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Integrated Environmental Studies to Propose Large-scale Zoning for Managing the Texcoco Lake Ecological Park, Mexico

J. SAN ROMÁN[2], PATRICIA MUÑOZ–SEVILLA[1], LILIANA MARÍN-GARCÍA[1], MIGUEL LÓPEZ-FLORES[1], PEDRO JOAQUÍN GUTIÉRREZ-YURRITA[1]*

[1] *Centro Interdisciplinario de Investigaciones y Estudios Sobre Medio Ambiente y Desarrollo (IPN). 30 de junio de 1520 S/N, La Laguna Ticomán. CP 07340. Distrito Federal (México)*
[2] *Aguas del Valle de México –Comisión Nacional del Agua, Delegación Coyoacán, C.P. 04340, México D.F.*

*Corresponding author; *E-mail: pgutierrezy@ipn.mx*

ABSTRACT

Lake Texcoco Ecological Park (LTEP) is the last natural area near one of the biggest and most densely populated cities in the world: México City and its metropolitan area. Due to its geographical location, is at serious risk of disappearing in the very short term. A master plan of the park management is necessary. And as a first approach requires a very precise diagnosis of physicochemical conditions to begin the zoning of the area, first step to manage the park. The aim of this study was to perform an integrated environmental diagnostic that would allow us to outline the first step to develop a master plan to manage the LTEP. Integrated environmental studies include geo-environmental procedures as well as water, soil and sediments quality analyses of the Lake Texcoco Ecological Park (LTEP). Geoenvironmental studies comprise vertical electrical sounding and electrical tomographies. Analyses of the quality of water, sediment and soil contamination were assessed monitoring trace metals in the LTEP and most influential rivers in the basin. Three factors have great influence on the quality of the monitored elements in the LTEP: the synergy of ancient human uses with existing uses, the random use of riverbeds that modify the water regime and hydro period of the lake, so that temporary ponds do not work as they should in the shelter of aquatic wildlife and migratory birds and waterfowl from the USA and Canada. And third, the leaching of contaminants deposited on the bed of the lake from the rivers that drain into it. Ecological and evolutionary importance of this natural landscape is that it is a relict of a single lake in the world (Lake hyper saline soda-lake type); Texcoco Lake is home to over 300 biological species. More than 150,000 aquatic birds, mostly migratory, use the lake for wintering, migrating from Canada and the northern United States of America. The wind-blown dust that runs from the lake to the city of Mexico contains spores, microbes and particles (PM_{10}) that cause gastrointestinal diseases to a population of over 22 million people. There were significant differences among areas in the environmental quality of the Park, these results allowed us to develop a first suggestion for zoning LTEP in its management master plan.

Key Words: Holistic Management, Conservation Biology, Crowded Cities, Migratory Waterfowl, Human Uses of Landscape.

INTRODUCTION

The lakebed of Lake Texcoco is the last natural area of Mexico City and its metropolitan zone. However, due to its geographical location, is at serious risk of disappearing in the very short term. It is located in the north-east of the Metropolitan Area of Mexico City and is surrounded by huge housing developments, industrial corridors; farmland and livestock areas where more than 5 million people (Gutiérrez-Yurrita and López 2011). The importance of this peri-urban area, from the standpoint of biological conservation, lies: *i)* The Lake of Texcoco is one of the few saline-soda-lakes in the world, and it is located into an endorheic basin (Codd 2000); *ii)* The Neovolcanic belt crossing the area in a longitudinal direction (east-west), this generates volcanic ridge runners in latitudinal direction represented by large ravines, yet, are almost insurmountable barriers for the vast majority of biological species since it reaches elevations above the 3000 m above sea level; *iii)* This region is a natural transition zone between two biogeographic regions of North America: Neotropical (South) and the Nearctic (North); this area is also a point of ecological transition among different aquatic eco-regions of North America. So, local biodiversity is enhanced by species from each geographic region (Luna et al. 2000), plus the endemic ones (Gutiérrez-Yurrita et al. 2002); *iv*) Another important aspect is that Lake of Texcoco, by its natural hydrology, has very marked hydroperiods and water system, providing a haven for large flocks of several species of birds and waterfowls, both migratory and resident (Cleary et al. 2008; Environment Protection Agency 2011); v) it is one of the places to recharge Mexico city aquifer (Edmunds et al. 2002; Ramos et al. 2010).

About 133 species of waterfowl have been categorized to the flooded area of the former Lake Texcoco (Hurtado et al. 2005), with an overall population density higher than 150,000 individuals –in some recent counts, population density has become until 350,000 individuals- (Cleary et al. 2008; Environment Protection Agency 2011). Many of these species are migratory from northern America (United States and Canada), Central America and South America. Approximately 250 species are protected by Mexican and international treatises (CONABIO 2012). When they arrive at Texcoco lake. They graze upon endemic vegetation, feed on endemic plankton and interact with natives of this habitat (Chávez and Huerta 1985). The loss of flooded area has affected the biological extinction of many species and many others are listed as threatened or endangered (AICA 2002). Interactions among species (residents and migratory) are stronger and the result is the increase of mortality of both, migratory and resident fauna (USFWS; CWS and SEMARNAT 2004). Aquatic biota are also peculiar in this extreme ecosystem, since it is adapted to hyper saline conditions, and were an important part in the cultural development of pre-Hispanic peoples of the basin (Gutiérrez-Yurrita and López 2011). The destruction of habitat and artificial alteration of water regimes has placed them in an endangered position (USFWS; CWS and SEMARNAT 2012).

Despite the ecological importance of Texcoco Lake, the lack of appropriate management of the area and land use raises many disadvantages to having this lakebed (Martínez and Jáuregui 2000). For instance, the large dust storm and sand whirlwinds that form during the summer-autumn season and, that are dragged by the northeast trade winds to the southwest; considerably degrade the quality of the Mexico City's atmosphere and surroundings considerably (Sujana and Anand 2011). The multiscale climate and atmospheric chemistry model, reveal that erosion processes of the dried lake region contributes about 80% of the total particulate matter PM_{10} in the air of the Metropolitan Area of Mexico City (Jáuregui 1989). Discomfort such as eye and skin irritation and, skin allergies are frequent due to the contamination by atmospheric micro particles in suspension, which may even be carcinogenic when there is heavy exposure to them. In addition, this kind or atmospheric pollution including its source comes from the salty soils of the lacustrine area of Texcoco, mainly from the region that is considered as natural protected area to restore ecological processes of the entire Texcoco Basin (Díaz-Nigenda et al. 2010). Other negative health impacts are caused by odours and fine organic matter suspended in the air currents from the sewers and streams with little water currently ply the lake dry, accompanying the spores and microorganisms that cause respiratory and enteroinstestinals diseases (Fernández-Luqueno et al. 2009). These diseases are not new to the inhabitants of the region. Since pre-Hispanic times there were sanitation sewage of major cities discharging to the Lake (Gutiérrez-Yurrita and López 2011).

The first step in the rehabilitation of Lake Texcoco was to develop environmental assessment studies with a holistic approach (Gutiérrez-Yurrita 2011); so that the social, economic and ecological region were analysed in a transversal way, including part of the Mexico City Metropolitan Area, one of the biggest cities in the world (more than 22 million people in the basin). The second step was to establish the area like a natural reserve, in this case Lake Texcoco Ecological Park. And finally, this work is the diagnosis of current geo-environmental conditions of the LTEP, in order to create a general zoning and a short-term management of the area. Before generating any program of action, we must generate a type of ecological land management based on ecological and socio-economic studies (Gutiérrez-Yurrita 2012). Consequently that while doing work for re-vegetation, water injection to induce recharge, cleaning soils of some pollutants etc., there are the work to stop urban sprawl, prevent the discharge of untreated urban water order the territory to offer residential and industrial areas and provide them with needed services, agricultural areas, and environmental protection (Valero 1985). In short, we work to reach the sustainable city model by means of holistic approach (Gutiérrez-Yurrita 2013). The main objective of this study was to perform an integrated environmental diagnostic that would allow us to outline the first step to develop a master plan to manage the LTEP.

MATERIALS AND METHODS

Area of study

The Lake Texcoco Ecological Park (LTEP hereafter) is located in basin of the former great Lake of Texcoco, at northeast of the Metropolitan Area of Mexico City. Bordered on the west by the Federal District and occupies three municipalities of the State of Mexico: Atenco, Texcoco and Tezoyuca in the Centre of the Mexican Republic (Figure1).

The progressive and synergistic impacts of man over the Lake Texcoco basin, especially the intense drainage schemes in tended from the XVII century and culminated in the XX century have made today only one flooded area to be less than 1% of the original area estimated at about 5,000 km^2. When the rainy season is over 700 mm and has all the temporary flooding of the lake, there are only about 55km^2 flooded, with a rainy season normal or below-average annual mean, the flooded area covers an area less than 15km^2.

It is worthy to notice the highly complex landscape of the basin, very different from any other environmental system managed by man, including salt lakes (San Román et al. 2012). At present, the Lake of Texcoco is a small endorheic lake system consisting of several reservoirs for shallow water, which in its whole does not exceed the 55km^2, as mentioned (Alcocer and Williams 1996). The area has hyper saline soils as a result of recurrent flood phenomena drying from its geological

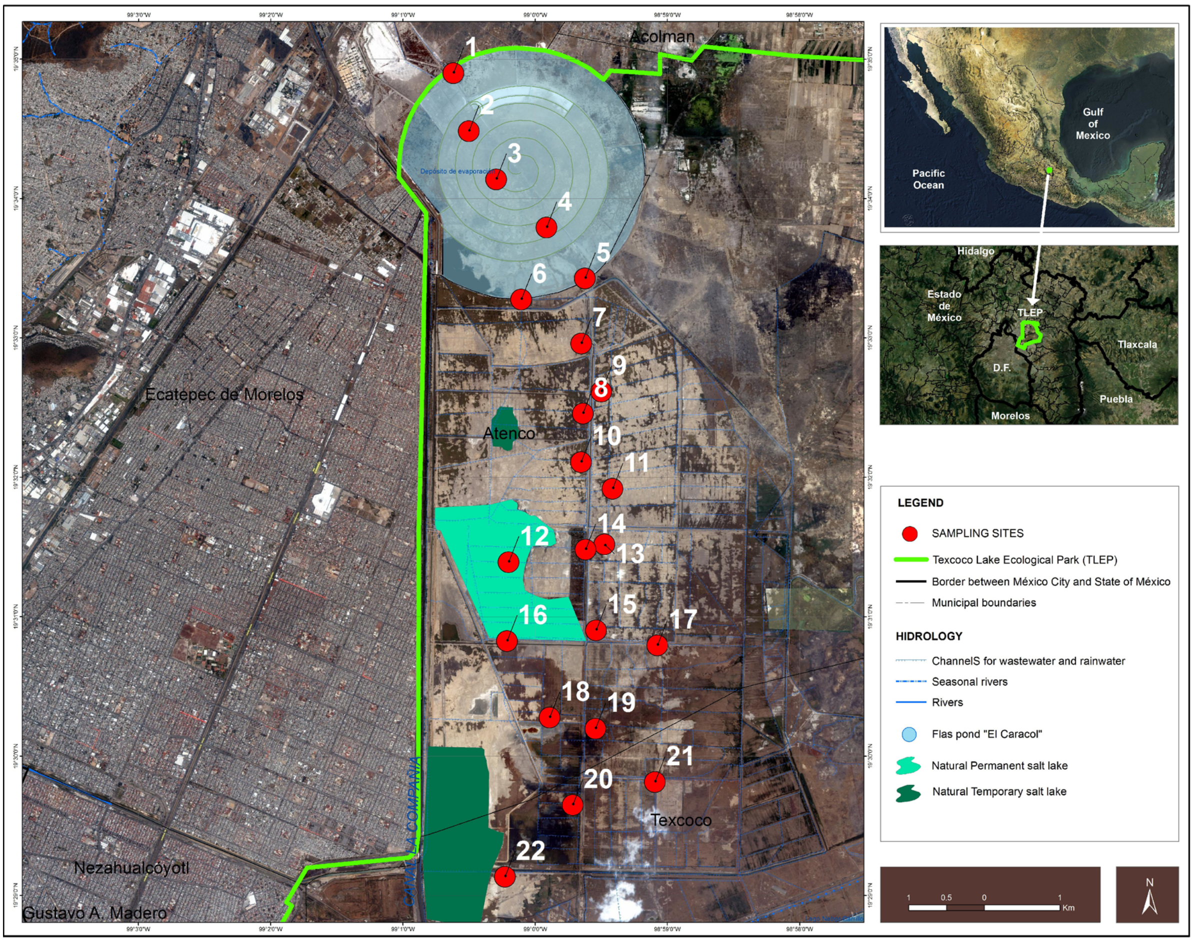


Figure 1. Location of the study area showing the sampling sites

origin, more than 350 million years. Thus, water regime and hydroperiods are two very important factors to determine water quality every season, producing a type of water very unusual in its chemical composition, sodium carbonate. This water is characteristic of the few lakes called Soda-Lake as well as having dissolved in water containing NaCl and Na_2CO_3, Na_2SO_4 also (San Román et al. 2011). It should be added, moreover, that this strange lake from the geo-hydrological point of view, is located in a densely populated area by human sand is severely impacted by industrial pollution activities, agricultural and urban, in the form of solid and liquid waste (Gutiérrez-Yurrita and López 2011).

Sampling

Theoretical sampling for analysis of the environmental quality of the LTEP, was systematic in that it had to choose representative sites for each type of analysis along a well determined transect in the direction north-south, following the natural flow riverbeds and historic salinity gradient. In addition 22 outstanding points were sampled because of their human health importance: El Caracol, residual water channels that drain into Lake Texcoco, natural rivers from the upper part in the basin until its entry into the dry lake bed, treatment plant for an urbanization o flow income housing and Thermoelectric discharge duct. The sampling network and study area location are presented in Figure 1. A transversal sampling in summer (at the beginning of the rainy season) in rivers and waterways that drain into Lake was made. Another sampling in the lake area, dry and wet, in winter (at the beginning of the season dry) was conducted. Classical physicochemical parameters were analysed in a laboratory internationally certified Laboratory belonging to the National College of Biological Sciences of the National Polytechnic Institute. Similarly, analyses of trace metals that marks the official Mexican standard to be considered in environmental studies. The methodology used in all analyses is that recommended by APHA (2012).

We performed 22 vertical electric soundings (VES) and electrical tomography (ET) considering the following data: AB distance: 290mor AB180mand 33scans of variable depth: 3 CT in each of the locations of the VES's, one of them making centre in the centre of the BSS's and guidelines on the survey line and the other way to cut the ends to the first perpendicular (EAEG 1980). The distance between electrodes was 3 m and had higher saturation data for the ET (Sánchez et al. 1987). The length of the scans was 31.5 m settlements with Schlumberger, reaching a depth of 8 to 9 m. The data was processed with the programs and IPI2W in RES2DINV (Orellana 1972). Water and sediment quality were assessed in field by specific electrodes. BOD_5 and COD were estimated in laboratory incubating the samples for five days (APHA 2012).

Data Analysis

The methodological approach of this project is based on Geo-environmental studies. Such studies include the analysis of physical and chemical properties of water (both discharge and industrial urban complex), resistivity substrates (vertical electrical sounding and electrical tomography) and, the determination of trace metals. The results are integrated and interpreted in Geo-environmental indicators, which distinguish natural and anthropogenic chemical compounds, as well as highlight the sedimentological origin of materials; metals and finally, these models sallow the development of geo-environmental indicators of environmental risk (Guardado-Lacaba et al. 2000).

The analysis of heavy metal contents that are used to evaluate the quality of water of temporary ponds was done on the basis of the official Mexican Standard (NOM-001-ECOL-1996). These standards set the upper limits of pollutants that are allowed in the unloading of residual water into the water and national assets and their methodologies are according to international standards such as APHA (2012). The Mexican authorities through the Official Mexican Standard (NOM-127-SSA1-1993) approved the methods used to characterize the environmental factors that may endanger human health. The other parameters were taken with the procedures authorized by public administration following all the environmental standards (NOM-001-SEMARNAT-1996). This standardised methodology is specific to environmental quality, designed to preserve life and ecological functions in environmental systems.

RESULTS

Results about trace metals that are present in the largest amounts are shown in Table 1. In most of the samples, lead is the heavy metal that shows a concentration at the upper limit or even above the value that is allowed by the NOM. In general, it was established that the analysed water samples did not show metal contents above the upper limits that are allowed by the Mexican standards. It is important to emphasize that Na, K and Mg concentrations are characteristic of this region due to its saline-soda-lake nature.

Table 1. Trace metal concentrations (mg L^{-1}) in the water of LTEP body

Site	Al	Pb	Fe	V	Mg	K	Na
3	5.09	<0.4	5.86	1.98	4.61	30.77	4411.15
4	5.33	<0.4	4.81	1.79	5.93	29.87	3995.79
5	<4.0	0.41	0.35	3.54	3.40	26.48	4873.82
6	4.21	<0.4	1.04	2.29	7.67	24.78	3853.84
7	4.30	<0.4	3.32	1.27	18.73	17.57	2733.96
12	9.70	0.87	11.92	11.94	8.09	94.52	14148.26
14	17.51	<0.4	12.51	0.36	3.88	1.24	210.30
16	<4.0	0.96	1.51	14.93	25.71	98.39	23971.48
17	<4.0	0.48	1.21	5.96	4.16	41.64	15238.89
19	13.80	<0.4	9.71	0.43	51.96	22.08	172.19
22	<4.0	<0.4	0.61	0.00	40.84	3.10	424.55

It is important to note that the physicochemical parameters of water quality, only total dissolved solids; total suspended solids; phosphates; sulphates; chlorides; biological oxygen demand at 5 days; chemical oxygen demand; and total nitrogen are higher than those authorized to irrigate agriculture fields for human consumption products and to preserve wildlife (Table 2). Oxygen ranged between 1 to 11 mg L^{-1}, temperature oscillates between 17 and 23ºC (Both factors are dependent on the time of day that were measured), and pH was higher than 7 in all the cases.

It is worthy to note that high toxic metals like arsenic (As), cupper (Cu), lead (Pb), mercury (Hg) and manganese (Mn) are present in natural conditions in the area (Table 3); just like trace metals and they do not represent serious damage to the human population neither to the wildlife.

Results of the metal concentration in soils and sediments in the most representative points of the LTEP area are shown in Table 3. Concentrations of Al, Ba, K and V are significantly higher than expected parameter from natural conditions in Mexico and from other saline lakes. In general conditions, two places of the LTEP are moderate to heavily polluted levels of these trace metals. And just one case of heavily polluted for Mg according to Mexican health and environmental regulations for water to use in agriculture, human consumption and preserve wildlife.

In the following, we show the electrical tomographies corresponding to the point sampling number 4, 5,

Table 2. Physical and chemical factors of water quality with concentrations (mg L^{-1}) higher than those permitted by Mexican environmental authorities.

Site	TDS	TSS	PO	SO	Cl	COD	BOD_5	Nt	Grease & oils	Faecal
3	15943	60	11.30			1181	382	**40**	14.5	NCD
4	14607	120	10.80	768	4963	1196	373	10.0	10.8	NCD
5	16636	17	11.40	813	4268	621	218	8.0	12.7	NCD
6	13753	67	10.10	895	4814	1098	372	13.0	11.5	NCD
7	9807	33	6.70	585	3871	746	287	9.0	13.3	NCD
12	53647	370	11.10	704	2233	2477	938	3.0	7.8	N.D
14	1280	933	<0.35	1018	17966	160	60	111.9	*	*
16	64550	23	82.40	163	533.0	1519	525	*	44.0	NCD
17	27910	37	40.40	990	*	2064	603	35.70	32.3	NCD
20	560	533	<0.35	910	*	131	53	30.1	*	*
22	1493	70	<0.35	145	24.0	1362	478	*	28.1	2400

TDS: Total Dissolved Solids; TSS: Total Suspended Solids; PO: Phosphates; SO: Sulphates; Cl: Chlorides; BOD_5: Biological Oxygen Demand at 5 days; Chemical Oxygen Demand; N_t: total nitrogen; ND: no colonies detected; *: no data available.

Table 3. Metals (mg kg^{-1}) in soil sediments of the LTEP.

Site	Pb	Al	Fe	As	Zn	V	Co	Mn	Ba	Cu	Mg	Hg	Cd	Cr	Ni	K
3	41.4	48183.9	11442.9	1.19	53.4	149.5	11.9	256.2	< 400	17.0	37190.5	0.30	< 2.6	< 40.0	< 40.0	10518.8
4	55.1	65785.8	19491.2	0.30	61.5	240.8	13.9	268.9	< 400	13.0	33705.1	0.41	< 2.6	< 40.0	< 40.0	8047.3
5	71.8	77903.5	23257.8	0.51	106.7	281.9	15.5	379.6	< 400	21.7	33581.3	0.33	< 2.6	45.3	42.1	7618.8
6	71.4	78896.9	23873.6	0.83	115.5	267.4	15.5	365.0	< 400	28.3	28510.4	0.40	< 2.6	47.8	45.4	8988.2
7	45.4	19330.4	6822.7	0.26	25.0	84.5	13.2	192.6	636.2	8.8	43651.8	0.25	< 2.6	< 40.0	< 40.0	3623.8
12	53.8	64518.5	21091.6	0.83	81.9	306.4	13.5	263.1	< 400	17.2	25720.4	0.46	< 2.6	< 40.0	< 40.0	10893.9
14	52.5	24396.1	12754.6	0.27	95.8	240.0	9.8	229.4	< 400	22.1	2202.5	0.41	< 2.6	< 40.0	< 40.0	386.4
16	53.7	45496.3	14386.7	0.63	52.2	210.0	12.0	264.8	< 400	13.0	52779.5	0.42	< 2.6	< 40.0	< 40.0	8157.4
17	51.2	59433.2	17879.6	0.26	53.5	171.6	12.4	260.9	< 400	10.8	44356.8	0.39	< 2.6	< 40.0	< 40.0	7193.7
20	48.7	63090.2	14690.4	0.36	43.1	151.5	12.9	258.0	556.8	12.5	35825.0	0.29	< 2.6	< 40.0	< 40.0	5257.3
22	57.0	89107.8	27643.6	0.43	65.6	149.5	17.4	319.5	< 400	12.4	21919.5	0.37	< 2.6	< 40.0	< 40.0	9136.9

12 and 20, which are typical sites of different ecological conditions of the area showing great differences in the electrical behavior in all the LTEP zone. In general, the tomographies do not exhibit electrical discontinuities or significant variability in the different sampling points, also with very low resistivity values are inferred saline wet sediment layers.

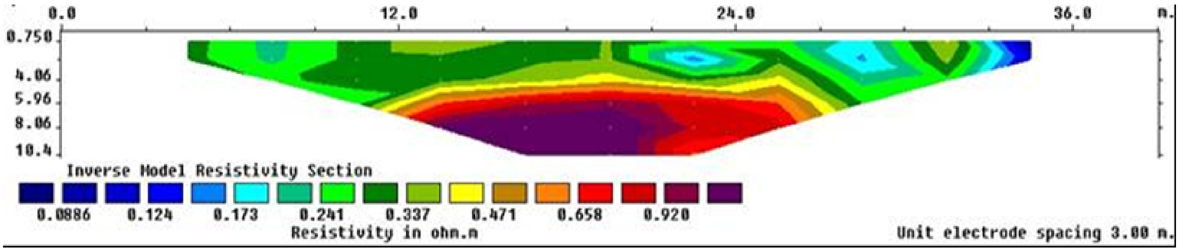
Figure 2 corresponds to the electrical tomography of the sampling site No. 4 in the sampling. Three electro strata (4a, 4b y 4c) were analyzed, and two of them have shown very low values of resistivity, reaching a 13 meters depth, which corresponds to the saline strattum. The third electro-stratum is much more resistive and it underlies the previous ones and can be considered to be free of salts. In the electro-vertical tomography 4a resistivities below 1 ohm-m are observed, which indicates that the whole soil is saline up to the reached depth. The tomography 4b has cut the saline stratum up to the reached depth, with maximun values of resistivity that are below 8 ohm-m; tomography 4c exhibits a similar behavior.

Figure 3 displays the results of the VES corresponding to point 5. As it can be observed, a electro-stratum of very low resistivity of 0.19 ohm-m, up to a depth of 18 m, and the resistivity increases after this point. This second electro-stratum has a depth of 75 m. In the electrical tomography one observes that, up to 18 m, the resistivity is below the 0.6 ohm-m. Beyond this point, the resistivity increases up to an undetermined depth.

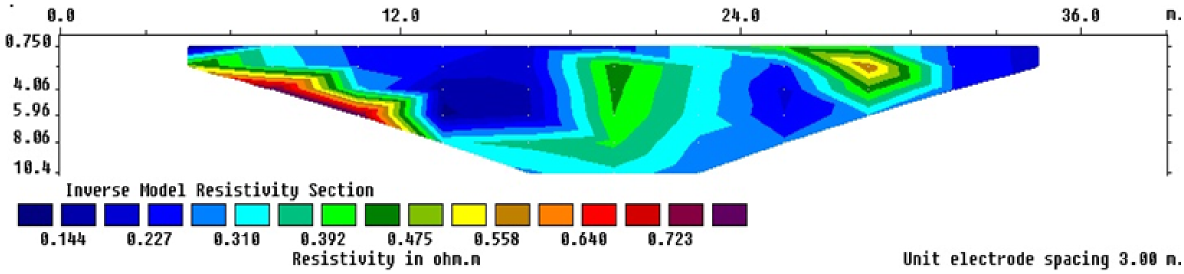
The electrical tomographies of point 12(12a, 12b and 12c) are shown in Figure 4. This survey shows three strata. It has detected the base of the conductive stratum at roughly a 13.8 m depth with resistivities below 1 ohm-m. The first one shows a resistivity of 4.29 ohm-m which is typical of a non-saline zone with a thickness of 1.26 m. The second and the third electro-strata have maximun resistivities of 0.6 ohm-m, which indicates a high conductivity due to the salt saturation reaching a depth of 13.8 m. Starting from this level, the resistivity increases to indicate a change of formation.

Figure 5 shows the vertical electrical tomography of point 20 with three electrical strata (20a, 20b and 20c). In all cases, values of resistivity below 1 ohm-m, which corresponds to the saline stratum, are observed. How-ever, a resistive anomaly is detected at approximately 12 m, which increases beyond 3 ohm-m and that can be associated to a nodule of another material body with a different granulometry.

Stratum 4a



Stratum 4b



Stratum 4c

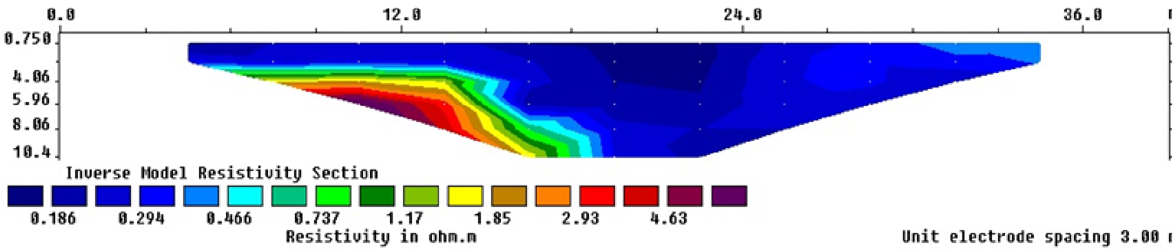


Figure 2. VES and ET in point number 4 (one of the saltiest regions of the PELT)

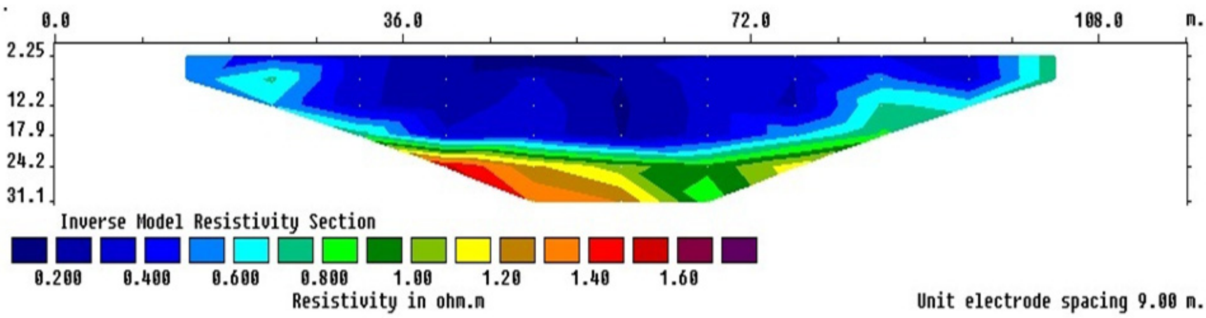


Figure 3. VES and ET in point number 5 (at the outer limits of the Caracol)

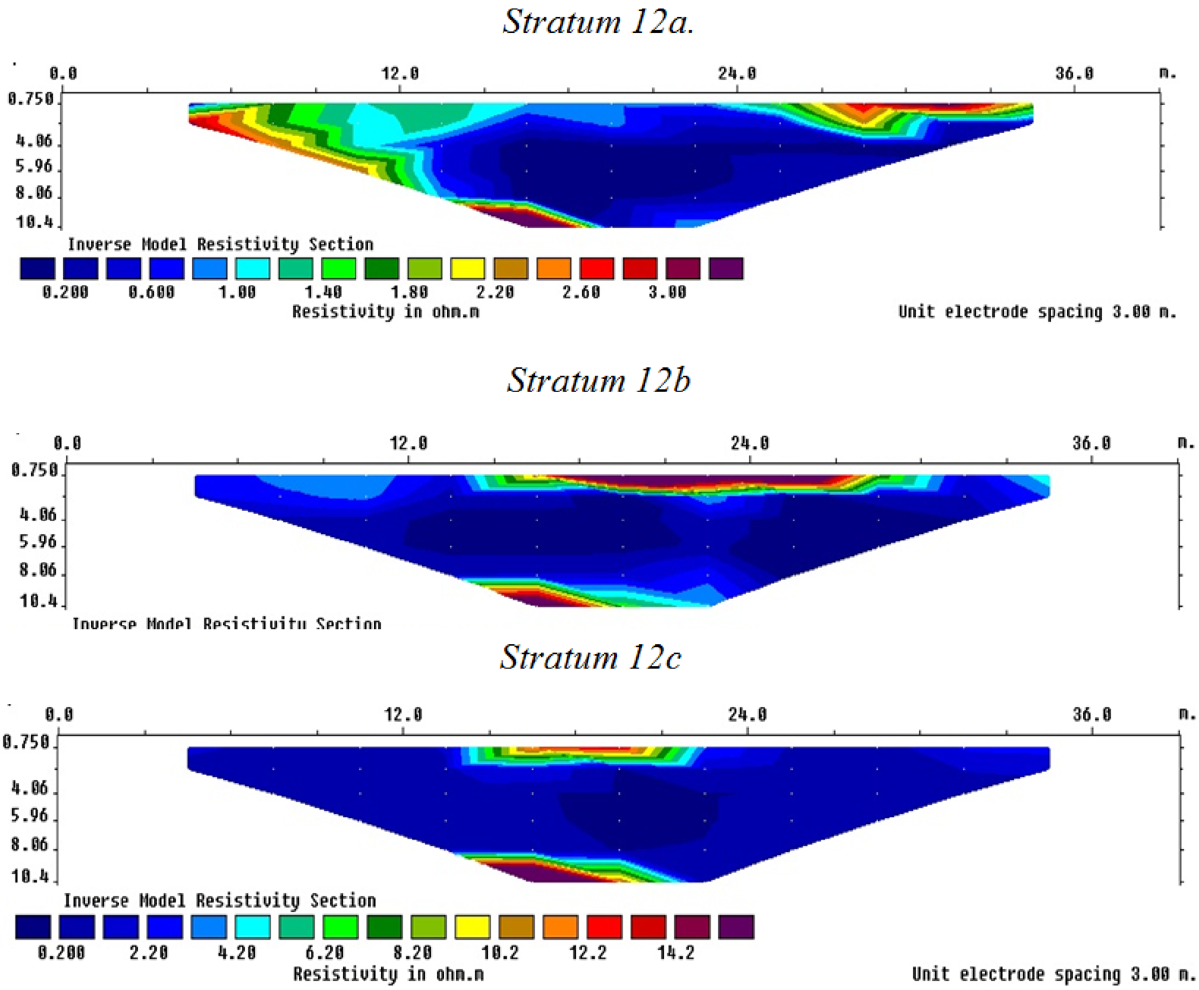


Figure 4. VES and ET in point number 12 (area with longer water retention into the PELT)

The biological oxygen demand and chemical oxygen demand are analysed separately because they represent greater importance than other factors in Lake Texcoco, given the sources of contamination previously detected. Figure 6 shows the spatial distribution of the values found in the BOD_5. Zoning is clearly seen in the values being the centre of the lake the most affected. Figure 7, for its part, shows the spatial distribution of the COD values. The spatial pattern is similar to the BOD_5. BOD_5 average value is 363mgl^{-1} with a maximum of 938 mg L^{-1}. COD average value is 1,141 mg L^{-1}. Highest concentrations of BOD_5 and COD parameters were recorded at stations 12, 17 and 16 located in wetlands with longer hydroperiods.

DISCUSSION

Gutierrez-Yurrita and López (2011) synthesised the uses by different groups who have inhabited the area since pre-Hispanic times to the present day, highlighting the multi-utility of it. Three areas of the temporal region of the former Lake drew attention to them, the area where now stand the Caracol and the external area around it and with which it shares boundaries –points 4 and 5. This area currently has geological and soil characteristics very different for one reason, the long history of human use (López et al. 2013). We realize how people have also greatly impacted the bottom salt of one of the largest lakes in North America (formerly more than 6,300 km^2)

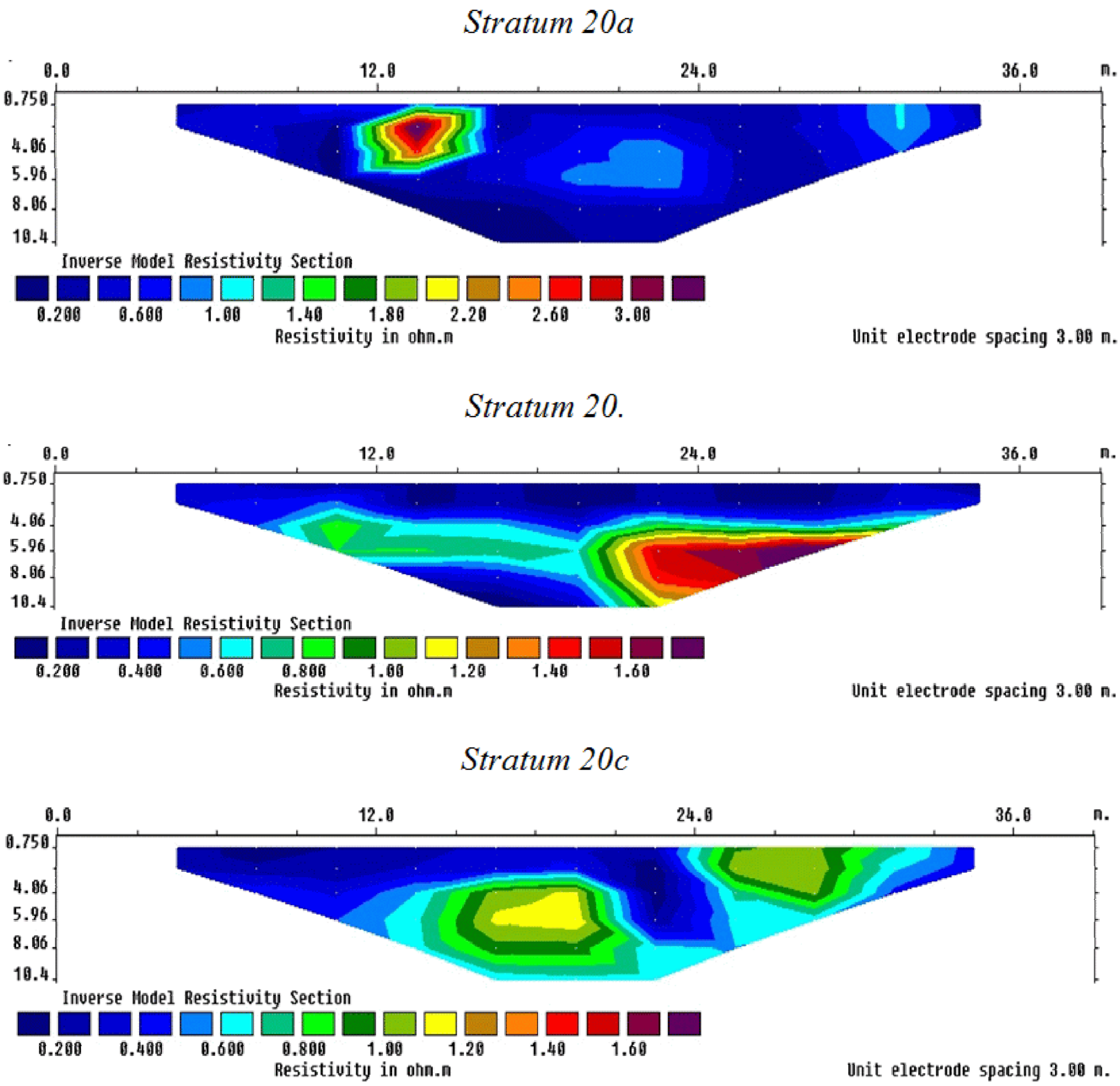


Figure 5. Tomography of point 20 (area with shorter water retention into the PELT)

(Alcocer and Williams 1996). Considering that the ancestral human impact in the area is enhanced by the current human impact, we have a natural area unique in the world, driven to the brink of extinction (CONAGUA 1991). The early human impacts consisted of flooding and drying a specific area for getting food (for instance: algae *Spirulina* spp., vegetation *Amaranthus* spp.) and, later management of the lake reservoirs were made to get animal food, both, terrestrial and aquatic (for instance: waterfowls (ducks *Aythya* spp., *Anas* spp.), crustaceans (*Artemia* spp., *Cambarellus montezumae*), insects (*Corisella* spp., *Ahuautlea mexicana*), endangered amphibians (axolote (salamander) *Ambystoma mexicanum*) and even endangered viviparous fishes (*Girardinichtys viviparous*) and other from the endemic genus *Chirostoma*. But finally, the banks of the lake were used for many species of plants called in native language quelites (water-weed, brushwood) (Alcázar 1980, Alonso 1994, Ezcurra 1995, Gutiérrez-Yurrita 2004, Alcocer and Bernal 2010, among others). In summary, biological richness of the basin allows developing one of the biggest civilizations of the world, the Nahuas (Romero 2003). Even more, they invented a special intensive agriculture in the water called *chinampas* (Merlin Uribe et al. 2012). Corn production in the chinampas may exceed 6 tonnes/ha/yr, while corn production in the current crop with chemicals and fertilizers reaches about 3 Mg ha^{-1} yr^{-1}, close to Texcoco basin (SAGARPA 2012).

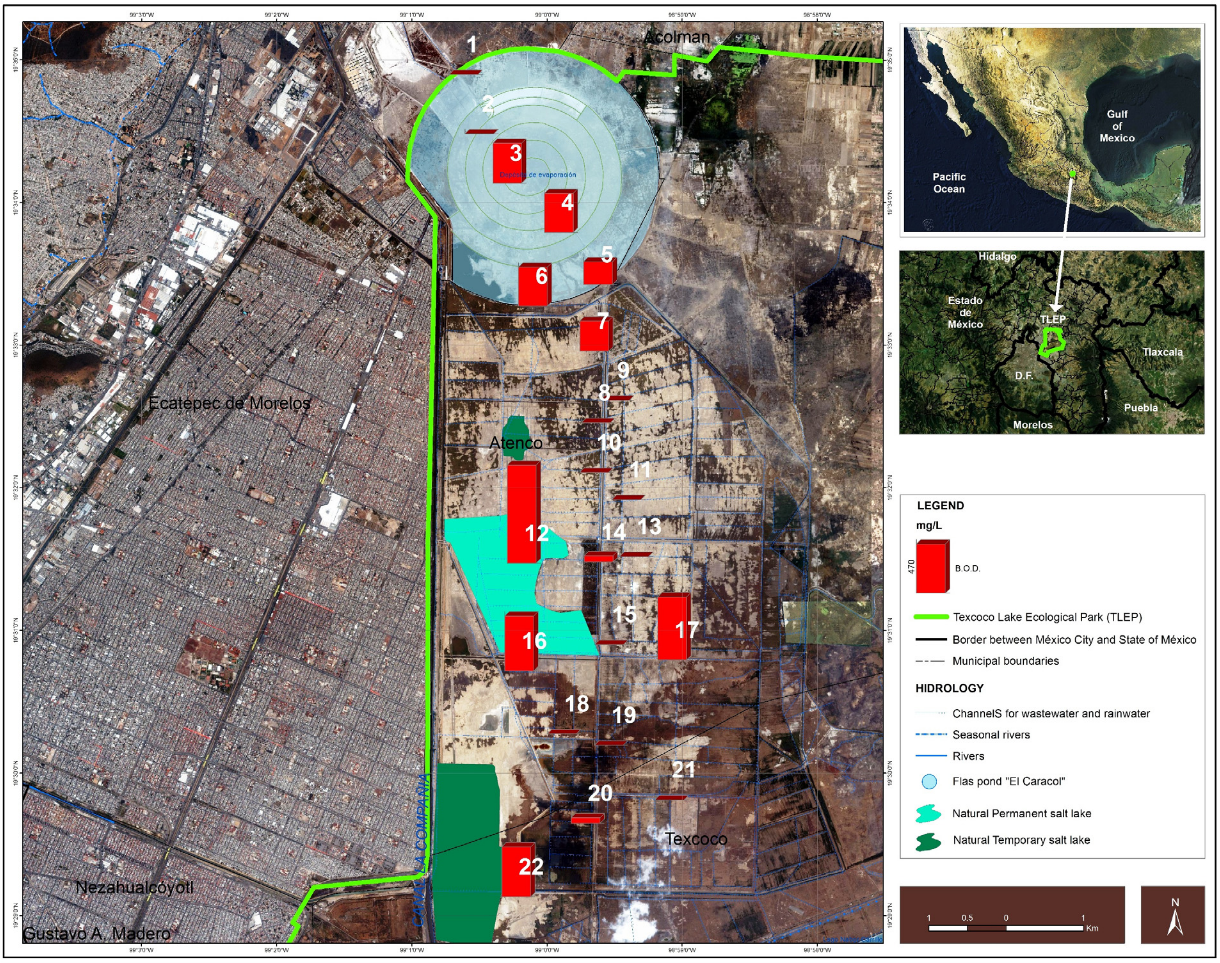


Figure 6. Spatial distribution of the values found in the BOD_5

The current impacts do not tolerate activities in the region for alimentary purposes, and increases the vulnerability of the human population to diseases, given the existing pollution (Gutiérrez-Yurrita and Lopez 2011, San Román et al. 2011). One of the major problems is contaminated water from the middle of the basin. The cause of pollution is the lack of water treatment plants in the cities and industrial corridors around the Lake. Over loads of organic matter increase BOD. In addition, different kinds of trace metals are present in sediments and wetlands (San Román et al. 2012).

The other important source of pollution into the LTEP is because of agricultural lands and by ranching (Luna et al. 2000). Peasants and livestock holders use to fertilise their lands and common lands by chemicals; they also tend to use insecticides and other pesticides without control; these irresponsible practices increase considerably COD in central areas of the Texcoco Lake (San Román et al. 2011). Consequently, the increase in the metal concentration in solid samples in comparison with results in water samples is due to accumulation of metals that reach this region via the liquid path and that are deposited in soil and sediments (Navarrete et al. 2012). The most important consequence of environmental pollution occurs in the dry season and is due to open-air exposition, because pollutants are dispersed towards the metropolitan zone due to strong winds (Jáuregui 1989). This phenomenon reinforces the environmental problems already present in Mexico City, which is one of the most populated and polluted cities in the World (Martínez and Jáuregui 2000). Point number 5 is probably the most representative of all the studied sites, given the depths that have been reached in this survey. Conductive stratum has reached between 18 and 20 m depth. In terms of the results of the two studies (VES and ET) and with resistivity values below 0.8 ohm-

Figure 7. Spatial distribution of the values found in the COD

m, we can conclude that, starting from this depth and up to at least 75 m, the resistivity increases its value up to 2.6 ohm-m, which corresponds quite probably to a sealed-shell that lies over a free aquifer (San Román et al. 2011).

It is noteworthy that other destinations of the pollutants (organic chemistry compounds and heavy metals) are the most inner shells in the subsoil, which is due to the level of water saturation and to the degree of compaction soils that it exhibits, which affects in an important way this ecosystem that also provides a refuge for an important number of local and migratory species of waterfowls (CONABIO 2012). Of the 300 waterfowl species recorded in the area, 14 are protected by Mexican regulations (NOM-059-SEMARNAT-2010). And 250 waterfowl species are protected by international treatises because of their migratory behaviour (USFWS, CWS and SEMARNAT. 2004; 2012). On the national agenda country planning, the Mexican government has declared to Lake Texcoco as number one priority for the Conservation of Birds, in the act called Area of Importance for the Conservation of Birds (AICA 2002, CONABIO 2012). In addition, about 200 of waterfowl species are registered in Neotropical Migratory Birds Conservation Act (NAWMP 2004). And the North America Central Flyaway is protected under the North America Free Trade (Kruse 2012). The decrease in the floodplain has been a serious problem for migratory birds. More than 200,000 migratory waterfowl plus residents can have a population of up to 350,000 birds in some years (Cleary et al. 2008). However, they do not have many places where to reach for wintering (Figure 1). If to the scarcity of sites for wintering, we add the pollution problems, as our results indicate that contaminated sites are precisely the places where waterfowl can get, survival of these species and the migration process are in serious risk.

The SEVs and physicochemical analyses of soil and water show hot spots where it should be pay attention to protect North American biodiversity. One of the first applications of these results in order to develop a master plan to manage the LTEP is in the regionalization of the park in environmental management units. Our results suggest that regionalization should start addressing two core areas for preserving ecological functions of the temporary salt lake and permanent salt lake. And two buffer areas for the conservation of the ecological processes of the lake, through the restriction of the use of the environmental services and ecological structure of the park. One of the buffer areas is the “Caracol”; and the other area is the natural grasslands, as a result of natural and induced desiccation of Lake water bed. These grasses have the peculiarity of being halophiles, and hold much of terrestrial and avian fauna of the basin. Criteria in managing the LTEP prioritize the environ-mental rescue of the permanent salt lake; secondly, restore hydro period and their ecological consequences of the seasonal salt lake. And thirdly, make a conser-vation program under the holistic perspective of the occasional flooding areas, which can be designated as areas of water public domain (Gutiérrez-Yurrita 2011).

Urban growth clashes with biodiversity conser-vation, button this site, both activities must go hand in hand more closely than elsewhere and at other times, since more than 22 million persons will not subsist without this important retention system of dust and wildlife refuge, and even, provider of flood for the surrounding population, which lives in a state of very high marginalization (Soulliere et al. 2007). All this through an appropriate management of its temporary water, sanitation in the middle of the river basin and preservation of the ecological functioning of the shore of lake (Gutiérrez-Yurrita 2012). Regionalization of Lake Texcoco is one of the first steps for the conservation and sustainable use of the territory in which man and nature win-win (López et al. 2013). Data from this study allow us to make the first approach.

In summary, integral environmental studies suggest the way in which should be a regionalization of the park (environmental management units), so that is integrated management of human activities, to those provided by the authorities in the program land use and above all, for the conservation of this distinctive lake system in the world. The regionalized pollution of Lake Texcoco vessel and different landscape mosaics that comprise it, attest that the same central area where we can find most of year a saline wetland, unique in the world, should be the region environmental management core and thus fully protected from any human impact.

The regions near the Caracol and south of the park should be considered as a territory of public water, in which case, human activities will be very restricted. Data analysis of this research promotes the idea that south-eastern areas are those that carry the greatest burden of human activities. Information gathered from this study allows us to develop the first stages of an integrative management program of the Texcoco Lake Ecological Park.

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Table 3. Metals (mg kg^{-1}) in soil sediments of the LTEP.

Site	Pb	Al	Fe	As	Zn	V	Co	Mn	Ba	Cu	Mg	Hg	Cd	Cr	Ni	K
3	41.4	48183.9	11442.9	1.19	53.4	149.5	11.9	256.2	< 400	17.0	37190.5	0.30	< 2.6	< 40.0	< 40.0	10518.8
4	55.1	65785.8	19491.2	0.30	61.5	240.8	13.9	268.9	< 400	13.0	33705.1	0.41	< 2.6	< 40.0	< 40.0	8047.3
5	71.8	77903.5	23257.8	0.51	106.7	281.9	15.5	379.6	< 400	21.7	33581.3	0.33	< 2.6	45.3	42.1	7618.8
6	71.4	78896.9	23873.6	0.83	115.5	267.4	15.5	365.0	< 400	28.3	28510.4	0.40	< 2.6	47.8	45.4	8988.2
7	45.4	19330.4	6822.7	0.26	25.0	84.5	13.2	192.6	636.2	8.8	43651.8	0.25	< 2.6	< 40.0	< 40.0	3623.8
12	53.8	64518.5	21091.6	0.83	81.9	306.4	13.5	263.1	< 400	17.2	25720.4	0.46	< 2.6	< 40.0	< 40.0	10893.9
14	52.5	24396.1	12754.6	0.27	95.8	240.0	9.8	229.4	< 400	22.1	2202.5	0.41	< 2.6	< 40.0	< 40.0	386.4
16	53.7	45496.3	14386.7	0.63	52.2	210.0	12.0	264.8	< 400	13.0	52779.5	0.42	< 2.6	< 40.0	< 40.0	8157.4
17	51.2	59433.2	17879.6	0.26	53.5	171.6	12.4	260.9	< 400	10.8	44356.8	0.39	< 2.6	< 40.0	< 40.0	7193.7
20	48.7	63090.2	14690.4	0.36	43.1	151.5	12.9	258.0	556.8	12.5	35825.0	0.29	< 2.6	< 40.0	< 40.0	5257.3
22	57.0	89107.8	27643.6	0.43	65.6	149.5	17.4	319.5	< 400	12.4	21919.5	0.37	< 2.6	< 40.0	< 40.0	9136.9