HYDROLOGIC AND GEOSPATIAL STUDY OF THE HYDRODYNAMICS OF THE CURRENT CONDITIONS OF THE WATER IN THE SAN JOSÉ DAM

Elvia Raquel Blanco Martínez, Clemente Rodríguez Cuevas and Isaac Aguayo Muñoz
Facultad de Ingeniería, Universidad Autónoma de San Luis Potosí (UASLP), Ciudad Universitaria.
Av. Dr. Manuel Nava No.8, San Luis Potosí, (C.P.78290) San Luis Potosí, México.

ABSTRACT

A Hydrologic and Geospatial study was done on the San José Dam, located on the outskirts of the city of San Luis Potosí, the capital of the state of San Luis Potosí, Mexico.

With the purpose of doing a comprehensive diagnosis of the current state of the dam, a bathymetric survey was carried out in order to determine the hydrodynamic movement of the water stored and to determine the percentage of sediments.

The dam provides 8% of the drinking water of San Luis Potosí's household water consumption; the other 92% is provided by deepwater wells. Therefore, it is of vital importance for the city to know the hydrodynamics of the reservoir to determine the amount of silts.

A hydrologic study was also carried out to determine the volume of water flowing into the dam from the surrounding basin, using different synthetic methods. In order to do this, ADCP (Acoustic Doppler Current Profiler), state-of-the-art technology manufactured by the company Teledyne RD Instruments, was used. ADCP allows us to measure the speed and depth of any body of water using the "Doppler Effect".

The results obtained from the bathymetric and hydrologic survey were captured into the Geographic Information System (GIS) in order to be easily viewed and understood.

Keywords: ADCP, Doppler Effect, Bathymetry, Silt

INTRODUCTION

A dam or reservoir is a structure built at the waterway of a river for the purpose of storing or diverting the water it collects. It is well known that the main characteristic of a waterway is its capacity to transport sediments.

This study was done on the San José Dam, located on the outskirts of the city of San Luis Potosí. The city is part of the state of San Luis Potosí, México. Fig. 1 [1]

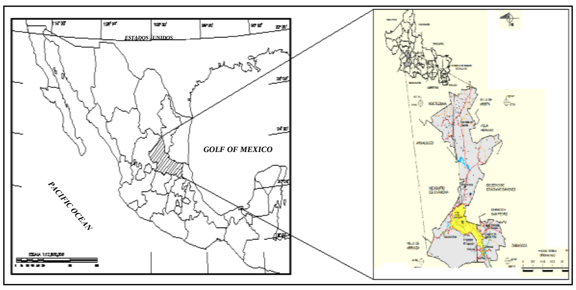

Fig. 1 Location of the San José Dam.

HYDROLOGIC STUDY

The general objective of this study is to quantitatively determine the volume of water flowing into the hydrologic microbasin of the San José Dam.

In order to define the area, perimeter and length of the main waterway, the watershed was established as shown in Fig. 2, and its data in Table 1.

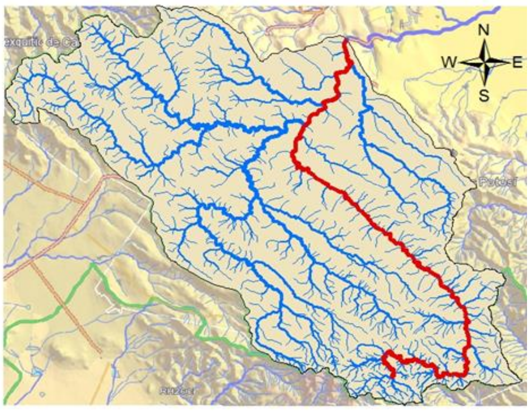

Fig. 2 Microbasin established at the reservoir of the San José Dam

Table 1 Microbasin Data

Micro Basin	Area (Km^2)	Perimeter (Km)	Length of Waterway (Km)
Mid-size Small	265.19	89	39.43

Climatological Stations

The data obtained by the stations helped to determine the average annual precipitation and the average precipitation with isohyets, in order to obtain the transportation factor and convert precipitation to annual series of maximum daily rain, which were applied to the Gama, Log-Person and Gumbel methods. Table 2.

Table 2 Average Precipitation Data

Climatological Base Station	Average Annual Precipitation (mm)	Average Isohyet Precipitation (mm)
24069 San Luis Potosí (DGE) S.L.P.	376.4	381.29

Probabilistic Distributions

The probabilistic distributions were obtained and compared with the historical distribution. Gamma was chosen, because it is the one which presents a better distribution Fig.3.

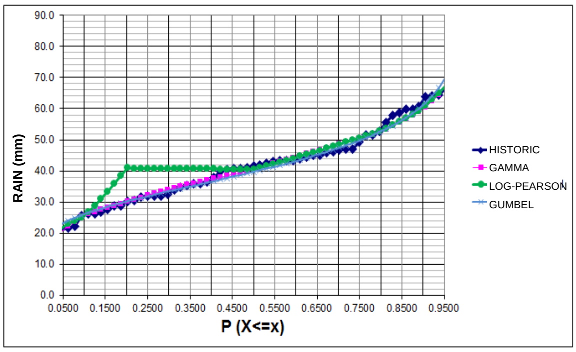

Fig. 3 Probabilistic Distributions

Concentration Time

To determine the concentration time, the Kirpich and USBR California formulas were used. The concentration time obtained for both formulas is shown in Table 3.

Table 3 Concentration Time

Concentration Time		
Waterway Length	39428.8785	m
Waterway Incline	800	m
Waterway Gradient	0.02	
Kirpich	5.04	hr
California	5.01	hr

Climatological Stations

With the results from the rain analysis and concentration time, the hydrograms corresponding to the 2, 5, 10, 50 and 100-year return periods are obtained, respectively. Three methods were used to obtain the hydrograms: The USBR Unitary Hydrogram, the Snyder Unitary Hydrogram and the SCS Unitary Hydrogram.

USBR Unitary Hydrogram

The peak volume of water $\mathbf{q_p}$ is obtained with the following expression:

$$q_p = 0.20 \frac{A}{t_p} \quad (1)$$

Being q_p the unitary peak volume of water, in $m^3/s/mm$; A is the area of the basin, in km^2; and t_p is the peak time, in hr Fig.4.

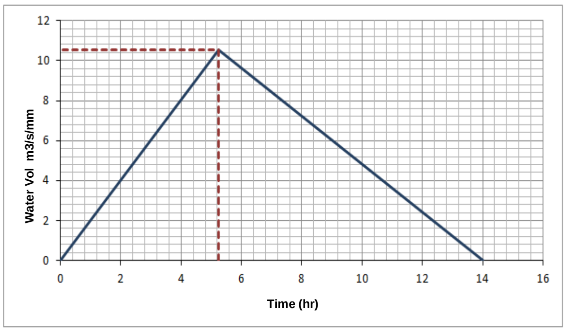

Fig. 4 Triangular Unitary Hydrogram for the Microbasin

SNYDER Unitary Hydrogram

The peak flow per square ml $\boldsymbol{u_p}$ can be estimated using the following expression:

$$u_p = C_p \left[\frac{640}{T_r + (T_c - t_s)/4}\right] \quad (2)$$

u_p represents the peak flow per area unit (in $feet^3/(s \cdot mi^2)$), t_r is the lag time in hours and C_p is a coefficient that depends on the topography of the basin, which varies between 0.5 and 0.8; in our case; C_p =0.8; t_s is the duration of the rain in hours and t_c is the duration of the effective precipitation in hours Fig.5.

Once the peak flow per area unit is obtained, the peak flow total is obtained as follows:

$$U_p = u_p A_c \tag{3}$$

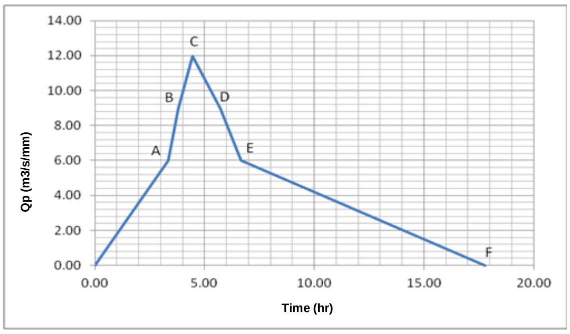

Fig. 5 Snyder Unitary Hydrogram Scheme

Soil Conservation Service (SCS) Unitary Hydrogram

In the metric system, the peak flow formula is:

$$q_p = \frac{0.208A}{t_p} \tag{3}$$

Being q_p = the peak flow of the Unitary Hydrogram 1 mm short of effective precipitation, in cubic meters per second; A =drainage area of the hydrographic basic, in square kilometers and t_p = peak time, in hours.

Once t_p y q_p has been determined, the SCS adimensional Unitary Hydrogram is elaborated is built by using the adimensional values in Fig.6.

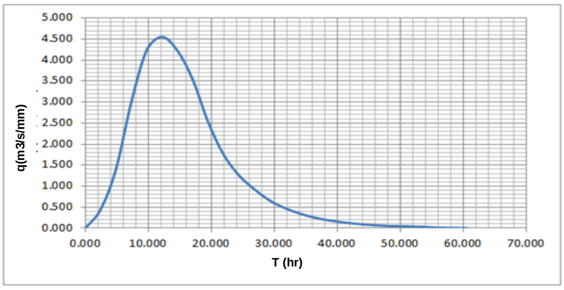

Fig. 6 SCS Adimensional Unitary Hydrogram

I-D-Tr Curves

The I-D-Tr curves are plotted after having the Gamma data according to a maximum 24-hour rain precipitation. With the curves, the peak volume runoff is estimated Fig.7.

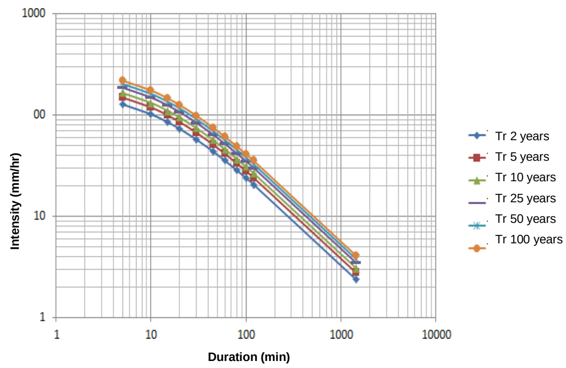

Fig. 7 I-D-Tr Curves

Water Volume Results of the Three Methods

Table 4 summarizes the water volume estimated using each one of the three methods, for the six return periods indicated in the microbasin.

Table 4 Return Periods

	Return Periods (years)		
METHOD	USBR	SYDER	SCS
2	474.30	639.34	205.22
5	632.41	852.45	273.63
10	685.11	923.49	296.43
25	737.81	994.53	319.24
50	843.21	1136.60	364.84
100	948.61	1278.68	410.45

HYDRODINAMIC STUDY

The hydrodynamic parameters speed, depth and temperature were measured using an ADCP (Acoustic Doppler Current Profiler), which is state-of-the-art equipment manufactured by Teledyne RD Instruments Fig.8.

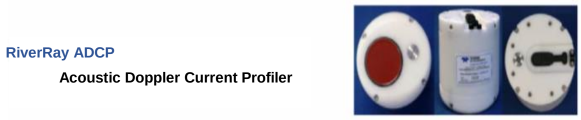

Fig. 8 RiverRay ADCP Equipment

The ADCP allows to measure the speed and depth of any body of water using the apparent frequency change of a wave produced by the relative movement of the source relative to the observer, called “Doppler Effect”.

The transducer is built to produce a beam of sound and has most of the energy concentrated in a cone which has a small amplitude. Each transducer produces a pulse of sound with a known frequency. Since sound travels through water, it is reflected in all directions by particles of matter, such as sediments, biological material and bubbles. Some parts of the reflected energy retrocede and travel along and to the transducer axis to where to where the electronic process measures the change of frequency. Through a simple reflection, the Doppler change measures the speed of the sound that travels along the acoustic beam Fig.9.

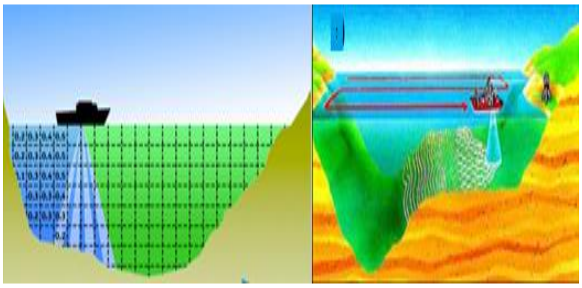

Fig. 9 Measuring system operated from a moving ship or boat.

Hydrodynamics Measuring Campaign

On November 29, 2015, a measuring campaign to obtain the hydrodynamic parameters of all the reservoir was carried out. In order to so, a boat which could zigzag all over the body of water was used.

The first thing done was to attach the RiverRay ADCP onto the hydroboard by connecting it and doing the configurations shown in Figs.10 and 11.

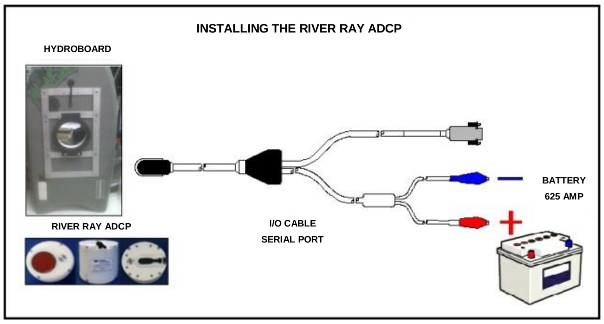

Fig. 10 Installing the RiverRay ADCP

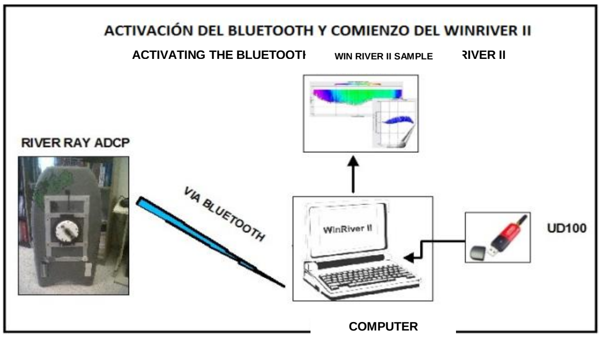

Fig. 11 Activating the WinRiver II program

The GPS and the GPS antenna were installed to obtain the latitude and length of the measured points. Fig.12.

Once the equipment had been configured, the Hydroboard was placed on the side of the boat. The flaps which are in the lower part of the Hydroboard must be in the same direction as the flow of water. Fig.13.

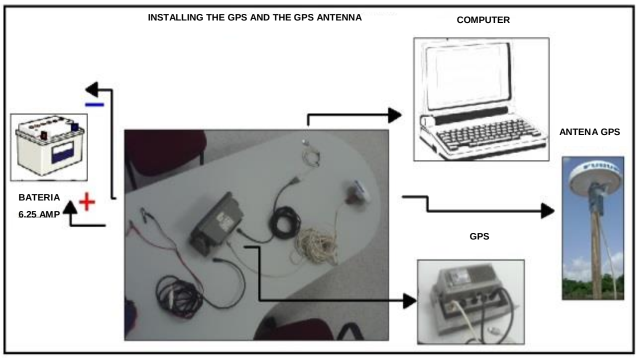

Fig. 12 – Installing the GPS and the GPS antenna

Fig. 13 Placing the Hydroboard.

The boat was kept away from the shore at all times, so the ADCP could have a water breakthrough no larger than 70 cm.

The path started upstream at the back end of the San José Dam, and it ended at the spillway Fig.14.

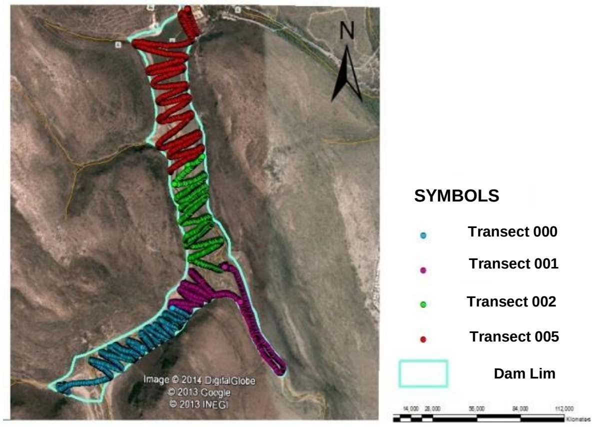

Fig. 14 Path of the 4 transects at the San José Dam

Analyzing and Interpreting Data Obtained in the Measuring Campaign

Once the measuring campaign was done, all the recorded data were processed using the WinRiver II program, in which each one of the transects can be reprocessed Fig.15.

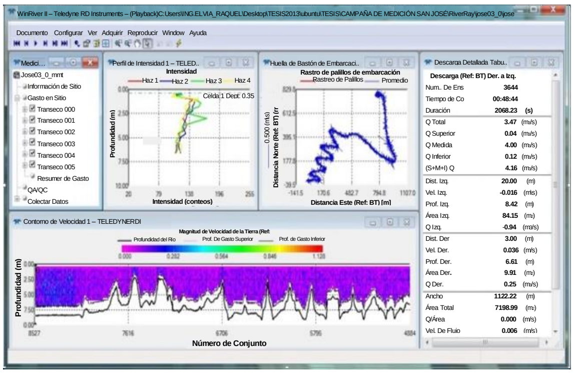

Fig. 15 WinRiver II Program

The program shows the depth, the magnitude of the speed of water in the reservoir, the 4 beams of sound which the RiverRay ADCP apparatus has, the trajectory followed by the flowmeter when going from one bank to the opposite one; it also shows the duration of the path of each one of the components of the section and the total value of the resulting flow.

Numerical Modelling of the Dam

A geographic information system was used to model the resulting data from the on-site bathymetric survey. ArcGis, version 10.1, allows to introduce the georeferenciated data to Google Earth providing an idea of the path done at the dam.

Using the Arc Scene program allowed to model on 3D both the measuring path and the city of San Luis Potosí with the purpose of having a better visualization of how close the San José Dam is to the city Fig. 16.

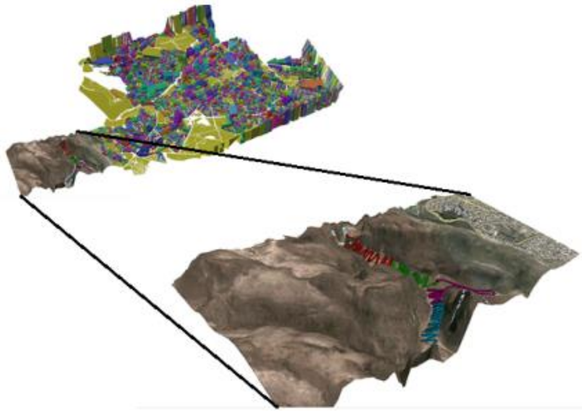

Fig. 16 3D Image of the Measuring Campaign

Visualization of the Speeds at the Bottom

Fig.18 shows the speeds at the bottom of the reservoir. The directions vary relative to the width of the body of water. Circle A indicates the end of the path followed by the last transect. Letter B upstream of the spillway is where the start of the trajectory of the measuring path was begun.

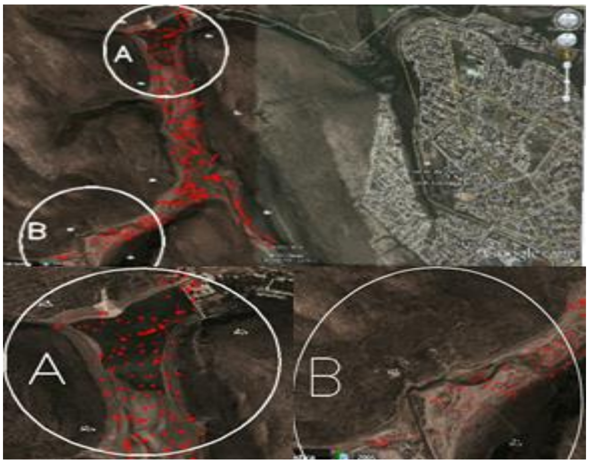

Fig. 17 Speeds at the Bottom

Visualization of the Speeds at the Surface

Fig.18 shows the speeds at the Surface, most of which tend to go upstream of the spillway.

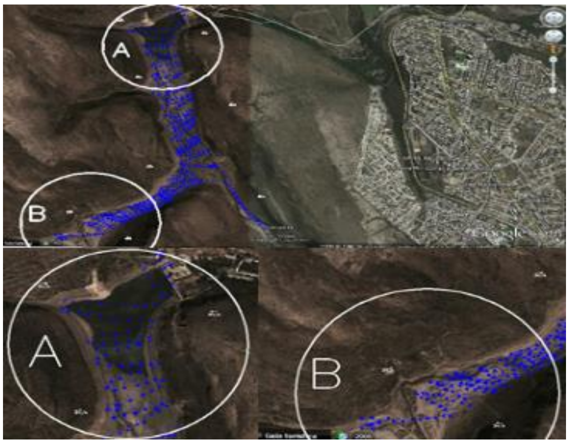

Fig. 18 Speeds at the Surface

Depths of the San José Dam

The results obtained in the measuring campaign show that the maximum depth, 14m, is found at the spillway. As we move away from the spillway, the depth decreases until it reaches a minimum value of 2m, Fig. 19. The color palette shows in diverse tones the different depths in order to have a much clearer visualization of the different depths of the reservoir.

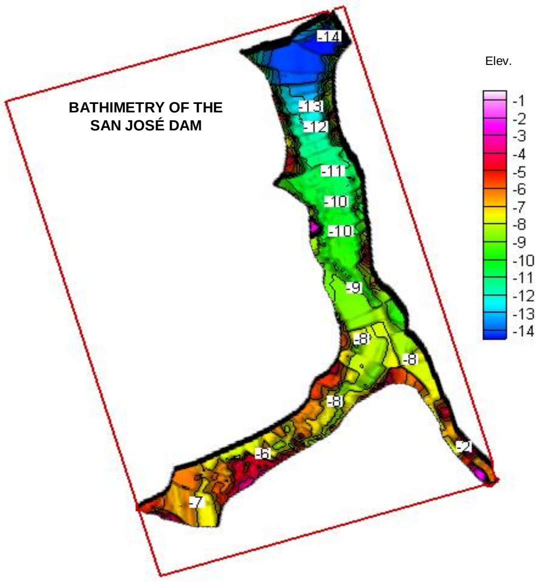

Fig. 19 Depths of the Reservoir of the San José Dam

CONCLUSIONS

One of the main results obtained was knowing the current capacity of storage of the reservoir: 4,805 million m^3 of water. Comparing the initial volume of which was 10.87 million m^3 of water, it was estimated that the dam had a 56% of silt.

According to the bathymetric survey done and with the estimates obtained, the dynamic movement of water in the reservoir was seen presenting changes of direction in the flow of water. This happened in the rainy season with the water flowing towards the spillway. However, when the rainfall drainage ceases, there is a backwater which provokes a change in the direction of the flow, being this time from the spillway upstream.

It is important to know the hydrological and hydrodynamic conditions of the San José Dam, because they are great tools to know about the current situation in which the reservoir is and thus be able to have the current information which allows to find concrete solutions to solve its problems.

REFERENCES

[1] Instituto Nacional de Estadística y Geografía, INEGI 2016 de México.

[2] Campos, A. D.F., 1988. Procesos del Ciclo Hidrológico, Editorial Universitaria Potosina, San Luis Potosí, S.L.P., México.

[3] Monsalve, S.G., 1999. Hidrología en la ingeniería, 2 Ed. Bogotá: Escuela Colombiana de Ingeniería.

[4] Ramírez, L.H, Barrios, P.H.A y Navarro, P.J.M. 2012. Dinámica ambiental de ecosistemas acuáticos costeros de México.

[5] Rojo H.J.D. y I.C. Recursos Hidráulicos. Estimación de Caudales Máximos usando Hidrogramas Unitarios Sintéticos y el Método Racional.

[6] CICESE. Centro de Investigación Científica y de Educación Superior de Ensenada Baja California México base de datos climatológicos nacionales, sistema CLICOM, http://clicom-mex.cicese.mx/mapa.html.