Scenarios of availability of water due to overexploitation of the aquifer in the basin of Laguna de Santiaguillo, Durango, Mexico

María de Lourdes Corral-Bermudez [Corresp., Equal first author, 1] , **Eduardo Sánchez-Ortiz** [Equal first author, 1] , **Dioselina Álvarez-Bernal** [2] , **Martín Omar Gutiérrez-Montenegro** [1] , **Erika Cassio-Madrazo** [1]

[1] Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Unidad Durango, Instituto Politécnico Nacional, Durango, Durango, México

[2] Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Unidad Michoacán, Instituto Politécnico Nacional, Jiquilpan, Michoacán, México

Corresponding Author: María de Lourdes Corral-Bermudez
Email address: mcorralb1000@alumno.ipn.mx

Background. The importance of water to life is unquestionable. Most of the fresh water we use for daily activities comes from the aquifers which in many cases due to misuse are over-exploited and at risk. This article studies the aquifer that appeared in Laguna de Santiaguillo basin; it should be noted that the most important economic activity in the basin is agriculture. **Methods.** By analyzing vector and demographic information, using GIS and with some field trips, the impact and risk on the level of disposition in every micro-basin that forms the basin were determined. **Results.** The different modeling scenarios demonstrate that the basin and sub-basins that conform Santiaguillo are overexploited. **Discussion.** The volumes concessioned are of such magnitude that they generate a condition of vulnerability to the activities of the basin and sustain the overexploitation conditions of the aquifer.

1 **Scenarios of availability of water due to overexploitation of the aquifer in the basin of**
2 **Laguna de Santiaguillo, Durango, Mexico.**

3 María de Lourdes Corral-Bermúdez[1], Eduardo Sánchez-Ortiz[1], Dioselina Álvarez-Bernal[2], Martín
4 Omar Gutiérrez-Montenegro[1], Erika Cassio- Madrazo[1]

5 [1]Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Unidad Durango,
6 Instituto Politécnico Nacional, Durango, Durango, México

7 [2]Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Unidad
8 Michoacán, Instituto Politécnico Nacional, Jiquilpan, Michoacán, México

9 Corresponding Autor:

10 María de Lourdes Corral-Bermúdez[1]

11 Sigma 119, Fracc. 20 de noviembre II, Durango, Dgo, 34220, México

12 Email: mcorralb1000@alumno.ipn.mx

13 **Abstract.**

14 **Background.** The importance of water to life is unquestionable. Most of the fresh water we use
15 for daily activities comes from the aquifers which in many cases due to misuse are over-exploited
16 and at risk.

17 This article studies the aquifer that appeared in Laguna de Santiaguillo basin; it should be noted
18 that the most important economic activity in the basin is agriculture.

19 **Methods.** By analyzing vector and demographic information, using GIS and with some field trips,
20 the impact and risk on the level of disposition in every micro-basin that forms the basin were
21 determined.

22 **Results.** The different modeling scenarios demonstrate that the basin and sub-basins that conform
23 Santiaguillo are overexploited.

24 **Discussion.** The volumes concessioned are of such magnitude that they generate a condition of
25 vulnerability to the activities of the basin and sustain the overexploitation conditions of the aquifer.

26 **INTRODUCTION**

27 Water is an indispensable resource to almost all life in the world; one of the characteristics of this
28 element is its potentiality to be renewable. The availability of superficial fresh water is calculated
29 between 9,000 and 14,000 km^3, and just 4,200 km^3 are available for human consumption (Cantu,
30 2012). Two percent (2%) of all fresh water is frozen in the polar ice caps. On the other hand,
31 groundwater is stored at a depth of 1000 m, representing 0.5% availability. This means a greater
32 availability than that in rivers and the sea (Fernandez, du Mortier, 2005).

33 The availability of fresh water in Mexico is about 475 km^3, 63 km^3 of this water is in the
34 underground, and the other 412 km^3 is surface water (Dominguez, 2011).The annual average

35   rainfall in Mexico is of a volume of 1511 km^3, which classifies Mexico as a country with low water
36   availability (Fondo para la Comunicacion y Educacion Ambiental, 2006).

37   The term average annual availability of surface water in a hydrological basin in its natural state
38   (without water use) is the limit of the annual average volume of water that can be granted or
39   assigned in a sustainable manner. On the other hand, in a basin in which some use is already made,
40   the average annual availability of surface water is the portion of that limit that continues to be
41   available for concessioning (Silva et al, 2013).

43   The concept of availability of the NOM-011-CNA-2000 has a juridical-administrative or
44   regulatory meaning, since it has the purpose of defining the existence of volumes of water
45   susceptible to being concessioned in a basin, without affecting the volumes previously granted (
46   Silva et al, 2013).

48   The availability of water is threatened due to some economic activities of great importance such
49   as industry and agriculture which require large volumes of fresh water to be carried out. As a result,
50   aquifers suffer overexploitation.

51   As Custodio states: "*an aquifer is considered to be overexploited, or at risk of overexploitation,*
52   *when the sustainability of existence is an immediate threat as a consequence of abstraction being*
53   *grater, or very close to, the annual mean volume of renewable resources, or when abstraction may*
54   *produce a serious water-quality deterioration*" (Custodio, 2002).

55   At a global level, aquifers present a serious threat due to both pollution and overexploitation caused
56   by urbanization, industrial development, agricultural activities, and mining ventures (World Bank,
57   2002).

58   In Mexico, the water administration has caused that 106 of the 653 aquifers be overexploited and
59   some of them show deterioration in the quality of groundwater, data expressed by experts during
60   the Second National Colloquium "Groundwater in Mexico" carried out in the senate (Reforma,
61   2015).

62   Groundwater is one of the most important natural resources, the overexploitation of aquifers
63   generates that the salinity of groundwater increases and continues to threaten the viability of
64   agriculture (Khenzzani, Bouchemal, 2018).

65   When an aquifer is declared overexploited, there are some actions and factors that should be
66   considered, some of them are the legacy and to inform the population of the conditions in which
67   the aquifer is found, as well as the remedial actions that can be carried out for the recovery and
68   recharge of the aquifer.

69   All the rules, issues and procedures involve peasants, sellers and groups with agriculture interests
70   as well as politicians, legislators and judges. They control the access to the means of production
71   and establish the economic and social interests in relation to the natural, technological and human
72   resources. But they also install the legitimate forms to transfer the resources either by allocation,
73   interchange, sale or heritage (Moreyra et al, 2012).

74 The capitalist-neoliberal model of food production is incapable of solving the problems of food
75 security. The control, form and conditions under which unregulated capital operates in the world
76 diet, activate the conditions for increasing insecurity, both in terms of food quantity and quality
77 (Altieri, 1999).

78 Modern agriculture, with intensive abuse of industrial chemicals and bad distribution of water, has
79 a negative impact on the environmental and human health. Soils, lakes, rivers and groundwater
80 suffer the impact of pollution (Martínez, 2009).

81 There are some studies that demonstrate the risk of an overexploited aquifer. An example of this
82 is the case of the aquifer of Disi in Jordan. The study reveals that the environmental consequences
83 of groundwater extractions generate dropping water levels, mobilization of some salty water
84 bodies in geologic units connected vertically with Disi aquifer such as Khureim Formation and
85 irrigation return flow waters with their high salt contents, biocides, and fertilizers concentrations
86 (Salameh et al, 2014).

87 The aquifers in Mexico
88
89 Mexico is divided into 653 aquifers, of which 448 national aquifers are in a condition of
90 availability, as of 2016, 105 overexploited aquifers were reported in the country, considering
91 overexploitation based on the extraction / recharge ratio (Statistics on Water in Mexico, 2017)
92 (http://sina.conagua.gob.mx/publicaciones/EAM_2017.pdf).
93
94 The north and center of Mexico, have the largest amount of overexploited aquifers, since there is
95 more population but less surface water, so that more groundwater is used (Diaz et al, 2013).
96
97 A poor use of resources places the population in an imminent risk. It is important to consider that
98 the risk is the vulnerability that is conjugated with the threat, taking into account that nature is not
99 generating said risks, but the social conditions themselves.

100 There is a discussion of socioeconomic vulnerability regarding the degree to which social classes
101 are differently at risk. Recognizing the conditions of socioeconomic vulnerability as a generator
102 of risk and disaster has a political dimension: it implies the acknowledgement that in the states of
103 risks and disasters there is a political and social responsibility, which refers to the notions of
104 environmental and spatial justice (Campos, Toscana, Campos, 2014).

105 It is important to emphasize that disasters are not only the products of threats, they are
106 consequences of the environmentally unsustainable economic development model from which
107 some sectors benefit, to the detriment of others, at all scales: global, national and regional (Campo,
108 Toscana, Campos, 2014).

109 Description of the area of study

110 Location of the basin of the Santiaguillo Lagoon

111 The endorheic basin of Santiaguillo Lagoon is located to the north of the hydrological region no.
112 11 of the Presidio and San Pedro rivers, with a surface of 2,542.16 km2. This basin partially covers

113 the municipalities of Canatlán, Coneto de Comonfort, El Oro, San Juan del Río, Santiago
114 Papasquiaro and Nuevo Ideal (CONAGUA, 2011).

115 "Santiaguillo" is the southeast region from the route followed by the migratory birds that come
116 from Alaska and Canada. These birds nest in Santiaguillo, which is why this site is considered one
117 of the 30 most important wetlands. International organizations place the basin in an under-pressure
118 water condition derived from the underground extraction, the pollution and the way to address the
119 management of water and drought (CONANP, 2012).

120 *Topographic profile*

121 Tracing a cut from south to north, the profile starts from a maximum altitude of almost 3,200
122 m.a.s.l. in the southeast zone, characterized by an accidental topography with steep slopes in the
123 first 15 km. After that, there is an extension of 30 km where the slope is very small and finally
124 there is an increase in altitude close to 2,000 m.a.s.l. in the north part.

125 *Orographic characteristics*

126 The zone belongs to the physiographic province of the "Sierra Madre Occidental", and the sub-
127 provinces are the Gran Meseta and the Cañones Duranguenses [Durango's ravines], which has its
128 origin in the southern part to the west of the territory; the rest is described as mountains and plains
129 of Durango (Figure 1).

130 The basin is located inside a "graben", that is, a depression limited on both sides by raised faults,
131 where the terrain of the internal part has sunk because of internal forces (Nieto- Samaniego et
132 al,2012), the area is characterized by the relief of the north and south zone that the surveys
133 perfectly close the graben thus giving origin to the endorheic sub-basin (Figure 2). Nieto describes
134 the site as: "The Santiaguillo graben forms the northwestern part of the regional San Luis-
135 Tepehuanes fault system, which is located between the Sierra Madre Occidental and the
136 physiographic Mesa Central. In the region of Santiaguillo graben, we identified eight
137 lithostratigraphic units with ages from Eocene to Quaternary" (Nieto Samaniego et al, 2012).

138   Figure 1. Topoform system map
139   Source: Own elaboration
140 Physical aspects

141 Weather

142 In the valley of Santiaguillo, two types of climates are identified: dry semidesert (BS) and a series
143 of mesothermal or temperate climates with dry period in winter (Cw). The temperature ranges
144 from 8 to 18 ° C, with an average precipitation of 300 to 800 mm (INEGI, 2010).
145 Table 1 shows the extension of each type of climate, to get the classification of weather it was used
146 the köppen classification.

147   Table 1. Types of climate and its extension in the sub-basin

148 Source: own elaboration with vector information of INEGI (For its acronym in Spanish, National
149   Institute of Statistics and Geography)

150 Hydrography

151   Figure 2. Hydrograhic Map Of Laguna de Santiaguillo Basin Source: own elaboration with
152   vector information of INEGI

153 The map of figure 2 shows the detailed hydrography, which allows to understand the behavior
154 shown in figure 3, where hydrology is presented by microbasins.

155 In this study case it is proposed the use of microbasins as a reference to the specific surface
156 exploitation areas.

157   Figure 3. Map of hydrology surface and division in micro-watersheds

158   Source: Own elaboration with vector information of INEGI

159 The most important micro-basin in the surface is located to the north, where the Tinajuelas stream
160 is formed, this is the main runoff and it has its origin in the northern mountain range ending in the
161 northern body of the Santiaguillo lagoon.

162 The streams of San Antonio, Grande, Hondo, San Francisco and the Tinajitas are its tributaries
163 from the northeast. From the northeast area are also the streams: Los Alamos, Palos Colorados,
164 Colorado and Salto de San Lucas. In this micro-basin it is also located the Zeta stream that rises in
165 the northeast area and empties directly into the north lagoon; the stream of El Toboso has its origin
166 in this area and it is the main contributor of water to the Zeta stream, which in turn joins the
167 Tinajuelas at the mouth.

168 The Gato stream has its origin in Santa Rosa hill which passes through the side of the town of
169 Nuevo Ideal and flows into the north lagoon. The Candado stream and Guatimape river or the
170 Molino are born in the mountain range of Epazote.

171 Its runoff ends in two bodies of water located in the central part of the basin aligned from north to
172 south, the topographic configuration around them is composed of areas of reduced extension, high
173 and steep, the largest are located towards the southwest and northeast of the sub-basin; the
174 topography of this site corresponds to mountain ranges of El Epazote, San Francisco and San
175 Miguel, the altitude ranges fluctuates around 3000 m.a.s.l., the average elevation is 2,160 m.a.s.l.
176 forming a valley that has allowed the development of important productive activities (CONAGUA,
177 2011)

178 The streams in order of importance are Tinajuelas, Guatimape, Tejamen, El Gato, El candado,
179 Torunos, Las Jarillas and El Trebol; these streams feed the northern lagoon body that has perennial
180 water. On the other hand, El Colorado, La Tinaja, Viborillas, Ojo de Lobo and Los monos feed the
181 southern lagoon which has an intermittent behavior.

182 The streams Alisos, Gigantes and Seco lead into the Astilleros stream, which is another principal
183 slope of the area. In the east area, there stand out the streams Hondo, Grande, Las Jarillas and
184 Coyotillos.

185 All the runoff forms the municipality of Nuevo Ideal and spills its waters into the northern lagoon.

186 In the municipality of Canatlán, the streams of La Soledad, Los Ladrones, Claveras and La Tinaja
187 have its slopes in the south lagoon.

188 Surface lithology

189 The Laguna de Santiaguillo basin is made up of alluvial soils, which are in the plain areas, and
190 cover 40.95%. These soils are known as alluvial fans, they are located next to mountainous belts
191 and they are materials transported by water; their size varies from clay to thick gravels, ridges and
192 blocks (Molina Garza, 2013).

193 Rhyolite- acid tuff rocks cover 40.45% of the area and are characterized by volcanic rocks
194 composed of quartz and alkali feldspar. Eleven percent (11%) of the surface rock is constituted by
195 lacustrine sedimentary media which allows the presence of detrital and biodetrital, chemical,
196 biochemical and organic sediments; these are located mainly in the bed of both lagoon bodies,
197 determining their important age (Ayala, 2010).

198 The rest of the geological composition of the area is Tufa-acid 3.13%, andesite 2.5% (volcanic
199 rock), conglomerate 1.37% (sedimentary rock), wind 0.25% (the accumulation of materials has its
200 origin in the wind), basalt 0.14% (volcanic igneous rock), intermediate tuff 0.06% and tonalite
201 0.05% (plutonic igneous rock), the sub-basin distribution presents the most representative values.

202 Soils

203 The soils that are distributed in the basin are of Vertisol type with 25.83% of the total area and it
204 refers to a type of clay soil, heavy and fine texture, it is impermeable, susceptible to floods. It is
205 hard to dry and tends to be a floor that turns or flips. Their presence reveals the lacustrine formation
206 processes in the basin from the erosions of the middle and upper basin areas, depositing by
207 dragging in the parts where the runoff speed is reduced due to the slope. It is present in temperate
208 and warm climate, the vegetation on this type of soil in the basin consists of pastures and bushes.

209 Lithosol is present in 23.9% of the sub-basin and due to its acid characteristics and its thickness of
210 about 10 cm of rock or limestone (tepetate), it is mainly used for grazing since it is not suitable for
211 crops. The regosol type covers 19.33% of the sub-basin present on the west slope under the pine
212 forests, it does not have horizons and it is a very permeable soil.

213 Solonchak is a type of salic soil characterized by being very permeable and it covers 8% of the
214 territory of the sub-basin it is particularly identifiable in the unflooded lagoon beds. According to
215 the vector data of the INEGI the water bodies do not apply in the matter of soil; their occupancy
216 is 4.75%; however, when the south lagoon dries, it reveals this type of soil on its bed (INEGI, 2004
217 and Silva M, 1981).

218 Regarding the texture of the soil, the sub-basin presents an average texture of 56% of its surface,
219 followed by a fine texture with 30.46%; the coarse texture occupies 9.01% of the territory; the
220 remaining 4.75% belongs to the southern lagoon and there is no data available regarding its texture
221 (INEGI, 2010) (Table 2).

222   Table 2. Soil surface by texture of the sub-basin

223   Source: Own elaboration with vector data of INEGI

224   Ground cover

225   In the sub-basin of Santiaguillo, there is vegetation of pine forests, most of it is located in the area
226   of the plateau occupying 20.75% of the area, the forest of oak-pine occupies 3.5% and its
227   distribution is in the eastern area, 2.43% oak forest is found in certain areas to the north, southeast
228   and south of the sub-basin. The pine-oak forest occupies 1.32% and extends from the north to the
229   east of the mountain range of Coneto.(INEGI, 2010)

230   The area studied has three types of grassland: 10.45% of the surface of the Santiaguillo valley
231   presents natural grassland, 3.47% induced pastureland and 2.58% is halophilic grassland. Three
232   point ninety-four percent (3.94%) of the surface is crasicaule scrub, the bushes of fleshy stems
233   such as nopales, Opuntia cactaceae and others are dominant (INEGI, 2010).

234   Description of the aquifer
235   The "Valle de Santiaguillo" aquifer has an average annual recharge of 50.7 million m3 / year,
236   against a natural discharge of 8.0 million m3 / year. The concessioned volume of groundwater is
237   60 million m3, and according to the CONAGUA it is in a deficit of -15.472461 million m3 / year
238   (CONAGUA, 2009).
239

240   With regard to the administrative situation, it is active for exploitation and use of national waters
241   and the aquifer in its entirety is free of delivery (CONAGUA, 2009).
242

243   According to the decree published on December 31, 1999, in the "Diario Oficial de la Federación",
244   3 zones are established for the availability of the aquifer. The 1039 belonging to the municipality
245   of Nuevo Ideal and located in the area of availability 6, 1001 of the municipality of Canatlán within
246   zone 6 of availability and 1032 of Santiago Papasquiaro within the area of availability 7.

247   CONAGUA establishes that the aquifer is in a state of vulnerability with an index value of 7,
248   which in the scale refers to a high contamination vulnerability (CONAGUA, 2009)

249   Economic and social aspects

250   Demography

251   According to the results of the INEGI census and counting the 151 locations located within the
252   basin, in a period of 10 years (2000-2010), 102 locations of the 131 had a decrease in their
253   population; 41 of them showed an increase and 9 maintained an equal number of inhabitants
254   (INEGI, 2010).

255   Of the 31,967 inhabitants of the basin, 21,091 (66%) live in rural areas (towns with less than 2500
256   inhabitants) and the rest live in the town of Nuevo Ideal with a population of 10,876 inhabitants
257   (34%) (INEGI,2010).

258   The analysis of the population pyramid reveals that the birth rate is higher in males than in females.
259   To the 2049 children registered under 2 years old, 965 were female and 1084 were males, the

260 difference remains constant until the age of the majority is exceeded since the range of 18-to-24-
261 year-old women (2,076) exceeded the number of men (2,026) due to immigration seeking better
262 employment opportunities. The third age (60 years and older) is 12% (3,872 individuals) of the
263 total population (INEGI,2010) (Figure 4).

264 Access to education

265 Regarding the literacy of the 24,123 people who were examined in this area, 1,952 persons (8%)
266 do not attend school, in this category small children who are not yet of school age are omitted,
267 including children over five years and adolescents up to 14 years old. 1,621 persons (7%) of the
268 individuals whose ages vary between 15 and 24 years attend school, while 4% (919 people
269 including children and adolescents ranging from 8 to 15 years old, and adults) were considered
270 illiterate. Nevertheless, the figures indicate that almost 70% of the population has unfinished
271 education, and in many cases incomplete basic education.(INEGI,2010)

272 Economic conditions

273 Of the 13 largest locations in the basin (20,363 inhabitants), only 35% (7,062 inhabitants) are
274 economically active. The first income for the families of these communities comes from men since
275 80% of the total economically active population is male (INEGI,2010).

276 Fifty-eight percent (58%) of the total population (18,593 inhabitants) are entitled to medical care
277 and health services in some public or private institution, 41% of them do not to have the right to
278 receive any medical attention, while a minority of 1% did not provide this information
279 (INEGI,2010).

280 Access to public health services

281 Of the results obtained by the sample of the thirteen locations with significant populations, 66%
282 have medical services and 34% (20,363 inhabitants) do not (INEGI,2010).

283 The total number of households in the 151 locations is 7,879, of which 6,122 are headed by a male
284 or head of a family (78%) and 1,757 are female-headed (22%) (INEGI,2010).

285 The households in which the head of family is male account for 81% of the total population, which
286 corresponds to 25,690 inhabitants; the households whose head of family was a woman are 19%
287 (5,959 inhabitants) (INEGI,2010).

288 Housing conditions

289 Of the 11,649 homes surveyed, 11,545 homes are private and only 7,959 (68%) are inhabited
290 dwellings; the density is 4 inhabitants per house (INEGI,2010).

291 Of the 7,879 inhabited private homes, 96% have a different floor than the land and only 4% have
292 a dirt floor; 70% have 2 or more bedrooms; 90% (7,080) of the houses are made up of 3 or more
293 rooms (kitchen, bathroom, living room, bedroom, etc.) (INEGI,2010).

294 Ninety-eight percent (98%) of the houses have electricity service, 94% have piped water service,
295 91% have a toilet, and 84% have drainage service connected to a municipal network, 80.3% of the
296 total houses studied in this analysis have all of the aforementioned services (INEGI,2010).

297 Marginalization index

298 According to the data provided by CONAPO (Comisión Nacional de Población) in 2015, the
299 municipality of Canatlán showed an index of marginalization of -0.822, Nuevo Ideal -1.001 y
300 Santiago Papasquiaro -0.676, which places the basin of the Laguna de Santiaguillo in a low degree
301 of marginalization (CONAPO,2015).

302   Figure 4. Population pyramid of the Laguna de Santiaguillo basin

303   Source: own elaboration with 2010 census information of INEGI

304 The aim of this article is to evaluate the availability of water in Laguna de Santiaguillo basin
305 derived from the overexploitation of the aquifer to propose the main ideas to get some sustainable
306 mitigation measures.

307   **MATERIALS AND METHODS**

308 To get the characterization of the sub-basin, the data employed was vector and demographic
309 obtained from the National Institute of Geography, Informatics and Statistics (for its acronym in
310 Spanish INEGI) and it was processed using geographic information systems. The information of
311 the hydraulic infrastructure of the principal rivers in the zone, the public register of the rights of
312 water and some of the vector data were obtained from the National Commission of Water (for its
313 acronym in Spanish CONAGUA). Meteorological information was collected from the register of
314 National   Meteorology   Service   (for   its   acronym   in   Spanish   SMN)
315 (http://smn.cna.gob.mx/es/informacion-climatologica-ver-estado?estado=dgo) and the spatial
316 analysis was made using the computer package Arcgis 9.3.

317 In the field, the outline of the sub-basin in the plane zones was studied by giving a terrestrial travel
318 verifying the watersheds corresponding to the limits of the sub-basin. A GPS Garming Oreon 550
319 was used, along with a UTM coordinate system with a Datum WGS84.

320 Each micro-basin was overlaid by layers putting together the natural data that influences the water
321 availability. The vector layers of hydraulic infrastructure, roads, locations and Agricola zone were
322 used to get the anthropic factors and the influence they have in the zone following water
323 availability. This allowed to attain knowledge of the natural dynamic and social conditions about
324 the water use and cycle in the zone.

325 A hydrological balance was carried out at micro-basin level using the methodology indicated by
326 the NOM-011- CONAGUA-2015 and the manual given by the Mexican Institute of Water
327 Technology (IMTA, for its acronym in Spanish).

328 The Nom 011 established the average annual availability of national waters in hydrological basins
329 and in aquifers. The method shall be considered as the minimum mandatory technical requirement
330 and does not exclude the additional application of complementary methods or the more

331 complicated and precise cases, when the available information allows it, in which case the
332 Commission shall review together with the users and determine which are the results that prevail.
333
334 The Norm basically signalize the availability annual average of surface water in the basin, annual
335 average volume of wring of the basin towards waters down, availability annual average of water
336 from the subsoil in an aquifer.
337
338 To determine the main channel at the outlet of the hydrological basin, by means of the following
339 expression:
340

$$\begin{aligned} \text{Availability annual average of surface water in the basin} \\ = \text{Annual average volume of the basin runoff towards water down} \\ - \text{Current Annual volume committed water down} \end{aligned}$$

341

342 Equation 1

343 The mean annual runoff volume of the basin downstream of the site of interest is determined
344 when applying the following expression:
345

$$\begin{aligned} Annual\ Average\ volume\ of\ runoff\ of\ the\ basin\ towards\ waters\ down \\ = Annual\ average\ volume\ of\ runoff\ from\ the\ upper\ waters\ basin \\ + Medium\ Volume\ annual\ runoff\ natural + Annual\ volume\ of\ returns \\ + Annual\ volume\ of\ imports - Annual\ volume\ of\ exports \\ - Annual\ volume\ of\ extraction\ of\ superficial\ water \\ - Annual\ average\ volume\ evaporation\ in\ reservoirs \\ - Medium\ volume\ annual\ variation\ storage\ in\ embalses \end{aligned}$$

346

347 Equation 2

348 To determine the average annual availability of subsoil water in an aquifer apply the equation:
349

$$\begin{aligned} Availability\ annual\ average\ of\ water\ from\ the\ subsoil\ in\ an\ aquifer \\ = Total\ recharge\ annual\ average - Discharge\ natural\ engaged \\ - water\ extraction\ groundwater \end{aligned}$$

350

351 Equation 3

352 Combined with the regulations, the runoff coefficients given in the manual were used: evaluation
353 of water resources, elaboration of water balance integrated by river basins
354 Derived from the runoff coefficients, the volumes that infiltrate, evaporate and drain are evaluated.
355
356 Starting from the scenario given by the balance of surface and groundwater other scenarios were
357 modeled by simulating the reduction of extraction to find the ideal conditions.

358 The analysis was based on the concept of natural runoff. Based on the above, the relative
359 availability understood as the ratio between availability and total human and natural demand was
360 determined. Under the usual criteria, a relative availability under 1.4 is classified as a deficit, from
361 1.4 to 3.0 is qualified as equilibrium, from 3.0 to 9.0 as availability and greater than 9 as abundance.

362 In this study case it is proposed the use of microbasins as a reference to the specific surface
363 exploitation areas, they could be linked in an specific area in the aquifer. Even as it is just one

364   aquifer, there are some areas in which the pressure is higher than in other areas, so it is propose
365   the needed to regionalizer with the use of the microbasins.

366   To delimit the microwatersheds their areas were determined, and the corresponding cuttings were
367   made in all the vector layers to generate the detailed cartography.
368   From the topographic mapping analysis, it was determined that the lake surface reaches 8% of the
369   total basin

370   The water availability criteria used are those presented by Shiklomanov (Table 3).

371   Tabla 3. Levels of water availability
372   Fuente: Shiklomanov, Igor, World Water resources at the beginning of the 21st century,
373   PHIUNESCO,2002

374   **RESULTS**

375   Land use

376   According to INEGI'S vector data 2012, the sub-basin presents the following land use (Figure 5):
377   51.08% of the area has a forest, livestock or agricultural use, this area covers the plains region of
378   agricultural use; 17.54% is considered for irrigation farming is at the largest area found in the
379   north. In the western zone, there is the Tejamen dam, where an extension of irrigated farmland
380   originates and reaches the central area of the sub-basin, covering the needs either by running water
381   or by the series of wells found in the zone according to the vector data of the REPDA, in the same
382   way the dam of El Candado presents a portion of irrigated farmland by water rolled in combination
383   with wells of water in the area, 82.46% is seasonal agriculture (Table 4).

384   Figure 5. Land use for agriculture in the sub-basin
385   Source: Own elaboration with vector information of INEGI
386   To obtain the map of figure 6 the information was used, the agricultural information provided by
387   INEGI was used, the information used corresponds to the year 2012
388   Hydrological balance of surface water

389   The determination of the relative availability at the micro-watershed level reflects a regionalized
390   manner of the different pressure conditions to which the resource is subject due to human activity.

391   All the determinations were based on the volumes concessioned and registered in the Public
392   Registry of Water Rights of the National Water Commission; therefore, the balance reflects only
393   the administrative condition and not necessarily the real one: however, in the absence of data
394   regarding the real extractions of the surface water volumes used and those extracted from
395   groundwater. This study allows us to evaluate the condition of vulnerability of the basin based on
396   the availability of the resource due to the way in which use is regulated.

397   In the micro-watersheds that contribute their runoff to the northern part of the Santiaguillo lagoon,
398   relative availability is obtained with deficit conditions in the micro-basins: "Presa Tejamen" to the
399   east of the lagoon body and "Torunos" located to the west, following the other micro-basins exert
400   a little pressure over the water resource. Abundance conditions are only found in the micro-basin
401   located upstream of the Dr. Castillo del Valle and La Redonda dams, which due to their natural

402 conditions are important generators of water that are not used. Moreover, in the case of La
403 Redonda there are conservation actions in the upper basin.

404 In the micro-basins that provide water to the southern part of the Laguna de Santiaguillo with
405 significantly smaller extensions, with human presence in practically all of them and with a high
406 pressure on a very limited resource, the general conditions of relative availability are deficit.

407 The results of the surface water balance (Table 5), in combination with the groundwater balance
408 (Table 6), describe the heterogeneity of the basin that favors differences in the amount of rainfall
409 within it. According to the calculations made, an annual total precipitated volume of 1,416 million
410 cubic meters is estimated.

411 The texture of the soil and the combination with the differences in the vegetation cover of the zone
412 propitiate a variation in the drained volume, the coefficient of average draining that was
413 determined is 10.45%.

414 The average annual volume of runoff was estimated at 341 million cubic meters. The Gato,
415 Tejamen and El Candado micro-basins present higher runoff coefficients due to the areas they use
416 for agricultural activity.

417 The surface lithology in combination with the types of soil and its texture allow an average
418 infiltration percentage of 1.84% of the total precipitation, the total annual average volume
419 infiltrated to the aquifer was calculated in 29.18 million m^3. The infiltration is attributed to the
420 types of soil and rock present in the micro-basin, it was observed that areas with less infiltration
421 have a combination of soils of the vertisol or solonchak type and tuffs.

422 Volumes of concessioned water

423 The area studied presented different volumes of surface water concessions, highlighting the El
424 Candado, Tejamen and Las Jarillas micro-basins with the most important hydraulic works and
425 surface concessions in the area.

426 Based on the results of the integral hydrological balance, it was observed that the micro-basins are
427 capable of capturing sufficient rainfall to satisfy the surface granted by CONAGUA; however, two
428 of them showed a deficit since their contribution is not enough to provide the volumes awarded.
429 Specifically in relation to the El Candado micro-basin, the results obtained showed surface water
430 availability conditions.

431 The average runoff in the basin is 135.79 millions of m^3/Year, the shallowness of the superficial
432 and underground natural reservoirs in the sub-basin favors the evaporation of 81 millions of m^3/
433 year. Added to this the geographical conditions of the sub-basin are short-term streams and a quick
434 discharge to the body of water called the Santiaguillo lagoon, only 16.26 millions of m^3 have been
435 concessioned in the middle and upper basin. With this, the surface availability is 38.53 millions of
436 m^3, thus resulting in a relative availability of 1.4 considered as deficit (Comisión Nacional del
437 Agua, 2011).

438 It was estimated that the natural surface availability per capita (amount of water that exists) can be
439 allocated to their economic activities, which was obtained by dividing the drained volume between

440 the number of inhabitants. Most micro-basins showed levels ranging from average to high. Based
441 on this data per person, the quantity of water used in different activities is obtained over 6,000
442 cubic meters on an annual basis per inhabitant.

443 The availability of development was determined by calculating the difference between the drained
444 volume with the surface water concessioned, to know if they have the capacity to provide surface
445 water to cover future demands in economic activities such as livestock or agriculture. The micro-
446 basins that provided sufficient surface water to satisfy demands in terms of agriculture and
447 livestock are El Candado, Guatimapé, Viborillas and Ojo de Lobo whose values of excess drained
448 water of the volume concessioned propitiate this condition.

449 Hydraulic Infrastructure

450 In the area, there are three small storage dams for agricultural irrigation use : La Redonda, Tejamen
451 and Dr. Castillo del Valle. They have storage capacities of 7.0, 3.0 and 0.8 Hm^3.

452 There is a significant number of deep wells that according to the public registry of water rights
453 (REPDA for its acronym in Spanish) amount to 1,958 works in the cut to 2011 (CONAGUA,
454 2011).

455 Hydrological balance of groundwater

456 Volume of concessioned groundwater

457 The aforementioned conditions also influence that the Santiaguillo Valley aquifer receives an
458 average annual recharge of 30.42 millions of m^3/ year with a committed natural discharge of 23.04
459 millions of m^3/ year, mostly by evapotranspiration. The aquifer presents concessions of 90.69
460 millions of m^3, almost three times the capacity of the average annual recharge, which favors
461 overexploitation, so that the underground deficit is 83.32 millions of m^3/ year (CONAGUA, 2011,
462 2002).

463 The number of underground extraction points counted for this study is 1,996 wells, distributed
464 throughout the lower part of the basin around the lagoon bodies. The concessions were
465 concentrated in Table 4, converting agricultural use as the main groundwater use with 1,329 wells
466 and over 5 million m^3 of annual concessions.

467 Table 4. Number and volume of the underground sources granted

468 Source: Own elaboration with information of the Public Register of water rights, of the National
469 Commission of water.

470 The use of groundwater in the Laguna de Santiaguillo basin has its greatest application in
471 agriculture; the percentages of the use are showed in the figure 6.

472 Figure 6. Use of groundwater in the Laguna de Santiaguillo basin (%)

473 Source: Own elaboration with CONAGUA Information

474 The analysis of the infiltration capacity of the micro-basins in comparison with the exploitation of
475 the aquifer supposes extractions that exceed their recharge capacity. A higher level of exploitation

476 was observed in the micro-basins located to the west and north, exceeding more than five times its
477 recharge capacity.

478 Given the condition of overexploitation of the aquifer and its limited recharge conditions, the
479 modeling of scenarios was carried out, which allowed to observe whether the expectations of
480 resolving the vulnerability of the basin are reachable or not.

481 To do this, the 5 scenarios were modeled making a reduction of extractions:

482 Socio-environmental vulnerability assessment

483 Delimitation of micro-basin

484 For the purposes of this investigation, the basin area was divided into 13 micro-basins of the
485 mentioned streams, as well as the lagoon bodies (Figure 7).

486 From the topographic mapping analysis, it was determined that the lake surface reaches 8% of the
487 total basin and, according to this, the northern lagoon that covers only 81.38 Km^2(3.2%) is fed
488 with the runoff of 1905.34 Km^2, that is to say, 75% of the surface of the sub-basin and the southern
489 lagoon that covers 136.21 Km^2 (5.4%) feeds on the runoff of 16.5%, which in part explains the
490 fact that the north lagoon has perennial water and the southern lagoon has a rather intermittent
491 behavior.

492   Figure 7. Map of aquifer overexploitation by micro-basins
493   Source: Self-made
494 Analysis of scenarios

495 Scenario zero

496 It arises from the hydrological balance made only with the natural conditions of rainfall and runoff
497 without taking into consideration the infrastructure and giving zero value to human uses, this
498 allows having an overview of the natural condition of the micro-basins in order to locate the criteria
499 of analysis. The results obtained in the indicators for this scenario are presented in Table 7.

500 Status quo scenario

501 The status quo scenario (Table 8) corresponds to the integrated hydrological balance of the current
502 conditions of the basin through the analysis of the water resource uses reported by the National
503 Water Commission (CONAGUA) in the Public Registry of Water Rights.

504 From this analysis, it can be summarized that the basin currently has an groundwater use of 318%
505 compared to the annual volume infiltrated to the aquifer; hence its condition of overexploitation,
506 the micro-basins that currently have the greatest pressure on the aquifer are: Tejamen (419%), El
507 Gato (721%), Tinajuelas (478%), Las Jarillas (356%), El Padrón (412%) and El Colorado (303%).

508 Low scenario

509 The results of the low scenario are presented in Table 9, under the schemes of normative regulation
510 of groundwater extraction for agricultural use mainly, low and medium technification in irrigation

511 systems. Proposing a reduction order of 20% of the losses and waste in these activities, particularly
512 those related to underground extraction.

513 The response of the basin in this scenario is an exploitation of the aquifer in 258% compared to
514 the recharge capacity, where the greatest impact is produced in the micro-watersheds: Tejamen
515 (349%), El Gato (699%), Tinjuelas (398%), Las Jarillas (295%), Padlock (337%) and Colorado
516 (248%), where there is a considerable decrease in the exploitation of the aquifer.

517 Medium scenario

518 It was carried out under a 65% extraction of the current annual volume concessioned. The response
519 of the basin in terms of groundwater is 210% exploitation of the recharge capacity of the aquifer.
520 Under this criterion, the exploitation by micro-basins is as follows: Tejamen has an underground
521 exploitation of 292%, El Gato shows an extraction of 502%, Tinajuelas explodes in 333%, Las
522 Jarillas presents an underground concession of 246%, El Candado exploits 278% and for the
523 Colorado the groundwater resource is submitted to 205%, all percentages are in relation to the
524 recharge capacity of the aquifer (Table 10).

525 Ideal scenario

526 It departs from the integrated hydrological balance where the reduction of uses is sought until
527 achieving a balance between production and use of water. This scenario allows visualizing the
528 conditions that would lead to sustainability in order to evaluate its viability, in which the
529 extractions are equal to the infiltrations of the basin (Table 11).

530 Viability of scenarios

531 Figure 8 shows the impact of the proposals of this investigation where it is observed that the viable
532 scenario allows to reduce the pressure in the aquifer going from 318% of extraction to 258% if the
533 technification of irrigation and good practices are adopted, reducing the current extraction to 20%,
534 which is not economically and socially feasible.

535 Effects on the potential social and economic development of the sub-basin

536 Analyzing the human activities that take advantage of the water in the basin could be reflected in
537 the balances of surface and groundwater. It can be deduced that the micro-basins of the north area
538 have small volumes of surface availability that are not very significant. The micro-basins of the
539 south zone due to their small surface area, the dominance of temperate semi-dry climate and the
540 strong relation of the area used for agriculture present deficits in all of them.

541 In contrast, the revision of the volumes of groundwater reflects an overexploitation of the aquifer
542 in relation to recharge ranging from 116% to 738% in 10 of the 13 micro-basins.

543 In general, the high evaporation in the basin, a low average rainfall, and consequently a limited
544 recharge of the aquifer also reduced by the high presence of alluvial soils in the lower part of the
545 basin. Added to the conditions of the endorheic basin for not being connected to the rest of the
546 territory, it generates an isolated space characterized by a fragile condition for the sustainability of
547 human activities, considering the great agricultural and livestock vocation of the region where

548 these activities are also based on the coexistence of cultures Mennonite and Mexican with deep-
549 rooted traditions on how to take advantage of intensive natural resources.

550 This combination of cultural practices and limited availability both on the surface and in the aquifer
551 could be understood as an intense pressure on the water resource, this generates a condition of
552 fragility to the sustainability of production systems based on water consumption (Figure 8).

553   Figure 8. Comparison of extraction reduction scenarios against overexploitation of the aquifer
554   Source: Own elaboration

555   Table 5. Results of the balance surface waters of the micro-basins of the Laguna de Santiaguillo Source:
556   own elaboration using NOM-011-CONAGUA-2015

557 Table 6. Results of the analysis of groundwater availability by micro-basin in the aquifer in Laguna de
558 Santiaguillo

559 Table 7. Availability indicators in response to the zero scenario

560 Table 8. Availability indicators in response to the status quo scenario

561 Table 9. Availability indicators in response to the low scenario

562 Table 10. Availability indicators in response to the medium scenario

563 Table 11. Availability indicators in response to the ideal scenario

564   **DISCUSSION**

565 The high pressures on water resources have caused a great number of problems of a political,
566 economic, social and environmental nature (Sernet *et al*, 2016). Therefore, it is very important to
567 carry out actions to ensure the sustainability of the aquifer and the society that lives in the Laguna
568 de Santiaguillo watershed.

569 The physiographic and socioeconomic conditions of the region are extremely important to know
570 the degree of vulnerability of the aquifer. There are political decisions that generate important
571 economic spillovers, but at a high environmental cost; an example of this is what happened in the
572 Disi aquifer in Jordan.

573 Towards the year of 1984, the Jordanian government allowed the establishment of four companies
574 producing wheat that later were dedicated to the extensive agriculture of fruits and vegetables,
575 taking the aquifer to an irreparable overexploitation. (Salameh, Alraggad, Tarawneh, 2013).

576 The endorreicity of the Laguna de Santiaguillo basin, its small size, the regulatory vacuum
577 concerning the protection of this type of aquifers in particular and the agriculture that takes place
578 within it are factors that accentuate the vulnerability of the overexploited aquifer. Currently the
579 aquifer is over-concessioned, as a result of poor resource management.

580 This places agriculture as one of the vital human activities for development that generate greater
581 water stress.

582 Water quality in an overexploited aquifer is worse than a well-maintained aquifer. A study
583 developed by Bicalho et al. concludes that greater volumes of water extraction and shorter times
584 characterize intensive extraction in aquifers. The mobilization of the deepest water levels increases
585 the mineralization of water while karstification is greater in an overexploited aquifer than in one
586 that is not (Bicalho et al, 2011).

587 It is quite relevant to note the need for studies that reveal the quality of water in the region since,
588 due to the exploitation of the aquifer, the extracted water presents a greater presence of salts and
589 minerals. In the case of the Laguna de Santiaguillo watershed, it is imperative to carry out the
590 construction of drainages associated with the tracing of the furrows in contour lines.

591 Some of the proposals mentioned by Palacios and Escobar are applicable for the Santiaguillo
592 aquifer, some of which are the formation of a technical committee for groundwater that is
593 responsible for the management of the aquifer, the artificial recharge of the aquifer and fostering
594 the collection and use of rainwater for domestic and backyard consumption (Palacios and Escobar,
595 2016).

596 The possibility is to guide the technification of irrigation, the control of the livestock population
597 within the basin and the conservation of the vegetation cover of the recharge areas, limiting the
598 expansion of the area devoted to agriculture, the productive conversion of high-yield crops
599 consumption, particularly forages.

600 However, even if this was possible, it is necessary to consider that the returns of the underground
601 extractions sustain with their contributions the volume of water in the wetland that now has a
602 RAMSAR classification. Therefore, it is necessary to carefully review the implications of such an
603 action as ideal as it may seem.

604 The balance sheets of this analysis have been made with the official information of the Public
605 Registry of Water Rights of the National Water Commission, in the absence of reliable information
606 from the underground extractions measured. It is not possible to affirm beyond the hypothesis of
607 a condition of physical overexploitation.

608 According to the CONAGUA in its report "Update of the average annual availability of
609 groundwater aquifer (1001) valley of Santiaguillo". The availability of groundwater in the
610 aquifer of Santiaguillo is obtained by subtracting from the volume of total annual recharge, the
611 value of the natural discharge committed and the volume of groundwater concessioned and
612 registered in the REPDA. -39,351,828 = 25,900,000 - 10,393,000 - 54,858,828; This indicates
613 that there is no available volume for new concessions in the hydrogeological unit called Valle de
614 Santiaguillo aquifer, in the State of Durango.
615 However, throughout this study it is demonstrated that the problem is even more serious than what
616 was proposed by the CONAGUA. Since according to the balance established in this work it was
617 demonstrated that the availability of groundwater is - 111,950,689.49 = 30,023,188.87 -
618 14,638,517.10 - 127,335,361.27 , this given that the conagua does not take into account all
619 concessions with title and those of folio 8 or national registration ballot

620 Brief explanation of Figure 7. The status quo represents the current state of the aquifer, which
621 reveals an over-concession of 318%. If we decrease the allowed extraction by 20%, we would be
622 talking about a low reduction of extraction achievable with changes in the cultural practices and
623 basic technifications as well as the reduction of the number of wells through the expiration of
624 rights, even so the extraction would be of 258%, which still places it in a large overexploitation.

625 Decreasing the extraction concession by 35% is considered an average reduction, which implies a
626 technification of greater scope particularly in irrigation techniques such as the use of central, or
627 lateral pivot systems, sprinkler irrigation, extended use of belt and multi-damper, this implies an
628 investment in all the uses and even the aquifer would be overexploited by 212%.

629 The 70% decrease in recorded extraction is actually a high reduction of extraction which implies
630 the advanced technification of irrigation systems such as micro-sprinkling, drip systems, deep
631 cultural change and changes in crops, which requires a high investment that would necessarily
632 force a government subsidy.

633 The sub-basins and dams: Guatimape, Tejamen Dam, Tejamen, El Gato, Tinajuelas, Dr. Castillo
634 del Valle Dam, Las Jarillas, El Trébol, Torunos, La Redonda Dam and El Candado are in balance
635 and feed the northern lagon that has the peculiarity of being a perennial body. On the other hand,
636 the sub-basins Ojo de Lobo, Tinaja, Los monos, El Colorado and Viborillas feed the southern
637 lagoon which is most dry most of the time (Table 5).
638 In contrast to the analysis of surface water is the analysis of availability of groundwater (Table 6),
639 the column of infiltration represents the estimated infiltration by rain and it is the most important;
640 however, it is affected by some human activities on the surface such as: agricultural activities and
641 changes in vegetation cover.
642 The second column presents the returns directly influenced by surface irrigation, only two micro-
643 basins present this type of infiltration: Guatimape and Tejamen, both belonging to the North zone.
644 The third column expresses the horizontal movements in the aquifer, that is to say, the interaction
645 of water that is found in the subsoil and that generates a dynamic that is affected to a greater or
646 lesser extent by the extractions.
647 The column of evapotranspiration alludes to the exchange that exists between the subsoil and the
648 atmosphere, the micro-watershed with greater affection by this factor is that of Tinajuelas.

649 The average annual recharge columns and the natural discharge committed reflect the behavior of
650 the system in a natural way; again the micro-basins of Guatimape and Tejamen turn out to have
651 the highest values in terms of aquifer recharge while having the highest values of natural discharge
652 committed.

653 The column of underground volume concessioned indicates the volume that is concessioned to the
654 different uses, agricultural, industrial, etc. In regard to underground availability per micro-basin,
655 it is observed that all the micro-basins are in deficit. Only three of them (Ojo de Lobo, Los Monos
656 and Viborillas) are in positive numbers; it is worth mentioning that the volume concessioned in
657 the latter is minimal

658   Finally, the exploitation/ recharge column indicates the relationship between extractions and
659   recharges in percentage. In this case, it is important to note the percentage of 783% in the micro-
660   basin of El Gato, where the pressure exerted on it is such that the recharge capacity is substantially
661   surpassed (Table 6 and Figure 7).

662   It is convenient not to lose sight of the fact that it is a single aquifer, the segmentation obeys to the
663   superficial distribution in micro-watersheds to describe in a regionalized way the pressure that
664   human activities exert on it.

665   From the comparison of both tables, it is possible to observe that it depends on most of the socio-
666   economic activities of the groundwater, which in terms of agricultural use is 5 times greater than
667   what the existing surface water infrastructure can provide.

668   It could be thought that one solution is to promote the use of surface water, but technically this is
669   not possible in all cases, due to the distribution of runoff and the regionalization of socioeconomic
670   activities. Based on the above, the degree of overexploitation of the underground aquifer is evident,
671   which shows the vulnerability of the system to sustain itself for a long time.

672   All the rules, issues and procedures involve peasants, sellers and groups with agriculture interests
673   as well as politicians, legislators and judges. They control the access to the means of production
674   and establish the economic and social interests in relation to the natural, technological and human
675   resources. Moreyra *et al* mention the relevance of legislation and the entities involved in food
676   production. It is worth mentioning the role of the market since it incentives environmental
677   overexploitation in general to satisfy demand, which most of the time fails to arise from necessity
678   but from overproduction (Moreyra *et al*, 2012).

679   In Santiaguillo Basin, there is little efficiency both by the regulator and by society. This apathy
680   may be due to various aspects including the small size of the aquifer as well as the lack of
681   knowledge on the part of some residents regarding the current conditions of overexploitation found
682   in the aquifer. All this contributes to an increase in the vulnerability of the aquifer.

683   It is, therefore, necessary to determine with sufficient precision the actual volume extracted by
684   direct measurements and monitoring of the volumes delivered by the underground wells, with the
685   purpose of knowing the dynamics and the affectation to specify the degree of vulnerability. With
686   the information generated from this study there is sufficient evidence to place focus on the basin.

687   In this study, it is evident that there is no way to solve the overexploitation of the aquifer of the
688   Laguna de Santiaguillo basin, but if actions are taken it is possible to mitigate the impacts on the
689   aquifer.

690   To achieve a good mitigation of the impacts caused to the aquifer, actions are visualized in three
691   sectors: technological actions, cultural practices and normative aspects.

692   Technological actions: change the way in which the risks are applied, it is necessary to establish
693   efficient water use system such as drip irrigation, high efficiency systems, sprinkler systems and
694   line, currently the irrigation that is carried out is by flood.

695 Cultural practices: that is, the way in which the land is worked, level curves, construction of
696 drainage networks.

697 Regulatory aspects: local agreements that can be built in the COTAS (in Spanish it stands for:
698 Underground Water Technical Committee) (http://www.cocurs.mx/cotas.php, consultation:
699 June/2018), this entity allows to group users working for the improvement and establishment of
700 own regulations. Self-regulations or regulations from an external entity are needed.

701 **CONCLUSIONS**

702 The population of the Santiaguillo Basin is vulnerable to the exploitation of the aquifer, since all
703 micro-basins remain at the level of water availability per day, it is important to emphasize that
704 agriculture is the economic activity supported by the population and, at the same time, it consumes
705 more than 90% of the water available in the aquifer. Even considering a scenario where extraction
706 is drastically reduced, the level of water availability for development is catastrophically low, which
707 shows that the remedial actions are unsustainable given the condition of the aquifer. Therefore, it
708 would only be possible to propose mitigation measures to sustain the aquifer and its population for
709 a certain period of time.

710 Activities such as extended forage production may collapse, thereby threatening farming in the
711 basin.

712 The micro-basin that has the greatest exploitation is the so-called "El Gato" where there are well-
713 established Mennonite communities, in which the fact of an excessive drilling of well stands out
714 since these communities are immune usually to the application of Mexican regulations on prudent
715 distance of the perforation between well and well. It is extremely important that the regulations
716 permeate all inhabitants of the region, since the actions of a few impact the entire aquifer and affect
717 all the inhabitants of the basin.

718 An exacerbation of the condition of overexploitation of the aquifer is foreseen, so the measures of
719 control and reduction of the underground water volumes concessioned would have to be a policy
720 established in particular for this area.

721 Maximizing the use of surface water could contribute, but only very marginally, to reducing
722 overexploitation of the aquifer.

723 Some of the possible mitigation proposals are: the technification of irrigation, the control of the
724 livestock population within the basin and the conservation of the vegetation cover of the recharge
725 areas, limiting the expansion of the area dedicated to agriculture, the productive conversion of
726 high-consumption crops, particularly forages.

727 It is necessary to generate governance processes in greater depth, so it is necessary to reach the
728 construction of local agreements between water users to detonate sustainability processes.

729 However, even if this was possible, it is necessary to consider that the returns of the underground
730 extractions sustain with their contributions the volume of water in the wetland that now has a
731 RAMSAR classification, so it is necessary to carefully review the implications of such an action
732 as ideal as it may seem.

733 It is therefore necessary to determine with sufficient precision the actual volume extracted by direct
734 measurements and monitoring of the volumes delivered by the underground wells.

735 It is considered that the results of this research project are sufficient to warn that in this small
736 endorheic sub-basin the productive activities and quality of life are at risk given the vulnerability
737 related to water availability.

REFERENCES

739 Altieri M. (1999). Biotecnología agrícola: mitos, riesgos ambientales y alternativas. Berkeley:
740 Universidad de California.

741 Cantú-Martínez, P. C. (2012). El conflicto ambiental del agua en los albores del siglo XXI. Ciencia
742 UANL, 15(59),20-29.

743 Campos-Vargas M, Toscana-Aparicio A, Campos-Alanís J (2014). Riesgos socionaturales:
744 vulnerabilidad socioeconómica, justicia ambiental y justicia espacial. Revista colombiana de
745 Geografía. Vol 24. No. 2. Bogotá Colombia. Pp 53-69.

746 CONAGUA. (April 20, 2015). Actualización de la disponibilidad media anual de agua en el
747 acuifero Valle de Santiaguillo (1001), Estado de Durango. Comisión Nacional del Agua,
748 Subdirección General Técnica. México, D.F.: Diario Oficial de la Federación. Retrieved on March
749 3, 2018,from https://www.gob.mx/cms/uploads/attachment/file/103632/DR_1001.pdf

750 CONAGUA. (2011). Análisis de Alternativas de Manejo de la Demanda y la Disponibilidad del
751 Agua de la Cuenca Alta del Rio Mezquital , Estado de Durango. Comisión Nacional del Agua,
752 Durango, México.

753 CONANP. (2 de Febrero de 2012). Humedales de México, Sitios RAMSAR. Obtenido de
754 Comisión   Nacional   de   Areas   Naturales   Protegidas:
755 http://ramsar.conanp.gob.mx/docs/sitios/FIR_RAMSAR/Ingresos2012/Durango/2012%20Mexic
756 o%20Laguna%20Santiaguillo%20RIS.pdf

757 COTAS (in Spanish it stands for *Comité Técnico de Aguas Subterráneas* , which may be translated
758 to English as: Underground Water Technical Committee) (http://www.cocurs.mx/cotas.php,
759 Retrieved on: June/2018)

760 Custodio, E. (2002). Aquifer overexploitation: what does it mean? Springer- Verlag,
761 Hydrogeology Journal 10, 254-277

762 Domínguez Alonso, A. P. (2011). La prestación de los servicios de abastecimiento de agua potable
763 y saneamiento por parte de los municipios en México. Multidisciplina, (9).

764 Comisión Nacional del Agua (2017). Estadísticas del Agua en México. Secretaría de Medio
765 Ambiente y Recursos Naturales. pp 291

766 Fernández, Cirelli, A. Y. P., & du Mortier, C. (2005). Evaluación de la condición del agua para
767 consumo humano en Latinoamérica. Tecnologías solares para la desinfección y descontaminación
768 del agua. Solar Safe Water, 11-26.

769   Fondo para la comunicación y la Educación Ambiental, Centro Mexicano de Derecho Ambiental
770   y Presencia Ciudadana Mexicana (2006). El Agua en México: lo que todas y todos debemos saber.
771   México: FEA- Cemda – PCM.

772   INEGI. (2005). Guia para la Interpretación de Cartografía Climatológica. Instituto Nacional de
773   Estadistica,   Geografía   e   Informatica.   Retrieved   from
774   http://internet.contenidos.inegi.org.mx/contenidos/productos/prod_serv/contenidos/espanol/bvine
775   gi/productos/historicos/1329/702825231781/702825231781_1.pdf

776   INEGI. (Diciembre de 2011). Censos de Población y VIvienda. Instituto Nacional de Estadística,
777   Geografía e Informática, México, D.F. Retrieved from http://www.censo2010.org.mx

778   INEGI (2018). Antares. Electronic consultation November 7, 2018.
779   http://antares.inegi.org.mx/analisis/red_hidro/siatl/#

780   Information on the weather regulations of the National Meteorological Service.
781   http://smn.cna.gob.mx/es/informacion-climatologica-ver-estado?estado=dgo.   Retrieved   on
782   November 5, 2018

783   Khezzani, B., Bouchemal, S. (2018). Variations in groundwater levels and quality due to
784   agricultura over-exploitation in an arid environment: The phreatic aquifer of the souf oasis (algrian
785   Sahara). Environmental Earth Sciences, 77(4), 1-18. Doi: 10.1007/ s 12665-018-7329-2.

786   Martínez R. (2009). Agricultura, alimentación y salud: debate crítico. Perspectivas en Nutrición
787   humana. Universidad de Antioquía. Medellín. Colombia vol. 11. No.1 pages 73-90 ISSN: 0124-
788   4108

789   Molina Garza, R. (2013). Centro de Geociencias Universidad Nacional Autónoma de México.
790   Recuperado el 16 de 06 de 2013, de Abanicos Aluviales, Tema del curso: Ambientes y procesos
791   sedimentarios   (Posgrado   en   ciencias   de   la   Tierra):
792   http://www.geociencias.unam.mx/~rmolina/documents/alluvialfanslecture.pdf

793   Moreyra A, Puricelli M, Mercader A, Rey M. (2012). El Acceso al agua de los agricultores
794   familiares de la región pampeana: un análisis multidimensional. Mundo Agrario 12(24), ISSN
795   1515-5994.

796   Nieto-Samaniego, Á. F., Barajas-Gea, C. I., Gómez-González, J. M., Rojas, A., Alaniz-Álvarez,
797   S. A., & Xu, S. (2012). Geology, structural evolution (Eocene to recent) and seismic events in the
798   Santiaguillo graben, Durango, México. Revista mexicana de ciencias geológicas, 29(1), 115-130.
799   Retrieved   on   March   3,   2018,   from
800   http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1026-
801   87742012000100008&lng=es&tlng=en

802   Norma Oficial Mexicana NOM-011- CONAGUA- 2015, Conservación del recurso agua que
803   establece las especificaciones y el método para determinar la disponibilidad media anual de las
804   aguas nacionales. Diario Oficial de la Federeación.27 de marzo del 2015. Electronic
805   Consultation: http://www.dof.gob.mx/nota_detalle.php?codigo=5387027&fecha=27/03/2015

806   Palacios-Vélez O, Escobar- Villagrán B (2016). La sustentabilidad de la agricultura de riego ante
807   la sobreexplotación de acuiferos. Tecnología y ciencias del Agua, Vol VII, núm. 2, pp 5-16.

808   Reforma, México D.F. México, Cervantes (2015). Advierten por deterioro en los mantos acuíferos.
809   Informe   Académico,   Accessed   5   July   2018,   MLA   8ª.   edición
810   http://link.galegroup.com/apps/doc/A434322141/IFME?u=pu&sid=IFME&xid=e05e5c48

811   Registro   público   de   derechos   del   agua   REPDA.   Electronic   consult:
812   https://app.conagua.gob.mx/Repda.aspx consult on november 2018

813   Salameh E, Alraggad M, Tarawneh A. (2013). Disi water use for irrigation- a false decisión and
814   its   consequences.   Clean-   soil,   Air,   Water   2014,   42   (12),   1681-1686.   DOI:
815   10.1002/clen.201300647.

816   Senet-Aparicio J, Pérez- Sánchez J, Bielsa-Artero A. (2016) Evaluación de la sostenibilidad de
817   cuencas mediterraneas semiáridas. Caso de estudio: cuenca del Segura, España. Tecnología y
818   ciencias del Agua, vol VII, núm. 2,pp 67-84.

819   World Bank. Banco Internacional de Reconstrucción y Fomento/ Banco Mundial. (2002).
820   Protección de la Calidad del Agua subterránea, guía para empresas de agua, autoridades
821   municipales y agencias ambientales. Ediciones Mundi- Prensa Libros, S.A. ISBN:84-8476-146-0.

Types of climate and its extension in the sub-basin

Table elaborated with vector information from INEGI (for its acronym in Spanish, National Institute of Statistics and Geography)

1   Table 1. Types of climate and its extension in the sub-basin

Climate	Hectares	Percentage
BS1kw(w)	180,668.15	71.07
C(E)(w1)	14,206.50	5.59
C(E)(w2)	14,601.78	5.74
C(w0)	26,044.58	10.25
C(w1)	18,695.20	7.35

2   Source: own elaboration with vector information of INEGI (For its acronym in Spanish, National
3   Institute of Statistics and Geography)

Soil surface by texture of the sub-basin

Table elaborated with vector data from INEGI

2   Table 2. Soil surface by texture of the sub-basin

Texture	Hectares	Percentage
Medium	141,793.72	55.78%
Fine	77,436.36	30.46%
Gross	22,909.04	9.01%
N/A Water body	12,077.11	4.75%

3   Source: Own elaboration with vector data of INEGI

Levels of water availability

Source: Shiklomanov, Igor, World Water resources at the beginning of the 21st century, PHIUNESCO,2002

Tabla 3. Levels of water availability

Availability of water in thousands m³ / hab / year	Water availability levels
<1	Catastrophically low
1.1 – 2.0	Very low
2.1 – 5.0	low
5.1 - 10	medium
10.1 – 20	high
>20	Very high

3   Fuente: Shiklomanov, Igor, World Water resources at the beginning of the 21st century,
4   PHIUNESCO,2002

Number and volume of the underground sources granted

Table elaborated with information from the Public Register of Water Rights, of the National Commission of Water.

1   Table 4. Number and volume of the underground sources granted

Use	Number of wells	Concession volume Thousands of m³
Agricultural	1329	5,233.70
Livestock	464	360.36
Domestic	49	20.76
Urban public	91	1,959.75
Multiple	26	607.86
Different uses	2	19.88
Industrial	5	6.87

2   Source: Own elaboration with information of the Public Register of water rights, of the National
3   Commission of water.

Results of the balance surface waters of the micro-basins of the Laguna de Santiaguillo

Results of the balance elaboration using the method given by the NOM-011-CONAGUA-2015

1   Table 5. Results of the balance surface waters of the micro-basins of the Laguna de Santiaguillo Source:
2   own elaboration using NOM-011-CONAGUA-2015

Name of the Hydrological Sub-basin	Cp.- Annual average volume of natural runoff	Ab.- Average annual volume of runoff from the basin downstream	Rxy.- Current annual committed downstream	Ab-Rxy	D.- Average annual availability of Surface water in the hydrological basin	Classification of relative availability
Guatimape	18.66	18.24	10.72	7.52	7.52	BALANCE
P Tejamen	3.75	3.61	7.24	- 3.63	- 4.51	DEFICIT
Tejamen	17.46	12.58	7.24	5.34	8.95	BALANCE
El Gato	14.81	14.72	5.57	9.15	9.15	BALANCE
Tinajuelas	37.35	36.81	21.20	15.61	15.61	BALANCE
Presa Dr. Castillo del Valle	0.50	0.42	0.02	0.40	0.31	ABUNDANCE
Las Jarillas	4.53	4.52	2.32	2.20	2.61	BALANCE
El Trébol	2.01	2.00	1.23	0.76	0.76	BALANCE
Torunos	5.15	5.08	3.67	1.42	1.42	DEFICIT
Presa La Redonda	3.54	3.33	0.17	3.16	2.95	ABUNDANCE
El Candado	9.72	9.54	3.65	5.90	9.23	AVAILABILITY
Laguna Norte	44.18	11.36	-	11.36	102.13	-
Ojo de Lobo	2.68	2.66	2.67	- 0.01	- 0.01	DEFICIT
Tinaja	5.26	4.87	6.32	- 1.45	- 1.45	DEFICIT
Los Monos	2.12	2.06	2.24	- 0.18	- 0.18	DEFICIT
El colorado	6.79	6.42	8.49	- 2.07	- 2.07	DEFICIT
Viborillas	4.86	4.83	4.47	0.36	0.36	DEFICIT
Laguna Sur	72.64	48.73	-	48.73	93.47	-

Results of the analysis of groundwater availability by micro-basin in the aquifer in Laguna de Santiaguillo

Analysis of groundwater availability by micro-basin

2   Table 6. Results of the analysis of groundwater availability by micro-basin in the aquifer in Laguna de Santiaguillo

Micro-basin	Rain Infiltration	Infiltration for returns	Horizontal entry	Evapo-transpiration	Total Annual average recharge	Natural discharge committed	Subscribed underground volume	Underground availability	exploitation / recharge
	Ip	Ir	Eh	Evt			B	Dm	
Guatimape	0.84	0.32	2.10	182.67	3.25	182.67	4.55	-183.97	140%
Tejamen	1.27	0.90	1.01	115.46	3.17	115.46	12.38	-124.67	390%
El Gato	1.09	-	0.41	98.52	1.49	98.52	11.68	-108.71	783%
Tinajuelas	5.37	-	2.04	314.06	7.41	314.06	40.75	-347.41	550%
Las Jarillas	0.77	-	0.31	36.01	1.08	36.01	6.57	- 41.50	608%
El Trébol	0.50	-	0.15	19.88	0.65	19.88	0.75	- 19.98	116%
Torunos	1.09	-	0.41	49.90	1.51	49.90	5.55	- 53.94	369%
El Candado	0.40	-	0.48	63.77	0.88	63.77	4.23	- 67.12	478%
Ojo de Lobo	0.26	-	0.18	0.24	0.44	0.24	0.00	0.20	0%
Tinaja	0.56	-	0.30	0.52	0.86	0.52	1.64	- 1.30	191%
Los Monos	0.21	-	0.18	0.19	0.39	0.19	0.02	0.18	6%
El Colorado	1.21	-	0.43	1.12	1.64	1.12	6.75	- 6.23	412%
Viborillas	0.32	-	0.14	0.30	0.46	0.30	0.03	0.14	6%

Availability indicators in response to the zero scenario

Source: Authors' own elaboration using Shiklomanov values

1   Table 7. Availability indicators in response to the zero scenario

Micro-basin	Natural Surface availability per capita m^3	Level of availability per capita natural water (Shiklomanov, 2002)	Availability for development m^3	Level of availability for development (Shiklomanov, 2002)	Natural availability underground per capita m^3	Level of availability per capita natural water (Shiklomanov, 2002)	Availability for development m^3	Level of availability per capita natural water (Shiklomanov, 2002)
Guatimapé	13,460.85	High	7,791.03	Medium	2,116.60	Low	1,768.71	Very Low
Tejamen	6,075.61	Medium	4,172.20	Low	652.01	Catastrophically Low	601.62	Catastrophically Low
El Gato	1,210.52	Very Low	873.74	Catastrophically Low	121.97	Catastrophically Low	65.67	Catastrophically Low
Tinajuelas	4,021.41	Low	2,312.49	Low	797.38	Catastrophically Low	737.78	Catastrophically Low
Las Jarillas	3,014.57	Low	1,949.25	Very Low	647.09	Catastrophically Low	328.32	Catastrophically Low
El Trébol	5,411.61	Medium	2,974.21	Low	1,736.09	Very Low	1,204.08	Very Low
Torunos	5,839.21	Medium	2,756.27	Low	1,707.23	Very Low	160.19	Catastrophically Low
El Candado	14,288.59	High	11,031.89	High	952.73	Catastrophically Low	837.89	Catastrophically Low
Ojo de Lobo	536,810.28	Very High	205,749.29	Very High	87,345.81	Very high	-123,176.01	Catastrophically Low
La Tinaja	6,063.64	Medium	1,169.80	Very Low	992.68	Catastrophically Low	-745.11	Catastrophically Low
Los Monos	41,663.46	Very High	13,562.84	High	7,659.71	Medium	-3,163.80	Catastrophically Low
El Colorado	3,852.35	Low	704.43	Catastrophically Low	929.50	Catastrophically Low	627.87	Catastrophically Low
Viborillas	41,149.90	Very High	17,949.19	High	3,932.24	Low	-3,096.35	Catastrophically Low

Availability indicators in response to the status quo scenario

Table made using NOM-011-CONAGUA-2015 and IMTA manual

1 Table 8. Availability indicators in response to the status quo scenario

Micro-basin	Natural Surface availability per capita m³	Level of availability per capita natural water	Availability for development m³	Level of availability for development	Natural availability underground per capita m³	Level of availability per capita natural water	Availability for development m³	Level of availability per capita natural water
Guatimapé	13,460.85	High	7,428.39	Medium	2,237.48	Low	60.08	Catastrophically Low
Tejamen	6,075.61	Medium	2,990.30	Low	826.17	Catastrophically Low	- 2,684.85	Catastrophically Low
El Gato	1,210.52	Very Low	932.75	Catastrophically Low	150.89	Catastrophically Low	- 992.72	Catastrophically Low
Tinajuelas	4,021.41	Low	2,597.11	Low	989.47	Catastrophically Low	- 3,800.38	Catastrophically Low
Las Jarillas	3,014.57	Low	1,748.41	Very Low	785.17	Catastrophically Low	- 2,331.70	Catastrophically Low
El Trébol	5,411.61	Medium	3,021.53	Low	1,797.15	Very Low	- 2,990.13	Catastrophically Low
Torunos	5,839.21	Medium	2,776.44	Low	1,922.16	Very Low	- 3,960.13	Catastrophically Low
El Candado	14,288.59	High	6,778.18	Medium	1,115.25	Very Low	- 3,597.86	Catastrophically Low
Ojo de Lobo	536,810.28	Very High	205,340.18	Very High	87,345.81	Very High	-123,362.21	Catastrophically Low
La Tinaja	6,063.64	Medium	1,105.08	Very Low	1,054.22	Very Low	- 3,228.21	Catastrophically Low
Los Monos	41,663.46	Very High	13,587.91	High	7,676.18	Medium	- 3,382.63	Catastrophically Low
El Colorado	3,852.35	Low	871.35	Catastrophically Low	1,048.01	Very Low	- 2,432.57	Catastrophically Low
Viborillas	41,149.90	Very High	17,802.71	High	3,932.24	Low	- 4,464.37	Catastrophically Low

Availability indicators in response to the low scenario

Table elaborated using Shklomanov criteria

1   Table 9. Availability indicators in response to the low scenario

Micro-basin	Natural Surface availability per capita m³	Level of availability per capita natural water	Availability for m³ development	Level of availability for development	Natural availability underground per capita m³	Level of availability per capita natural water	Availability for development m³	Level of availability per capita natural water
Guatimapé	13,460.85	High	7,396.70	Medium	2,214.03	Low	402.54	Catastrophically Low
Tejamen	6,075.61	Medium	2,931.51	Low	794.29	Catastrophically Low	- 2,024.61	Catastrophically Low
El Gato	1,210.52	Very Low	920.26	Catastrophically Low	145.11	Catastrophically Low	- 781.03	Catastrophically Low
Tinajuelas	4,021.41	Low	2,538.73	Low	951.06	Catastrophically Low	- 2,892.74	Catastrophically Low
Las Jarillas	3,014.57	Low	1,706.35	Very Low	758.23	Catastrophically Low	- 1,799.02	Catastrophically Low
El Trébol	5,411.61	Medium	3,004.28	Low	1,784.94	Very Low	- 2,151.29	Catastrophically Low
Torunos	5,839.21	Medium	2,719.68	Low	1,879.52	Very Low	- 3,135.72	Catastrophically Low
El Candado	14,288.59	High	6,734.41	Medium	1,091.64	Very Low	- 2,701.81	Catastrophically Low
Ojo de Lobo	536,810.28	Very High	205,340.18	Very High	87,345.81	Very High	- 123,362.21	Catastrophically Low
La Tinaja	6,063.64	Medium	1,085.84	Very Low	1,042.16	Very Low	- 2,731.34	Catastrophically Low
Los Monos	41,663.46	Very High	13,587.91	High	7,676.18	Medium	- 3,382.63	Catastrophically Low
El Colorado	3,852.35	Low	836.78	Catastrophically Low	1,024.31	Very Low	- 1,820.48	Catastrophically Low
Viborillas	41,149.90	Very High	17,802.71	High	3,932.24	Low	- 4,464.37	Catastrophically Low

Availability indicators in response to the medium scenario

Table elaborated using NOM-011-CONAGUA-2015 and Shiklomanov criteria

1   Table 10. Availability indicators in response to the medium scenario

Micro-basin	Natural Surface availability per capita m³	Level of availability per capita natural water	Availability for development m³	Level of availability for development	Natural availability underground per capita m³	Level of availability per capita natural water	Availability for development m³	Level of availability per capital natural water
Guatimapé	13,460.85	High	7,372.93	Medium	2,196.45	Low	659.38	Catastrophically Low
Tejamen	6,075.61	Medium	2,887.43	Low	770.38	Catastrophically Low	- 1,529.43	Catastrophically Low
El Gato	1,210.52	Very Low	910.89	Catastrophically Low	140.78	Catastrophically Low	- 622.27	Catastrophically Low
Tinajuelas	4,021.41	Low	2,494.95	Low	922.25	Catastrophically Low	- 2,212.02	Catastrophically Low
Las Jarillas	3,014.57	Low	1,674.81	Very Low	738.02	Catastrophically Low	- 1,399.51	Catastrophically Low
El Trébol	5,411.61	Medium	2,991.35	Low	1,775.78	Very Low	-1,522.15	Catastrophically Low
Torunos	5,839.21	Medium	2,677.11	Low	1,847.54	Very Low	- 2,517.41	Catastrophically Low
El Candado	14,288.59	High	6,701.58	Medium	1,073.94	Very Low	- 2,029.77	Catastrophically Low
Ojo de Lobo	536,810.28	Very High	205,340.18	Very High	87,345.81	Very High	-123,362.21	Catastrophically Low
La Tinaja	6,063.64	Medium	1,071.41	Very Low	1,033.12	Very Low	- 2,358.68	Catastrophically Low
Los Monos	41,663.46	Very High	13,587.91	High	7,676.18	Medium	- 3,382.63	Catastrophically Low
El Colorado	3,852.35	Low	810.84	Catastrophically Low	1,006.53	Very Low	- 1,361.41	Catastrophically Low
Viborillas	41,149.90	Very High	17,802.71	High	3,932.24	Low	- 4,464.37	Catastrophically Low

Availability indicators in response to the ideal scenario

Table elaborated using NOM-011-CONAGUA-2015 and Shiklomanov criteria

1   Table 11. Availability indicators in response to the ideal scenario

Micro-basin	Natural Surface availability per capita m³	Level of availability per capita natural water	Availability for development m³	Level of availability for development	Natural availability underground per capita m³	Level of availability per capita natural water	Availability for development m³	Level of availability per capital natural water
Guatimapé	13,460.85	High	7,317.48	Medium	2,155.41	Low	1,258.67	Very Low
Tejamen	6,075.61	Medium	2,784.56	Low	714.58	Catastrophically Low	- 374.00	Catastrophically Low
El Gato	1,210.52	Very Low	889.04	Catastrophically Low	130.67	Catastrophically Low	- 251.82	Catastrophically Low
Tinajuelas	4,021.41	Low	2,392.80	Low	855.02	Catastrophically Low	- 623.66	Catastrophically Low
Las Jarillas	3,014.57	Low	1,601.20	Very Low	690.88	Catastrophically Low	- 467.32	Catastrophically Low
El Trébol	5,411.61	Medium	2,961.17	Low	1,754.41	Very Low	- 54.18	Catastrophically Low
Torunos	5,839.21	Medium	2,577.78	Low	1,772.92	Very Low	- 1,074.69	Catastrophically Low
El Candado	14,288.59	High	6,624.99	Medium	1,032.63	Very Low	- 461.69	Catastrophically Low
Ojo de Lobo	536,810.28	Very High	205,340.18	Very High	87,345.81	Very High	- 123,362.21	Catastrophically Low
La Tinaja	6,063.64	Medium	1,037.73	Very Low	1,012.03	Very Low	- 1,489.16	Catastrophically Low
Los Monos	41,663.46	Very High	13,587.91	High	7,676.18	Medium	- 3,382.63	Catastrophically Low
El Colorado	3,852.35	Low	750.34	Catastrophically Low	965.05	Catastrophically Low	- 290.26	Catastrophically Low
Viborillas	41,149.90	Very High	17,802.71	High	3,932.24	Low	- 4,464.37	Catastrophically Low

Figure 1

Topoform system map

Map using INEGI data
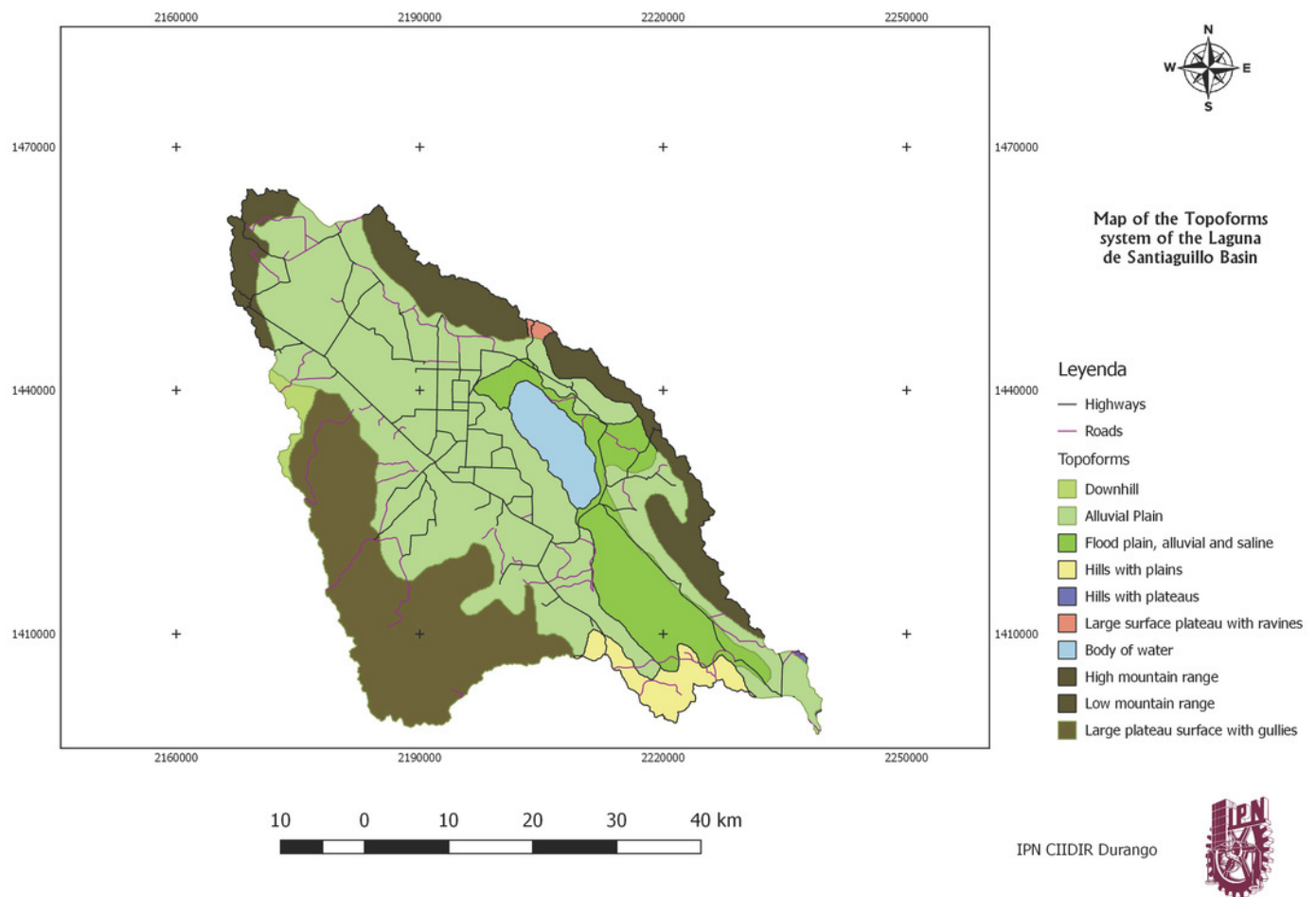
Figure 2

Hydrograhic Map Of Laguna de Santiaguillo Basin

Map made with vector information of INEGI
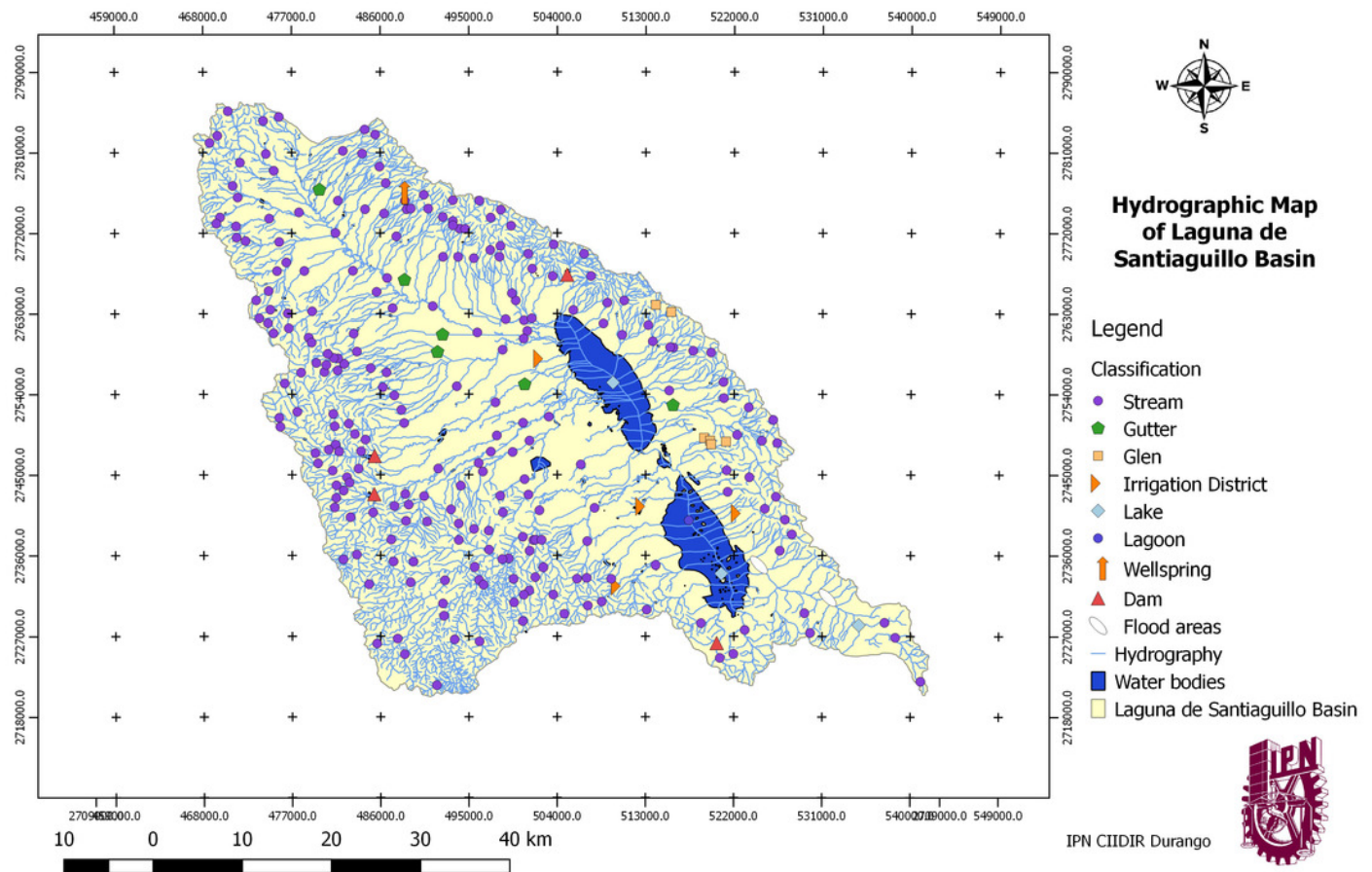
Figure 3

Map of hydrology surface and division in micro-watersheds

Map made with vector information of INEGI
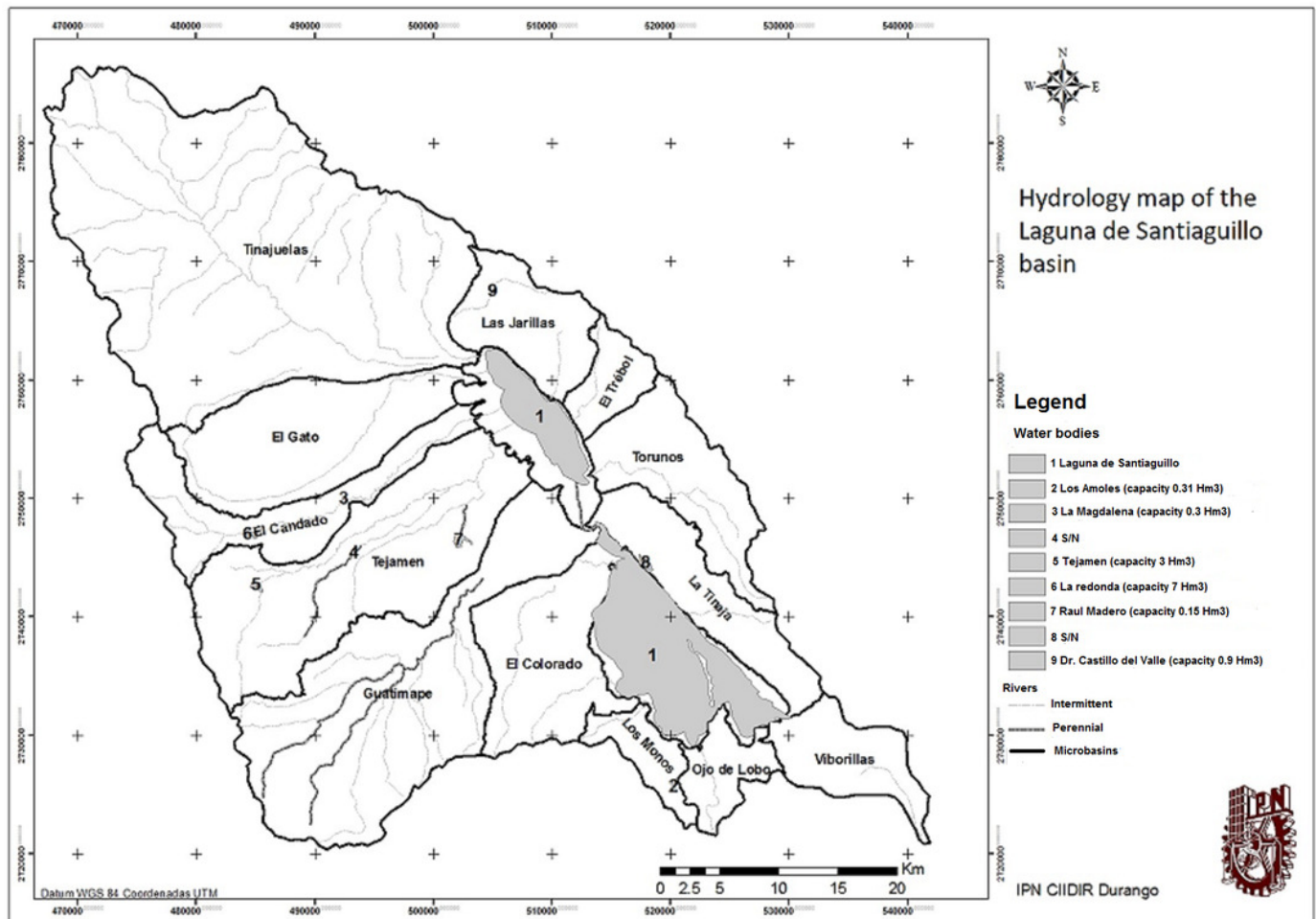
Figure 4

Population pyramid of the Laguna de Santiaguillo basin

Source: own elaboration with 2010 census information of INEGI
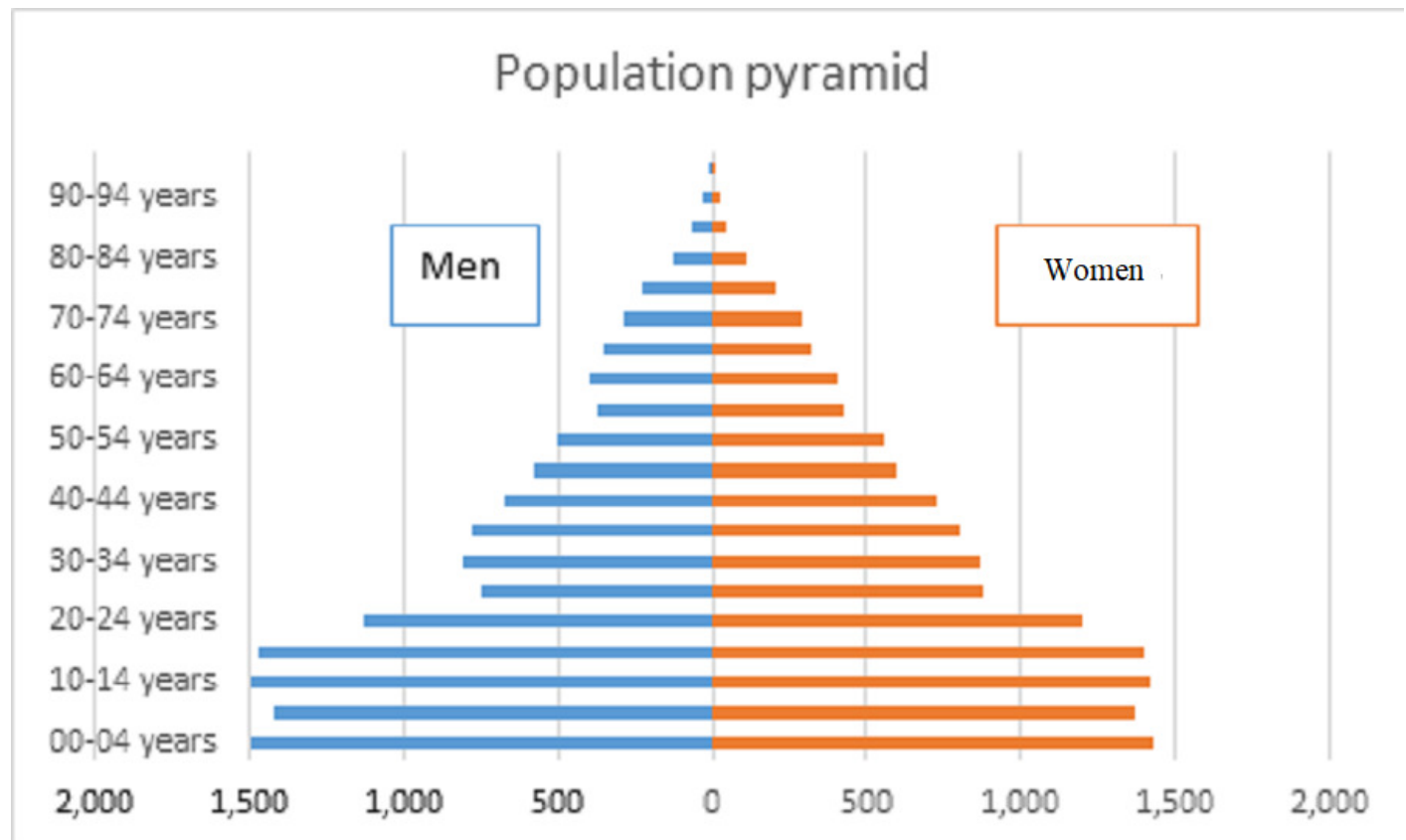
Figure 5

Land use for agriculture in the sub-basin

Map made with vector information of INEGI
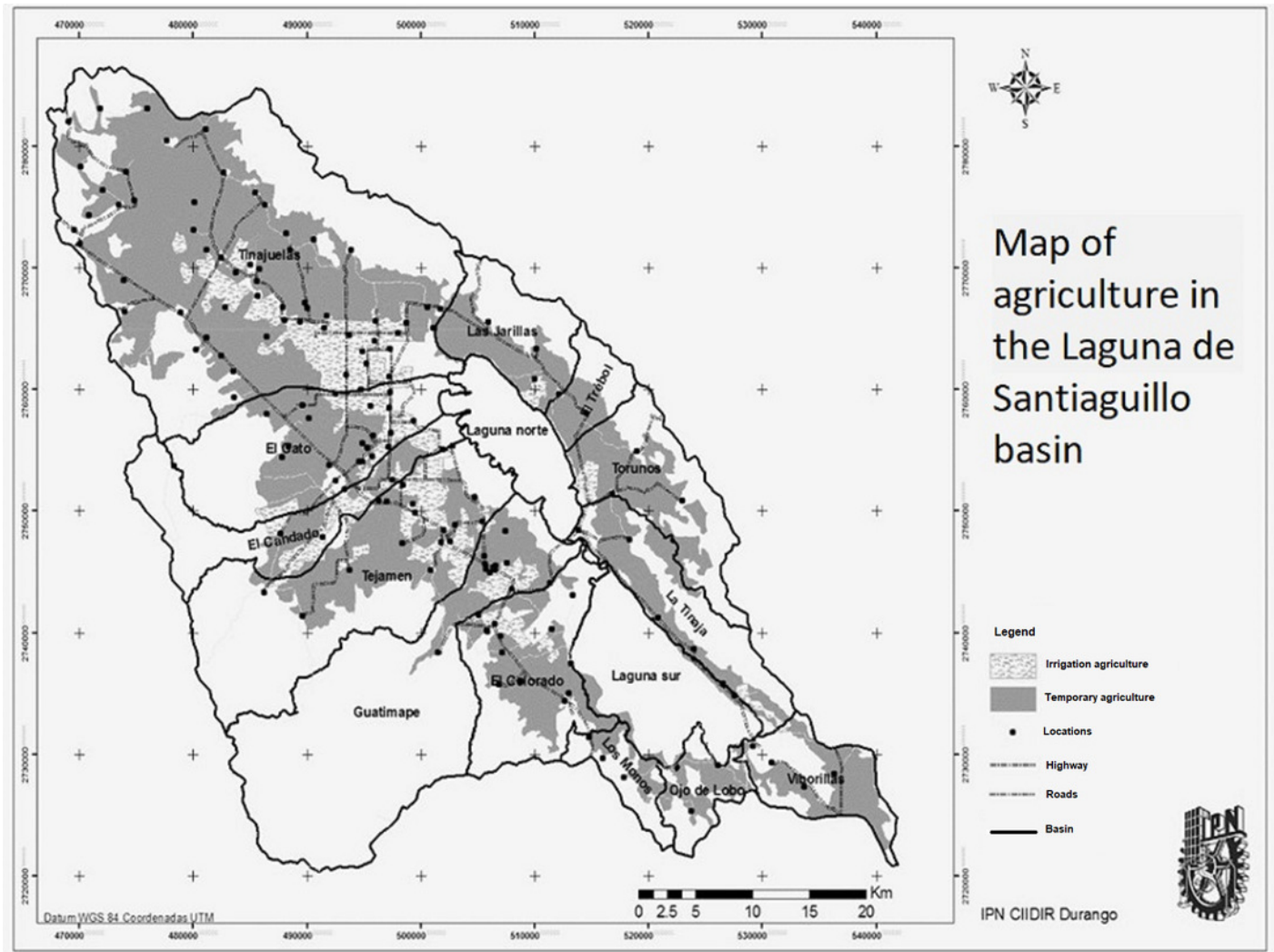
Figure 6

Use of groundwater in the Laguna de Santiaguillo basin (%)

Made with CONAGUA Information
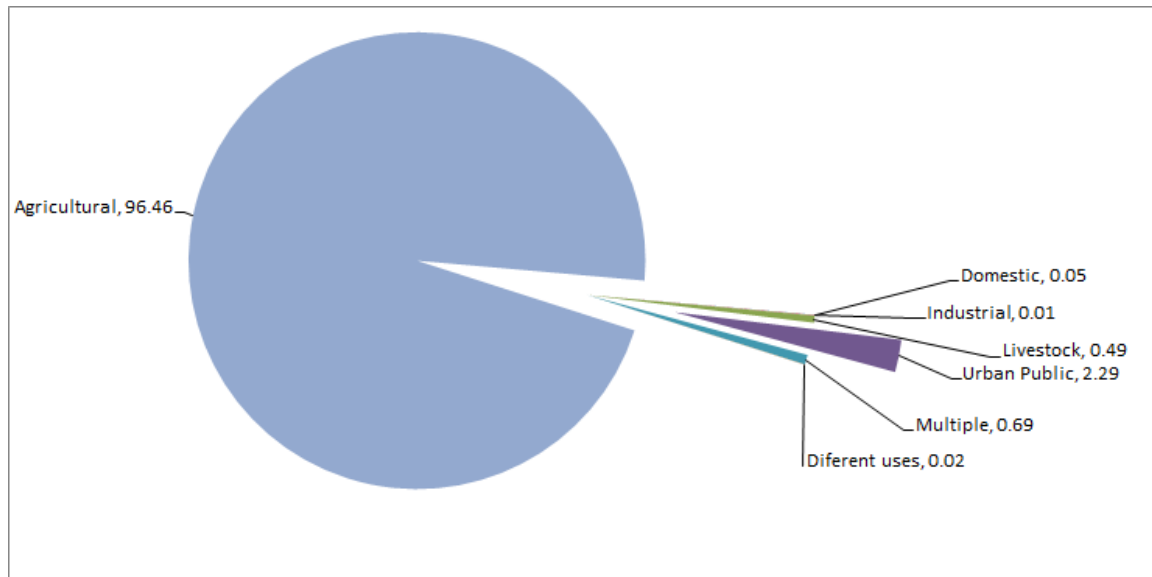
Figure 7

Map of aquifer overexploitation by micro-basins

Overexploitation by micro-basins
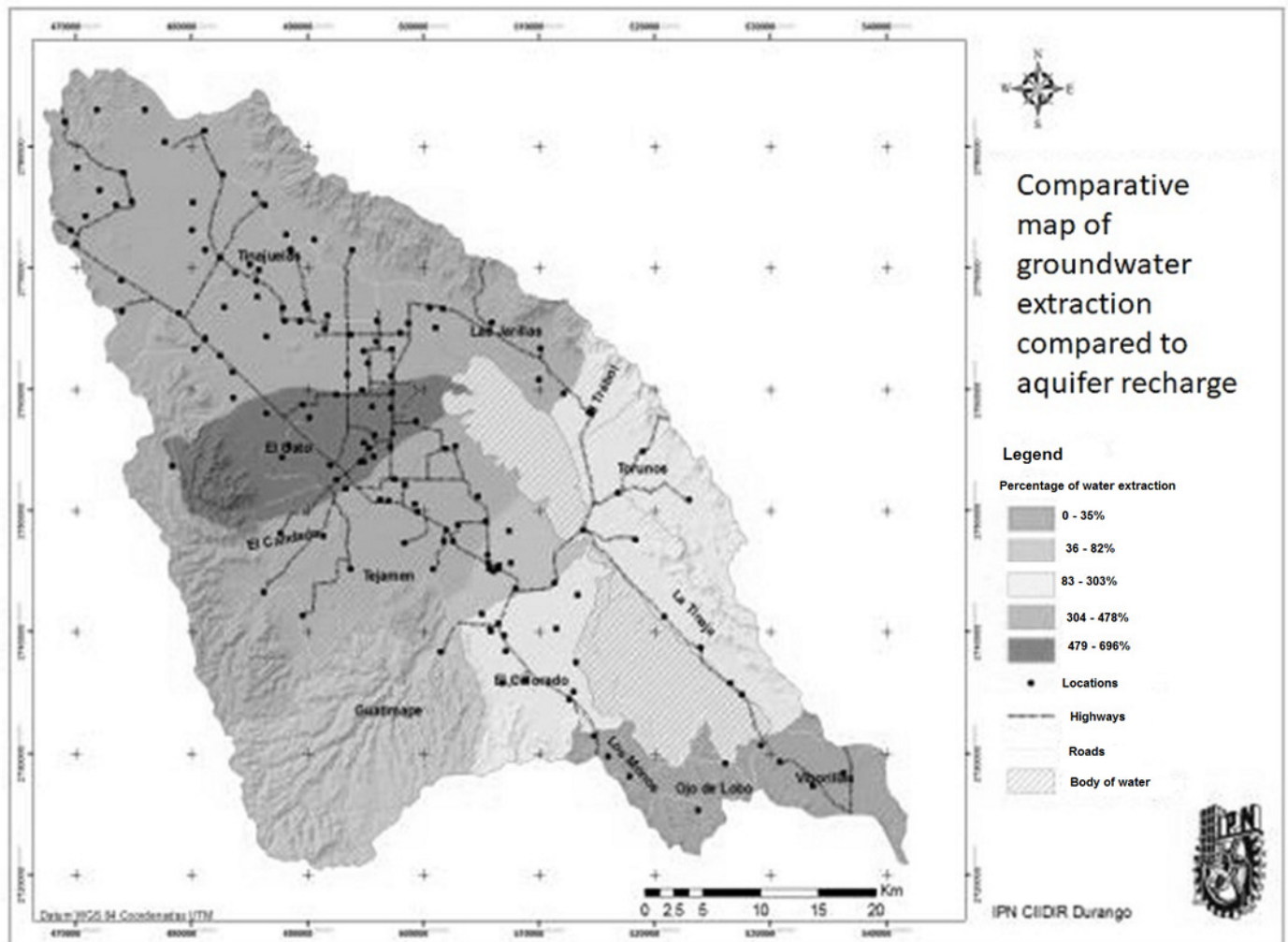
Figure 8

Comparison of extraction reduction scenarios against overexploitation of the aquifer

Comparison of extraction reduction scenarios