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CONTRIBUTION OF SEDIMENTS FROM AN INTERMEDIATE BASIN TOWARDS A RESERVOIR: CASE LUIS L. LEÓN DAM, CHIHUAHUA, MÉXICO

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ABSTRACT

Sedimentation is one of the most important factors that affect the storage capacity of a reservoir. A proposed model has been developed to estimate the sediment load in the reservoir of the Luis L Leon (El Granero) dam, by integrating the Universal Soil Loss Equation (USLE); integrating the factors involved in the estimation through a Geographic Information System. The developed model was validated using both the topographic survey prior to the construction of the dam and the existing bathymetric studies for the reservoir. The estimated gross erosion of the basin was 8.65 T/ha/year, with a sediment contribution to the reservoir of 50.52 m3/km 2-year; based on the analysis performed since the beginning of the operations (1986) until the last bathymetry, the settled volume during this period was 40,189 hm3 equivalent to 12.08% of its capacity, which represents an average loss of 47,455 m3/km2-year. These values are considered low taking into account the size of the basin, being an intermediate basin and having several reservoirs located upstream that capture the sediments that occur in the upper basin. By comparing the estimated sediment production with the application of the model, the sediment delivery coefficient (SDC), and from the bathymetries, based on these it can be considered that the proposed model, once calibrated, can reasonably estimate well the sediment load in the studied portion of the Conchos River.

KEYWORDS: *Basin, Sedimentation, Universal Soil Loss Equation (USLE), Watershed, Water Erosion*

Article History

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INTRODUCTION AND OBJECTIVES

Soil erosion plays an important role in the shelf life of a reservoir, although it is a discontinuous process in the study area, it is linked to the occurrence of extreme rainfall events, followed by long periods of extreme drought. It is important to note that the desertification processes, to which the basin is held, largely due to the anthropic impacts, accelerate the erosive process. Vegetation is an indicator of the condition in which an ecosystem is found, so a change in the vegetation cover and land use affects the basin's hydric balance. The lower the vegetation, the greater the erosion and soil loss, which can lead to sterile soils and decreased storage capacity in water bodies due to sedimentation.

The amount of sediments that are transferred, over a period of time, from a basin to a reservoir, can be estimated using models of water erosion that shows the efficiency of sediment transport, supported by morphological information of the hydric network and basin (Kirk by and Morgan, 1980; Walling 1983; Ferro and Minacapilli, 1995;), or from information obtained from bathymetric measurements (Masa, 1996; Carvajal and Giráldez, 2000; Bodoque*et al*, 2001; Laiz and Flores, 2010).

The lack of field measurements realized in historical periods is a constraint for estimating water erosion. In this research, to determine the degradation of the basin of the Luis L. León dam "El Granero", was used the empirical method of the Universal Soil Loss Equation (USLE), implemented in a Geographic Information System (GIS). The fact of having bathymetric measurements realized in the reservoir and the utilization of the Sediment Delivery Coefficient method (SDC), allowed to develop a better validation of the methodology used.

LOCATION

The basin of the Luis L. León dam "El Granero" on the Río Conchos, is located in the central and southeastern parts of Chihuahua State, Mexico and a small part of the North of the Ocampo's Municipality in Durango State (Figure 1), its starting point is in the Southeast part of Aldama's Municipality, Chihuahua. The Comisión Nacional del Agua (CONAGUA), the Administrative Water Organization in Mexico, has separated the Country in 37 hydrologic regions (HR) that represent the natural limits of the large basins in the Republic; these are, as well, grouped into 13 Hydrological-Administrative Regions (HAR). The basin of the Luis L. León dam forms part of the hydrological region 24 "Bravo-Conchos", which corresponds to the Hydrological-Administrative Region 6, Río Bravo. It is drained by intermittent and perennial currents and its mainstream is the Río Conchos (CONAGUA, 2015), its surface is 24,092.6 Km^2 (Figure 2). For the purpose of estimating water erosion and being an intermediate basin, it was considered that the discharge began on the dams "La Boquilla", "Francisco I. Madero", "Pico de Águila", "Parral" and "Chihuahua", and its closing point is the Luis L. León dam.

Figure 1: Location of the Basin of the Luis L. León Dam "El Granero"

This basin is considered an altered watershed, as two major irrigation districts are located on it, such as 005, Delicias and 103, Río Florido, the latter with an approximate surface of 7.365 ha for Chihuahua State; In addition, important Cities are located in it, like a Chihuahua, Delicias and Camargo, in addition to others of lower population density.

METHODOLOGY

Part of the superficial runoffs generated in the Río Conchos basin are mainly dammed by the dams La Boquilla, Francisco I. Madero and Luis L. León, and to a lesser extent by the Chihuahua dams, Pico de Águila, and Parral, which, one way or another have been affected by sedimentation and consequently decrease in its useful capacity.

Taking into consideration all previously mentioned, the objectives of this work is to analyze the sedimentation rate in the dam of the Luis L. León Reservoir, it is also to dimension the differences in the production of accumulated sediments in reservoirs located in headwater basins (without Important storage that retains sediments) and others located in intermediate watersheds that have one or more upstream reservoirs, as is the case of the reservoir under study.

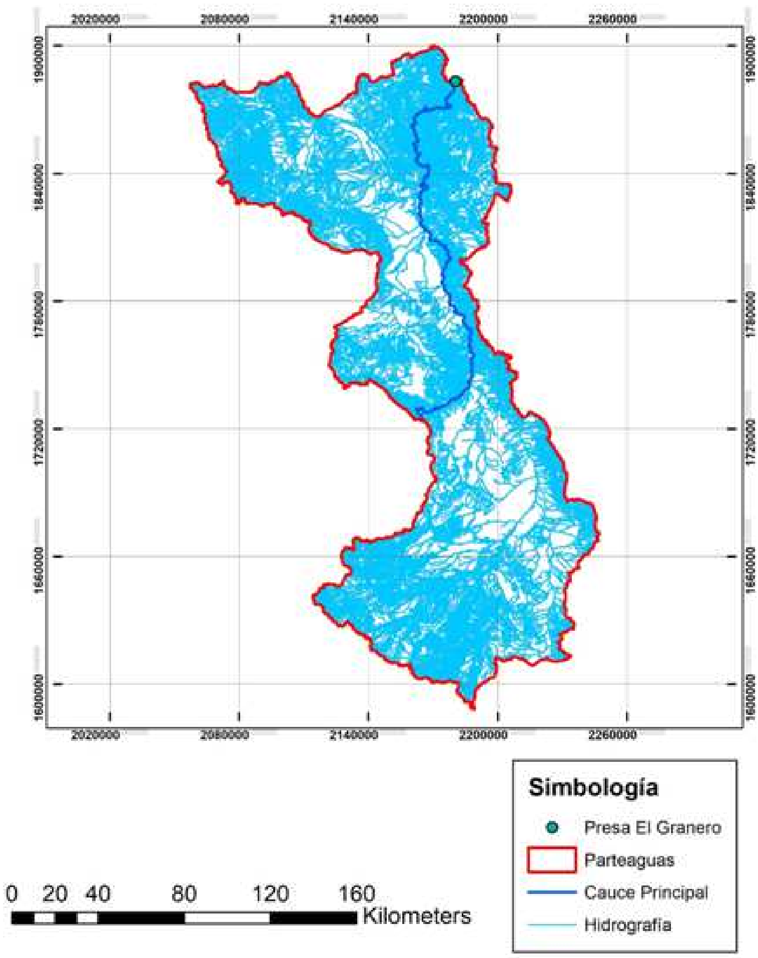

Figure 2: Hydrograph of the Basin Luis L. Leon Dam

In the characterization of the basin, it was used the software ArcGIS 10.3 and AutoCAD 2014, the Digital Elevation Model (DEM) of INEGI CEM 3.0 with a cell size of 15 m for 15 m of the study area. The hydrography was generated from the program INEGI, SIATL 1:50 000, were used shapefiles of INEGI with information of coverage: Edaphology, land use, and vegetation and geology, scale 1:250.000.

Geomorphology

The average slope of the basin is an indicator of the impact of the surface runoff in the water erosion. The slope estimated with the software Arc Gis 10.3 gives a value of approximately 6%, which classifies the basin as slow runoff response, with good infiltration capacity and low sediment production. According to Saavedra (2001), the basin is classified as "hilly medium" terrain. Analyzing it by sub-basins, they vary from 9.09% for the Luis L. León sub-basin, to 4.71% for the Las Burrassubbasin.

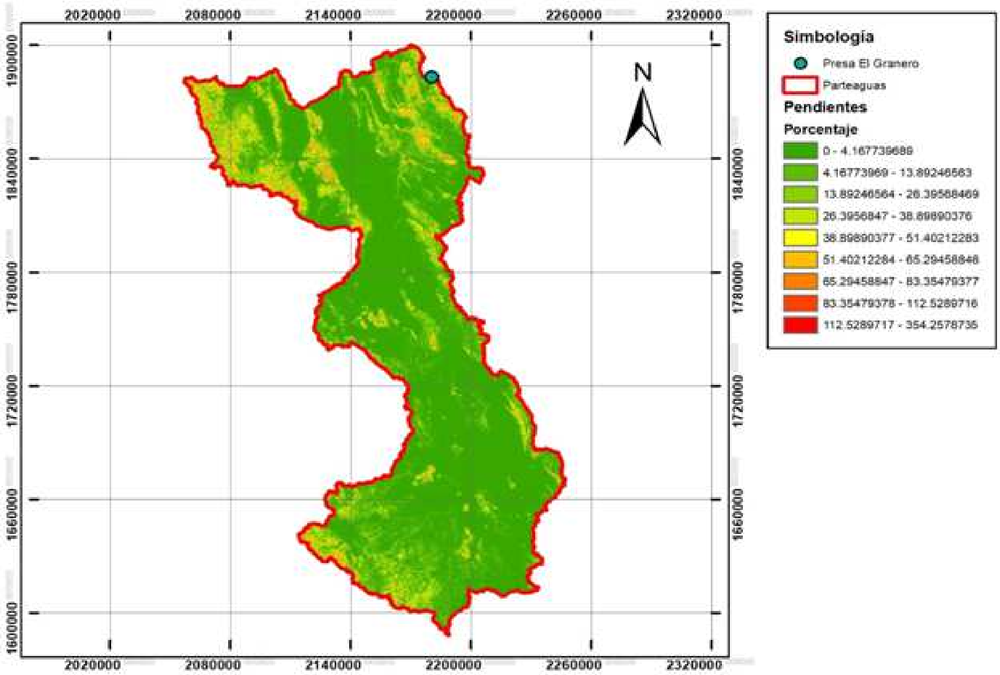

Figure 3: Average Slope of the Luis L. León Basin from the MDE Scale 1:50,000, INEGI

The perennials and intermittent currents density of the basin is 2.53 streams/km^2, which qualifies it as poorly drained since according to Campos (1984), it requires more than 3.5 streams/km^2 for a basin to be considered as well drained.

The degree of torrentiality in a basin is determined from the *bifurcation ratio* (R_B), which varies between 3 and 5 for basins in which geological structures do not distort the drainage model. According to Aparicio (1996), the minimum value theoretically possible of 2.0 is, in natural conditions, difficult to reach, so the average value is in the order of 3.5. Very high values of this ratio (R_B> 4), is determining terrains with steep slopes and very eroded soils. Moreover, these basins have a large hydrographic network with many tributary streams with rapid response to precipitation. The degree of torrentiality R_B is what conditions the loss of soil mainly in a basin (Soriano and Pons 1994). This value is used in different methodologies to calculate water erosion, including the Universal Soil Loss Equation (USLE). In this study, a value of R_B equal to 1.78 was determined; this represents a low value of torrentiality with low erosive power, which could be confirmed with the estimation of the elongation ratio (Re) whose value was 1.1, which explains that the basin is in the plain regimen.

Table 1: Type of Land in a Basin According Its Slope (Saavedra, 2001)

Slope	Type of terrain
0 – 2	Flat
2 – 5	Mild
5 – 10	Hilly medium
10 – 15	Hilly
15 – 25	Strongly hilly
25 – 50	Abrupt
> 50	Very abrupt

Vegetation and Land Use

The basin of the Luis L. León Dam, according to the V series of INEGI, scale 1: 250 000, the vegetation is mainly composed of natural grassland and its secondary vegetation (15.01%), predominating in the topographically high parts. While in the lower parts, near the dam, predominates the microphyllous and rosetophylousdesert scrubland (31.69%) and its secondary shrub vegetation (28.98%)

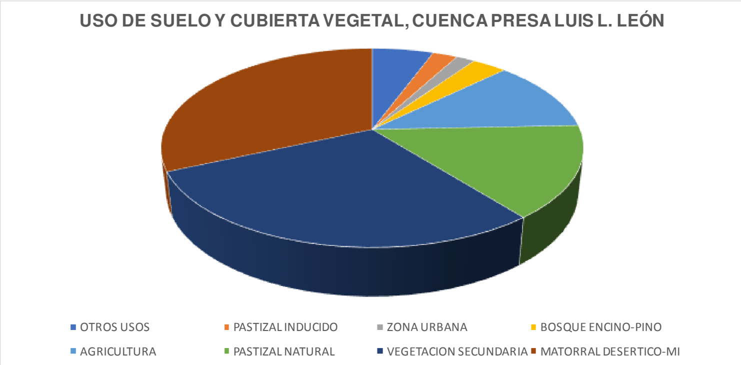

Figure 4: Percentages of Land Use and Vegetation Cover in the Luis L. León Dam Basin

Edaphology

Edaphology is a determining factor in the production of sediments, due to water erosion in a basin and its subsequent transport and deposit in a reservoir, mainly in basins with the high and medium slope. In the basin predominates poorly developed dry soils with high content of clays sub soils such as Xerosol (35.98%), and thin soils like Litho sol (23.14%) and Regosol (13.30%), in smaller percentage Castañozem (7.02%), among others (Figure 5).

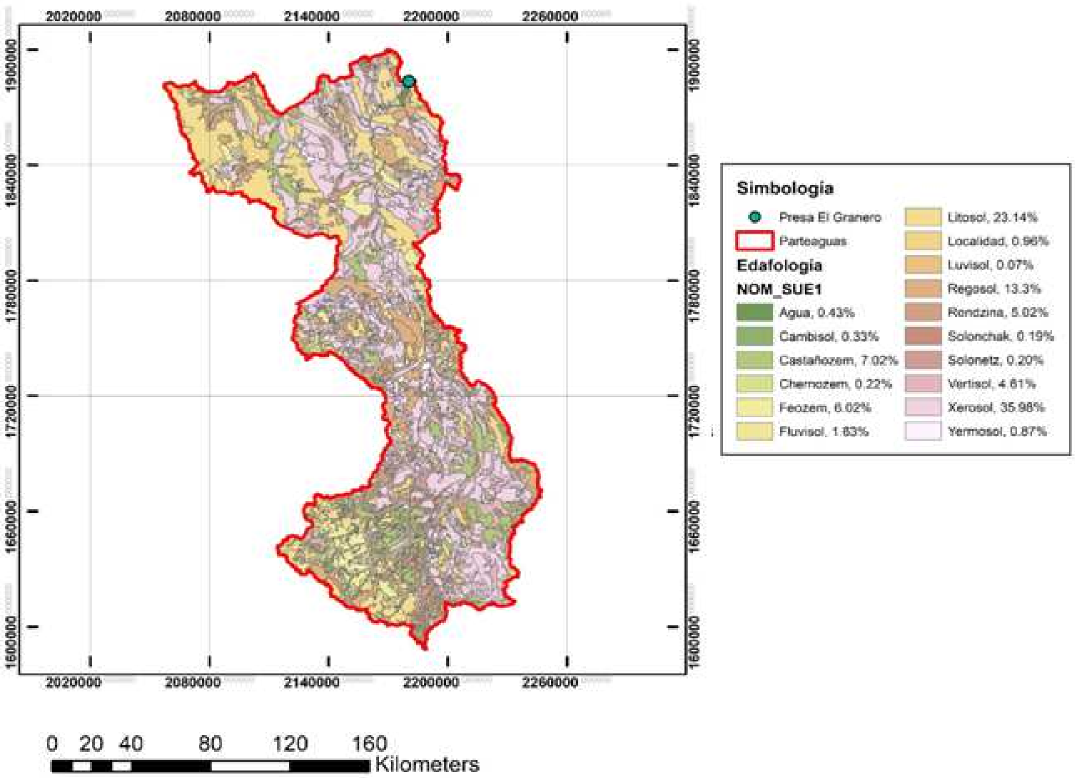

Figure 5: Edaphology of the Luis L. León dam Basin"El Granero" (INEGI, Series 1)

Precipitation Regime

The precipitation's behavior in the area of the basin and in seasons that affect it, is summer regime since between July and September 76% of the accumulated annual is precipitated. Monthly rainfall records were provided by the Comisión Nacional del Agua(CONAGUA) of Chihuahua city.

coefficient R = 0.85 which indicates a high level of confidence.

To standardize the historical record in all the stations (1950 – 2010), for the Rosario station, located in MelchorOcampo's Municipality, Durango (1963 – 2007), the missing data was estimated, using the data from the Hidalgo del Parral station and applying the linear regression method (Figure 6).

The annual rainfall of the watershed was obtained by using the software ArcGIS 10.3 for the tracing of the Thiessen polygons (Figure 7), using the stations within the basin and those with an influence area.

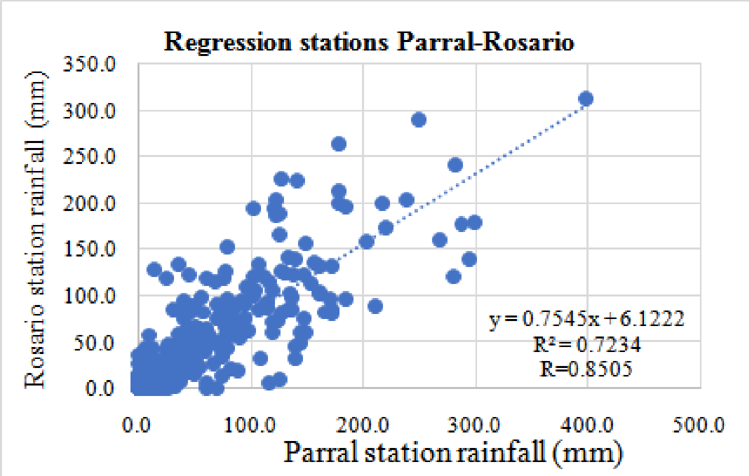

Figure 6: Regression between Hidalgo Del Parral Chihuahua and Rosario Durango Stations, Obtaining the Correlation

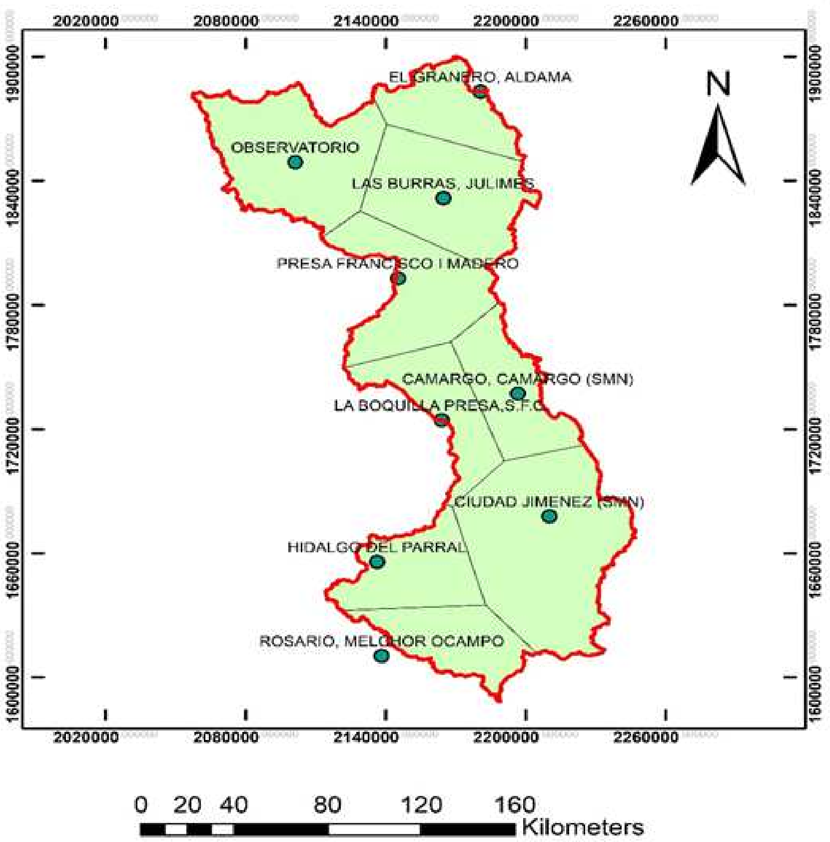

Figure 7: Plan of the Basin's Thiessen Polygons

Water Erosion

USLE is a parametric model based on inductive logic. According to Garcia (1993), this model is not very useful if it is not calibrated properly and validated for local conditions. Five main factors are involved in this model: climate, edaphology, slope, land use and conservation practices. The mathematical model is represented with the equation:

$$A = R\ K\ L\ S\ C\ P \quad (1)$$

Being **A** the annual soil erosion per surface unit in t/ha year, **R** the rainfall erosivity factor in MJ. mm/(ha. hr), **K** the soil erosion factor in ton.ha.hr/MJ. mm. ha, **LS** length factor and slope degree, dimensionless, **C** vegetation factor, dimensionless; and **P** factor of cultivation practices, dimensionless.

The factor **K** is a quantitative value determined experimentally by direct measurement in a field that establishes the susceptibility of the soil to suffer losses by erosion. In the absence of soil characterization by sampling, the method used was FAO (1980), where the factor K is determined according to the unit to which the soil belongs in the classification FAO-UNESCO and the texture of the surface layer.

The factor **R** for lack of detailed information to calculate the value of EI_{30} proposed by Wischmeire and Smith (USDA, 1978), this factor was determined by equation (2), proposed by Figueroa *et al.* (1991) for Region 04, according to the average annual precipitation (P) in millimeters (Figure 8), obtaining an average value of R = 1476.91, considered by Rivera and Gómez (1991), quoted by Castelán Vega *et al.* (2014), as very low erosivity (Table 3).

Figure 8: National Regionalization of the Facto R (Becerra 1997)

$$R = 2.8559P + 0{,}002983P^2 \quad (2)$$

Table 3: Classification of Rainfall Erosivity According to the Value of R (Castelán Vega, 2014)

Class	Erosivity R (MJ*mm/ha)	Classification
1	< 1000	Natural
2	1 000 a 2 500	Very low
3	2 500 a 5 000	Low
4	5 000 a 7 500	Moderate
5	7 500 a 10 000	High
6	10 000 a 15 000	Very high
7	15 000 a 20 000	Severe
8	> 20 000	Extremely severe

Length and degree of slope **(LS),** this factor represents the effect that the topography has on water erosion. The factor considers the length and slope degree of the terrain, to calculate LS the following equation was used:

$$LS = \lambda^m (0.0138 + 0.00965\ S + 0.00138\ S^2) \quad (3)$$

Where: *LS* is the degree factor and length of the slope, λ is the length of the slope, *S* is the average slope of the terrain and *m* parameter whose value is 0.5.

Vegetation Factor **(C). R**epresents the protection degree that the vegetal cover offers to the soil and which contributes to stop erosion. Wischmeier and Smith (USDA, 1978) proposed values between 0 and 1 for this parameter that depend on the type of existing vegetation and its coverage degree. As the soil vegetation cover increases, the value of C is reduced and can reach values close to zero.

Cultivation Practices Factor **(P)** Relates soil losses that occur under some soil conservation practices and the losses occurring on the same surface without conservation practices. In Mexico, conservation practices have been carried out on a very low scale so they were not considered in the basin of the "El Granero" dam.

USLE as most models for the prediction of water erosion requires a database that goes from high to moderate, with continuous or annual timescales, for this reason, although properly calibrated from direct measurements, can present inaccuracies in its prediction (Chaves and Nearing, 1991). According to Hua Lu *et al.* (2006), soil erosion models, such as USLE, calculate the gross soil erosion figure at plot scale, and therefore the erosion rates estimated by this model are higher than those measured at the intake points.

In this work, the water erosion modelEUPS was used, to estimate soil loss in the basin (A) and the Sediment Delivery Coefficient (CES) proposed by Avendaño*et al.* (1994) and quoted by Bodoque*et al.* (2001), to estimate the volumes of sediments arriving at the reservoir, using national databases to feed the model and using equations 4 and 5. Calculations were performed on the ArcGIS 10 platform. The model was calibrated from the initial operating capacity of the dam (1959) and its bathymetry for the year 2004 (Figure 9), information provided by the Comisión Nacional del Agua (CONAGUA), Chihuahua.

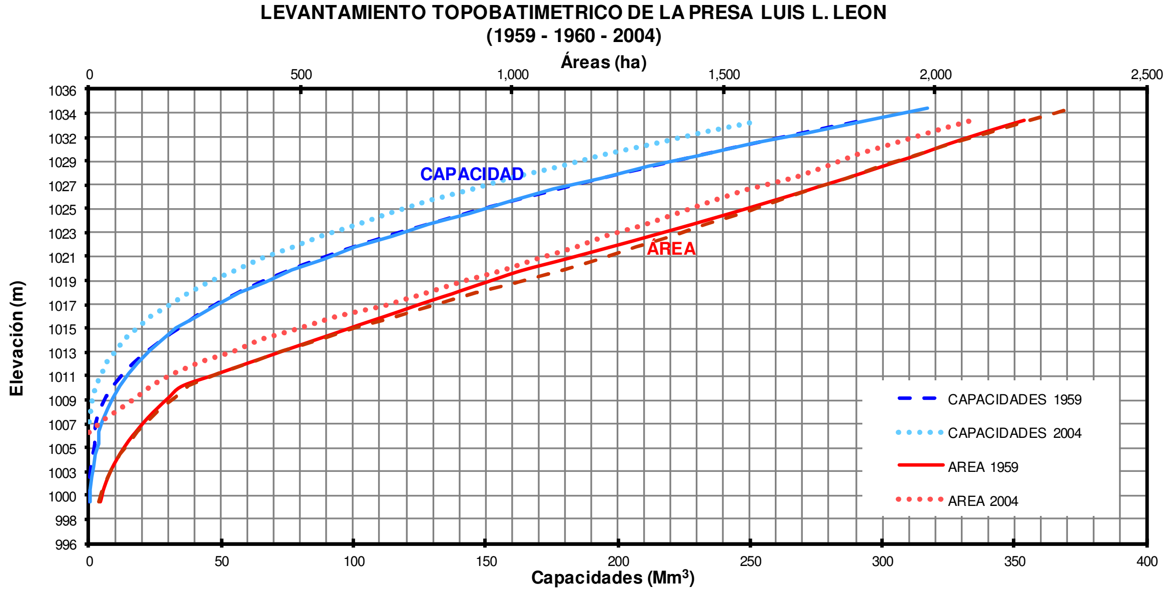

Figure 9: Curves Elevation-Area-Capacity of the Luis L. León Dam (CONAGUA, Management Chihuahua)

From the soil eroded in a basin, some of the material will be deposited or trapped in the basin itself, or in the riverbeds. Depending on the available information, different methods can be used to determine the quantity of sediments entering the reservoir, such as: the capacity of the transport of solid flows by the current at the entrance of the vessel, direct measurement of sediments deposited in the reservoir (bathymetry) and use of prediction models.

$$AS = CES * A \tag{4}$$

$$CES = 36A_C^{-0.2} - \frac{2}{\log P} + \log BR \tag{5}$$

Where: CES represents the percentage of the total eroded material in the basin, same that comes out of it; A_C is the area of the basin in km^2; P is the slope of the main channel, and BR is the bifurcation coefficient of the hydrographic network.

DISCUSSIONS OF RESULTS

The basin, due to its large size, makes a study of direct measurements in the field of water erosion expensive and long, for this reason it was decided to use the empirical USLE model, from which the values of K and C factors were calibrated, relying on the bathymetric information prior to the construction of the dam and the subsequent bathymetry of the same reservoir.

The slope of the basin played a crucial role in the process of water erosion; the basin having large extensions with low slopes causes a decrease in the velocity of the flow and consequently in erosion and in the transport of sediments towards the reservoir. In addition, the effect of the dams located upstream of the zone in the study is important, since in addition to functioning as storage dams also function as sand-trap structures by retaining the sediments that are generated in the areas subject to greater water erosion.

The sediments of the Luis L. León dam equal 40.189 hm^3, equivalent to 12.08% of its capacity, which represents an average soil loss equal to 47.445 m^3/km^2-year, for a similar analysis period, is significantly smaller with respect to the dams of the headwaters located upstream. According to Estrada *et al.* (2015), the sedimentation rate for the La Boquilla dam until 2004, date of the most recent bathymetry, was 317.445 hm^3, with an average loss of 260.345 m^3/km^2-year, while for the Francisco I Madero dam was 145.055 hm^3 corresponding to 29.61% of its capacity and an average loss of 253.98 m^3/km^2-year.

CONCLUSIONS

- The average annual value of the rainfall erosivity factor estimated for the studied basin was R = 1476.91, considered by Rivera and Gómez (1991), quoted by Castelán Vega *et al.* (2014), as very low erosivity.
- The basin's perennial and intermittent currents density of 2.53 stream/km^2, qualifies it as poorly drained and low impact of surface runoff in water erosion.
- The gross erosion of the basin was 8.65 T/ha/year with a contribution of sediments to the reservoir of 50.52 m^3/km^2-year estimated by USLE and calibrated from the bathymetric measurements; From the analysis carried out between the differences of storage of the original topography of the dam at the beginning of operations (1968) and the last bathymetry performed (2004), the settled volume during this period was 40,189 hm^3, equivalent to 12.08% of its capacity which represents an average loss of 47,445 m^3/km^2-year.
- In the basin of the Luis L. León dam "El Granero", being an intermediate basin, the sediments generated in the

headwater basins are retained in the reservoirs of the dams. In addition, its slope of approximately 6%, allows classifying it as slow runoff response, with a good capacity of infiltration and low production of sediments.

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