Floods at Km 82+426 – Final Report

October 2017

Revision	Date	Elaboration Responsible	Approval Responsible	Comments
0	16/10/2017			Initial version
1				
2				
3				

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1. Introduction

Historical records from year 1925 show that railway at new location km 82+426 was severely flooded that year with levels approximately +48.50 m which is almost 0.60 m over railway elevation. Therefore the consultant was asked to develop a flood study for that location.

2. Objective

Determine bridge span and lower deck elevation at new location km 82+426 from the hydrological and hydraulical point of view in order to have a reasonable protection from flood risks.

3. Information used

- 1925 flood record blueprint
- Digital Terrain Model (RENARE-MGAP)
- Uruguay Soil Types Chart
- Railway elevation profile

4. Methodology

A hydrological study of the catchment and hydraulical model of the stream were performed in order to assess flood risk with current and future infrastructure.

Bridge at km 82+426 is over a stream called *"Cañada Las Piedras"* which is affluent of the "*Santa Lucía Chico"* river downstream of Paso Severino Dam.

A hydrological study of whole *"Cañada Las Piedras"* catchment with closure point at "*Santa Lucía Chico"* river was performed, and was discretized in three sub catchments. First one, from highest elevations until railway, another from railway downstream for the medium flows, and a third one near *Santa Lucía Chico*. Design hydrographs for 100 years return period were calculated using software HEC-HMS from United States Army Corps of Engineers (USACE).

A hydraulical model of *"Cañada Las Piedras"* from approximately 2 km upstream of railway until Santa Lucía Chico river was performed in software HEC-RAS from USACE. Geometry of stream was represented by cross sections obtained from Digital Terrain Model (DTM), hydrographs from hydrological study were used as upstream boundary conditions as input flows. Simulations with existing bridge, projected bridge, and recommended bridge were done and its results are herein after presented.

All calculations were done considering events of 100 years return period, which is consider appropriate for the railway to protect and the asset being design.

5. Results

5.1. Hydrological studies

Flooded bridge is located at new railway chainage km 82+426 that is between Santa Lucia and Florida cities as shown in Figure 5-1.

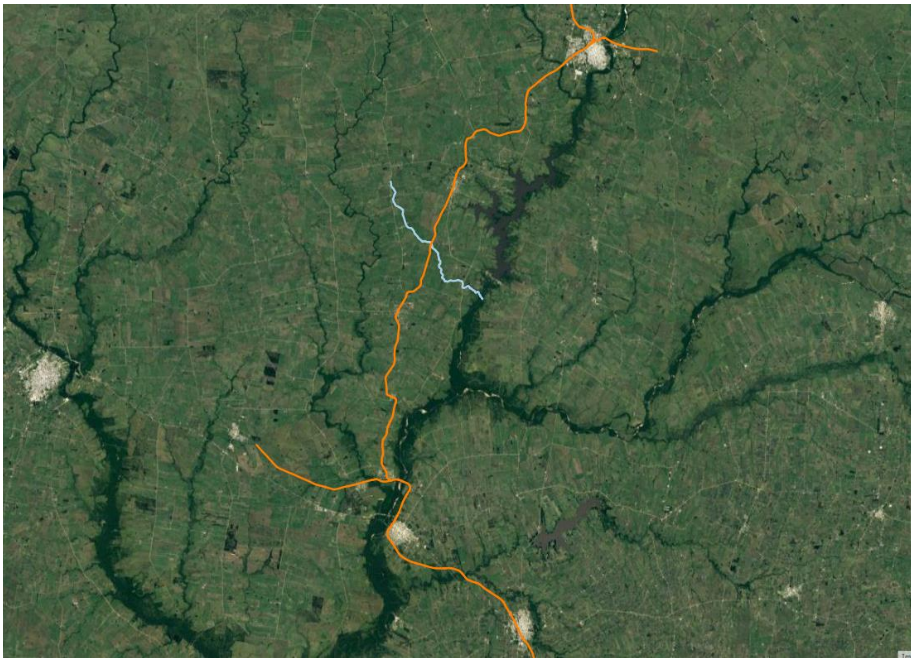


Figure 5-1 Railway and stream location between Santa Lucia and Florida

In Figure 5-2 a closer image is presented, with the railway in orange, stream in blue and satellite image. It can be seen that the flood reach is between Cardal and 25 de mayo towns, and that is close to Paso Severino Dam. Actually the flooded stream which Cañada Las Piedras discharges into Santa Lucia Chico river downstream of Paso Severino Dam.

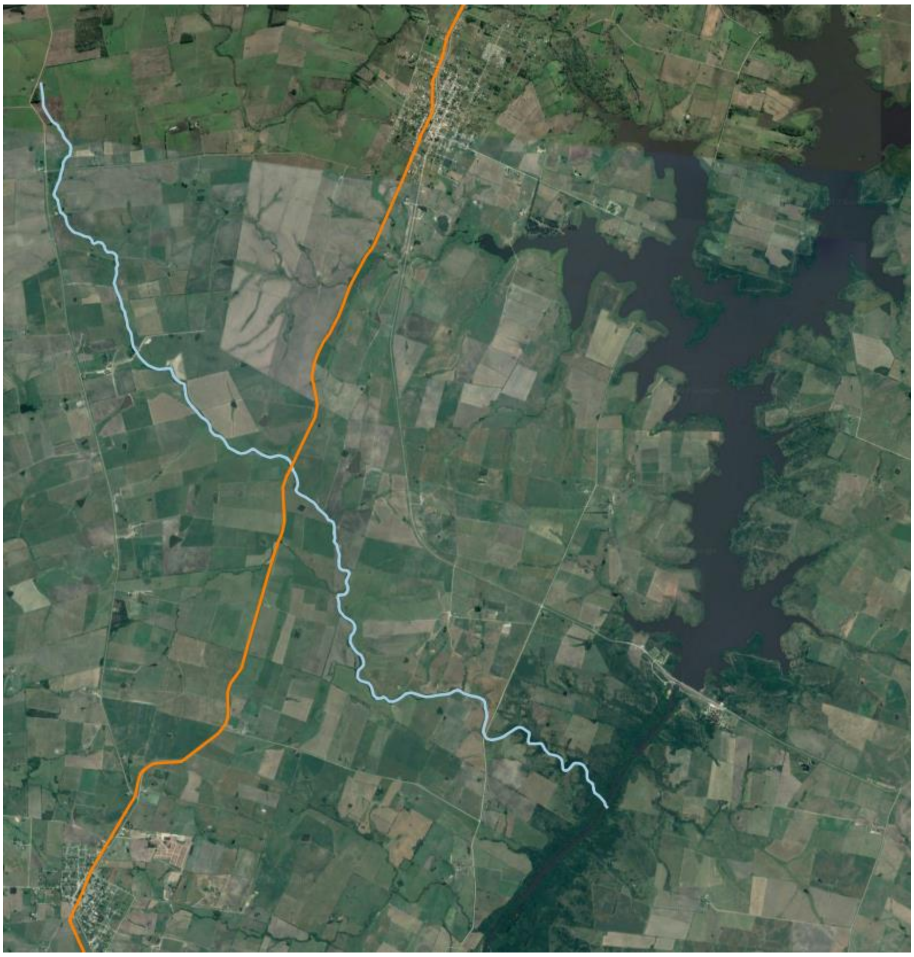


Figure 5-2 Railway and stream location between Cardal and 25 de mayo

Catchment of Cañada Las Piedras was discretized into three subcatchments, one that contributes to the railway bridge, another that discharges near the bridge but downstream of railway, and a third one at the downstream end as shown in Figure 5-3.

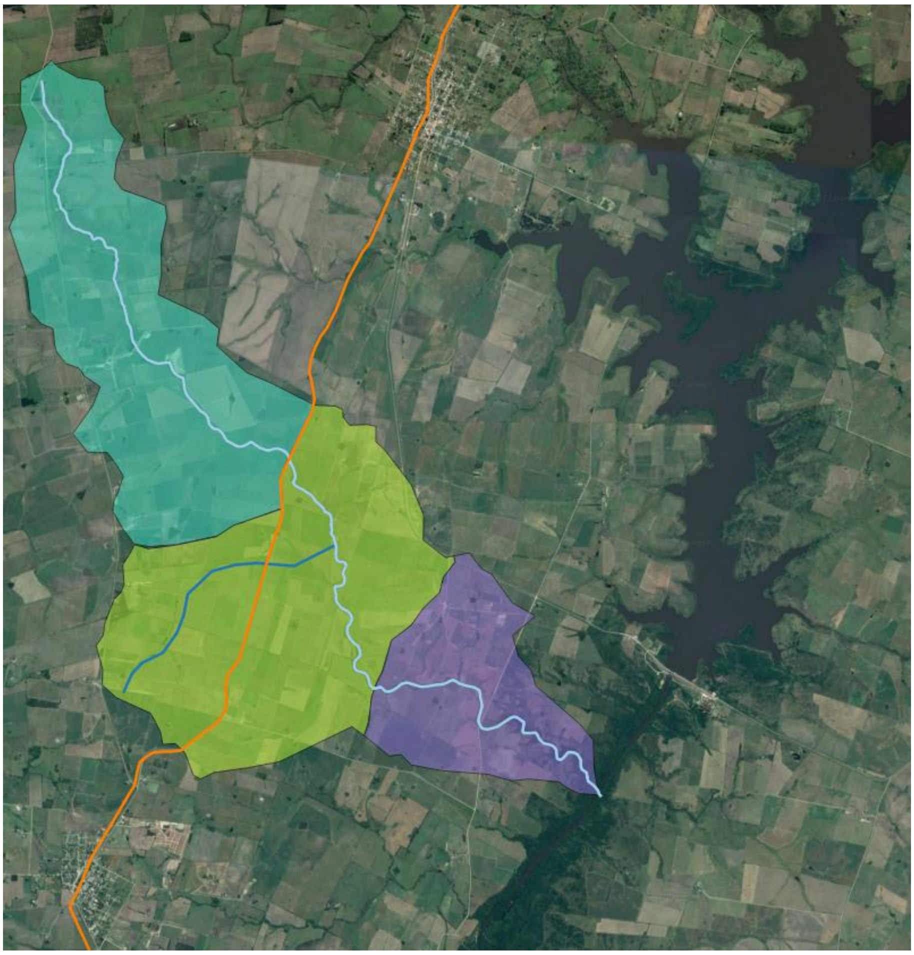


Figure 5-3 Subcatchments considered over satellite image

In Figure 5-4 railway, streams and subcatchments are presented over the DTM.

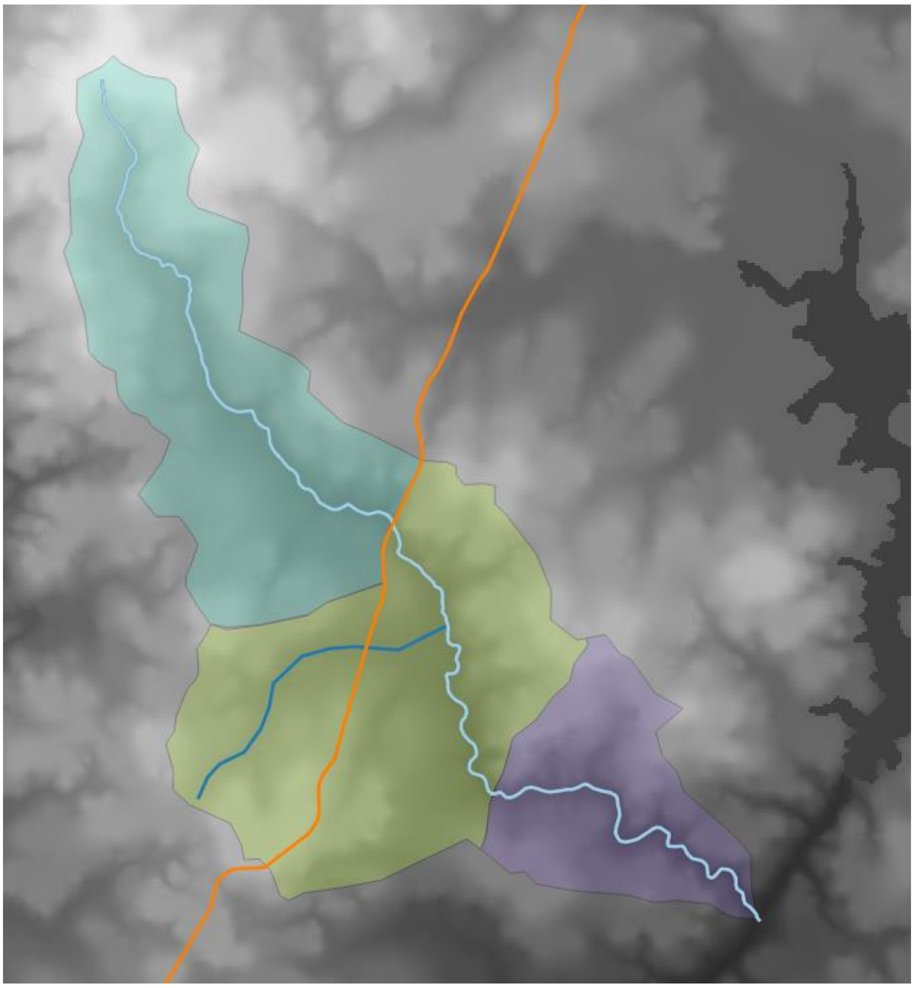


Figure 5-4 Subcatchments considered over DTM

With the length of stream and the elevations from DTM the concentration time of the subcatchment of the railway was calculated and is presented in Table 5-1.

Table 5-1 Time of concentration

Concept	Unit	Value
Length	m	7278
Upstream elevation	m	90
Downstream elevation	m	43
Elevation difference	m	47
Slope	%	0.65
Time of concentration	hs	2.18
Lag time	hs	1.31

Considering the time of concentration of the subcatchment a design storm was calculated with the alternate block method, with a duration of almost twice the time of concentration, with twelve 20 minutes blocks, 100 years return period, and an increase in precipitation intensities of 20% in order to consider possible effects of climate change. In this sense many European countries countries are considering increases of up to 40%, in this case 20% was considered reasonable without increasing so much the required infrastructure.

In Figure 5-5 the design storm introduced in HEC-HMS is presented.

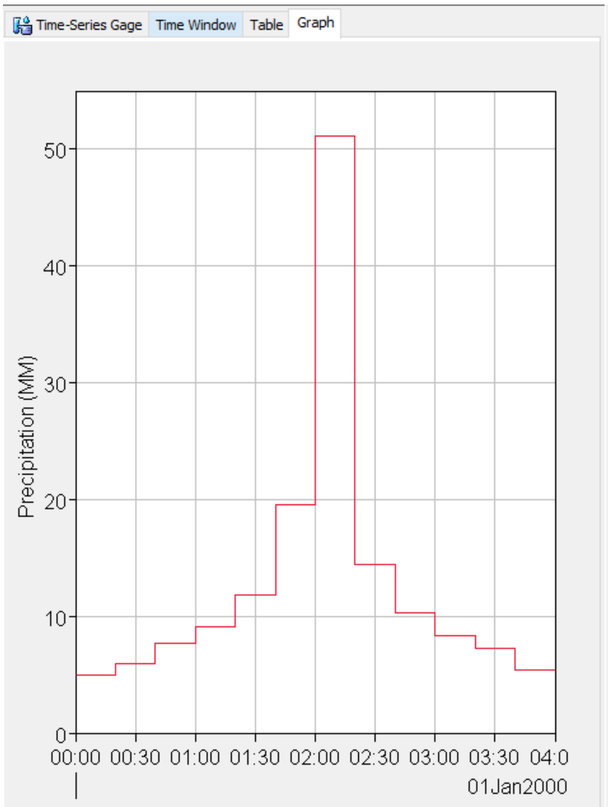


Figure 5-5 Design storm (TR100)

Afterwards, a study of the soil types and land uses in the catchment was done in order to account for the Curve Number to use in the National Resources Conservation Service (NRCS) hydrograph estimation method.

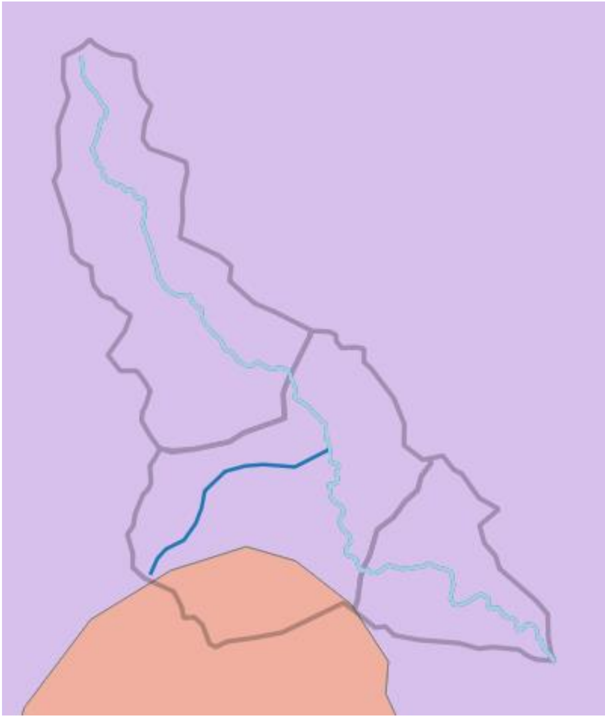
Soil types near the catchment area are presented in 

Figure 5-7, and in more detail in Figure 5-7. It can be seen that most of the catchment presents soil type Isla Mala (violet) and a little of Tala-Rodriguez (orange). The first one has a hydrological group C and the latter C/D, it was consider a C hydrological group.

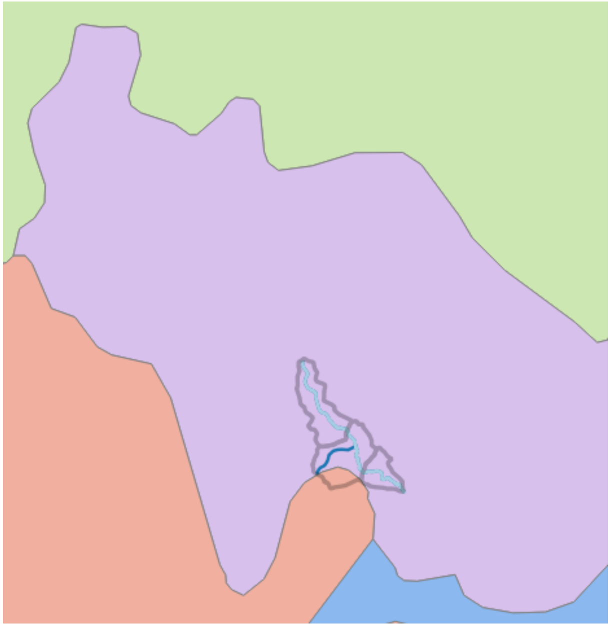


Figure 5-6 Soil type near catchment area

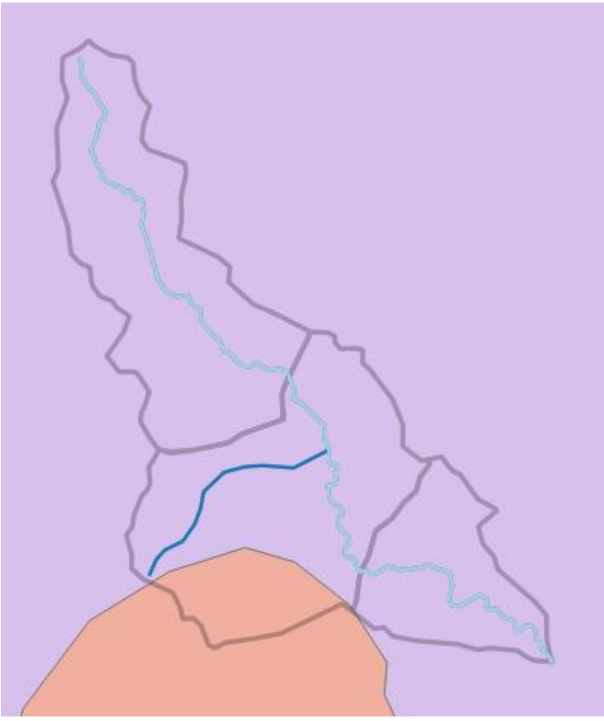


Figure 5-7 Soil type in catchments

By observing satellite image mainly meadows with straight lines were identified as land use, and with a soil type with hydrological group C and average of good and bad hydrological condition, a Curve Number of 83 was used to account for the effective rainfall.

In Figure 5-8 and Figure 5-9 the resultant hydrograph for the subcatchment upstream and downstream of the railway respectively are presented.

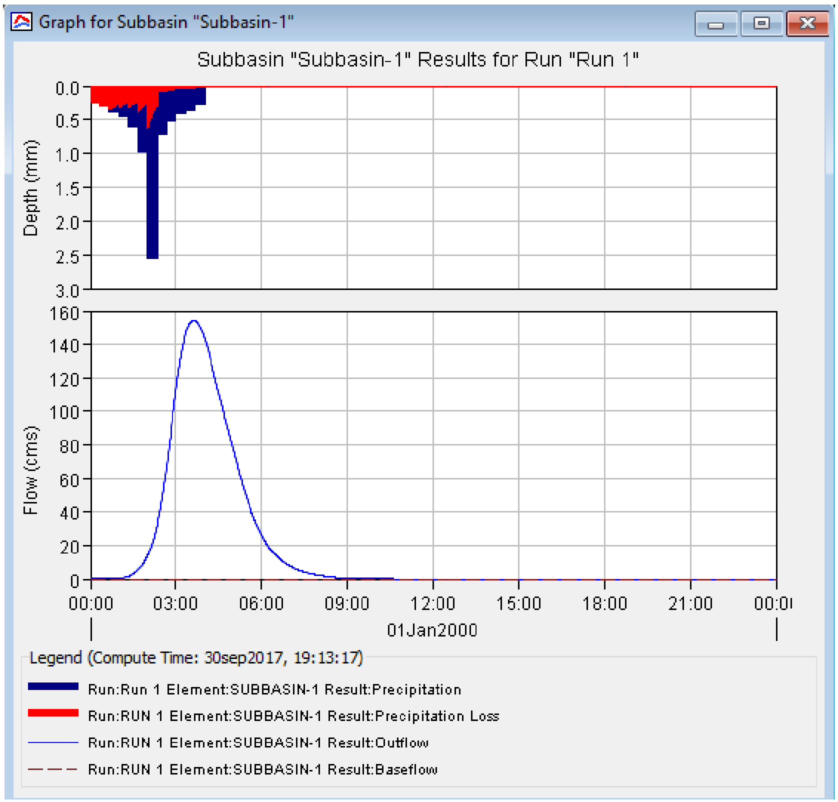


Figure 5-8 Railway catchment hydrograph

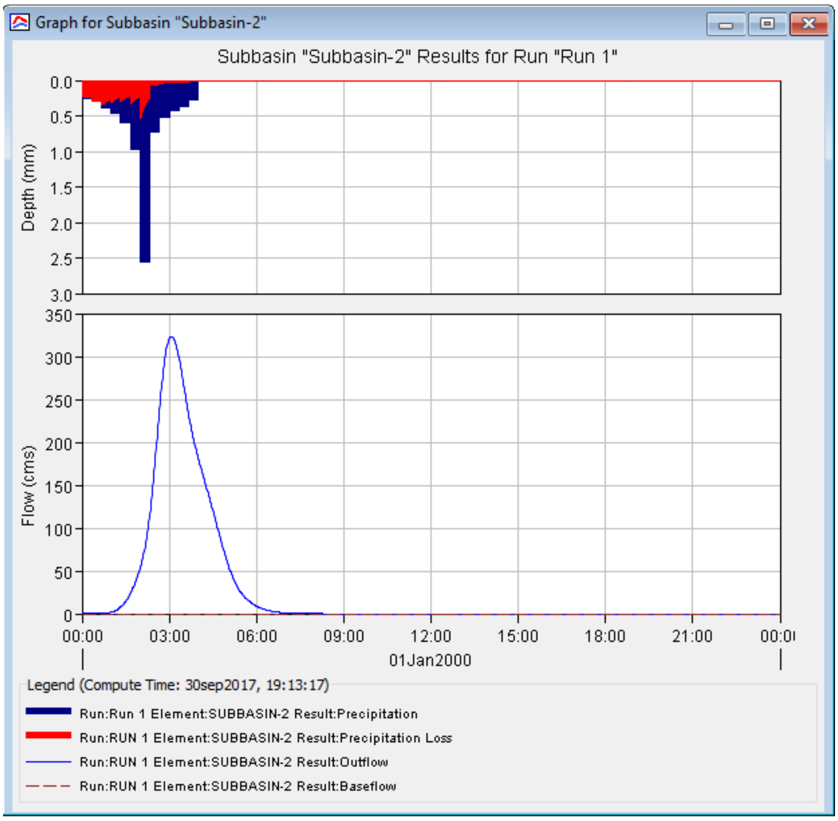


Figure 5-9 Downstream catchment hydrograph

5.2. Hydraulical studies

To account for the hydraulical studies of the stream and bridges, software HEC-RAS from USACE is used. First a representation of the stream with natural cross section obtained from DTM is done in order to assess which would have been the flood levels before the construction of the railway. Then the current railway embankment and bridge is introduced to the model and the flood levels check with those of 1925. Finally other types of bridge are introduced to the model in order to find the most suitable one to reduce the risk of floods.

5.2.1. Natural cross sections

Model was squematized with cross sections obtained from DTM, in Figure 5-10 the selected cross sections are presented over satellite image. There are some upstream of the railway, approximately 2 km upstream in order not to laminate hydrograph too much, several near the bridge and some downstream in order to account for the entrance of downstream flows and to obtained downstream boundary condition from Santa Lucia Chico River.

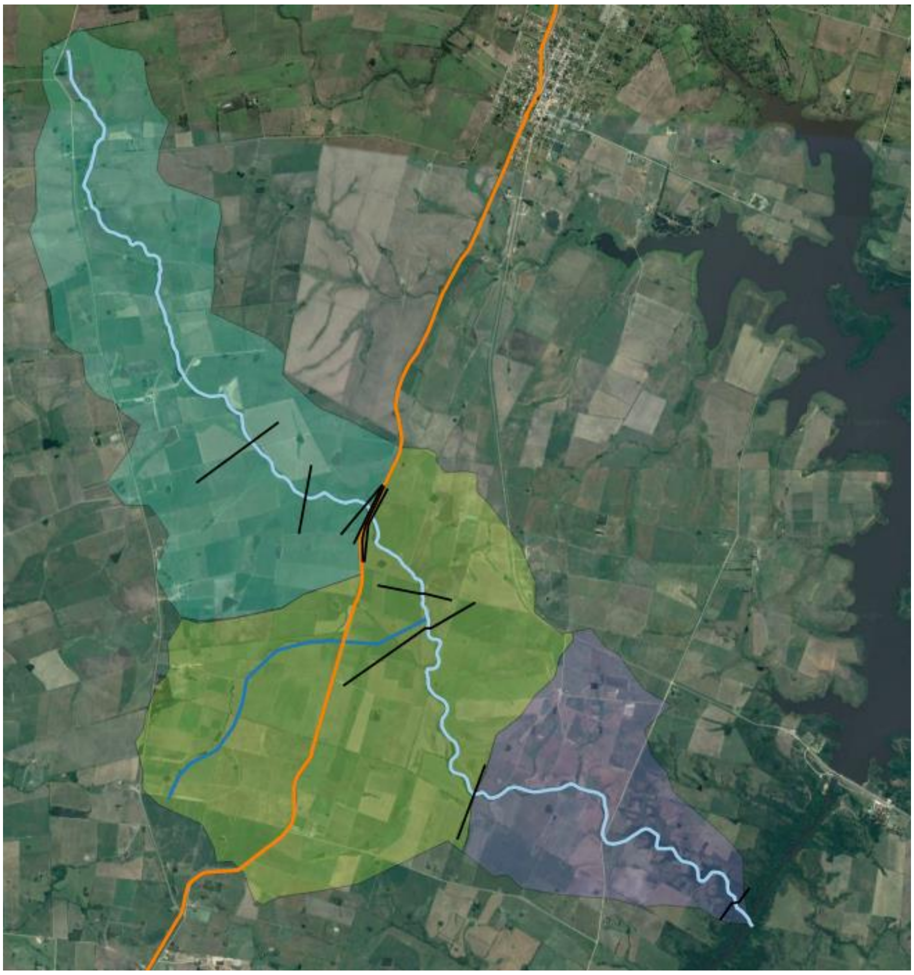


Figure 5-10 Cross sections for hydraulical model over satellite image

In Figure 5-11 cross sections are presented over the DTM used to obtain their elevations.

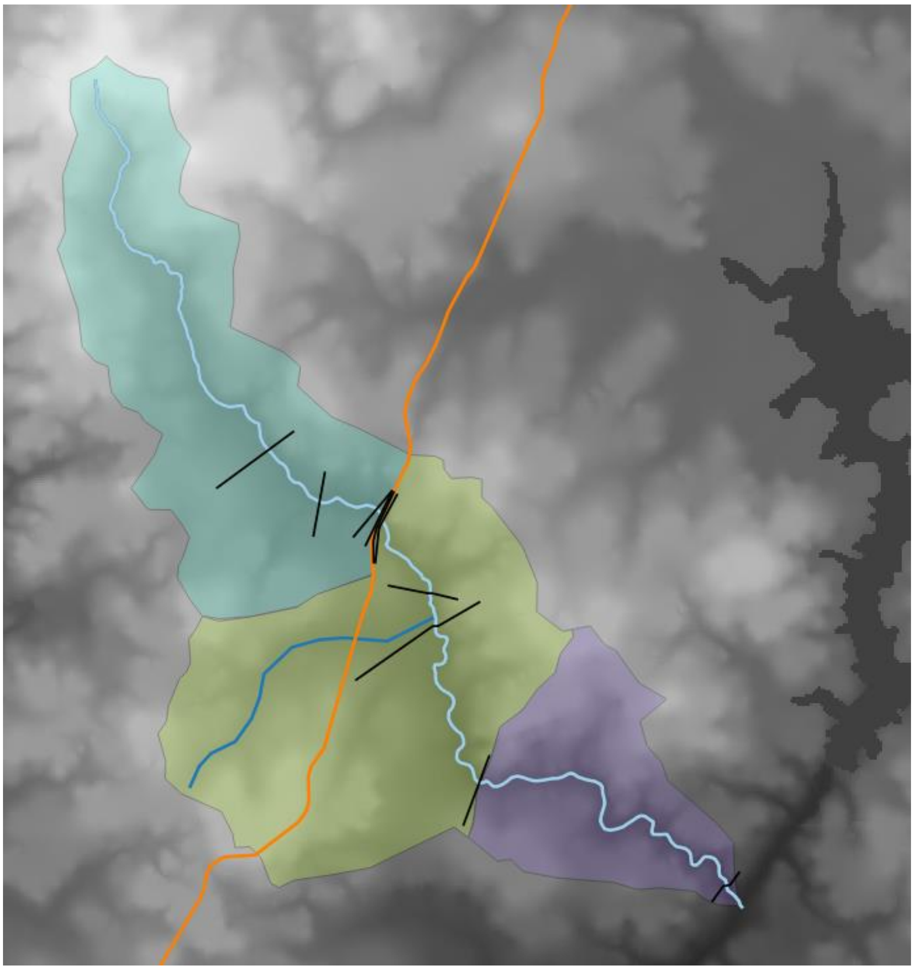


Figure 5-11 Cross sections for hydraulic model over DTM

With the obtained cross sections and distances one dimensional hydraulical model was built in HEC-RAS as shown in Figure 5-12.

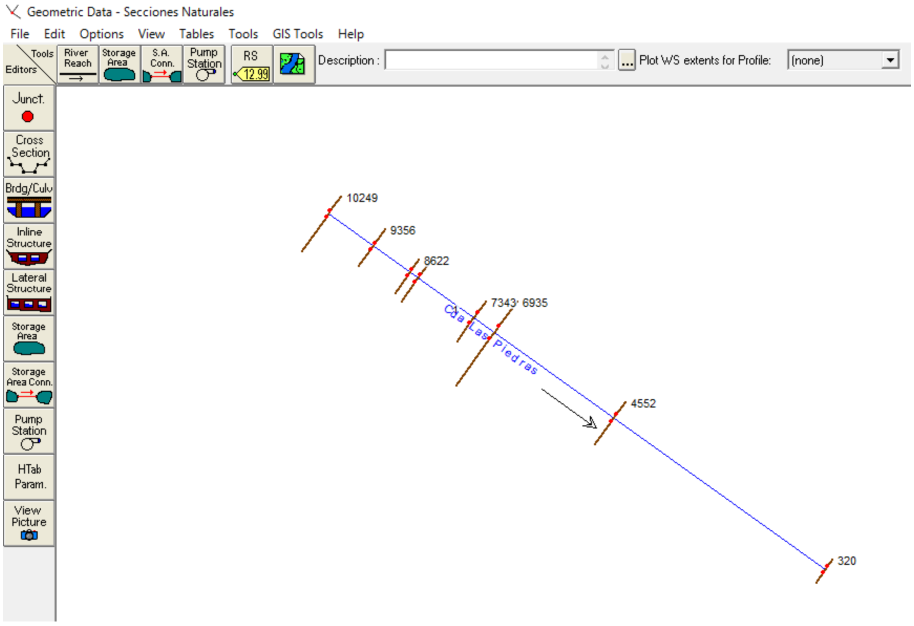


Figure 5-12 Geometry of stream

Vegetation in flood plain was observed in satellite image as shown in Figure 5-13 in order to assess the Manning roughness value, due to the presence of brushes a value of 0.1 was adopted for main channel and floodplains. Also by experience of flood modeller in other studies with available levels data to calibrate roughness value, this value seems reasonable, which was afterwards proved.

Figure 5-13 Railway embankment and stream vegetation

As an example the cross section upstream of the bridge is presented in Figure 5-14, the rest of cross sections are shown in the annex chapter.

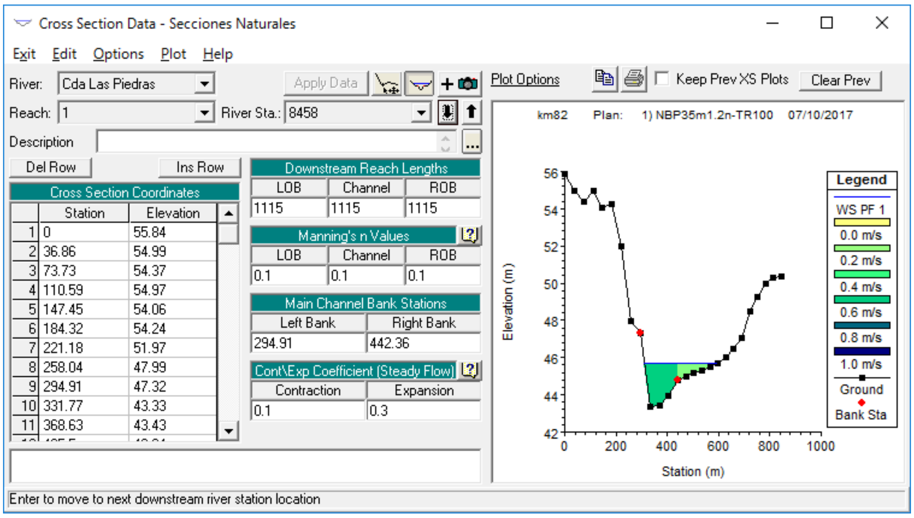


Figure 5-14 Cross section 8458

5.2.1.1. Downstream boundary condition

In order to assess the influence of the downstream boundary condition in the railway area three different stages were considered, low, high and very high.

a) Low level, critical depth

First a low level in Santa Lucia Chico river was consider and results in the railway area analysed, in Figure 5-15 the maximum water elevation profile is presented and in Figure 5-16 the maximum water elevation in the cross section upstream of railway is shown, a level of +45.96 m is appreciated.

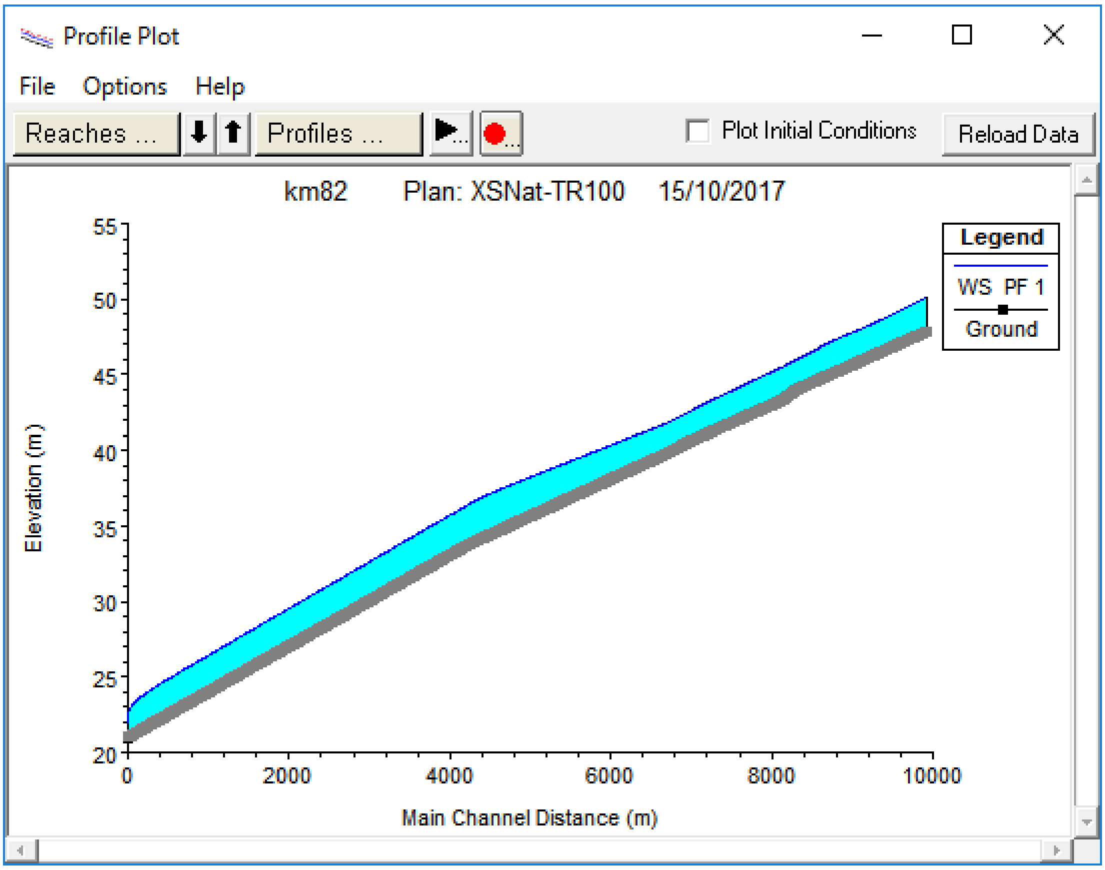


Figure 5-15 Maximum water elevation profile with low level downstream boundary condition

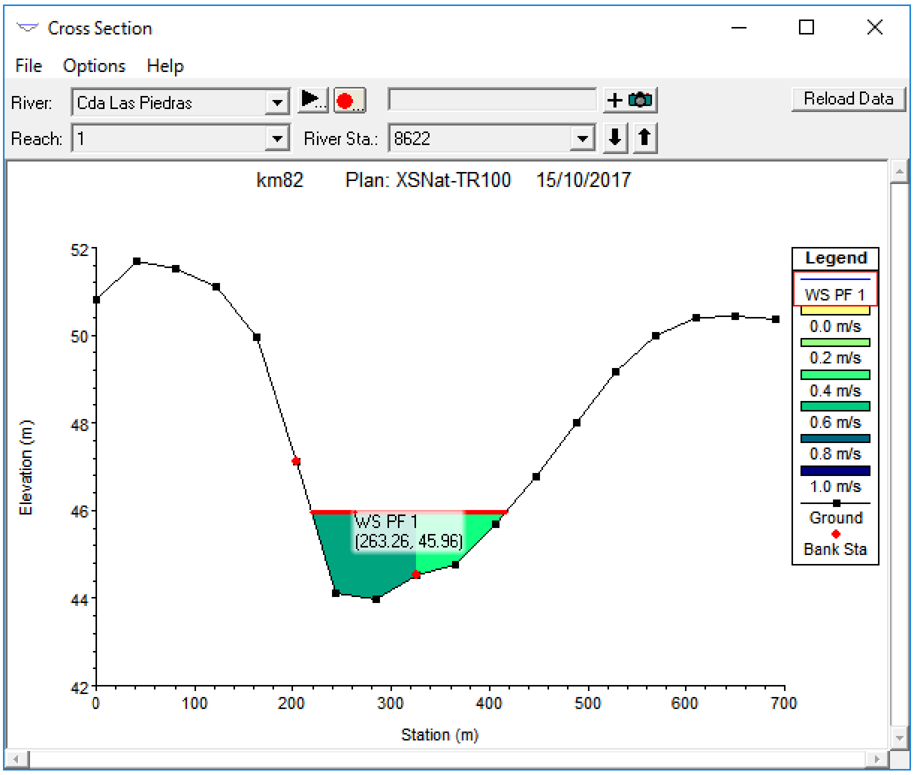


Figure 5-16 Maximum water elevation at cross section upstream of bridge, with low level downstream boundary condition

b) High, 30 m

Maximum water elevation profile with a boundary condition of 30 m in Santa Lucia Chico river is shown in Figure 5-17 and the maximum water elevation upstream of railway cross section of +45.96 m in Figure 5-18.

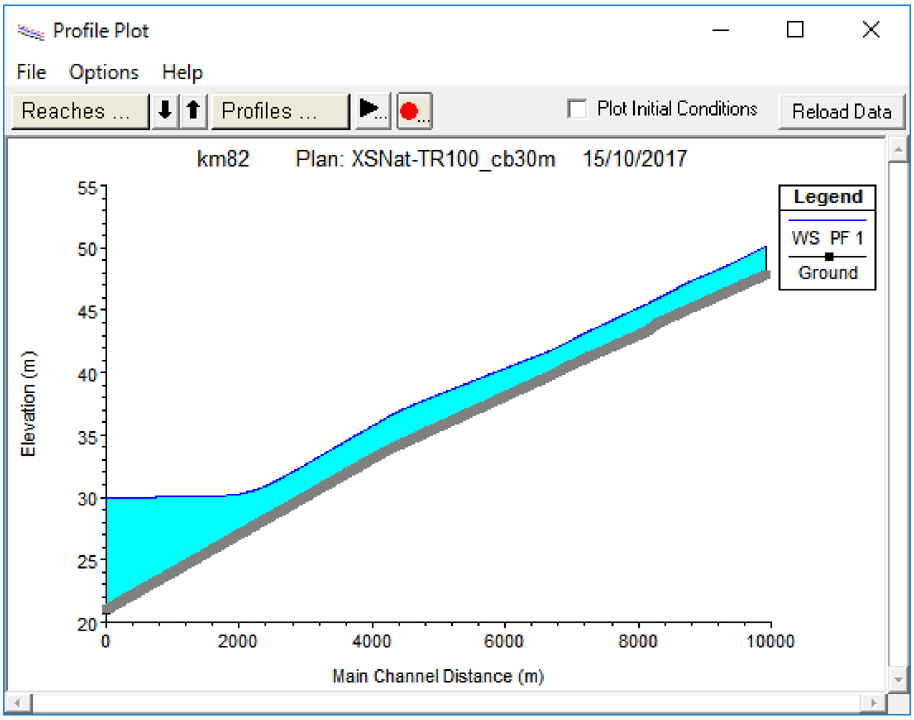


Figure 5-17 Maximum water elevation profile with natural cross sections and high level downstream boundary condition

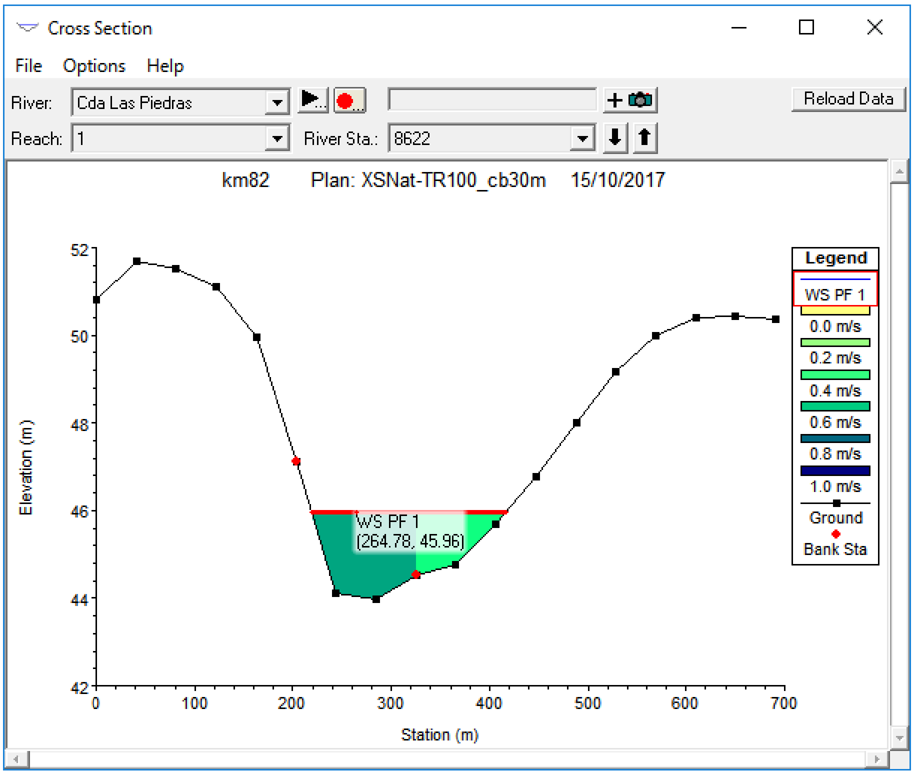


Figure 5-18 Maximum water elevation at cross section upstream of bridge, with high level downstream boundary condition

c) Very high, 40 m

A very high level of 40 m was also analysed in case of Paso Severino Dam weir elevation being raised and a dam break occurs. Results are shown in Figure 5-19 and Figure 5-20, as it can be seen the railway section is not affected by the downstream boundary condition as maximum water levels are +45.96 m for every scenario.

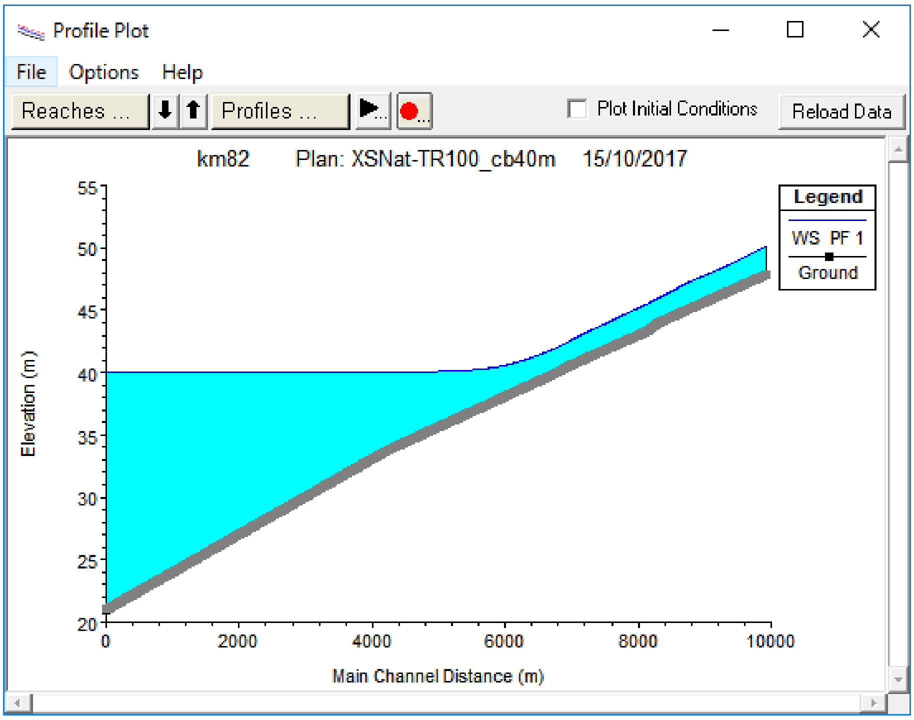


Figure 5-19 Maximum water elevation profile with natural cross sections and very high level downstream boundary condition

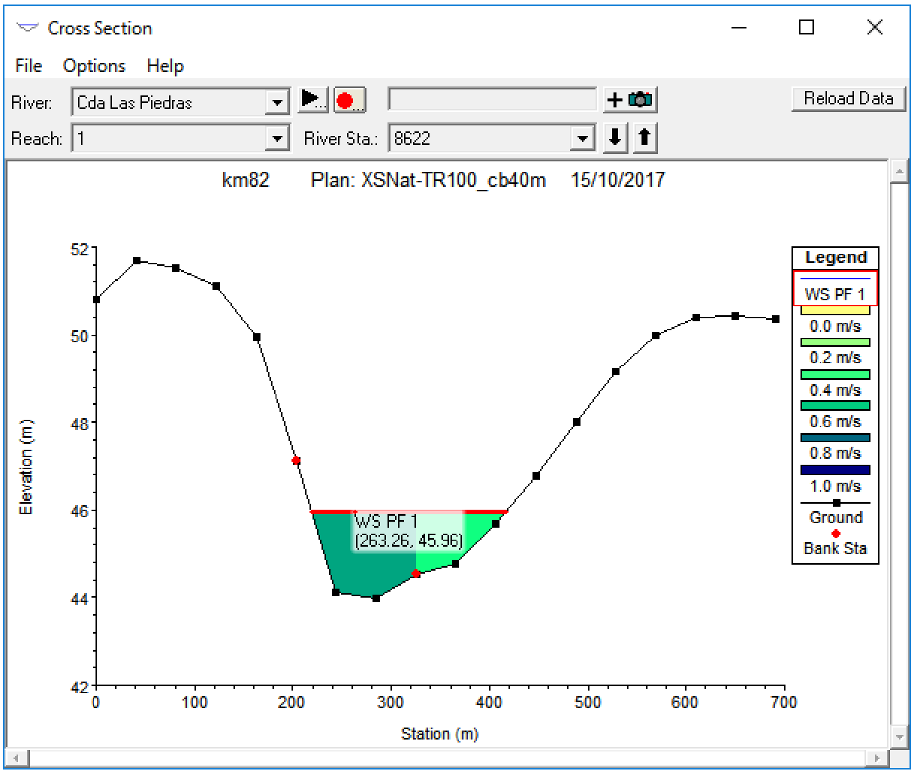


Figure 5-20 Maximum water elevation at cross section upstream of bridge, with very high level downstream boundary condition

As main conclusions of this analysis, railway area is not affected by Santa Lucia Chico river levels, and that the maximum water elevation for 100 years return period without railway embankment and bridge, just natural cross sections is +45.96 m official zero.

5.2.2. Existing bridge

Afterwards, the current railway embankment, abutment and bridge were introduced to the model.

In Figure 5-21 and Figure 5-22 the railway profile and year 1925 flood levels are shown, it can be seen that current bridge has a span of 9 m, and that flood levels were between +47.74 m and +49.19 m.

Actually, with a closer look, considering left side image, flood level is between +48.48 m and +49.04 m, interpolating an estimated +48.76 m. In the right side is between +47.74 m and +49.19 m, interpolating +48.10 m is estimated. Averaging estimations from both sides a value of +48.43 m might have been reached in 1925 which is almost 100 years ago as the design storm being considered. Therefore it is expected that when running simulation with 100 years hydrographs and railway embankment and bridge flood levels get near that value.

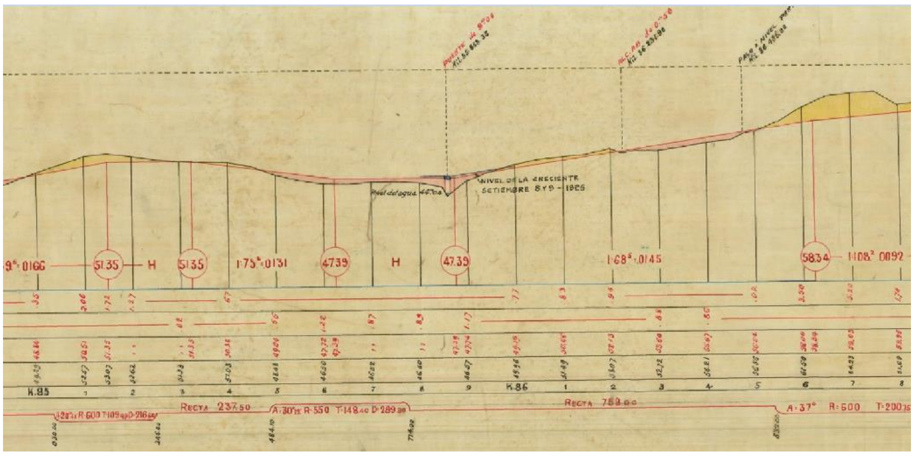


Figure 5-21 Railway old profile with 1925 flood level mark

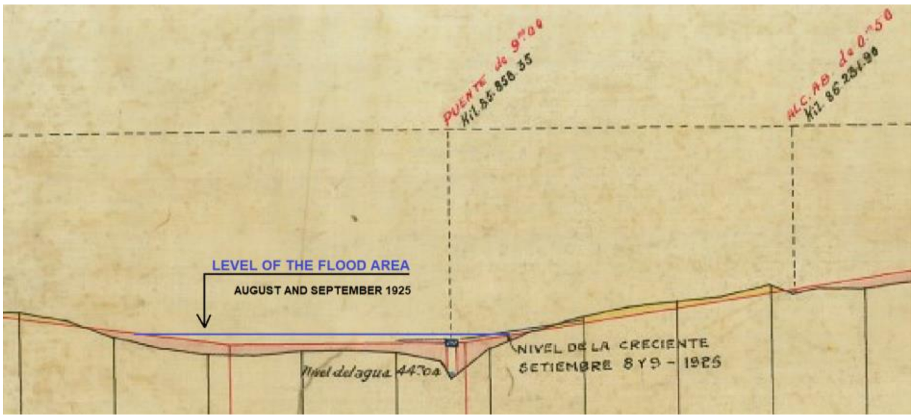


Figure 5-22 Railway profile with 1925 flood level and bridge span of 9 m

Even though old blueprint displays a span of 9 m of existing bridge this was confirmed by observation of satellite image as shown in Figure 5-23.

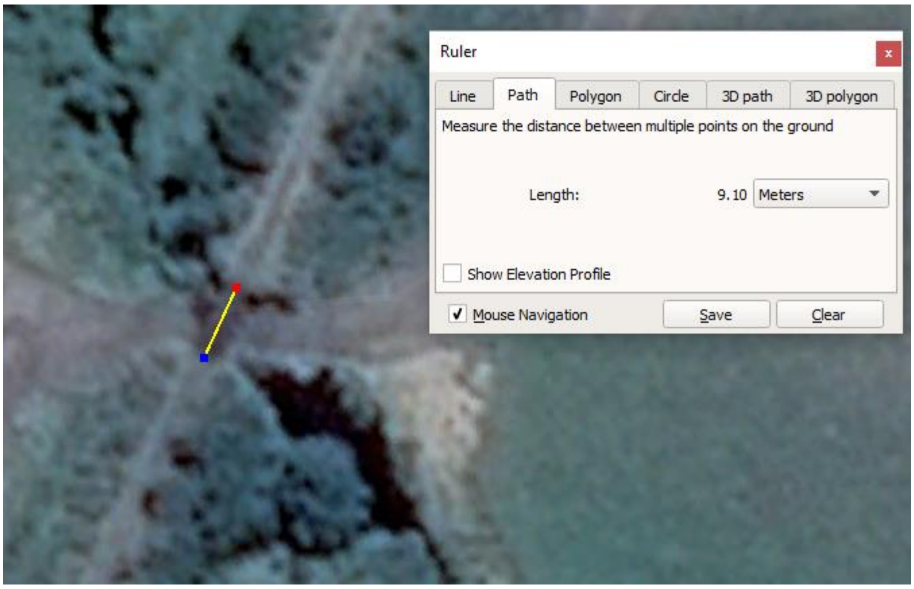


Figure 5-23 Bridge span confirmation with satellite image

In Figure 5-24 the bridge abutments introduced to the model are shown.

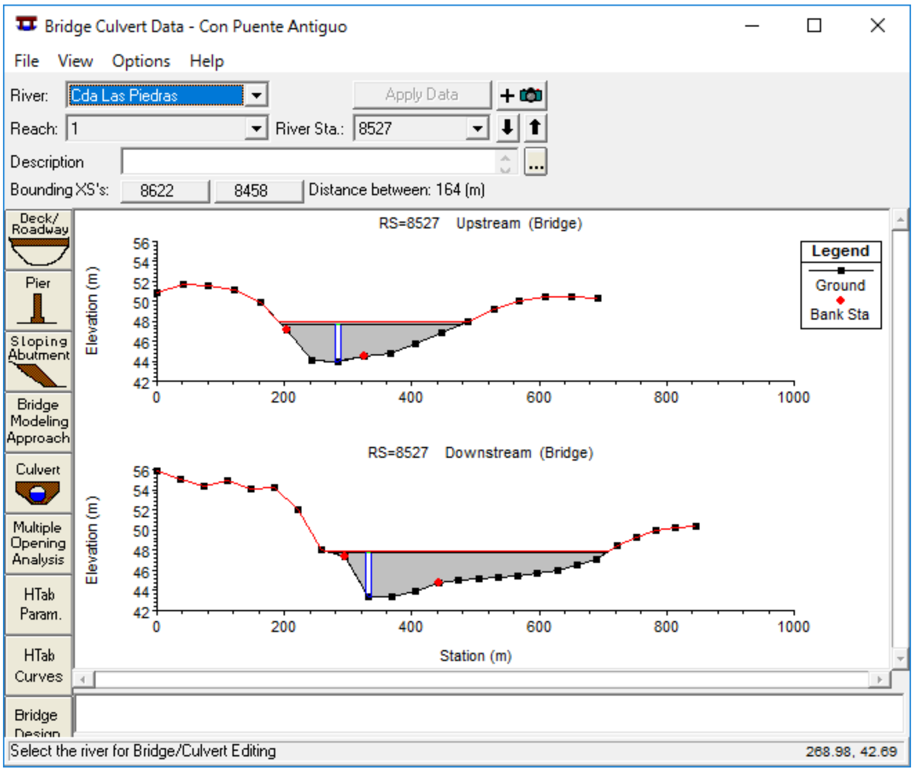


Figure 5-24 Input of railway existing embankment and bridge

Model was run with existing bridge and high downstream water level and results are shown hereafter.

In Figure 5-25 maximum water elevation profile is shown, it can be seen how embankment, abutment and small existing bridge work as a dam for catchment flows increasing water levels upstream significantly including overtopping railway elevation as was expected and can be seen in Figure 5-26 with level reaching +48.49 m very similar to the +48.43 m expected. This is proof of the model good representation of reality and therefore it can be used to design the new necessary bridge.

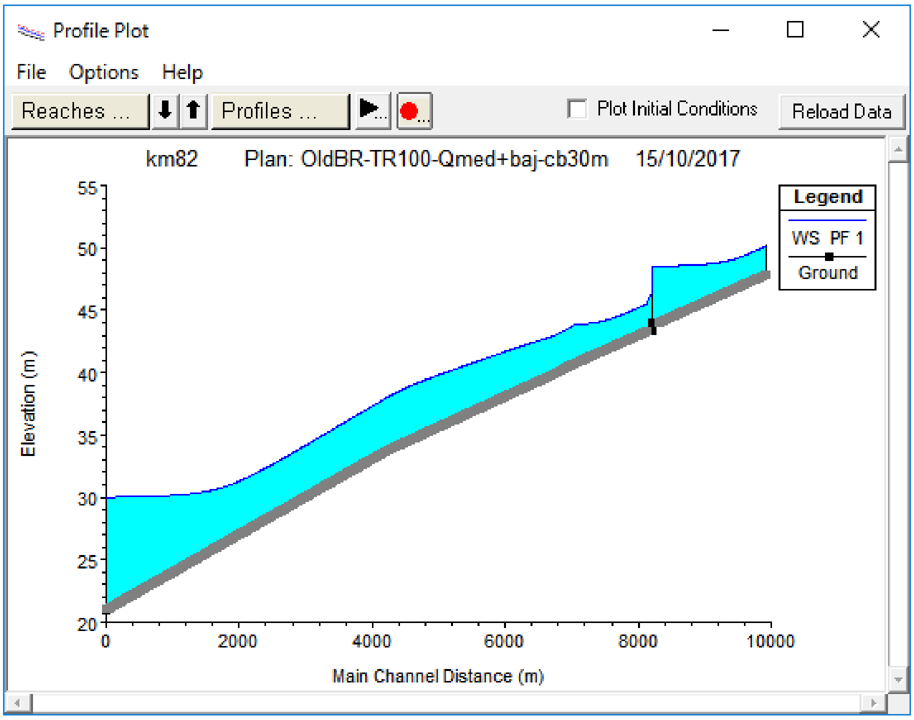


Figure 5-25 Maximum water elevation profile with existing bridge

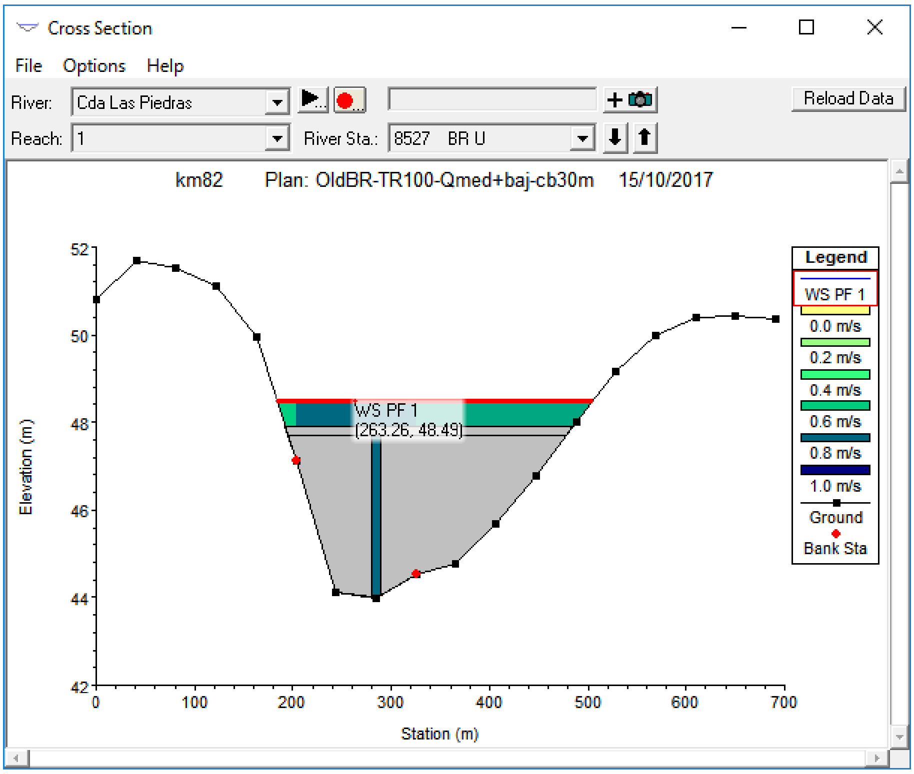


Figure 5-26 Maximum water elevation at existing bridge

Last figure not only shows that the event of 1925 can be represented, but also that the level of protection of the railway at that location is nowadays well below 100 years return period.

In Figure 5-27 maximum water elevation upstream of bridge is presented. A value of +48.54 m official zero is reached.

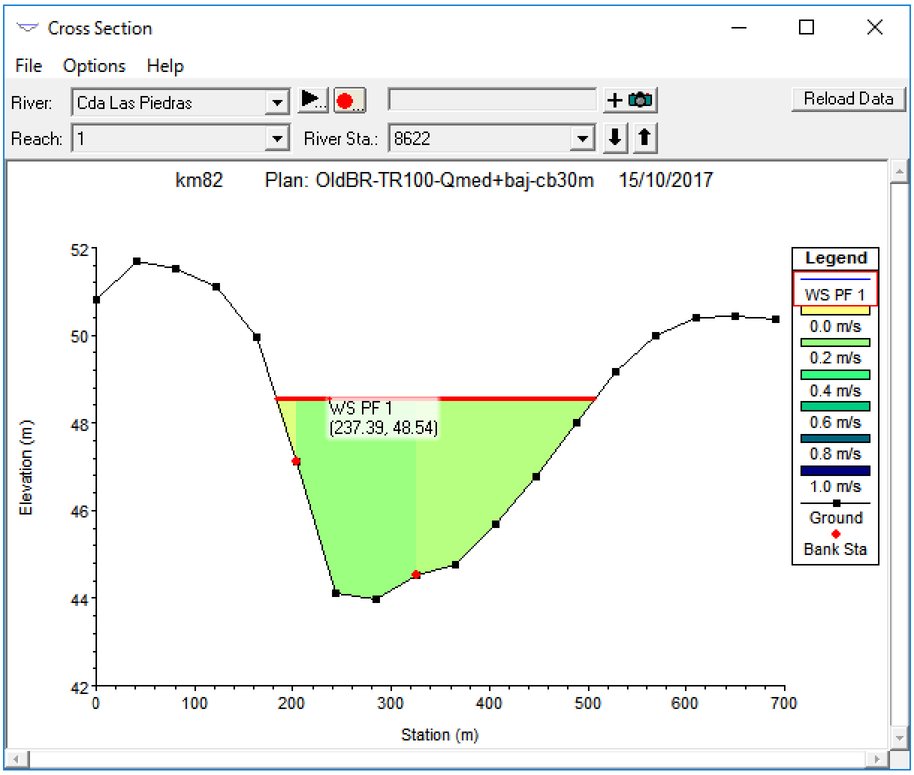


Figure 5-27 Maximum water elevation upstream of existing bridge

5.2.3. 15 m span bridge

Then a bridge of 15 m span was introduced to the model in order to assess its feasibility as shown in Figure 5-28.

Maximum water elevation profile is displayed in Figure 5-29, it can be seen that water elevation upstream does not increase so much as this span does not represent such a contraction to flow.

In Figure 5-30 and Figure 5-31 maximum water elevation upstream and at railway cross sections are shown.

In Figure 5-32 and Figure 5-33 maximum velocities at the upstream and downstream sections of the bridge are displayed, 3.25 m/s and 4.66 m/s respectively. These velocities are very high and not admissible from the bridge hydraulical design point of view which usually a maximum of 2.5 m/s is admissible in order not to have high contraction and local scour at abutments and piles which are the principal reason for bridges failures.

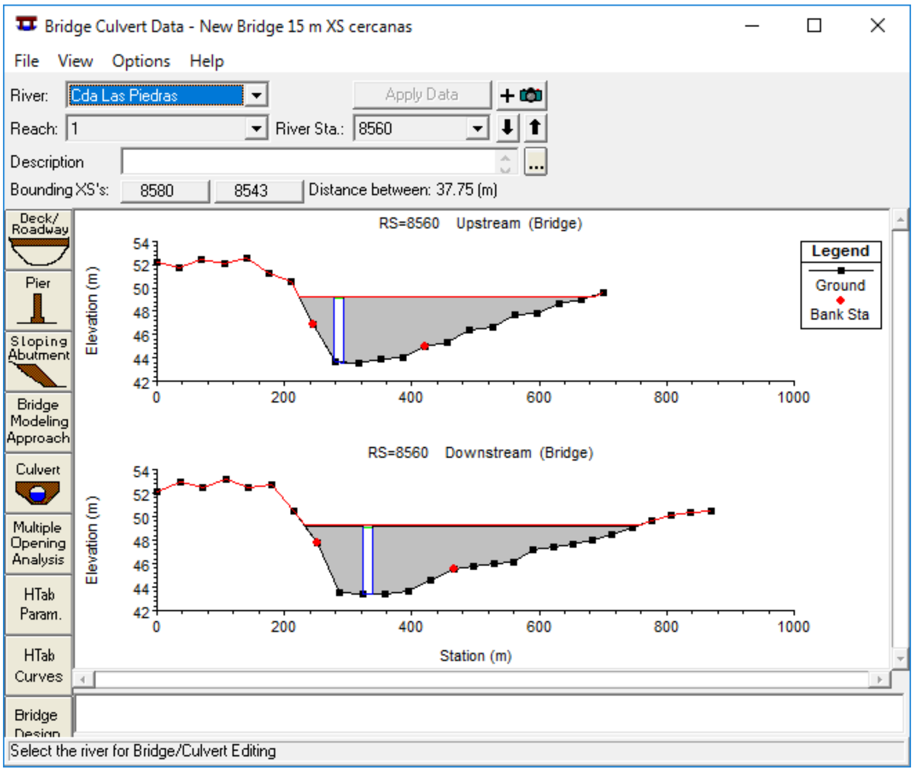


Figure 5-28 Input of 15 m span bridge

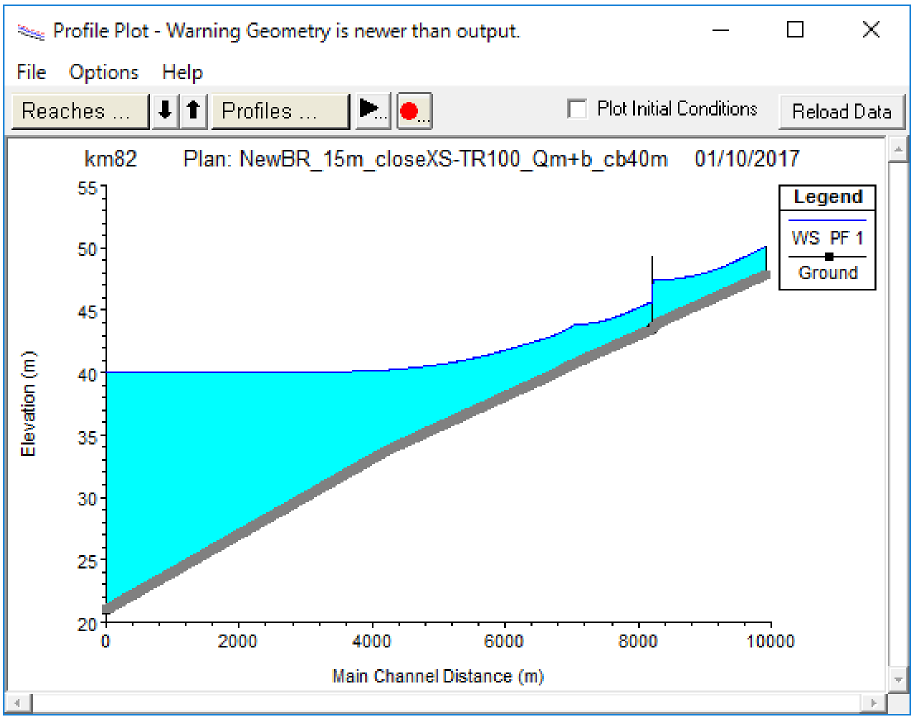


Figure 5-29 Maximum water elevation profile with 15 m span bridge

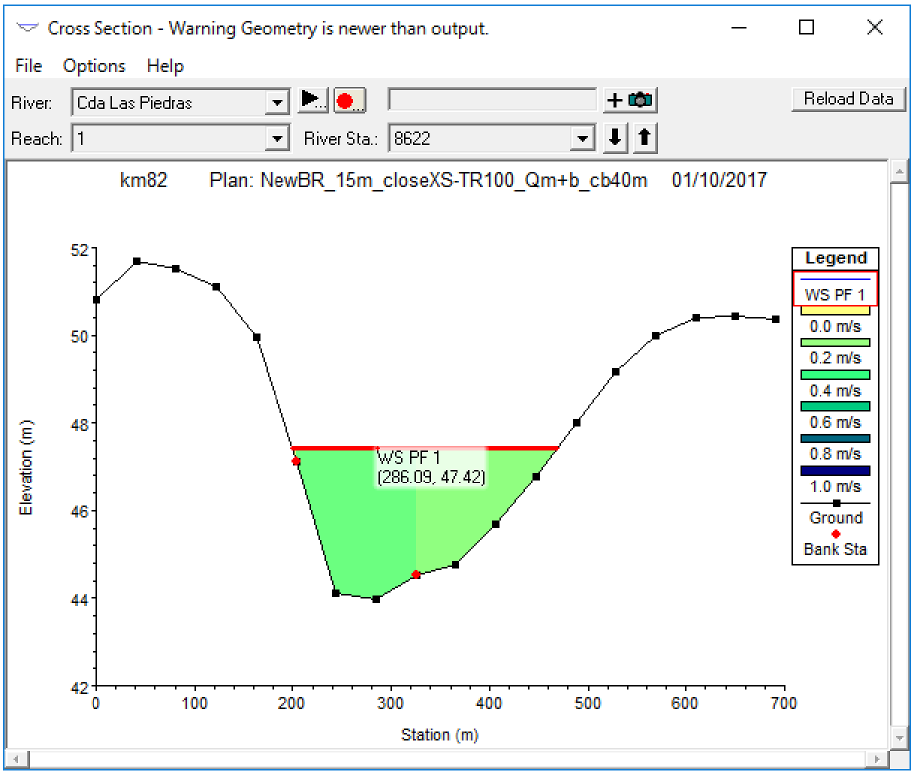


Figure 5-30 Maximum water elevation at cross section upstream of 15 m span bridge

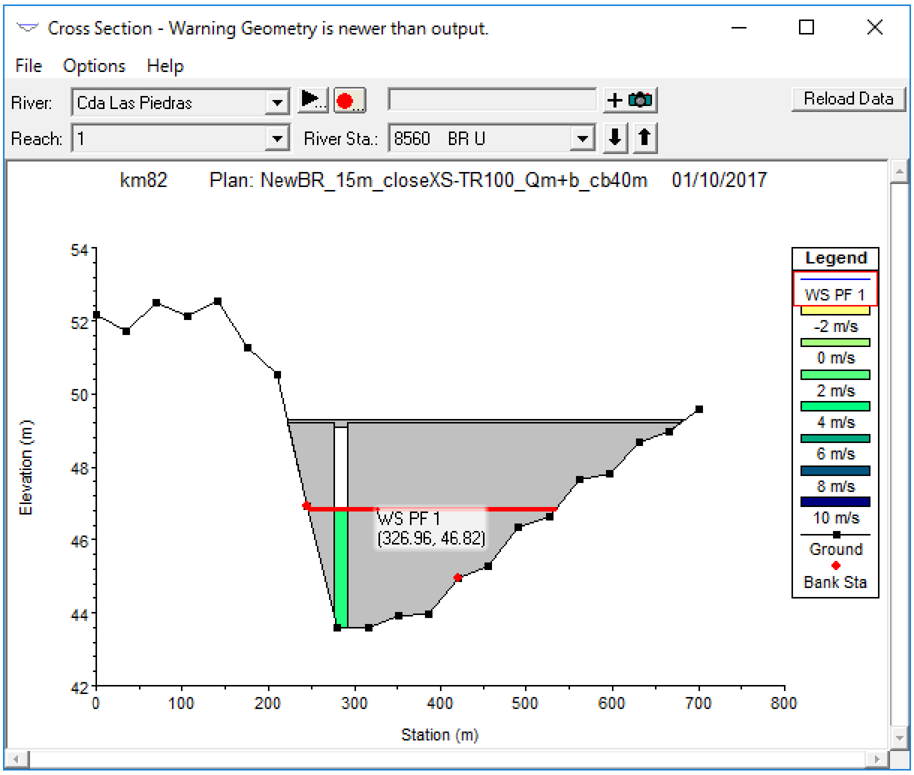


Figure 5-31 Maximum water elevation at 15 m span bridge

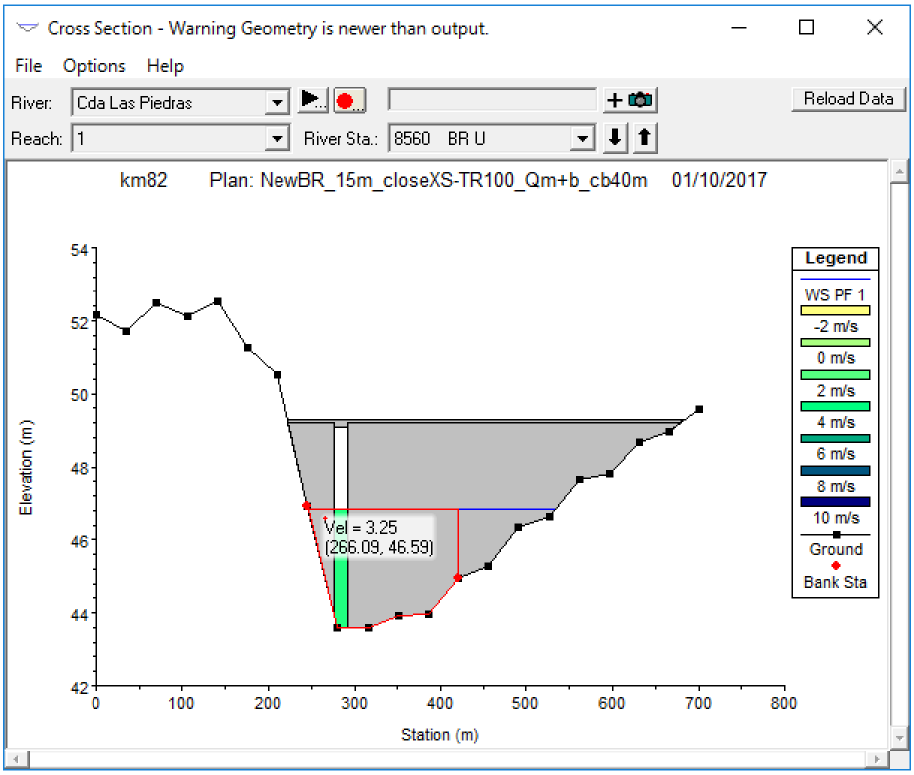


Figure 5-32 Maximum velocities upstream of 15 m span bridge

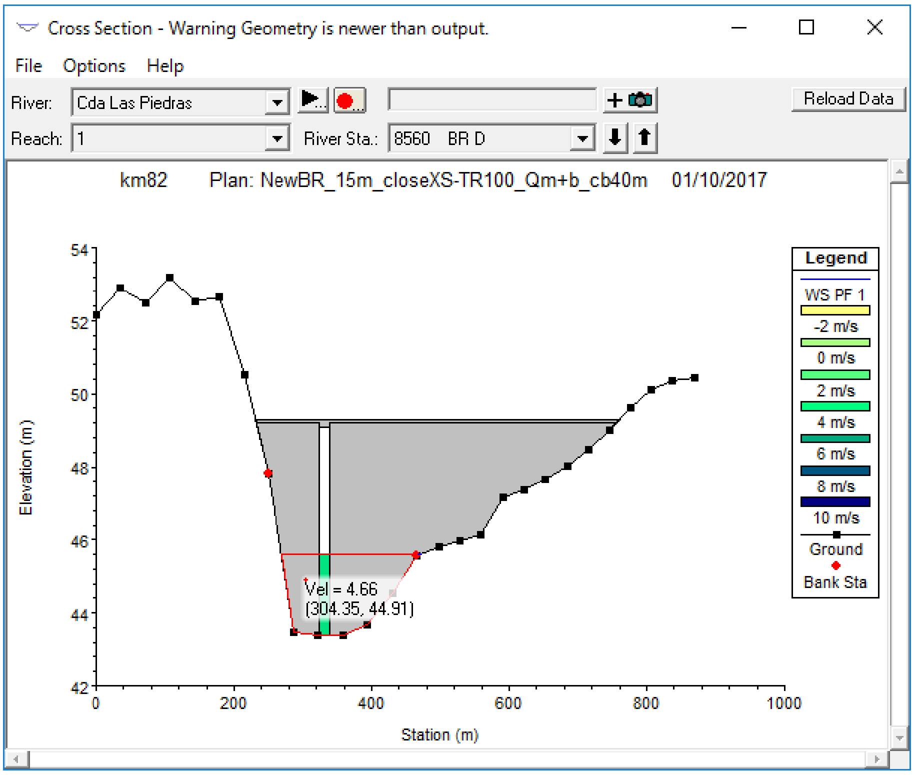


Figure 5-33 Maximum velocities downstream of 15 m span bridge

5.2.4. 35 m span bridge with two 1.2 m diameter piles

Finally, with an admissible velocity of 2.5 m/s through the bridge as objective a 35 m span bridge with two 1.2 m diameter piles was projected and proved with the model. This design can be seen in Figure 5-34.

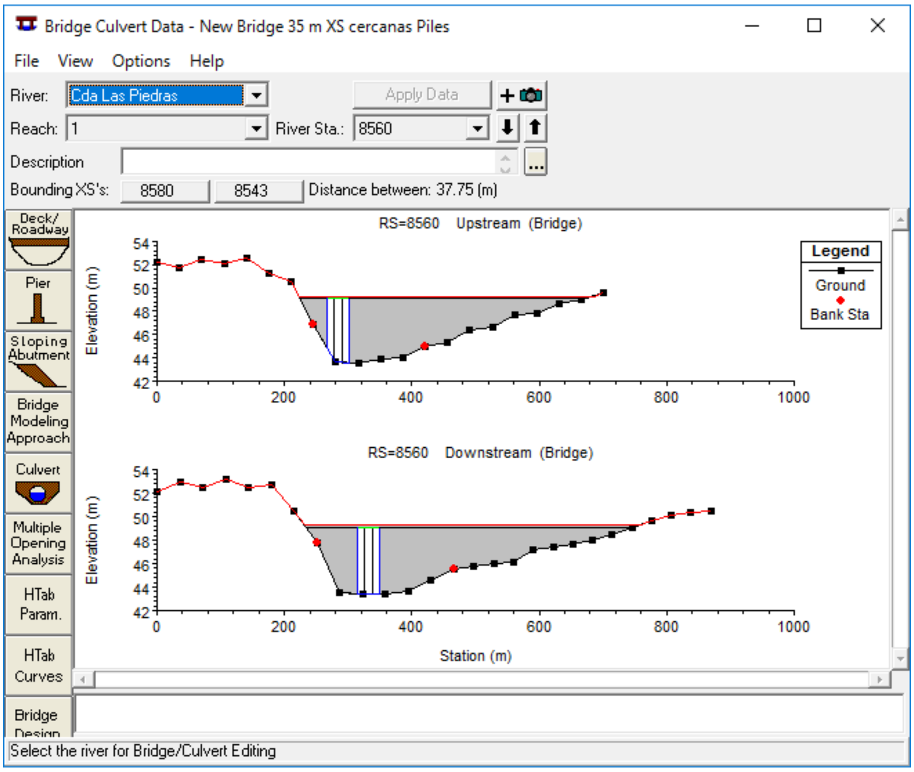


Figure 5-34 Input of 35 m span bridge with two 1.2 m piles

Maximum water elevation profile is shown in Figure 5-35, it can be seen that bridge increases levels upstream but it is a reasonable head loss and contraction to flow.

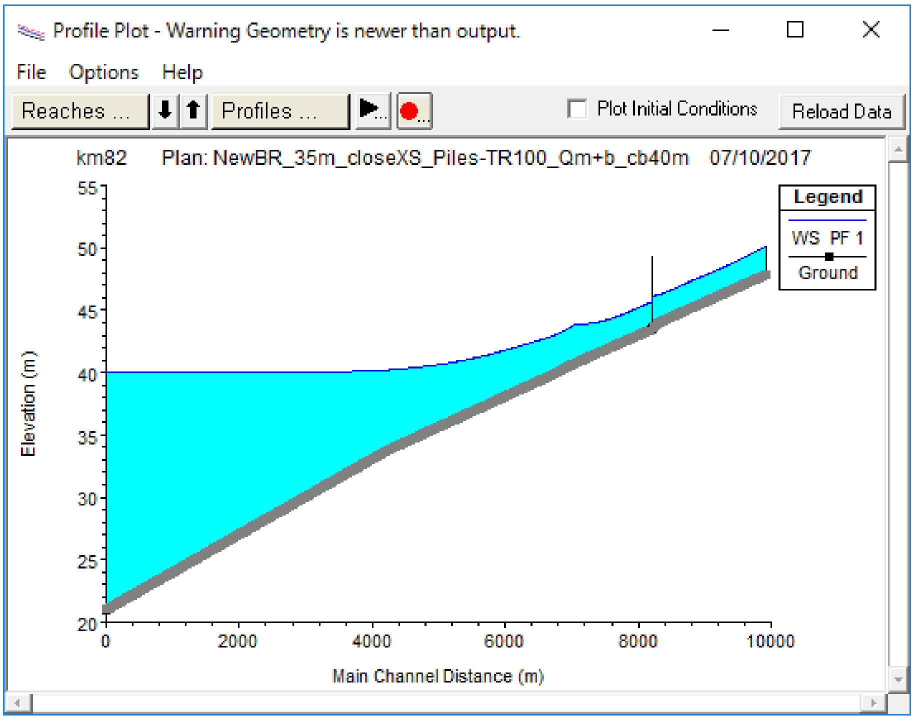


Figure 5-35 Maximum water elevation profile with 35 m span bridge with two 1.2 m piles

In Figure 5-36 the maximum water elevation upstream of bridge is presented, a value of +46.15 m is reached, this value is used to set the minimum bridge deck elevation by considering a free board of 0.90 m.

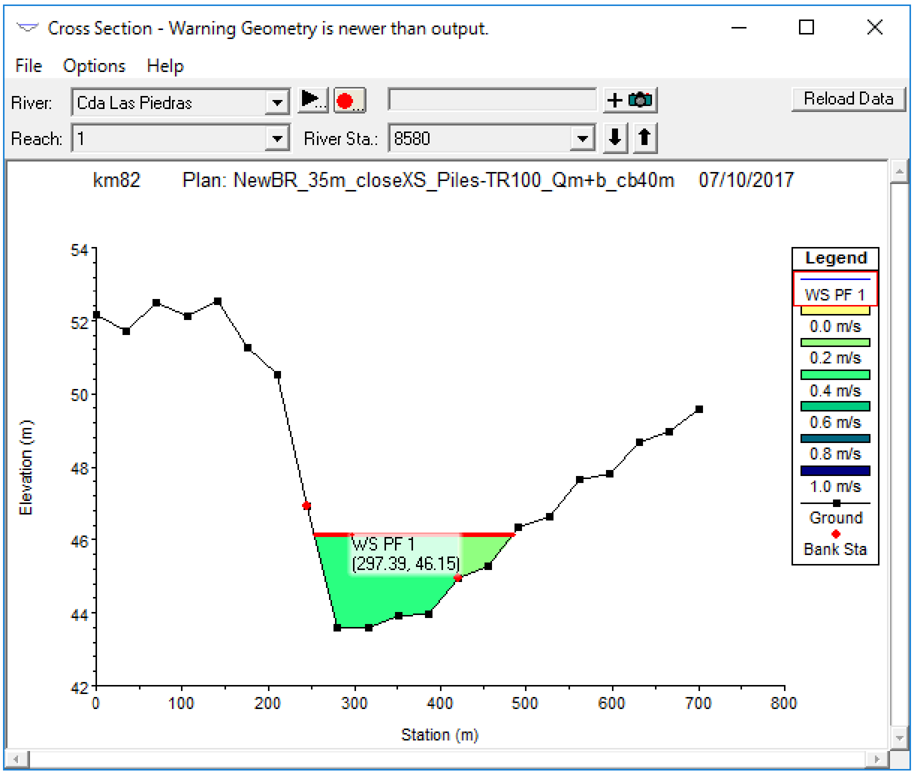


Figure 5-36 Maximum water elevation at section upstream of 35 m span bridge with two 1.2 m piles

In Figure 5-37 and Figure 5-38 maximum velocities at the upstream and downstream side of the bridge respectively are presented, values are under the recommended 2.5 m/s.

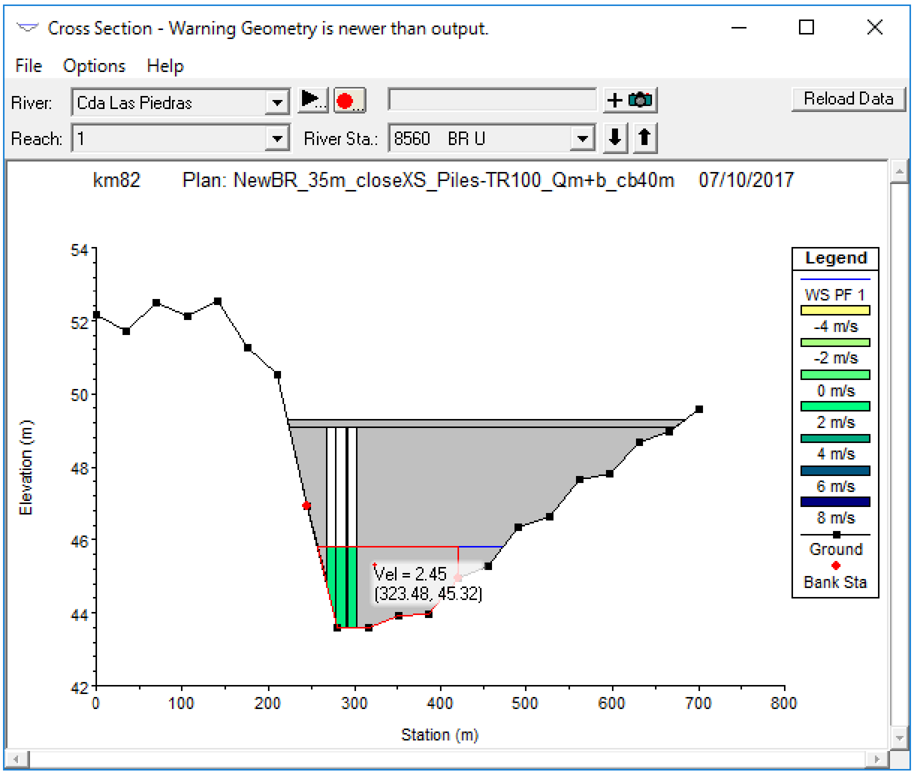


Figure 5-37 Maximum velocities upstream of 35 m span bridge with two 1.2 m piles

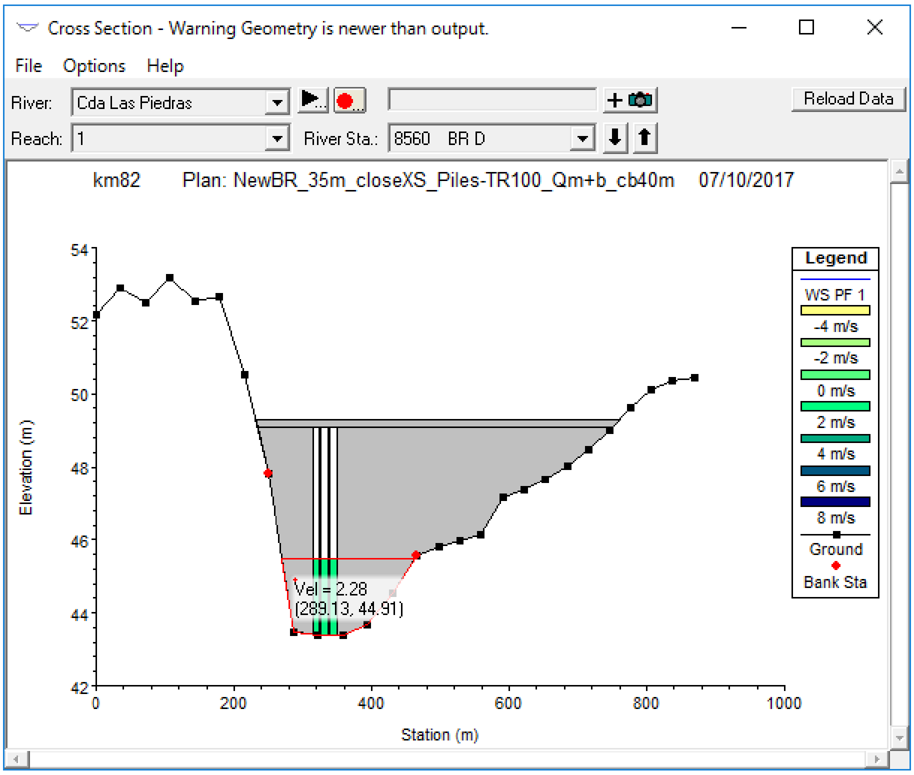


Figure 5-38 Maximum velocities downstream of 35 m span bridge with two 1.2 m piles

6. Conclusions

A first simulation without bridge was performed in order to assess which would be the flood levels without infrastructure, as a natural stream, result was +45.96 m.

When adding the existing bridge and railway abutments, flood level increase towards +48.54 m, which is very similar to the 1925 year flood levels. This is not only a proof of model having good representation of what happens but also that the existing 9 m span bridge is an important contraction to expected flow for that catchment.

After, a simulation with the projected 15 m span bridge and railway elevation was done. In this case expected flood levels upstream of bridge is + 47.68 m, which mean that with railway elevation at +49.29 m there are 1.61 m for free board and deck height. We recommend 0.90 m free board to prevent floating logs and debris to hit deck of bridge, in that case 0.71 m are available for bridge deck. Nevertheless, velocities through the bridge are very high, 3.5 m/s and 4.7 m/s upstream and downstream respectively. This could produce heavy erosion at piles and abutments and compromise bridge stability. Therefore greater span is recommended and further analysed.

Next, a 25 m bridge was simulated, with velocities between 2.9 and 3.3 m/s, which are still high considering recommendations of maximum velocities through bridges of 2.5 m/s.

Then, a 35 m bridge was performed, with results complying with normal bridge hydraulical design criteria. Velocities range from 2.1 to 2.4 m/s, and upstream flood level expected is +46.04 m. If today railway elevation of +47.91 m is consider it means there is 1.87 m clearance for free board and deck height. Considering a 0.90 m freeboard, deck of new bridge lower elevation should be higher than +46.94 m.

Finally, two piles of 1.2 m diameter were added to the 35 m bridge. Velocities range from 2.28 to 2.45 m/s, and upstream flood level expected is +46.15 m. Considering a 0.90 m freeboard, deck of new bridge lower elevation should be higher than +47.05 m.

A new bridge of approximately 35 m span or horizontal clearance is recommended, with two circular piles of 1.2 m of diameter, and lower deck elevation higher than +47.05 m.

If from structural point of view, bridge requires different piles, results should be recalculated.

7. Annex

7.1. Cross sections

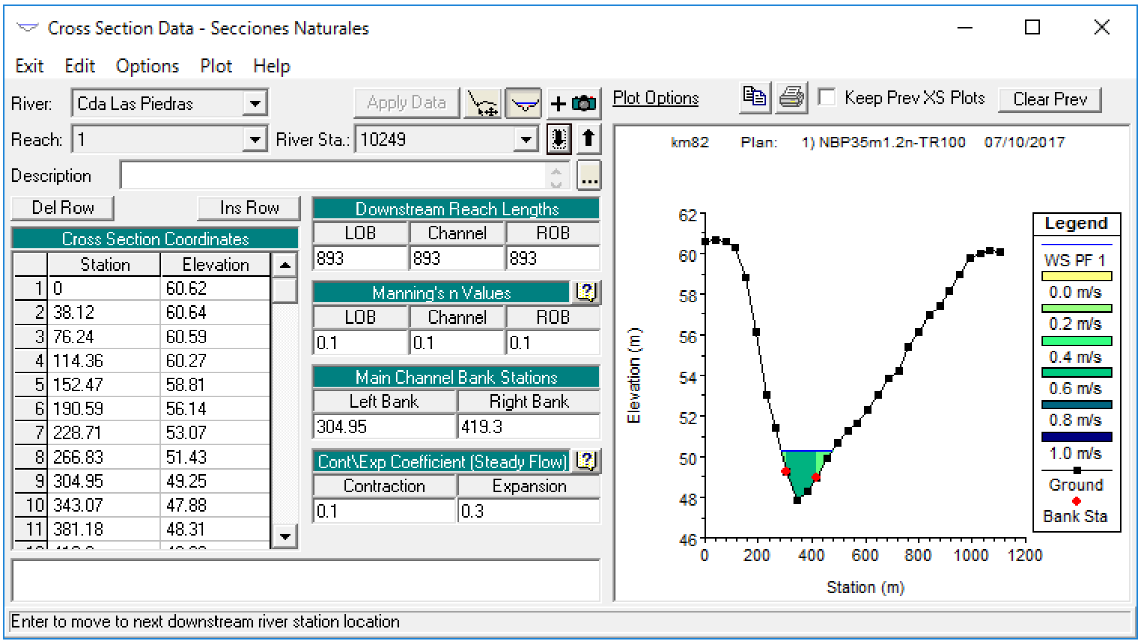


Figure 7-1 Cross section 10249

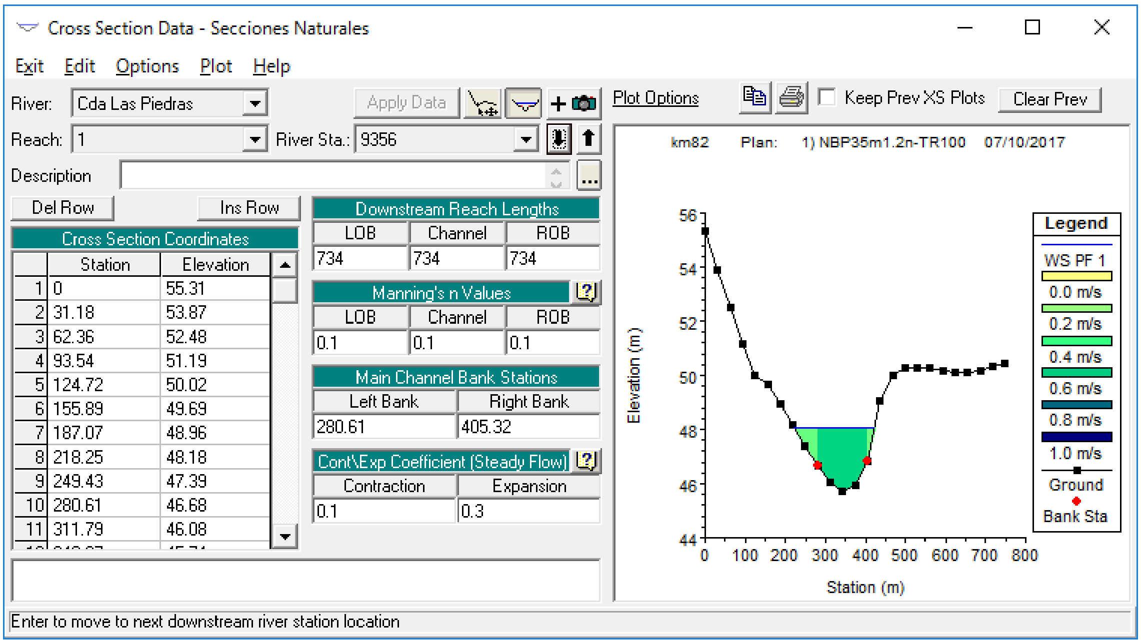


Figure 7-2 Cross section 9356

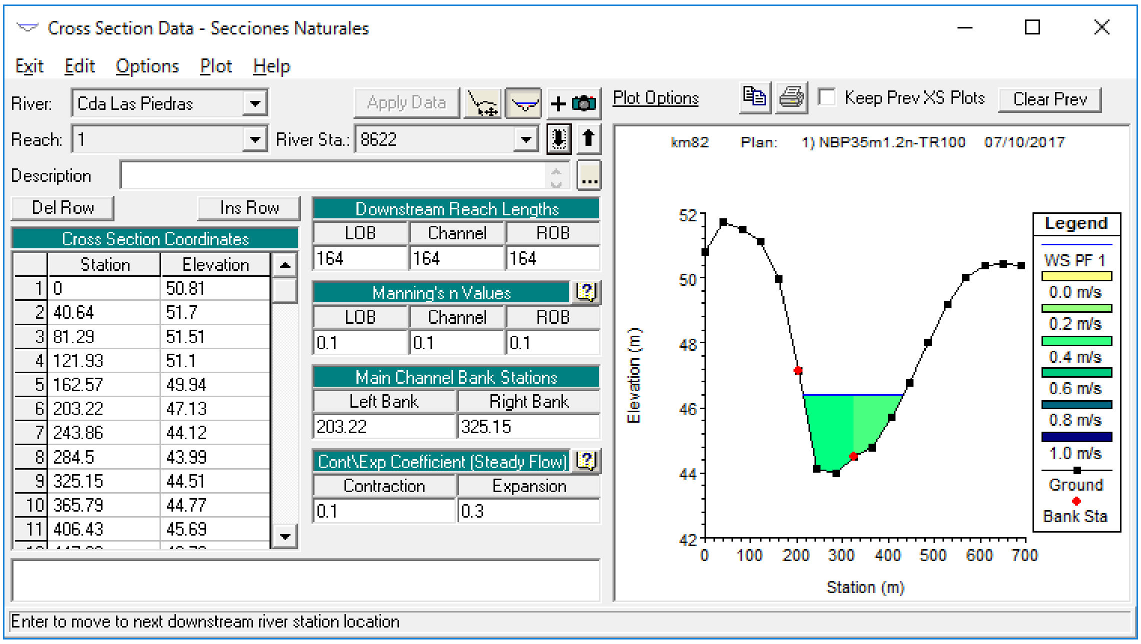


Figure 7-3 Cross section 8622

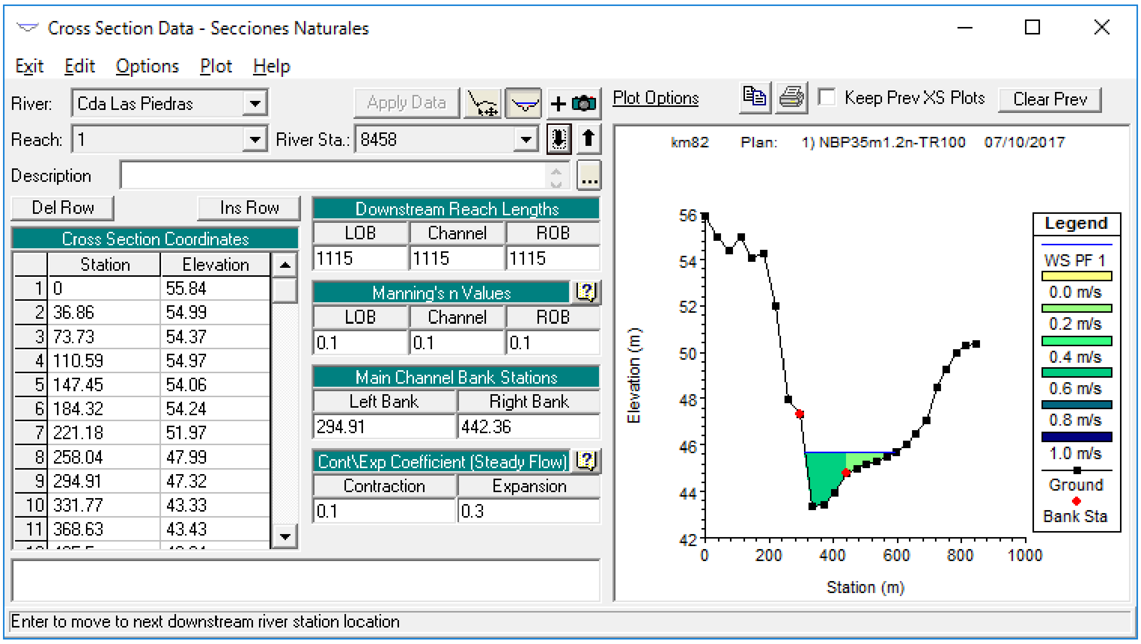


Figure 7-4 Cross section 8458

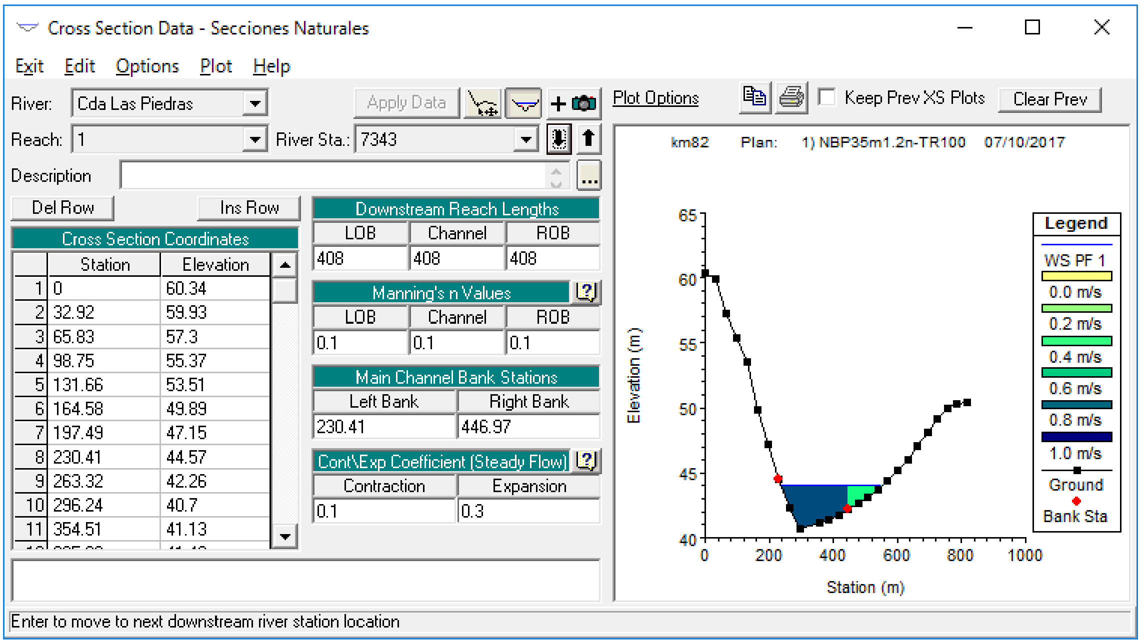


Figure 7-5 Cross section 7343

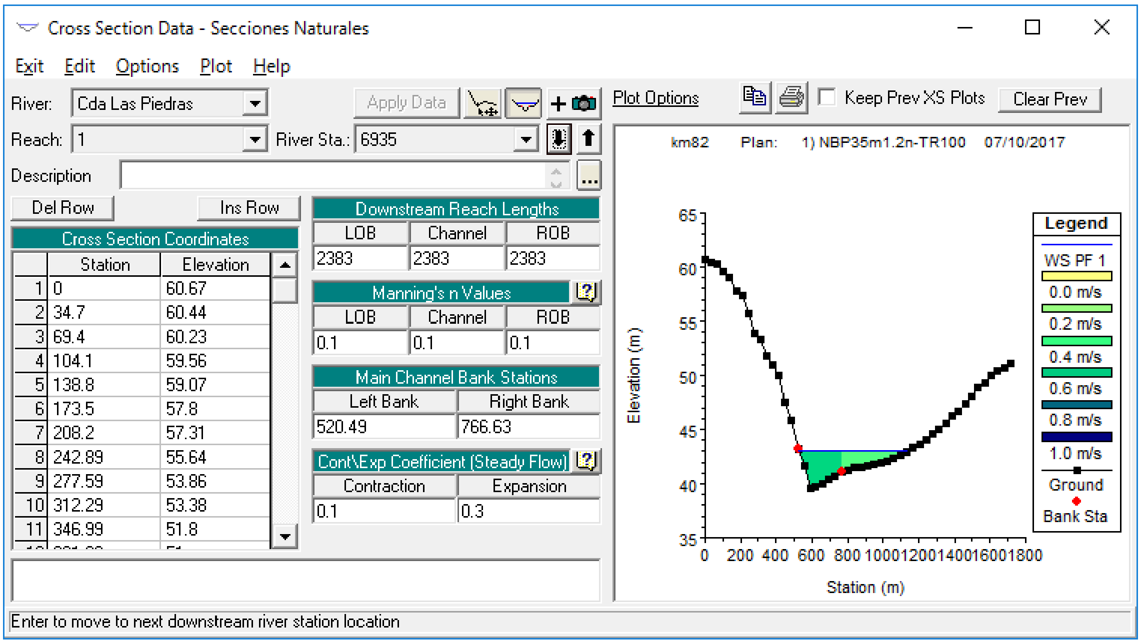


Figure 7-6 Cross section 6935

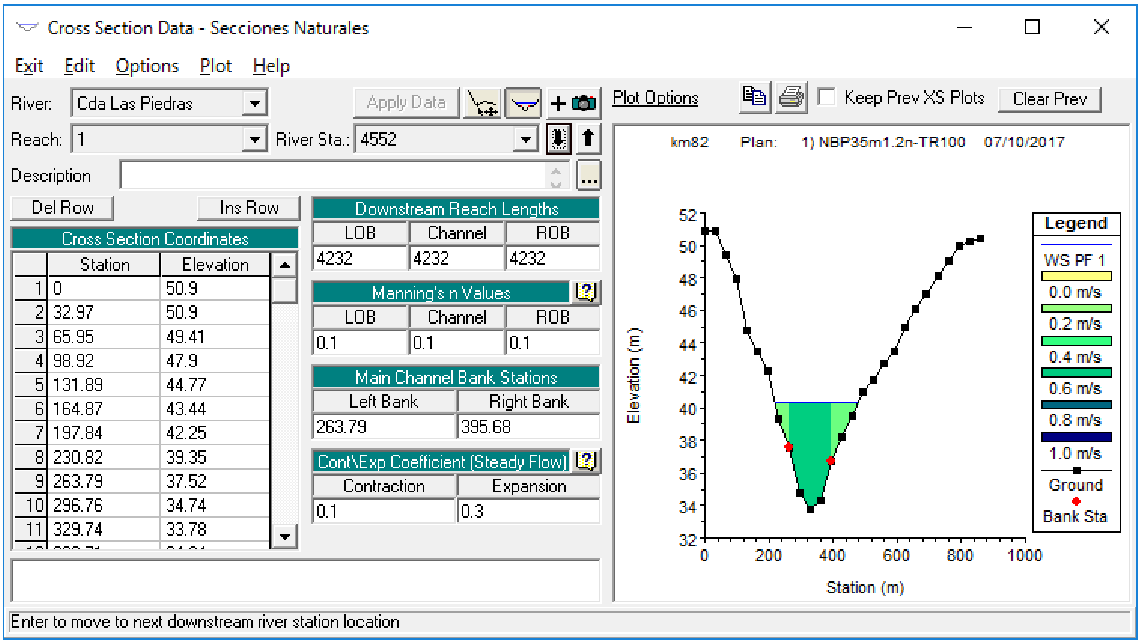


Figure 7-7 Cross section 4552

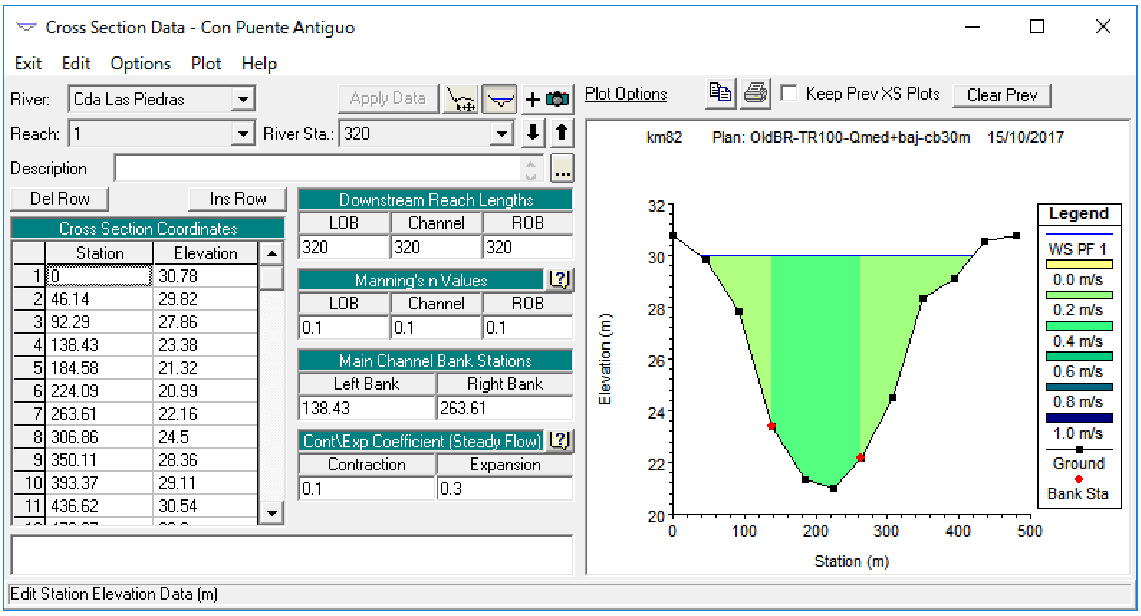


Figure 7-8 Cross section 320