Preliminary Assessment of Water Resources including Climate Considerations for the Los Cabos and La Paz Municipalities in the State of Baja California Sur, Mexico

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Abstract

The Baja California Sur Aquifer, Renewable Energy and Desalination Project is in an initial stage of implementation, beginning with an assessment of the available water resources in the context of existing and proposed development, and specific climate impacts for water resources for the Municipalities of Los Cabos and La Paz in the State of Baja California Sur.

Keywords: assessment water aquifers desalination climate impacts Baja California Sur

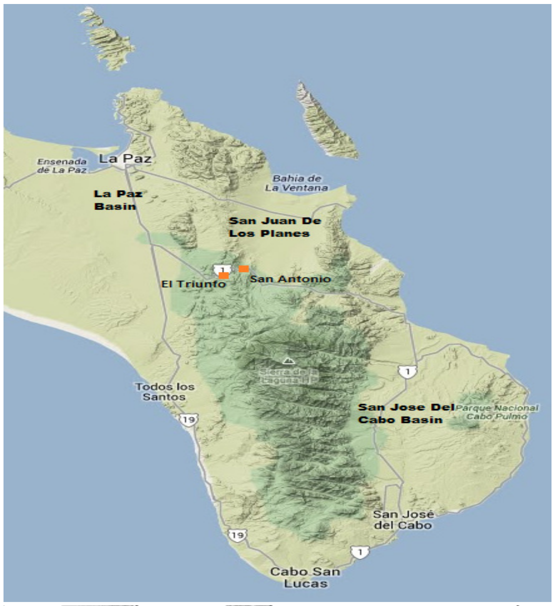
Introduction

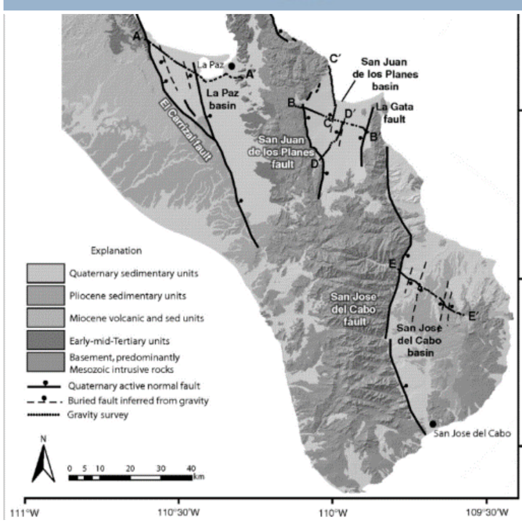
The State of Baja California Sur is an arid region that relies on precipitation that is collected in different aquifers. The water assessment for the Municipalities of Los Cabos and La Paz is preliminary as further knowledge is required of the capacity and dimensions of aquifers, including whether they are connected as systems. Aquifer sustainability considers quantity factors such as flow volumes, recharge, discharge, time, scale, permeability, storage and pressure. Quality factors are also important such as land-based and coastal contamination, saline intrusion, and diffusion of contaminants.

Since 2006, there is a public desalination concession in Los Cabos, with a second desalination concession being proposed for Los Cabos, and an initial concession being proposed for La Paz. Additionally, many hotels, golf courses and marinas have private desalination plants, and also waste water treatment. Further analysis needs to be done on public and private desalination opportunities for these municipalities. Most electricity in the municipalities including that required for desalination is generated from diesel. While additional water resources are required to support economic growth, desalination and renewable energy can have key role for these water resources.

This paper contains a preliminary assessment of the available water resources in the Municipalities of Los Cabos and La Paz, focusing on aquifers and desalination. Utilizing on the 2013 study conducted by the Centro Mario Molina, the paper also considers specific climate scenarios and impacts on water resources for the municipalities.

Preliminary Assessment of Water Resources for Municipalities of Los Cabos and La Paz





The analysis of water resources focuses on the Municipalities of La Paz and Los Cabos in Baja California Sur. This area hosts tourism and urban developments, agriculture and mining. Both existing and future developments could stress or contaminate the aquifers. Future proposed developments include large scale gold mining and mega resorts. Thus, it is important to know the location of the aquifers, their condition and connectivity, and the impact of developments on the aquifers. To get a better understanding of these water sources, it is important to simultaneously consider various factors such as terrain, landscape, precipitation and geology.

The region is arid and features various terrains from flat coastal plains to mountain chains. It is known that the largest sources of water originate from precipitation in the higher altitudes, particularly from the Sierra de la Laguna Mountains. This precipitation is collected in small dams through surface water collection, absorbed into the aquifers as groundwater, or returned directly to the water cycle via run-off or evaporation.

Because the region is arid, it experiences drought. An incident of drought was experienced in 2011. Although the precipitation pattern remained similar, the volume was significantly less. Conversely, significant precipitation could be observed between 2001 and 2002 around Cabo San Lucas and San Jose as a result of Hurricane Juliette. The southern tip of the Baja peninsula can be prone to some Pacific hurricane activity. Despite this, changing climate and weather patterns may make droughts more frequent.

CONAGUA estimates water availability for all Mexican aquifers every three years. The most recent estimates for 2013 for the aquifers being considered are contained in Table 1 below. Numbers in this table are based on CoONAGUA's Diario Oficial: Segunda seccion (20 December 2013), except for the Los Planes aquifer where numbers based on CONAGUA's 2012 report, Disponibilidad del los "acuiferos" en Baja California Sur segun CONAGUA. The numbers in the table based on pre-existing research and reports, and the authors do not have sufficient background information to comment on the accuracy of these numbers. The numbers also do not address the sustainability of the aquifers, or quality issues in relation to the aquifers. The formula used in Table 1 below for calculating water availability or deficit for all aquifers in the Municipalities of Los Cabos and La Paz is as follows: $\mathrm{AAV} - \mathrm{CND} - \mathrm{VAC} = \mathrm{WA}$.

Table 1: Water Availability for Aquifers in Municipalities of Los Cabos and La Paz

Aquifer	Clave *	Average Annual Recharge (M m3/Yr)	Compromised Natural Discharge (M m3/Yr)	Volume of Allocated Groundwater (M m3/Yr)	Volume Extracted During Technical Study (M m3)	Availability (M m3/Yr)	Deficit (M m3/Yr)
Municipality of Los Cabos							
Migriño	316	0.9	0.6	0.292	0.3	0.008	0
Cabo San Lucas	317	2.7	2.2	5.111382	0.7	0	4.611382
Cabo Pulmo	318	2.2	2	0.88857	0.2	0	0.68857
San Jose Del Cabo	319	35.9	10.8	27.726013	29	0	2.626013
Santiago	320	24.5	4.6	19.012603	13.2	0.887397	0
Municipality of La Paz							
Santa Rita	307	3.2	2	0.763251	1.2	0.436749	0
Las Pocitas-San Hilardo	308	4	0.3	2.439388	2.2	1.260612	0
El Cone Jo-Los Viejos	309	5.8	3.7	2.320295	2.4	0	0.220295
Meliton Albañez	310	2.5	0.4	2.2355	3.3	0	0.1355
La Matanza	311	5.1	2.6	2.18538	2.5	0.31462	0
Cañada Honda	312	2.8	1.8	0.678187	1	0.321813	0
Todos Santos	313	18.4	14.7	2.51804	3.7	1.18196	0
El Pescadero	314	8.2	5.1	2.949186	2.8	0.150814	0
Plutarco Elias Calles	315	2.8	1.8	0.97704	1	0.02296	0
San Bartolo	321	10.9	6.9	0.988376	0.6	3.011624	0
El Carrizal	322	14.2	0	11.977581	10.5	2.222419	0
Los Planes**	323					0	4.028117
La Paz	324	27.8	0	29.018892	30.5	0	1.218892
El Coyote	325	3.2	2.7	5.23524	0.7	0	4.73524
Alfredo V. Bonfil	326	2.4	0	2.127094	3.2	0.272906	0

Considering the geology and aquifers, rocks that contain and store water are characterized by porosity and permeability. However, these features are not linked. Porosity is the void spaces within the rock itself. Porosity is the volume fraction of space divided by the bulk volume of the rock. Effective porosity is pore space that is not contained by the matrix of the rock, and is the most important for aquifers. Porosity is a dimensionless quantity either represented as a decimal or a percentage. There are many methods to calculate porosity such as mercury injection or gas expansion. The formula for porosity is:

$$\varphi = \frac{V_{\mathrm{space}}}{V_{\mathrm{bulk}}} = 1 - \frac{\rho_{\mathrm{bulk}}}{\rho_{\mathrm{particle}}}$$

Where:

φ – Porosity

V_{space} – Volume of total pore space of sample (m3)

V_{bulk} – Volume of sample (m3)

P_{bulk} – Density of a sample (kg/m3)

$P_{particle}$ – Density of rock particle

Permeability is the transmissibility of a fluid within the rock formation. The permeability of fracture rock is proportional to width of the fracture. The flow of fluids through a porous media can be characterized and modeled using Darcy's Law .Permeability has the SI units of m^2. Water in the porous media can flow because of a hydrostatic pressure differential created by elevation gradients, or by pressure gradients created by groundwater pumps. The formula for permeability is:

$$q = \frac{KA}{\mu} \nabla P$$

Where:
q - Flow rate (m3/s)
K - Permeability (m2)
μ- Viscosity (pa s)
P- Pressure (pa)
∇ - Gradient: $\nabla = (\frac{\partial}{\partial x} i + \frac{d}{dy} j + \frac{\partial}{\partial z} k)$

Permeability is used in earth sciences and fluid mechanics to describe the ability of material, in this case rocks and soils, to allow fluids, usually water, to pass through it. Hydraulic conductivity is the property of rocks and soils that describes the ease with which a fluid, usually water, can move between pore spaces and fractures; depending on factors such as the intrinsic permeability of the material, the density and saturation of that material, and the viscosity of the fluid. While permeability and hydraulic conductivity are important and related concepts for aquifers, the paper will only refer to permeability given the preliminary nature of this water resource assessment and the scale at which the aquifers are considered.

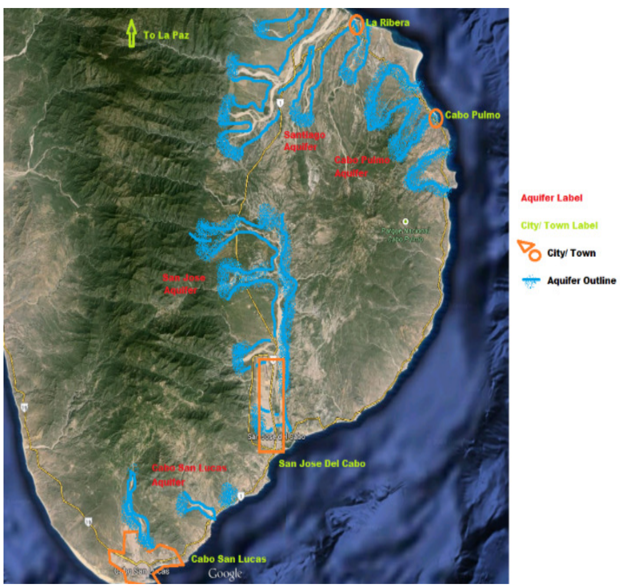
In order for precipitation to be collected in an aquifer, the main criteria of an aquifer is whether it is a porous or highly fractured formation. Aquifers may be deep, or shallow as found in proximity to rivers or lakes. They be made of sand, gravel, conglomerates, sandstone or fractured granite, all of which allow water to be contained in void spaces. The primary candidates for deep aquifer bearing formations are the younger quaternary sedimentary rocks.

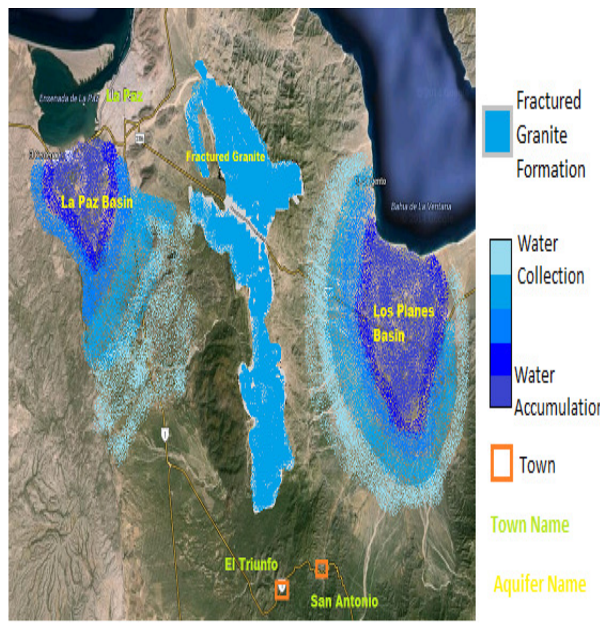
Shallow geology shows large areas of quaternary sedimentary rocks in the basins of La Paz, San Juan de Los Planes, and San Jose del Cabo. Geological studies reveal that a thin layer of sedimentary rock exists near the surface on top of tertiary volcanic and granite rock formations. The layer of conglomerate and sedimentary rock is a result of the accumulated deposits of rock and mineral erosion from the mountains adjacent to the basin. These eroded sediments are carried by precipitation run-off in to the basin through naturally carved river ways where they settle and accumulate. Over the years, the accumulation in sediments grows to form a layer of considerable thickness. It is in these layers where the aquifers exist. Although there are many areas that contain these deposits, the largest have been identified in the basins mentioned earlier.

The San Jose del Cabo basin contains two known significant aquifers: San Jose, and Santiago. The minor aquifers include Cabo Pulmo and Cabo San Lucas. It is not clear whether any of the aquifers are effectively connected by either through a continuous porous or fractured formation, and/or through fault lines. The San Jose del Cabos and Santiago aquifers are located beneath seasonal river beds that are also known arroyos. As aquifers are located beneath riverbeds, the long and narrow relative to their width.

The approximate outline of the aquifers in the Los Cabos Municipality can be identified in satellite images by the features of the riverbed in Figure 1 below. Although the riverbeds can be superficially identified, they do not necessarily reveal the entire dimensions of the aquifer, particularly their thickness. Due to the proximity of the San Jose del Cabos and the Santiago aquifers, and the proximity of Santiago aquifer to the Cabo Pulmo aquifer, there is potential for connectivity between aquifers and possibly diffusion. If that is the case, developments in one aquifer may be able to affect the quality of water in other aquifers.

As illustrated in Figure 2, for the La Paz Municipality, the basins of La Paz and Los Planes contain aquifers. These basins have a similar depositional history or process of formation as the aquifers in the San Jose del Cabo basin. One study for the La Paz basin examined the various qualities of the region including precipitation, geology, and terrain while evaluating the locations of rainfall recharge areas (Cruz-Falcon et. al).





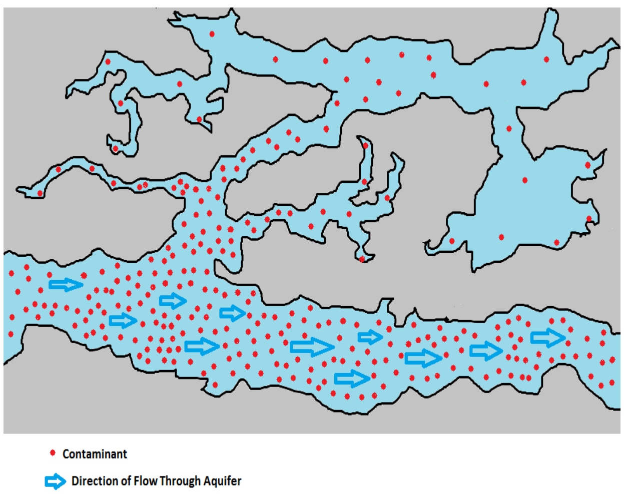
It was found that there is a fractured granite formation, along the east edge of the basin, would be one of the best areas for rainfall recharge. The area containing the fractured granite also has higher annual precipitation since it is at a higher elevation away from the coast. It has been evaluated as being very good for containing water. From this granite formation, it can flow underground to the actual aquifer located within the basin, and replenish it. Due to its proximity to the San Juan de Los Planes basin, the fractured granite may also help replenish the aquifer of that basin.

The quality of the water in an aquifer, as well as the maintenance of quality, is important for the sustainability of the region. This means that it is important to prevent any type of contamination from human activity. Contaminations can flow though porous media via capillary pressure/rise, hydrostatic pressure differential, and by diffusion. Capillary pressure is created by a pressure differential created by surface tension across the interface of different fluids. This property can cause fluids to go against gravity, and quickly move through pores especially when in contact with a fluid that does not wet the rock, generally petro chemicals. With respect to soluble chemical, the effects of capillary pressure in a porous media creates more channels for the contaminants through diffusion.

In the case of diffusion through pores, diffusion can be expressed by Fick's Second Law:

$$D\frac{\partial^2 C}{\partial x^2} = \frac{\partial C}{\partial t}$$

Where:
D – Diffusivity constant (m2/s)
C – Concentration (mol/m3)
x – Distance along pore (m)
t – Time (s)



Diffusion is a natural phenomenon in which a substance will disperse by molecular collisions. Concentration is the driving factor causing a substance to move from a point of high concentration to low concentration until an equilibrium is obtained. Equilibrium generally occurs when the concentration of the substance is equal throughout the medium. The main carrier of contamination will be the sum of all three means. The hydrostatic pressure gradient allows for water to slowly flow through the formation (Darcy's Law), while diffusion takes place at the same time. Figure 3 illustrates these relationships.

Considering the San Jose del Cobas aquifer, it provides water to two major cities. The aquifer is very close to San Jose del Cabos, running through and parallel to the city. Using Google Earth, three potential sources of contamination can be identified: point sources such as gas stations and airport fuel centers, and larger zones of contamination such as agriculture and golf courses. Gas stations are of particular concern because of petroleum compounds, such as n-heptanes and benzene (a carcinogenic aromatic compounds), are known to emanate from these locations. These chemicals can be displaced through the porous media when in contact with water because of the effects of capillary pressure. Both golf and agricultural areas draw large volumes of water and risk contaminating the aquifer as well, due to generally excessive use of pesticides and fertilizers.

Other significant sources of contamination may exist in the industrial zones of the San Jose Del Cobas through deterioration and leakage from local infrastructure, especially stormwater and wastewater pipes. Although the Santiago aquifer is a considerable distance from major urban centers, it may be prone to contamination from current and future agriculture and mining activities in the La Paz and Los Planes basins.

The La Paz basin faces similar contamination risks as the San Jose del Cabo aquifer with agriculture and point sources of contamination like gas stations, and coastal saline intrusion in the vicinity of the city of La Paz. The Los Planes basin is one of the largest agriculture centers in the area and prone to soil salinization. As the municipality becomes a more popular tourist destination, future developments could impact aquifers in the La Paz basin.

The most significant threat to the La Paz and Los Planes basins is a proposed large gold mining project near the town of San Antonio, south of the La Paz Basin. Historic and ongoing artisanal gold mining operations over the past 200 years have contributed to current arsenic contamination in the Los planes basin which exceeds the Mexican federal standards. Argonaut Gold‘s San Antonio project has leases which overlap into the Los Planes basin. Large scale gold mining could release naturally occurring arsenic in rock, and release cyanide used in gold processing into the basin. The former may occur through the leaching of arsenic from mine till, while the latter could occur due to cyanide spills from tailings ponds, both being transported through aquifers and precipitation run-off.

The San Antonio mining leases are located along the drainage divide, and over the fractured granite formation putting the La Paz basin at risk of contamination. Other aquifers and basins could be affected over time depending on connectivity between aquifers, and hydrostatic pressure occurring due to elevation gradients and permeability.

In addition to having major aquifers at risk of contamination, there is also a growing potential that that aquifers in both municipalities will be drained. Large resort complexes are one of the largest consumers of water, though they reduce their direct water consumption with desalinated sea water and wastewater recycling. Desalination also creates its own environmental impact by releasing concentrated brine back into coastal ecosystems.

One planned but subsequently cancelled resort in the Cabo Pulmo area, Cabo Cortez, planned to meet its water needs with aquifers and desalination. Desalination would have accounted for 65% of its water needs with the rest coming from the Santiago aquifer. Cabo Cortez itself was cancelled in 2011. However, a similar proposal has been subsequently made. Since the Santiago aquifer is further away from San Jose Del Cabo, and Cabo San Lucas, it isn’t drawn on as much as the local San Jose Del Cabo Aquifer.

Desalination Projects Within and Proposed for Municipalities of Los Cabos and La Paz

Since 2006, the Los Cabos Municipality receives water from a desalination project operated under a concession. A further concession is being considered for Los Cabos, and an initial concession is being considered for La Paz. Currently, private desalination is used to meet all or part of water demand for many hotels, resorts, golf courses and marinas located in Cabos San Lucas, San Jose Del Cabos, and the tourism corridor between these two urban centers. As they are derived from seawater, all desalination projects create incremental water resources for the municipalities.

Table 2 illustrates the scope of private desalination projects in the Los Cabos Municipality, particularly in the tourism corridor. The table was updated by internet survey, but predominantly based on Table 2: Private Desalination Plants in Los Cabos, Baja California Sur, contained in the 2008 report: Desalinization and Wastewater Reuse as Technological Alternatives in an Arid, Tourism Booming Region of Mexico (A. Pombo et al.).

Table 2: Private Desalination Projects in Los Cabos Municipality

Names	Daily Production (m3/day)	Annual Production (m3/year)
Hotels		
Terrasol Cabo San Lucas	189.00	68,985.00
Bay Of Dreams	283.91	103,627.15
Coonos Del Pedregal (1)	3,785.00	1,381,525.00
Coonos Del Pedregal (2)	2,850.00	1,040,250.00
Vista Serena	3,785.00	1,381,525.00
El Dorado	1,140.00	416,100.00
Capella Pedregal	420.00	153,300.00
Cabo Hacienda	400.00	146,000.00
Solmar Suites Hotel	180	65,700.00
Playa Grande Resort	534	194,910.00
Hotel Finisterra	647	236,155.00
Pueblo Bonito: Sunset Beach	1460	532,900.00
Pueblo Bonito: Los Cabos	82	29,930.00
Villa Del Palmar	474	173,010.00
Melia San Lucas	180	65,700.00
Fiesta Americana Los Cabos	432	157,680.00
Hilton Los Cabos (golf)	180	65,700.00
Holiday inn	321	117,165.00
Plaza Las Glorias	220	80,300.00
Royal Solaris	180	65,700.00
Villas Baja	130	47,450.00
Cascades	200	73,000.00
Casa Coral	118	43,070.00
Property Development		
Condominios Gardenias	160	58,400.00

Future Water Scenarios under Changing Climate for Los Cabos and La Paz Municipalities

In a 2013 study, Sistemas Urbanos en Zonas de Extrema Aridez, Propuestas para el Manejo Sustentable del Agua, the Center Mario Molina (CCM) identified the most appropriate actions from the environmental, social and economic perspective for the Municipalities of La Paz and Los Cabos to cope with scenarios of less water from 2013 to 2018. The study determines the gap between water supply and water demand, and overviews the operating conditions of the operating organisms to determine measures to close gaps. The approach and specific considerations for La Paz and Los Cabos are described below.

The study integrates the analysis of phenomena related to climate change (drought) and the economic analysis of climate change mitigation (construction cost curves for closing gaps). The integration of the two facets generates valuable information for the design of public policies and comparison of alternatives to mitigate climate change. Water is a strategic resource for Mexico because of its economic, social and environmental value, which is why it is essential to preserve it for present and future generations. In Mexico, municipalities are constitutionally required under Article 115 to provide the drinking water, sewage treatment and disposal of wastewater, so they have created institutions focused on managing water known as operating organism (OO).

Due to its geographic location and socioeconomics, Mexico has a high vulnerability to climate change. According to the most recent modeling, it is estimated that in the northern region a decrease in precipitation of 30 % will be recorded until the late 21 century, effects that may occur from the first quarter of this century. For example, the decrease in precipitation expected for Baja

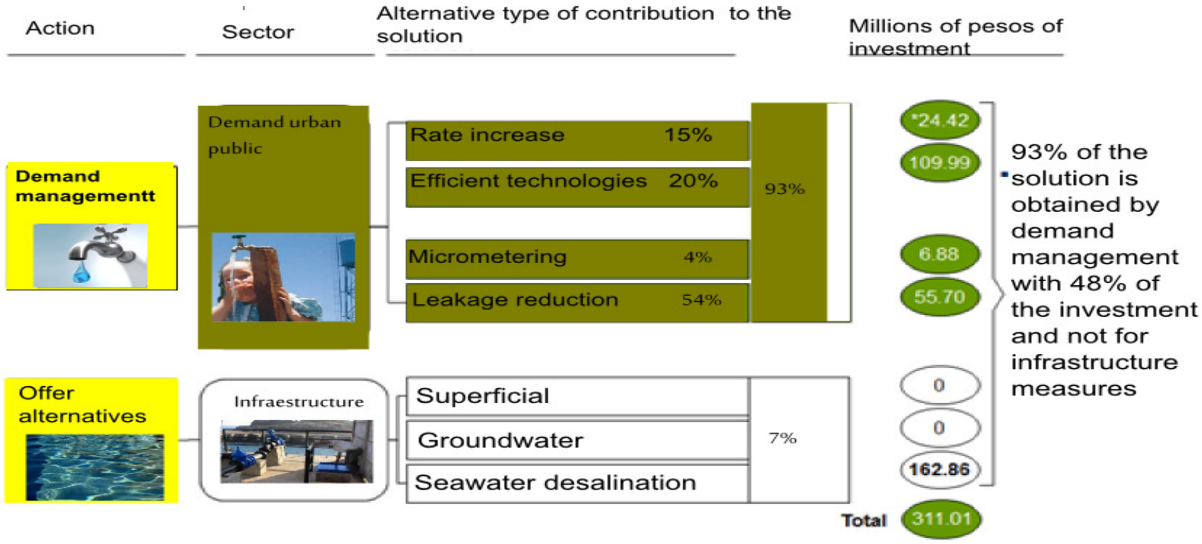
California Sur is minus 60 %. In addition, population growth and economic development will increase per capita consumption of water, and the overall demand for water resources. The effects of climate change are recurrent and severe droughts are expected, which will decrease water availability. On the other hand, there is a growing demand for the resource will result in a shortfall in availability. Therefore, it is necessary to identify actions to increase the capacity of urban water and reduce the difference between the water availability and demand.

The overall objective of the study was to identify the most appropriate actions from the environmental, social and economic perspective to the cities of La Paz and Los Cabos to cope with scenarios of reduced water availability derived from recurrent droughts and higher intensity. Specific objectives of the study were to quantify and extrapolate scenarios of supply and demand of water in the urban systems, calculate the difference between the demand and supply of water to the worst scenario of climate change (gap calculation), identify key technically feasible, economically viable and environmentally sustainable actions that allow OO to provide water supply, and develop a portfolio of actions to meet the different scenarios of drought due to climate.

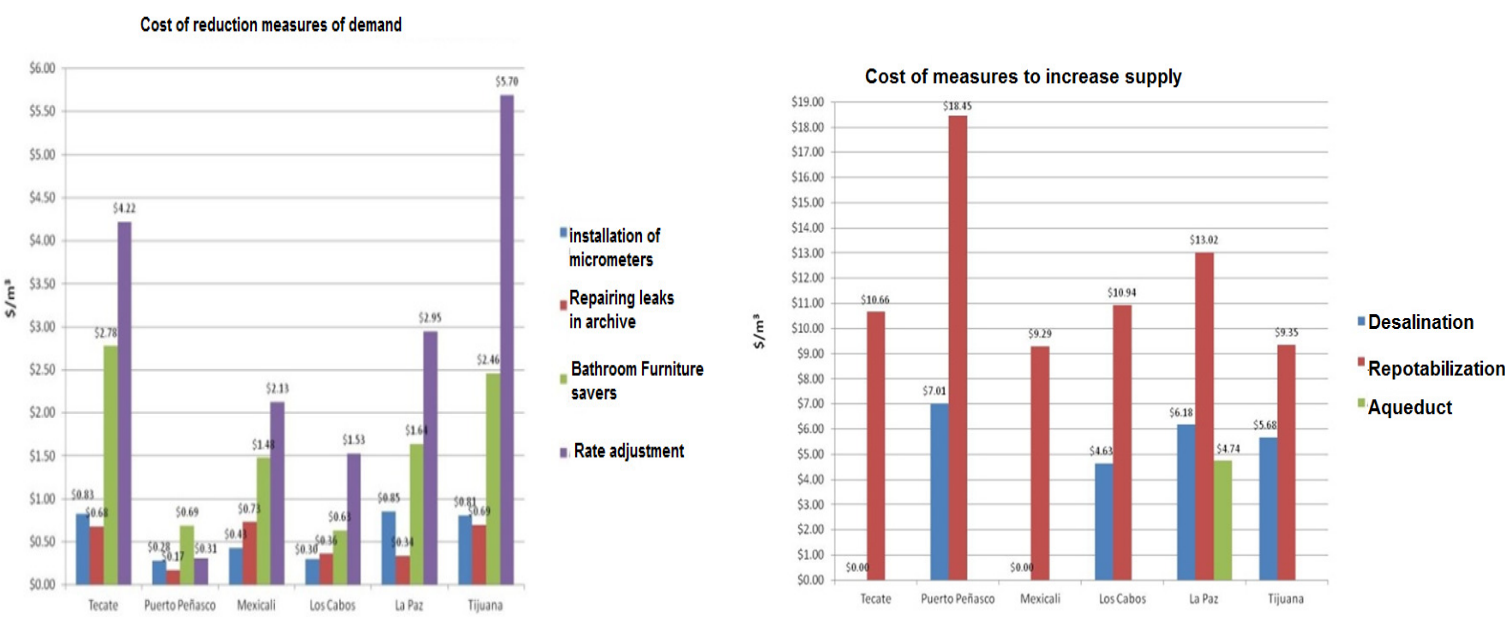
The difference between the availability of water in urban systems and resource demand by users was calculated based on information provided by the OO responsible for water service. To estimate availability, in addition to the official statistics in the three levels of government, climate scenarios and the impact of drought on the various sources of supply such as groundwater and surface water were evaluated. Through the methodology established in the Mexican Official Standard NOM-011 -CNA -2000 Conservation of Water Resources, which sets the specifications and the method for determining the average annual availability of national waters, a model was developed current and future availability of water.

The performance of similar water systems was considered to identify opportunities for improvement. Therefore, the CCM carried out an analysis (benchmarking) in which OOs studied were compared with their national counterparts. This provided an overview of the conditions in which they are operating, and identification of opportunities, which were also used to establish proposals for action to close gaps. Measures for demand management were rate increases, micro-metering and leakage reduction; measures for increasing supply included desalination, water treatment, and additional groundwater sources. A portfolio was created for each alternative which described their main features, increases in water availability, and costs and cost curves per city. The Figure 4: Options for Closing Gaps graphically illustrates the range of options for closing gaps.

Figure 4 Options for Closing Gaps (CCM, 2013).



According to climate scenarios, Los Cabos and La Paz may have significant reduction in the availabile water due to a decrease in precipatation. The most extreme case would be Los Cabos, where the reduction would be almost 50%, while in La Paz the reduction could represent 30% of current availability. For La Paz, the gap would increase over 40% in 5 years, and in 10 years the demand would be 2.5 times the offer. For Los Cabos, in 2018 the gap would be 16%, while in



2028 the gap would exceed 215%. The OO of the cities of La Paz and Los Cabos have low levels of efficiency compared with other OO of similar size (64 % respectively). In most cases, the demand management measures, such as the installation of bathroom fixtures, handling fees and eliminating leaks, were less expensive options for increasing water supply than desalination and new sources of water (see above Figure 5: Cost of measures to reduce the gap (CCM, 2013)).

In the CCM study, there is a difference between the rates currently charged by water systems for their services and best rates from an environmental standpoint. These optimal rates are those which included opportunity costs of water, in addition to the costs of operation, maintenance and the investments. The quantification of costs should also include minimum performance parameters to not transfer service inefficiencies of the service. There is also a societal benefit in knowing the cost of water services, which would help raise awareness of the conservation and wise use of water. The reduction in water availability was a constant for the next few year, as OOs currently have no incentive to plan and make long term decisions.

In the study, CCM suggests would be useful to work in the existing legal and institutional framework and consider the following possible proposals:

- The creation of state regulatory agencies that are responsible for setting goals and long-term to various OOs.
- Transfer pricing power to the councils and conferences to regulatory agencies, who could authorize tariffs that include the costs of operation, maintenance, and which are sufficient to meet OOs objectives and long-term investment.
- Advance the autonomy of OOs so that these are not subject to local political cycles.
- Implement committees to make responsible investments in OOs, discussing plans and investment projects, their costs and benefits, and making decisions.
- Facilitate social performance verification of OOs through periodic reporting obligations for investments and budgets, and results achieved for efficiency and quality of service.
- Promote organized participation of society by creating councils or citizen committees.

The study found it was necessary in the future to further analyze the side effects of implementing measures to manage demand and expand supply. The study was performed using a static approach, and that model does not capture the effects of implementing each of the proposed measures. Additionally, it will necessary to evaluate the environmental costs of increasing the supply of water in arid areas through desalination plants and aqueducts, as there will be an increased energy demand and the production of brine. The study recommends that model gap analysis and economic evaluation of alternatives be part of the planning and design of public policies to adapt to climate change, objectively comparing the different alternatives according to their potential to mitigate the effects of climate change and the costs associated with each alternative.

The study proposes considering the implementation of tariff schemes that incorporate environmental costs for all users, including farmers who were not considered in the 2013 study. It is expected that these measures provide incentives to all users to optimize the use of water and to find recycling options, reuse and exchange of water uses less economic value to activities of higher value. The evaluation of all projects must be considered so that not only the portion of increased supply is considered in the design, but the potential aquifer recharge, recovery of watersheds and water exchange reduction in demand. Additionally it is necessary to complement the implementation of management measures demand and increase in supply, with shares of awareness and education to the population. The study was an innovative way to integrate the analysis of environmental problems arising from climate change and the economic analysis of climate change mitigation phenomena. The integration of the two facets generated valuable information for the design of public policies in order that decision makers compare the different alternatives for mitigating the effects of climate change.

Conclusions and Recommendations

This paper illustrates a preliminary assessment of water resources for the Municipalities of Los Cabos and La Paz, combined with an initial assessment of the impact of project climate changes on these water resources. Subject to the active engagement of the municipalities and the Centro Mario Molina, the following next steps are recommended to ensure sufficiency of water resources for the municipalities in light of expected climate changes. First, it is recommended to develop further understanding of aquifers and other water sources for Municipalities of Los Cabos and La Paz, including quantity and quality issues. Second, it is recommended to explore desalination projects, and possible role of renewable energy, for public concessions and private projects in these municipalities. Third, it is recommended that the CCM study be continued and deepened to consider impacts of climate change on water resources and availability for these municipalities.

References

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Argonaut Gold. http://www.argonautgold.com/_resources/projects/San-Antonio-Project-District-Schematic-Map.pdf (Assessed 14 March 2014)

San Antonio Gold Project Baja California Sur, Mexico NI43-101 Technical Report (2001), p. 28 http://www.argonautgold.com/_resources/projects/San_Antonio_NI_43-101_Technical_Report_August_2_2010.pdf (Assessed 14 March 2014).

Carrilo A., Drever J.I. Absorption of arsenic by natural aquifer material in the San Antonio-El Triunfo mining area, Baja California, Mexico. Environmental Geology, (September 1998), Volume 35, Issue 4, pp 251-257.

Carillo-Chavez A., Drever, J.I., Martinez M., Arsenic content and groundwater geochemistry of the San Antonio-El Triunfo, Carrizal and Los Planes aquifers in southernmost Baja California, Mexico, Environmental Geology, October 2000, Volume 39, Issue 11, pp 1295-1303.

Centro Mario Molina, Sistemas Urbanos en Zonas de Extrema Aridez, Propuestas para el Manejo Sustentable del Agua (November 2013).

CONAGUA: Dario Oficial, Segunda seccion (Dec. 20 2013), and Mexican Official Standard NOM- 011 -CNA -2000 Conservation of Water Resources (2012).

Cruz-Falcón A., Troyo-Diéguez E., Fraga-Palomino H. and Vega-Mayagoitia J. Location of the Rainfall Recharge Areas in the Basin of La Paz: Figure 2. Delimitation of the basin of La Paz, and Terrain elevation model (TEM); Figure 4. Geology model of the basin of La Paz; and Figure 8. Precipitation model of the basin of La Paz. http://www.intechopen.com/books/water-resources-planning-development-and-management/location-of-the-rainfall-recharge-areas-in-the-basin-of-la-paz-bcs-m-xico (Assessed 18 March 2014).

McEvoy J. Desalination and Development: The Sociological and Technological Transformation of the Gulf of California. Doctorate dissertation, University of Arizona (2013). http://arizona.openrepository.com/arizona/bitstream/10150/301684/1/azu_etd_12924_sip1_m.pdf (Assessed April 18, 2014).

Muir M. and Leinweber K. Desalination research for Los Cabos and La Paz Municipalities based on internet surveys (unpublished 2014).

Pombo A., Breceda A., and Valdez Aragon A., Desalinization and Wastewater Reuse as Technological Alternatives in an Arid, Tourism Booming Region of Mexico. Frontera norte v.20 n.39 México ene./June 2008.

Porse E., Managing Arroyos in Los Cabos, report of SCI Affiliated Researcher Porse in cooperation with IMPLAN Los Cabos (2013).

PRONACOSE, Materiales del primer Taller de capacitación Apoyos cartográficos: Baja California Sur: 01 precipitation normal 71 00. http://pronacose.uacj.mx/Carpeta1erTaller/6.%20APOYOS%20CARTOGRAFICOS/01_Baja%20California%20Sur/ (Assessed 11 March 2014).