

## **Bathymetric curve (75 years old) validation, using the soil erosion transportation at Cuitzeo Lake Watershed**

J. Lafragua<sup>1</sup>, A. Gutiérrez<sup>1</sup>, A. Bahena<sup>1</sup>, G. Moriel<sup>2</sup>  
& S. Fernández<sup>2</sup>

<sup>1</sup>*Mexican Institute of Water Technology, Mexico*

<sup>2</sup>*Secretary of Communications and Transports, Michoacán Center, Mexico*

### **Abstract**

A new main road called Copandaro-La Cinta was built in the state of Michoacán, México; with a length of seventeen kilometers this road crosses Lake Cuitzeo (the section under study). In order to preserve the hydrological regime of this water area, the road structure was built with twenty sewers and four boat passages. With a 4000 km<sup>2</sup> basin area, Lake Cuitzeo's watershed transports 1,296,461 tons of sediment per year. Due to this great amount of material, a hydrological study was carried out. A hydraulic study was prepared including elevation-storage and elevation-area relationship curves since 1930. Using a longitudinal profile of the study section from April 2003, several bank levels are used to make an adjustment between the bathymetric curve and longitudinal profile, fixing some main structures points. In order to select the best alternative (to verify hydraulic works dimensions), soil erosion in the watershed is calculated using the Universal Soil Loss Equation (USLE); a sediment yield ratio is also obtainable. The results show that only 7 percent of the soil loss computed by the USLE appears as sediment yield in the watershed outlet. In the alternative selected, this quantity represents approximately 19 cm of sediment near the study section. With this alternative, the zero level in the longitudinal profile and in the bathymetric curve is at an elevation of 1823.34 and 1818.00 masl, respectively. Thus, all points of the bathymetric curve were adjusted at 5.34 m. Flow routing through Lake Cuitzeo shows that the structures hydraulic capacity was enough to allow free water flow.

**Keywords:** *soil erosion, hydrologic routing, inflow hydrographs, bathymetric curve, Lake Cuitzeo.*



## 1 Introduction

The new Copandaro-La Cinta main road on the Morelia-Salamanca freeway crosses the western area of Lake Cuitzeo. This structure has twenty sewers and four boat passages, and a bridge called Dren La Cinta. In previous years, this bridge allowed the passage of flows from Lake Cuitzeo to Lake Yuriria. To check the dimensions of the existent hydraulic works and verify their proper hydraulic operation it is necessary to consider the volumes of inflow for different return periods. Lake Cuitzeo's basin is divided into 25 sub-regions Lafragua *et al.*, [6]. To carry out the hydraulic flow analysis, a bathymetric curve fundamental; however, the only one available was for the year 1930 (provided by the National Water Commission, Conagua). The objective of this study is to correct the bathymetric curve, taking into account the longitudinal profile of the road (2003), provided by the Secretariat of Communications and Transport (SCT). The amount of sediment deposited in the Lake is also required.

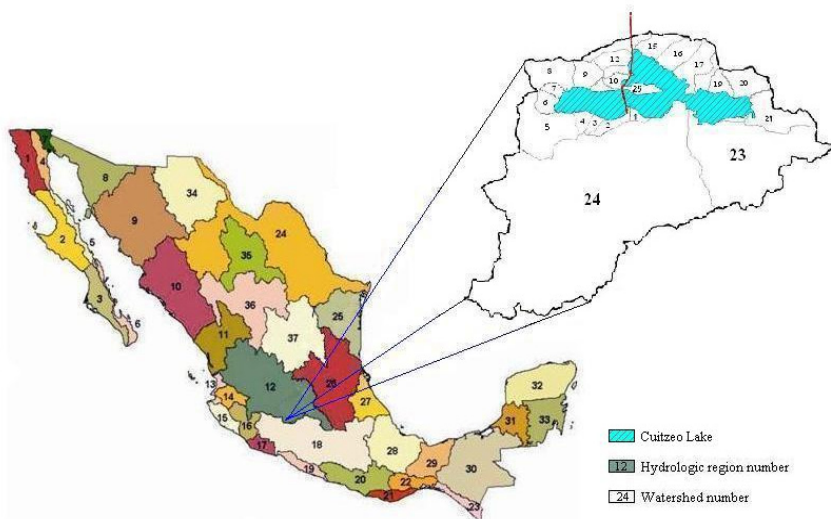


Figure 1: Location map of the study site.

## 2 Study area

Cuitzeo's watershed is located in the central part of the state of Michoacán, Mexico, between the coordinates  $19^{\circ}24'$  to  $20^{\circ}05'$  north latitude and  $100^{\circ}41'$  to  $101^{\circ}33'$  west longitude, and is part of hydrologic region number 12 called Lerma-Santiago, figure 1. Total watershed surface is  $4,000 \text{ km}^2$ , of which  $409.82 \text{ km}^2$  of the Lake include hydrophyte vegetation and open water. The main river is Rio Grande of Morelia, with a drainage area of  $2,043$  square kilometers. The climate is temperate and subhumid with summer rainfall. The annual mean

temperature ranges from 13°C to 20°C, and mean annual precipitation is 804.0 millimeters. The Copandaro-La Cinta new main road crosses Lake Cuitzeo along seventeen kilometers (section in study) and has twenty sewers and four boat passages, in addition to La Cinta drain, figure 2.

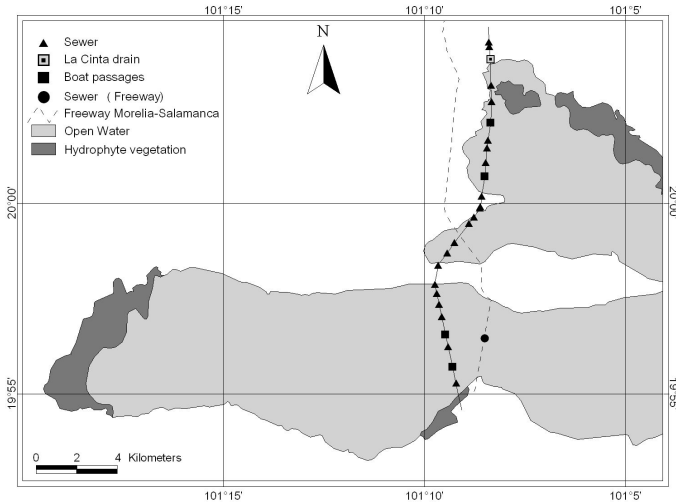


Figure 2: Hydraulic works location.

### 3 Procedure description

A bathymetric adjustment was conducted because there is no common level between the bathymetric curve (Conagua curve) and the longitudinal profile (SCT profile) of the study section. The procedure was as follows:

- Drawing a longitudinal profile of the study section with the bathymetric curve information (Conagua Profile).
- Analyzing possible alternatives of elevation similarities between the Conagua profile and the SCT profile.
- Selecting the best alternative, by using the erosion value of the watershed outlet.

In order to calculate the annual erosion of Lake Cuitzeo's watershed, the Universal Soil Loss Erosion (USLE) equation was used, Ponce [7], given by

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

where  $A$  is the annual mean soil loss in tons  $\text{ha}^{-1}$ ,  $R$  ( $\text{MJ mm ha}^{-1} \text{h}^{-1}$ ) is the rainfall erosivity index, calculated according to Figueroa *et al.* [4],  $K$  ( $\text{tons ha h ha}^{-1} \text{MJ}^{-1} \text{mm}^{-1}$ ) is the soil erodibility factor, calculated according to the FAO [3] methodology,  $C$  is the cover and management factor, and  $P$  is the support practice factor, assumed as 1.0, Izurieta *et al.* [5].  $L$  is the slope length factor

and  $S$  is the slope gradient, both are known as topographic factors and were calculated according to Izurieta *et al.* [5].

$$L = \left( \frac{\lambda}{22.1} \right)^m \tag{2}$$

where  $\lambda$  (m) is the slope length. For this study area, according to Cortes [1], value  $\lambda$  can be considered as 100 m and value  $m$  is the slope-dependent dimension factor, considered as 0.4.

$$S = 10.8 \operatorname{sen}(sg) + 0.3 \text{ with } s < 9\% \tag{3a}$$

$$S = 16.8 \operatorname{sen}(sg) - 0.5 \text{ with } s > 9\% \tag{3b}$$

where  $sg$  and  $s$  are the slope of the land expressed in degrees and in percent, respectively.

With eqn (1), the amount of solid material eroded due to rainfall in one year is estimated; however, the total volume of material is not necessarily arriving at the watershed outlet. Escalante [2] declares that there are differences between soil loss in the watershed and the amount of sediment that the watershed outlet is receiving, and suggests using the following equation:

$$AS = DR A \tag{4}$$

where  $AS$  (tons  $\text{ha}^{-1}$ ) is sediment in the watershed outlet,  $A$  is the value calculated by eqn (1), and  $DR$  is the sediment yield ratio, calculated by,

$$DR = 0.417662 Ac^{-0.134958} - 0.127097 \tag{5}$$

where  $Ac$  ( $\text{mi}^2$ ) is the watershed area.

Table 1: Fixed points.

Alternative	Point number	Characteristic	Elevation difference (m) (SCT minus Conagua)
A-1	5	High point and located outside the Lake.	5.83
A-2	41	High point.	4.43
A-3	47	Without major inflow.	5.70
A-4	27	High point and without major inflow.	5.34
A-5	49	High point and without major inflow.	5.27

4 Results and discussion

Using the Conagua elevation curve, 55 points were selected, including the 25 hydraulic works, to draw the longitudinal profile of the new main road. Many alternatives were analyzed by fixing points where erosion was not observed through time. Table 1 shows five alternatives indicating the fixed point

considered, and table 2 shows the differences between the Conagua profile and the SCT profile, the rest of the alternatives showed a similar behavior.

Table 2: Selected points and elevation differences.

No.	Hydraulic work	Elevation (SCT)	Elevation (Conagua)	A-1	A-2	A-3	A-4	A-5
1		1827.18	1820.50	-0.85	-2.25	-0.98	-1.34	-1.41
2		1826.01	1820.00	-0.18	-1.58	-0.31	-0.67	-0.74
3		1825.63	1819.50	-0.30	-1.70	-0.43	-0.79	-0.86
4		1824.80	1819.00	0.03	-1.37	-0.10	-0.46	-0.53
5		1824.33	1818.50	0.00	-1.40	-0.13	-0.49	-0.56
6		1823.87	1818.00	-0.04	-1.44	-0.17	-0.53	-0.60
7		1823.86	1818.00	-0.03	-1.43	-0.16	-0.52	-0.59
8		1823.81	1818.00	0.02	-1.38	-0.11	-0.47	-0.54
9		1823.83	1818.00	0.00	-1.40	-0.13	-0.49	-0.56
10		1823.88	1818.50	0.45	-0.95	0.32	-0.04	-0.11
20		1824.38	1820.50	1.95	0.55	1.82	1.46	1.39
21		1824.48	1820.50	1.85	0.45	1.72	1.36	1.29
22		1824.76	1820.00	1.07	-0.33	0.94	0.58	0.51
23		1824.93	1819.50	0.40	-1.00	0.27	-0.09	-0.16
24		1824.56	1819.00	0.27	-1.13	0.14	-0.22	-0.29
25		1824.59	1819.00	0.24	-1.16	0.11	-0.25	-0.32
26		1824.66	1819.00	0.17	-1.23	0.04	-0.32	-0.39
27		1824.85	1819.51	0.49	-0.91	0.36	0.00	-0.07
28		1825.15	1819.86	0.54	-0.86	0.41	0.05	-0.02
29		1825.85	1820.00	-0.02	-1.42	-0.15	-0.51	-0.58
30		1825.59	1820.50	0.74	-0.66	0.61	0.25	0.18
40	VC10	1824.40	1819.62	1.05	-0.35	0.92	0.56	0.49
41	VC11	1824.55	1820.12	1.40	0.00	1.27	0.91	0.84
42	VC13	1824.85	1819.31	0.29	-1.11	0.16	-0.20	-0.27
43	VC14	1825.05	1819.17	-0.05	-1.45	-0.18	-0.54	-0.61
44	VC15	1824.45	1818.99	0.37	-1.03	0.24	-0.12	-0.19
45	VC16	1824.35	1819.00	0.48	-0.92	0.35	-0.01	-0.08
46	VC17	1824.60	1819.03	0.26	-1.14	0.13	-0.23	-0.30
47	VC18	1825.30	1819.60	0.13	-1.27	0.00	-0.36	-0.43
48	VC19	1824.80	1819.70	0.73	-0.67	0.60	0.24	0.17
49	VC21	1825.24	1819.97	0.56	-0.84	0.43	0.07	0.00
50	VC22	1825.24	1819.98	0.57	-0.83	0.44	0.08	0.01
51	PL1	1823.85	1818.02	0.00	-1.40	-0.13	-0.49	-0.56
52	PL2	1823.85	1818.02	0.00	-1.40	-0.13	-0.49	-0.56
53	PL3	1824.60	1819.00	0.23	-1.17	0.10	-0.26	-0.33
54	PL4	1824.85	1819.38	0.36	-1.04	0.23	-0.13	-0.20
55	PEMEX	1824.45	1819.10	0.48	-0.92	0.35	-0.01	-0.08

For each alternative, total sediment area was obtained by considering the differences shown in table 2. Figure 3 shows the sediment areas of alternative 4, of 34,800 to 45,504 km. Assuming a uniform distribution along the longitudinal profile, an average sediment height is estimated, table 3.

In table 3, the negative values indicate that the fixed point was eroded; therefore, these alternatives were eliminated. The rest of the alternatives have an average (elevation) height of between 0.18 and 1.5 m. Consequently, we compared water levels measured by Conagua and SCT during the construction of the road, obtaining an average difference of 5.18 m. Otherwise, we considered the incrustation value designated by the SCT (0.60 m), then the points with



differences between 0 and -0.60 m were counted. In alternatives 4 and 5, more points, 30 and 32 points, respectively, were found. Therefore, alternatives 4 and 5 are good options. In order to select only one alternative, watershed outlet soil erosion was considered. The variable values for each watershed from eqn (1) are shown in table 4.

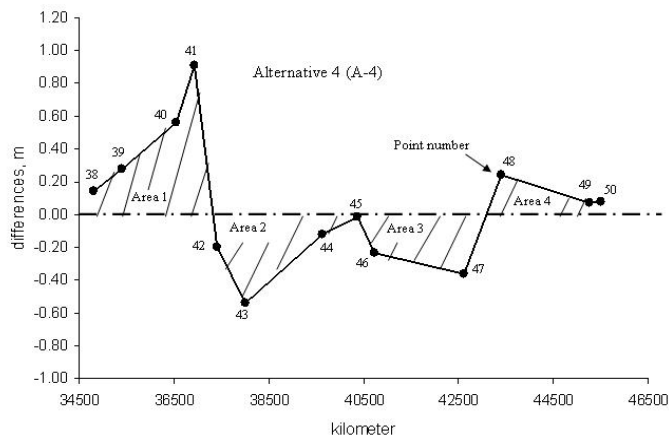


Figure 3: Sediment area along the new main road.

Table 3: Area and average sediment height.

Alternative	Total sediment area, (m <sup>2</sup> )	Average sediment height, (m)
A-1	-5442.41	-0.31
A-2	18784.97	1.08
A-3	-3192.73	-0.18
A-4	3037.17	0.18
A-5	4248.54	0.24

The results of applying eqn (1) and eqn (2) are shown in the table 5. Soil loss in all watersheds in Lake Cuitzeo is 17,672,146 tons year<sup>-1</sup>, but only 7 percent appears as sediment yield at the watershed outlet. Assuming that 1,296,461 tons of sediment arrived at the Lake per year in average, then in 75 years, the Lake has received 97 hm<sup>3</sup> of sediment. Due to unavailable information, we assume that the sediment is first deposited into the deeper areas, resulting in 70 cm of sediment in these areas and 19 cm approximately in the study area, figure 4. Finally, alternative 4 was selected because it exhibits the value closest to 19 cm, obtained by calculating the erosion.

In the selected alternative, the zero level in the SCT and Conagua profiles is at an elevation of 1823.34 and 1818.00 masl, respectively, therefore, every point of the bathymetric curve was adjusted at 5.34 m. Figure 5 shows the adjusted bathymetric curve.



Table 4: USLE variables for each watershed.

Watershed number	Area (ha)	Rainfall (mm)	$S$ (%)	$R$	$K$	$LS$	$C$	$P$
1	1194.11	705.79	17.0	2445.68	0.02	3.91	0.04	1.00
2	2549.69	833.20	16.9	2883.03	0.02	4.09	0.13	1.00
3	1293.56	845.52	16.6	2925.26	0.02	4.22	0.16	1.00
4	2081.71	843.01	15.7	2916.70	0.02	3.81	0.20	1.00
5	17517.45	802.72	13.0	2778.56	0.02	3.03	0.17	1.00
14	4052.99	670.76	7.2	2325.29	0.02	1.41	0.34	1.00
15	4862.76	625.53	6.1	2168.99	0.03	1.11	0.29	1.00
16	5777.69	640.41	4.9	2220.35	0.03	0.83	0.23	1.00
17	7207.63	715.52	10.2	2478.98	0.02	2.01	0.15	1.00
18	2578.24	720.54	18.2	2496.25	0.02	5.09	0.24	1.00
19	2898.54	720.54	17.6	2496.25	0.02	5.02	0.28	1.00
20	6807.55	734.05	12.9	2542.42	0.03	3.16	0.29	1.00
21	10859.16	784.39	13.7	2714.75	0.03	3.25	0.16	1.00
22	707.42	742.85	16.4	2572.35	0.02	3.95	0.10	1.00
23	55985.36	767.67	16.9	2657.86	0.03	4.47	0.21	1.00
24	204294.24	860.61	12.2	2977.92	0.02	2.93	0.23	1.00
25	2513.50	714.65	7.3	2476.29	0.02	1.68	0.42	1.00

Table 5: Erosion results for each watershed.

Watershed number	Eqn. (1) (tons ha <sup>-1</sup> yr <sup>-1</sup> )	DR	Eqn. (4) (tons yr <sup>-1</sup> )	Watershed number	Eqn. (1) (tons ha <sup>-1</sup> yr <sup>-1</sup> )	DR	Eqn. (4) (tons yr <sup>-1</sup> )
1	7.39	0.21	1877.97	14	27.47	0.16	17932.76
2	28.19	0.18	12912.61	15	17.77	0.15	13312.72
3	36.75	0.21	9940.18	16	10.67	0.15	9100.33
4	39.67	0.19	15538.25	17	17.36	0.14	17454.16
5	26.89	0.11	51531.12	18	67.23	0.18	31059.16
6	18.06	0.17	9160.92	19	84.92	0.17	42924.66
7	24.06	0.20	7189.23	20	67.41	0.14	64968.17
8	33.96	0.13	39552.37	21	42.58	0.13	57874.83
9	22.46	0.16	16011.22	22	25.87	0.24	4347.56
10	128.75	0.23	25097.48	23	80.84	0.08	339784.28
11	51.41	0.19	17831.81	24	46.85	0.04	408418.37
12	101.81	0.20	33020.48	25	37.71	0.18	17084.97
13	52.54	0.16	32535.29	Total	1098.61	0.16	1296460.88

The adjusted bathymetric curve was used by routing floods with the storm design of 50 years. We consider tree scenarios: a) inflow from the east and west during the same time, figure 6, b) only inflow from the east, and c) only inflow from west. The hydraulic results including the 25 hydraulic works located in the study site and the sewer located in the freeway are shown in table 6. Maximum elevation at the end inflow was 1824.53 masl from hydraulic work VC1 to VC5 and 1824.67 masl from VC10 to La Cinta drain. The maximum discharge obtained in the hydraulic works was 4.94 m<sup>3</sup> s<sup>-1</sup> and maximum velocity was 1.33 m s<sup>-1</sup>. In the freeway sewer, the maximum discharge was 11.89 m<sup>3</sup> s<sup>-1</sup> and maximum velocity was 2.8 m s<sup>-1</sup> Lafragua *et al.* [6].



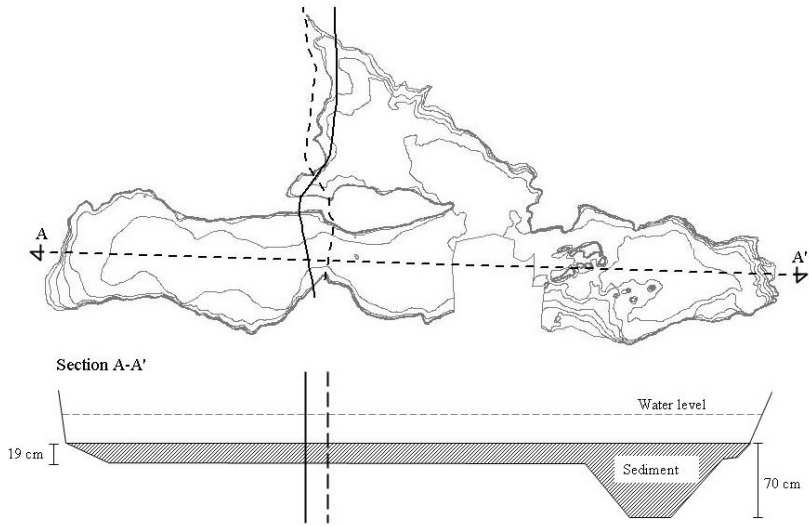


Figure 4: Scheme showing sediment deposit into Lake Cuitzeo.

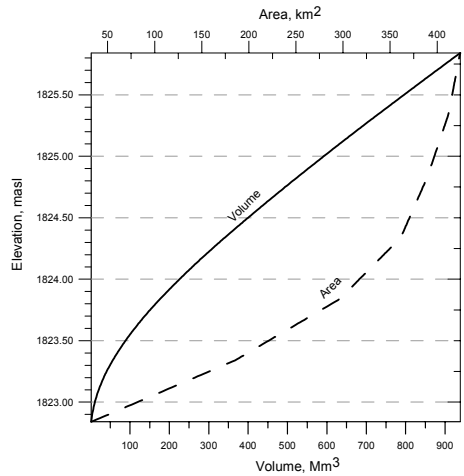


Figure 5: Adjusted bathymetric curve.

## 5 Conclusions

A bathymetric curve from 1930 was adjusted by using a longitudinal profile of the study section from 2003, and one sediment yield ratio was used in order to select the best alternative. All points of the bathymetric curve were adjusted at 5.34 m. Also considered were water levels measured by SCT and Conagua during the building of the new main road, furthermore, 60 cm from incrustation designed by SCT was considered.





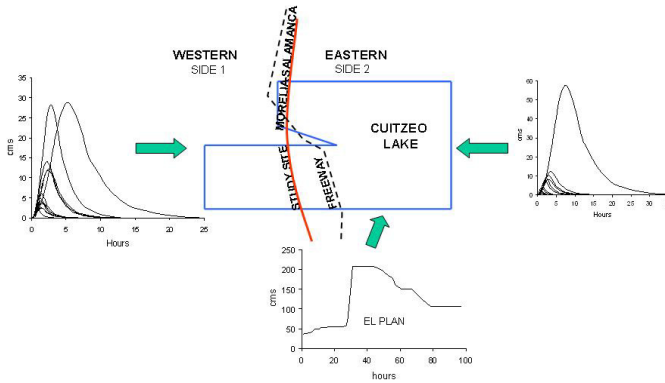


Figure 6: Input floods for rainfall (50-years).

Table 6: Hydraulic results.

Hydraulic Work	Footing Elevation (masl)	Grade Elevation (masl)	Initial Elevation (m)	End Elevation (m)	Initial Depth (m)	End Depth (m)	Area (m <sup>2</sup> )	Discharge (m <sup>3</sup> s <sup>-1</sup> )	Velocity (m s <sup>-1</sup> )
VC1	1823.95	1826.60	1824.50	1824.53	0.55	0.58	1.10	0.42	0.38
PL1	1823.85	1829.75	1824.50	1824.53	0.65	0.68	20.38	4.71	0.23
VC2	1823.80	1826.60	1824.50	1824.53	0.70	0.73	1.40	0.58	0.42
PL2	1823.85	1829.65	1824.50	1824.53	0.65	0.68	20.38	4.94	0.24
VC3	1823.85	1826.60	1824.50	1824.53	0.65	0.68	1.31	0.41	0.32
VC4	1823.95	1826.60	1824.50	1824.53	0.55	0.58	1.11	0.44	0.40
VC9	1824.55	1826.30	1824.50	1824.71	-0.05	0.16	0.30	0.30	1.03
VC10	1824.40	1826.30	1824.50	1824.67	0.10	0.27	0.35	0.41	1.15
PEMEX	1824.45	1826.30	1824.50	1824.67	0.05	0.22	3.43	1.21	0.35
VC11	1824.55	1826.30	1824.50	1824.67	-0.05	0.12	0.07	0.03	0.41
VC13	1824.85	1826.30	-	-	-	-	-	-	-
VC14	1825.05	1826.30	-	-	-	-	-	-	-
PL3	1824.60	1830.90	1824.50	1824.67	-0.10	0.07	1.90	0.07	0.04
VC15	1824.45	1826.30	1824.50	1824.67	0.05	0.22	0.26	0.24	0.95
VC16	1824.35	1826.30	1824.50	1824.67	0.15	0.32	0.45	0.60	1.33
VC17	1824.60	1826.30	1824.50	1824.67	-0.10	0.07	0.13	0.01	0.06
PL4	1824.85	1830.90	-	-	-	-	-	-	-
LA CINTA	1823.70	1829.40	1824.50	1824.67	0.80	0.987	24.35	0.28	0.01
Sewer freeway (D=5 m)	1823.34		1824.50	1824.64	1.16	1.30	4.13	11.89	2.88

The adjusted bathymetric curve was used by routing floods with the storm design of 50 years. Flow routing through Lake Cuitzeo shows that hydraulic structures were enough to permit a free flow through them.

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