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Fire Impacts to Quality of Reservoirs San Roque and Los Molinos

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ABSTRACT

Córdoba along with its hinterland is one of the most important cities in Argentina with a population in 2010 of more than 1,400,000 inhabitants. In this city, water is supplied by the San Roque Los Molinos reservoirs. The region is subject to strong variations in its hydrological cycles. Besides, a steady population growth experienced in recent years in the city and its hinterland has derived in conflicts in the water supply which were protracted by droughts, floods and changes in the land use. Additionally, periodic fires in the basin seriously deteriorated both reservoirs routing with very serious consequences. this study is presented to perform the assessment of impairment suffered annually by both lakes due to fires occurring in the Sierras de Cordoba. This study attempts to determine the increased siltation in reservoirs that supply water to the city as a result of fires. The model used to calculate the specified degradation in the basin is the Djorovic & Gavrilovic (1974). Results show a decrease in time lag to reach a total siltation of the reservoirs due to fires in the upper basin.

Keywords: Drinking water, sources of pollution, fires, province of Cordoba.

1. Introduction

In the province of Cordoba (see fig. 1), Argentina, between the months of July and September numerous fires affecting large tracts of its territory occur. This is generally coincided with the dry season, from May to September. Its importance depends, among other factors, on temperatures, winds present, abundance of combustible material and the anthropic factor accidentally or intentionally, triggered claims over the years.

The environments are affected among others such as forest formations, cultivated fields, pastures, forest regions and even peripheral urban areas.

In addition to the direct risks associated with fires as the loss of life, loss of crops, livestock and tourism revenue the occurrence of the same affects in different ways and at different stages, soil productivity, erosion, landscape, biodiversity and water sources.

The growing deficit manifest sources of fresh water worldwide, particularly those providing the resource to the city of Córdoba, is mainly due to the following factors:

- Population Growth
- Increase in non-regulated provision and supply for different uses and services.
- Biological, chemical and physical contamination.

Fig. (1): Location of Cordoba within Argentina.

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As a result of fires and loss of organic matter by absorption capacity of the soil occurs, the runoff is favored, and consequently the transfer and accumulation of ash in water bodies. All this creates eutrophication, which facilitates algal blooms, fish kills, and reduced dissolved oxygen concentration, among other things. This results in higher costs for purification of water bodies that are used for human consumption.

Increasing the solid matter that reaches the reservoirs decreases its useful storage capacity which is disclosed as embankment.

The present study was made with the objective to assess more accurately the degree of impairment of sources of water supply to the city of Cordoba and Cordoba against large fires to provide a basis to serve in the development of action plans for the control of fires and mitigation of their consequences.

The Greater Córdoba, with a population in 2010 of more than 1,400,000 inhabitants (estimate by the Municipality of the City), is mainly supplied by the San Roque reservoir basin, and second-degree reservoir Los Molinos, which derives its flow through the channel Los Molinos - Cordoba, to the South of the city of Cordoba.

Each system is divided into subsystems. Drinking water is conducted by pumping (using 13 pumping stations) and gravity. Each subsystem has specific characteristics of supply. Given by the flows, this can be effectively conducted and distributed by gravity and pumped through existing infrastructure.

The system's supply area to the upper basins of the rivers Suquia and Los Molinos . These basins are currently regulated by dams San Roque and Los Molinos, respectively. Through various channels and major ducts, raw water is conveyed to the treatment plants Suquía and Los Molinos (or Bouwer), respectively, where the process of purification is performed.

Each water treatment plant supplies water to a section of the city that receives the name of the system. The water produced by plant Suquia (Suquia System) supplies the area north of Suquía River and west of the Glen with a capacity of 5 m^3/s, while the plant Los Molinos System (Los Molinos) serves the southeast sector city with a capacity of 2 m^3/s.

In the last decades protracted droughts and floods occurred, accompanied by changes in land use, new developments in the basins (particularly Suquía) competing for this resource. Added to this is the progressive contamination in neighboring basins and siltation and eutrophication in reservoirs, generating situations where demand exceeds water availability of the system itself.

As a result of this situation, measures are being taken to ensure water supply to Greater Córdoba and maximize the sustainable use of the resource for years to come. As part of these studies, a clearer understanding of the quality of the various sources and processes involved will define action plans and structural measures to help conserve and enhance the ability of these resources.

One of the most important phenomena related to the contamination of surface waters is eutrophication of lakes and reservoirs, such as the San Roque and Los Molinos, so particular emphasis on this phenomenon in the development of this report is made.

2. Methodology

To perform the assessment of impairment suffered by Lake San Roque and Los Molinos against fires occurring at the Sierra de Cordoba each year the following procedure was adhered to:

1. Carrying out Literature and informative Digest for the main characteristics and status of reservoirs (degree of embankment and eutrophication) that supply water to the city of Cordoba.
2. Generating a digital elevation model (DEM) of each basin to associate it with the fires reservoirs and observe effects.
3. Analysis of the influence of fires on the useful capacity of reservoirs (embankment). This is to be achieved through several methods that estimate the specific degradation of the basin considering different parameters or the occurrence of fires.
4. Valuation of increased siltation in reservoirs that supply water to the city as a result of fires, to quantify the degree of involvement. The model used in this study to calculate the specified degradation in the basin is to Djorovic & Gavrilovic (1974).

2.1 Current Status of the San Roque Dam

The old San Roque Dam, designed by Dumesnil and Cassafousth Engineers in 1884 aimed to control and uses the waters of the avenues for irrigation in the highlands of the city of Córdoba. In 1930 Volpi Ballester and engineers proposal to build a new dam increased capacity and safety, 130 meters downstream of the anterior wall. This is the current San Roque Dam, whose multiple objectives included provision of water to the City of Córdoba, increased attenuation, irrigation water, hydroelectric power and recreation.

The dam reached a height of 51.3 m and a length of 145 m coping, headworks are feeding the San Roque hydroelectric plant downstream discharge and to the wall by a valve jet. Your dump is a well with flared tunnel entrance and with a maximum discharge of 280 m^3/s. The lip height weir is 35.30 m, with an area of 1501 ha and reservoir storage of 201 hm^3. The module is approximately 9.46 m^3/s. The values of the reservoir at elevation 29 m (637 m) 29.5 m quoted are for maximum depth, average depth 6.43 m, 30.72 km perimeter, length 8.40 km, 1.47 km and average width time minimum 247 and maximum stay of 28 days.

The upper basin of the river Suquía has an area of 1750 km^2 and is approximately rectangular in shape, 70 km in the NS direction along Punilla Valley, with an average width of 25 km.

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Its geographic location, latitude 31º S and 64º W longitude, corresponds eminently temperate continental character, with large temperature variations, ranging from several degrees below 0°C in winter to 42°C in summer. Evapotranspiration peaks in the summer months of about 7 mm/ day, reduced in winter to 2.5 mm/day period.

The rainy season extends from October to March, with mean values of 620 mm, while the minimum period between April and September only reaches 80 mm. This marked difference influences the variability of the levels of the reservoir; annual fluctuation is approximately 8 m, which restricts their use.

The hydrographic network consists of the Cosquín (or Grande de Punilla) and San Antonio rivers modules approximately 5.5 m^3/sec 3.5 m^3/s, respectively and streams The Mojarras and Los Chorrillos with about 0.3 m^3/s each.

The hydropower generation is performed by the San Roque plants with an installed capacity of 26,000 kW and 4,000 kW La Calera, located in stages downstream of the dam San Roque.

The development of human activities on its banks and surrounding areas, are mostly related to tourism: camping, fishing clubs (rental boats, jet skis), yacht clubs (yachts, sailboats, etc.). Also practice water sports (Jet Ski, windsurfing, etc.) are performed.

The San Roque Dam is the main source of drinking water for the city of Córdoba. Your eutrophic condition is evidenced by its lack of transparency, presence of hypolimnetic anoxia events and frequent algal blooms due to high nutrient inputs from the watershed and lake margins. Numerous studies (Rodriguez, 2003; Reyna *et al*, 2006); have been developed whose main objectives are to determine the water quality and the status of the San Roque reservoir sediments.

To this end, in recent years, there have been conducted a number of campaigns which are already preliminary results. A summary of these is presented in the following section.

2.2. Water Quality from San Roque Dam

The San Roque dam has a eutrophic state for several years due to the high load of nutrients via both external source (from the basin and through its tributaries) and internal sources (their own sediments)(Granero *et al*., 2002).

Due to its monomictic regime which manifests a stratification period a year the hypolimnion becomes anoxic. As a result of this phenomenon variables such as pH and redox potential decrease significantly (Bustamante *et al.*, 2007).

Ions such as Mn^{2+} and Fe^{2+} and to a lesser extent, Ca^{2+} and Mg^{2+} are released from the sediment to play a key role in the release of PRS, necessary to sustain the life of the phytoplankton.

P release coefficients estimated to reach 1.33 mg PRS / m^2/day, which demonstrate high activity in the sapropel in the summer (Bustamante *et al*., 2007).

Fires in both basins produced a significant increase in P in both reservoirs by soil washing. This additional contribution helped to aggravate the problem of eutrophication.

After the episode of fire, the development of blooms of species that cause problems in the purification process as *Hirundinella Ceratium* and *Microcystis aeruginosa cyanophytes* as could be observed.

2.3. Current Status of the Reservoir Los Molinos

The Los Molinos dam creates a reservoir on the river in West Los Molinos center of the province of Córdoba, Argentina, at 769 m, near the resort town of Los Molinos.

The dam stores water in a watershed of 980 km^2. Its wall is 60 m high and 240 m long. The reservoir is 24.5 km^2 and a volume of 399 million cubic meters (399 hm^3); the maximum depth is 57 m.

The dam was built between 1948 and 1953, and its basic purpose was to regulate the river flow and produce hydroelectricity. Today, the water supply to Cordoba has become a central objective for the same. The power plant generates 148 Los Molinos I MW grid for the Central Region of Argentina (CEM).

The lake is bordered by the provincial route No.5. Much used by fishermen (silversides), swimming, water skiing, sailing.

2.4. Reservoir Water Quality from Los Molinos

The Los Molinos reservoir is classified as a hydrologically shallow reservoir; as a result, the wind produces the mixture of the whole body of water. Those reservoirs in which the wind is not strong enough to prevent stratification of the water body, they are considered as deep hydrologically. According to its area and its volume its category is among small to medium. The contribution of total phosphorus from various sources, both natural and anthropogenic, are estimated: The River Espinillos (30%), Mina Clavero river (24.8%), direct discharge of animal origin (18%), the Río del Medio (10 %), discharge of sewage origin (6.2%), San Pedro (5%), agricultural runoff from perilago (4%), atmospheric deposition (1.1%), ponds (0.15 %) and runoff of forested land (about 0.1 %).

Annually Los Molinos reservoir undergoes changes in its level leading to exposed areas. Raising the level of the reservoir, flood covering vegetation that has developed, which decomposes, providing organic matter and nutrients to the water body. Approximately 10 t (metric tons) per year of the total phosphorus and 400 t per year of total nitrogen would be incorporated into the body of water when the area is flooded (Corral *et al*., 2004).

In the spring - summer temporary daily presents varied climate unstable by surface heating of the upper layers, as a result of the prevailing climatic conditions (sunny days and very little wind). The phenomenon of mixed water column during winter and summer stratification , besides the fact that its surface temperature never drops below 4 ° C make the Los

Molinos reservoir is classified as warm monomictic (Wetzel, 1981).

In warm periods presented in oxygen saturation surface as a result of the photosynthetic action hypolimnetic hypoxia, high concentrations of nutrients and chlorophyll low transparency and a marked decrease in phytoplankton diversity as a result of excessive growth of algae that had a inhomogeneous distribution with increased turbidity in the areas of higher density with consequent deterioration of water quality of the reservoir.

In late November 1999, excessive algal blooms, accompanied by a fish kill event took place in Los Molinos reservoir. Test results indicated that time in high concentrations of ammonium in the death and according to pH and temperature, 20% would have been dissociated, exceeding the value considered lethal to fish (0.02 mg N/l) and can be was one of the causes of that mortality .

3. Digital Elevation Model

For proper identification of the sources of nutrient inputs to each of the reservoirs that make up the supply system, a model based on balance considerations are detailed below was generated.

The domains of each system were defined in the first instance. the water cycle is the main determinant in the mobilization of nutrients necessary to define precisely each watershed. For this purpose a digital elevation model (DEM) using the digital sampling of ASTER images of the area of influence was generated. Map existing information regarding projection system and datum (UTM, WGS 84) was observed in the first instance. Thus every element that integrates the model is perfectly geospatially referenced.

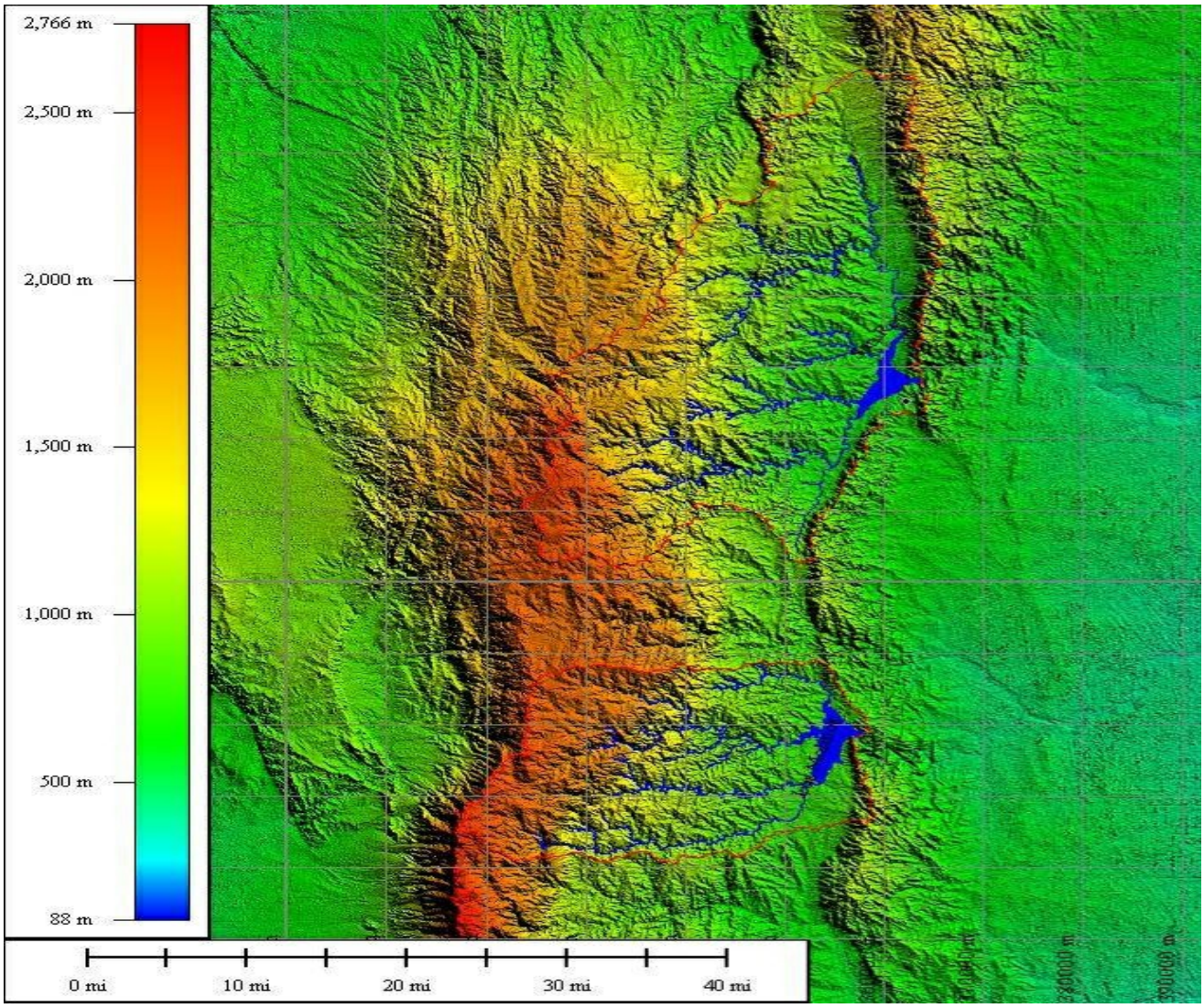

Fig. (2): Digital Elevation Model - Basins contribution to the San Roque Dam and the Los Molinos. (Source: ASTER images).

By using maps and satellite images anthropogenic and natural oddities within the watershed that should be considered in defining the contribution areas (roads, secondary courses, reservoirs, outcrops of crystalline basement, drilling, etc. were identified).

Geological, soil maps, rainfall and land use, water reports, geological and production sector were analyzed achieving a finish understanding of natural and anthropogenic characteristics of each basin.

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They needed to combine and mix this information with respect to units and scales of time and space (flow, meteorological data input coefficients, etc.). The coefficients of each nutrient associated with different types of source are taken from specialist literature, indicated in each case, contemplating for assignment, the similarity of the areas which were calibrated thereof. Where this was not possible values of the coefficients given by different authors were averaged.

When extended border control volume model of the reservoir to the basin, the contribution for tax was considered separately under each of the sources or both point and diffuse components.

4. Calculation of the Specific Degradation

A component associated with the quality and quantity of water from reservoirs corresponds to sediments deposited in the water body, year after year, as a result of water erosion on their basins.

The need to estimate the volumes associated with water erosion, boost the development and application of different methods which are intended for the qualitative or quantitative assessment of this phenomenon.

The Djorovic & Gavrilovic model (1974), selected for this study, is one of the most used models. The model calculates the specific degradation in watersheds, considering parameters and defining precipitation, temperature, soil, topography, vegetation, degree and type of intensity that have reached the existing erosion processes in the watershed.

Applying the method of the average solid volume is obtained m^3/year of sediment yield by surface erosion.

Table (1) presented the parameters used to estimate the specific degradation of neighboring basins to the reservoirs under study.

Table 1: Parameter used to estimate the specific degradation

Embalse	Unit	SAN ROQUE	LOS MOLINOS
Wettest month precipitation	(mm)	120	145
annual rainfall	(mm)	700	843
Area of the basin	(km^2)	1750	978
Input modulus	(m^3/seg)	10	9.49
H mean- H average	(m)	1250	1370
Relief / longitude.	(m/km)	31	33
Average annual temperature	(ºC)	15	16
Capacity of the reservoir	(Hm3)	201	307
Year inauguration		1944	1953

First these values will be determined without regard to the occurrence of fires and then include them, so what will quantify the degree of involvement of the same. The affected area was estimated based on the records of recent years. Table (2) shows the percentages of occupation of the basin.

Table 2: percentages of occupation of the basin

LAND USE	**SAN ROQUE BASIN**		**LOS MOLINOS BASIN**	
(Elaborado en base a informes del Ministerio de Agricultura, Ganadería y Alimentos	w/o fire	w/ fire	w/o fire	w/ fire
Woods / Forest	42.2%	32.2%	39.2%	29.2%
Fires	0	10.0%	0	10.0%
Urbans	3.6%	3.6%	2.4%	2.4%
Agricultural	0.6%	0.6%	23.4%	23.4%
Others	0.4%	0.4%	2.5%	2.5%
Livestock	53.1%	53.1%	32.5%	32.5%

5. Results

Table 3 and the fig (3) show the embankment reservoirs in San Roque and Los Molinos without considering and considering the effect of fire on watersheds and when You reach different levels of embankment in each.

Table 3: Summary of the values of reservoir embankment in San Roque and the Molinos in both situations.

Reservoir	Build Construction	Original Reservoir Volume	Embankment			
			2011 (%)	50% (year)	75% (year)	100% (year)
Without considering the effect of fires						
SAN ROQUE	1944	201	22%	2094	2169	2244
LOS MOLINOS	1953	307	9%	2281	2445	2609
Without considering the effect of fires						
SAN ROQUE	1944	201	29%	2061	2119	2178
LOS MOLINOS	1953	307	11%	2213	2343	2473

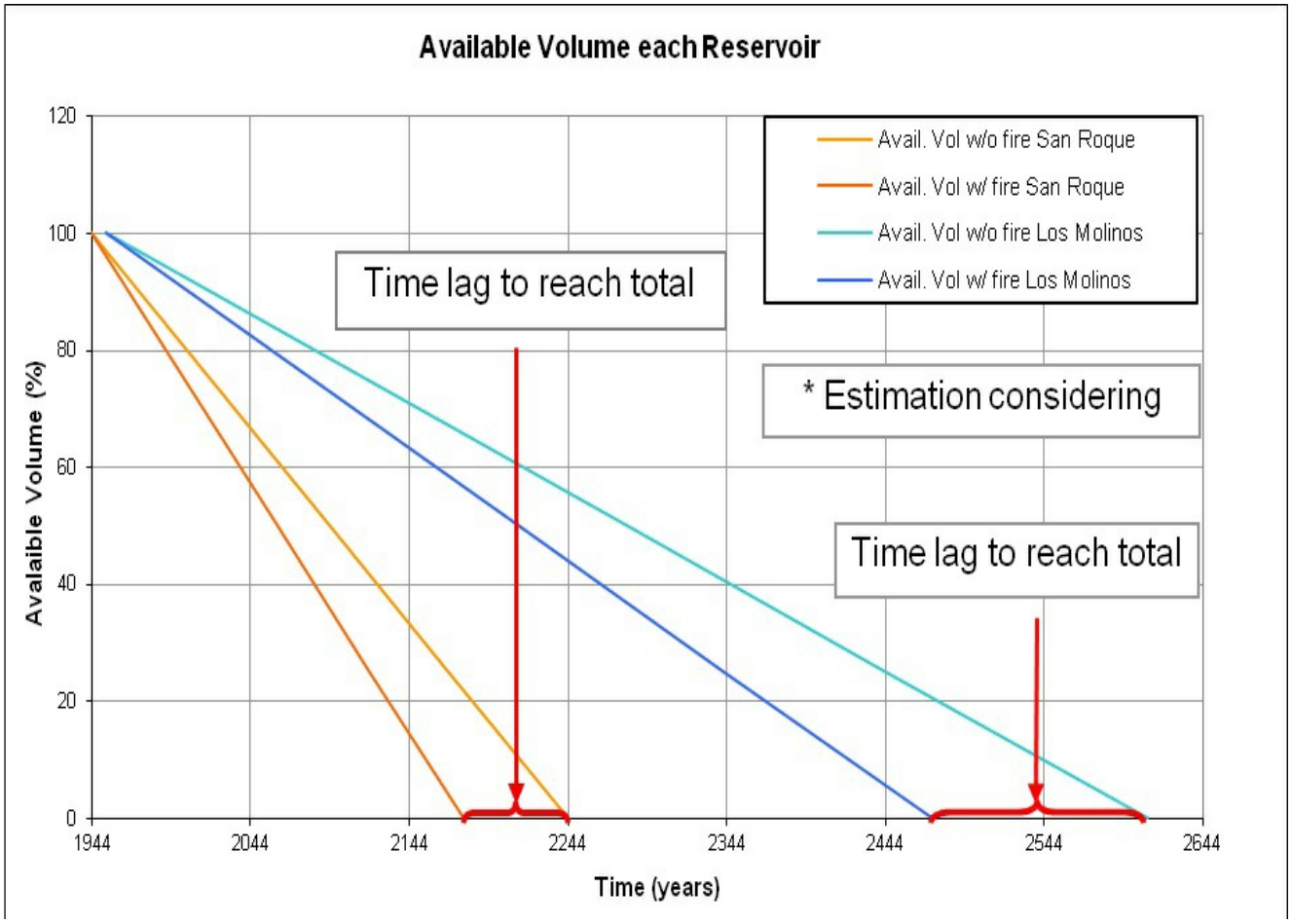

Fig. 3: Decrease of Volume Available for Reservoir

With respect to quality parameters in the lake San Roque phosphorus input from the untreated sewage discharge from the city of Carlos Paz represents 29.5 % of the total. This value equals the contribution by farming practices that develop in the entire basin. For the case of nitrogen occurs something like that because it just percentages, the differences do not appear to be as significant. Sewage discharges increase tourism throughout the valley Punilla involved in 12% of the contribution of phosphorus and 18% nitrogen. Fires contribute a percentage may seem small but it represents considerable magnitudes of total contribution (4.3 % to 2.7% PT and NT).

Due to the lower degree of deterioration in the quality presented by the Los Molinos reservoir relative importance among sources changes from the San Roque Lake. The contribution of phosphorus fire contributes 10.6% which exceeds the contribution for sewerage of the most populous locality (5.6% in Potrero de Garay). The same happens with the input of nitrogen. Sewage discharges increase tourism throughout the basin involved in 24% of the contribution of phosphorus and nitrogen by 19%, which shows a lack of infrastructure linked to effluent treatment.

6. Conclusions

As a result of the natural watershed degradation erosion and sediment deposition occur in vast land areas and mainly in the riverbeds. The consequence of this type of erosion is larger section of runoff to deepen the bed and increase its width, increasing the carrying capacity of the river.

The obstacle of dams for sediment discharge in rivers draining upstream thereof, causes accumulation of sediment and widespread erosion in the downstream reaches. Along with the drag of solid material degradation product of the basin, the rivers are important nutrient loads directly related to the chemical characteristics of soils and soil involved.

Agricultural activities not regulated, overgrazing and fires among other actions that depend on man especially in the basin headwaters, as could be demonstrated in the calculations presented increased rates of sediment generation directly affecting the net volume of reservoirs and in quality.

To reduce these effects suitable for implementing the land use practices in the watershed, controlling deforestation actions and implementation of prevention and control of unwanted fires is required.

Regarding the storage capacity of reservoirs and for proper planning of water resources, in what refers to the ability of regulation and involvement by embankment, conducting bathymetry that will generate some basis for required monitoring and control.

On the other hand it is necessary, first, to extend the existing sewer systems and ensure proper connection to the treatment systems to ensure proper operation of wastewater treatment plants and expand capacity where it does not satisfactorily cover the entire flow treated. Addition of tertiary treatment should be provided to existing treatment plants that have not yet possess.

In the high pastures should be regulated by setting maximum stocking fillers in terms of heads per hectare and rational use of washes avoiding overgrazing.

Furthermore, the use of agrochemicals should be regulated for not exceeding the suggested global standards for nitrogen content primarily.

Finally, it should implement reforestation of areas affected by fires to reduce the degradation of the basin with their respective nutrient drag and develop and maintain plans for protection and conservation of forest remaining "serrano" through the creation of protected areas, increasing the number of guards and rangers faunas.

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