is also recommended.

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Table 3 | Results for wells close to the discharge of the San Carlos and Las Ánimas creeks

Site	Site name	Date (2015)	T °C	pH	BOD_5 ($mg\ L^{-1}$)	TSS ($mg\ L^{-1}$)	Oils and grease ($mg\ L^{-1}$)	Turbidity (NTU)	NO_3–N ($mg\ L^{-1}$)	NH_4–N ($mg\ L^{-1}$)	PO_4–P ($mg\ L^{-1}$)	TDS ($mg\ L^{-1}$)	FC (org/100 mL)	TC (org/100 mL)
	San Carlos creek													
7	Adam Marrón	19 May	20.5	7.36	7	<2	<2	0.5	2.7	0.5	0.4	**2.540**	<2	<2
		03 Aug	21.1	7.17	<2	<2	<2	0.2	1.6	5.5	0	**2.750**	<2	<2
		22 Sep			<2	<2	<2	2	1	1	1	**2.700**	**2**	**2**
8	CESPE 2R	04 Jun	21.5	7.47		<2	<2	1	4.5	2.6	0.3	**1.320**	<2	<2
		22 Sep			5	<2	<2	1	5.8	1	0.3	**1.460**	<2	<2
9	15 – Karla Sofía Calderón	04 Jun	19.4	7.29		<2	<2	1	**30.2**	0.6	1	**2.150**	**23**	**23**
		22 Jun	20.7	7.27	<2	<2	<2	0.5	**29.7**	4.4	1.2	**2.030**	**17**	**23**
10	Mario Barrón	13 Jul	24.5	7.20	3	<2	<2	0.7	**32.7**	0	0.5	**2.560**	**2**	**2**
		03 Aug											<2	<2
11	12 – Virginia González	22 Jun	22.9	7.12	<2	<2	<2	0.5	6.2	4.6	0.5	**2.820**	<2	<2
12	Ernesto Ávalos	19 Nov	23.1	7.04	<2	28	<2	NR	<2	<2	<1	**4.480**	**23**	**30**
		03 Dec	22.4	7.01	<2	<2	<2	NR	<2	<2	<1	**3.070**	**300**	**300**
	Las Ánimas creek													
13	164 – Salvador Bravo	19 May	23.1	8.41	<2	<2	<2	<1	7	0	1	**1.850**	<2	<2
		13 Jul	24.5	7.28	4	4	<2	17	7	2.7	0.5	**2.560**	<2	<2
		08 Oct			<2	<2	<2	<1	6	2.2	1	**2.130**	<2	<2
		03 Dec	20.9	7.13	<2	5	<2		6.1	1	1	**2.070**	<2	<2
14	455 – José Luis Alcalá	18 Aug	21.6	7.08	<2	<2	5	3.5	11.8	1	1	**5.950**	**13**	**23**
		07 Sep	21.2	7.01									**23**	**23**
15	133 - Miguel Olivas	18 Aug	20.9	6.70	<2	4	5	1	7	1	1	**3.270**	<2	<2
16	2 – Daniel Magaña	07 Sep	21.2	7.01	<2	<2	<2	<2	5.4	1	1	**5.230**	**4**	**4**
17	131 – Ernesto Murillo	07 Sep	29.1	6.73	<2	<2	<2	<2	**29.9**	1	1.2	**6.650**	<2	<2
		19 Nov	20.3	6.67	<2	<2	<2	<2	**29.5**	1	1	**6.930**	<2	<2
18	144 – Isabel Rodríguez	07 Sep	29.7	6.97	<2	<2	<2	2	16.2	1	1	**5.820**	**23**	**23**
19	José Jiménez	07 Sep	20.5	6.80	<2	<2	<2	2	**38.5**	4.2	1	**5.900**	**8**	**30**
20	145 – José Valenzuela	08 Oct	20.9	6.86	<2	<2	<2	4	1	15.1	1	**4.080**	**23**	**23**
21	132 – César Cárdenas	03 Nov	20.8	6.58	<2	<2	<2	2	9,9	1	1	**3.810**	<2	<2
		19 Nov	20.3	6.86	<2	<2	<2	2	9	1	1	**4.470**	<2	<2
22	Ramón Verdugo	19 Nov	22.4	6.80	<2	<2	<2	2	11.3	1	1	**5.890**	**2**	**2**
23	148 – Ricardo Díaz	19 Nov											<2	<2
		03 Dec	23.7	6.82	<2	<2	<2		7.5	1	1	**9.310**	<2	<2
24	Urderal Buena Vista	04 Jun	22.3	7.35		<2	<2	1	7	0.5	1	**1.720**	<2	<2

Data in bold and underlined are above maximum levels permitted by Mexican legislation for potable water NOM-127-SSA1-1994.

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Table 4 | Microbiological indicators results for soils (in most probable number – MPN g^{-1})

Site	Depth (cm)	17 Aug		21 Oct		14 Dec	
		Total coliforms	Fecal coliforms	Total coliforms	Fecal coliforms	Total coliforms	Fecal coliforms
S1	0–30	<2	<2	3,300	20	170	<2
	30–60			80	<2	20	<2
S2	0–30	<2	<2	1,100	70	<2	<2
	30–60			800	170	<2	<2
S3	0–30	<2	<2	300	80	20	<2
	30–60			220	<2	20	20
S4	0–30	<2	<2	130	20	<2	<2
	30–60			40	<2	<2	<2
S5	0–30	<2	<2	80	40	<2	<2
	30–60			<2	<2	20	<2
S6	0–30	<2	<2	<2	<2	<2	<2
	30–60			<2	<2	<2	<2

Impact on crop production

Results so far have been very encouraging. Approximately 200 ha of flowers and fodder, mostly desertified three years ago, have been irrigated with RW. This cropland has been reactivated as the high salinity of the wells made agriculture prohibited. Production has been calculated at several million dollars and the creation of 1,200 jobs (unpublished data supplied by Mr Alejandro Guzmán, Chief Operating Officer COTAS Maneadero).

According to the average results for ammonia, nitrate, and phosphorus, the RW provided 15 mg l^{-1} of nitrogen and 6 mg l^{-1} of phosphorus for crops in Maneadero. Such values are low compared to average wastewater, which are 50 mg l^{-1} for nitrogen and 10 mg l^{-1} for phosphorus (Lazarova & Bahri 2005). However, assuming an irrigation rate of 5,000 m^3 per hectare, the amount of N and P applied in Maneadero would be 75 kg of N per year and 30 kg of P per year, which are similar to those required by sunflower for nitrogen and double as needed for phosphorus (Ali *et al.* 2014). It is well known that N and P in wastewater suffer seasonal variations. Therefore, it is important to keep monitoring nutrient content in the RW and soil and even consider crop rotation and denitrification as control measures.

As mentioned earlier, nitrogen in the form of nitrate can be used by crops. However, in excess, nitrate is highly mobile and can contaminate groundwater. Current results indicate that nitrogen is present in low concentrations in RW so, assuming an irrigation rate of 5,000 m^3/ha, it is unlikely it would cause pollution to groundwater, more so if groundwater is already polluted by nitrate. Phosphorus, on the other hand, could be a problem in the long term as its concentration in RW and assuming an average application of 5,000 m^3 per hectare would exceeds crops' requirements (Ali *et al.* 2014).

CONCLUSIONS

Seventy-nine percent of the RW samples complied with the particular discharge permit for El Naranjo WWTP; however, CESPE has to have better control of its WWTP to avoid spikes, like those detected for coliforms in water and soil. The presence of fecal coliforms in soil samples at the surface and 30–60 cm depths can indicate that farm workers could be at risk during the handling of the product. Therefore, it is highly recommended that workers be provided with clothes and shoes that will protect them from direct contact between their skin, and water and soil. Moreover, basic hygiene measures such as washing hands thoroughly after work must be enforced. Immunization for all workers is also recommended. Results from monitoring wells

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adjacent to Las Ánimas and San Carlos creeks showed on some occasions the presence of fecal and total coliforms that could indicate infiltration. The source however, needs to be assessed in detail. The concentration of nitrogen and phosphorus in the RW is sufficient to provide for the fertilization of crops such as sunflowers. From a management perspective, it is necessary to have direct communication between CESPE and the farmers, to have frequent monitoring of the RW and activate a working group in order to detect problems and respond to contingencies. The sum of all steps, namely, (1) RW quality, (2) groundwater quality, (3) water management options, (4) stakeholders' negotiation and institutional arrangements, and (5) monitoring and impact on the environment, were decisive in consolidating the water reuse scheme in Ensenada. This case study can serve as an example for other sites around the world facing similar problems and challenges.

ACKNOWLEDGEMENTS

This investigation was partly funded by the Agriculture Department of the State of Baja California (SEFOA). We are very grateful to Mr Alejandro Guzmán, Chief Operating Officer of COTAS Maneadero for his invaluable insight and comments that enhanced the content of this investigation. Many thanks also to Aimeé de la Cerda, Saúl Salgado, and Christian Gilabert for their help during fieldwork and laboratory work. Finally, we are grateful to the comments from two anonymous reviewers for their suggestions and critical comments that helped to improve the manuscript.

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First received 8 February 2018; accepted in revised form 30 July 2018. Available online 20 August 2018

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