Determination of the water level for 100 year return period for the new railway toward the plant near Paso de los Toros – Final Report

October 2017

Revision	Date	Elaboration Responsible	Approval Responsible	Comments
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1				
2				
3				

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Acronyms

CN	Curve Number
DINAGUA	National Water Directorate
DINASA	National Water and Sanitation Directorate
IDF	Intensity – duration - frequency
NRCS	Natural Resources Conservation Service
SCS	Soil Conservation Service
Tr	Return period

1. Introduction

The location of the new railway towards the plant, near Paso de los Toros, seems to be in the flood area. This study determines the water elevation in the area for the 100 year return period event.

As the new railway line is located between two creeks, the water elevation associated to the 100 years return period was computed for the two watercourses. For this, a hydrological and a hydraulic study were conducted for each creek.

The hydrological studies were done using the NRCS method and included the characterization of each catchment, the computation of its time of concentration, effective rainfall and finally the design hydrograph.

The hydraulic studies were done with the HEC-RAS software form the US Corps of Engineers. The models created simulate the behaviour of each creek.

2. Hydrologic study

2.1. Catchments delimitation

As the new railway line is located between two creeks, two catchments are relevant for this study. They are called in this study “Catchment 1” and “Catchment 2”. The following figure presents the delimitations of the catchments and the following table the coordinates of their closing point. The Table 2-2 presents the characteristics of the catchments.

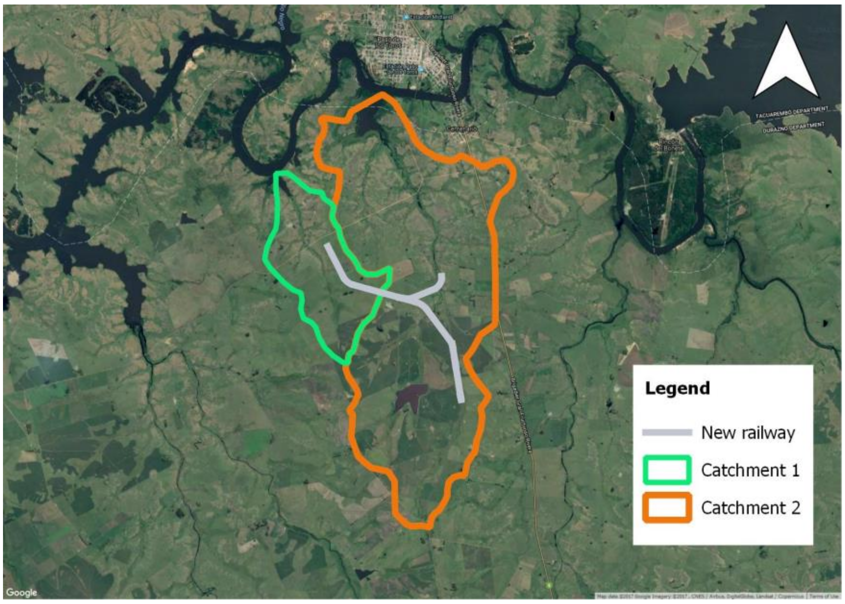

Figure 2–1 Catchment 1 and Catchment 2 delimitation

s	E (referred to UTM84-21S)	S (referred to UTM84-21S)
Catchment 1	541059.94	6365922.53
Catchment 2	544503.86	6368450.67

Table 2–1 Coordinates of the closing point of Catchment 1 and Catchment 2

	Area (km^2)	Main length (km)	ΔH (m)	Slope (m/m)
Catchment 1	11.76	7.27	50	0.007
Catchment 2	50.88	18.0	60	0.003

Table 2–2 Physical characteristics of the catchments

2.2. Input flow

The method of the Natural Resources Conservation Service (NRCS)[1] of the United States was used to define the input flow to the catchments. This method calculates the runoff for extreme events, given the precipitation, soil characteristics and catchment cover. In addition, it proposes the use of a Triangular Unit Hydrograph to estimate the maximum flow and its associated hydrograph, from the effective rainfall.

The method consists of three stages:

- Synthetic Storm (Alternating Block Method).
- Effective rainfall (SCS Curve Number Method)
- Unit Hydrograph (SCS triangular hydrograph).

2.2.1. Design Storm

The storms for both catchments were built for 100-year-return period and constructed using the Alternating Block Method, recommended in Chapter 7.3.3 of the Urban Storm Water Design Manual of the National Water and Sanitation Directorate (DINASA[2], for its name in Spanish). For the construction of these hypothetical storms, the available information of intensity-duration-frequency curves presented in Chapter 7.3.2 of DINASA's manual was used.

In the Alternating Block Method, rainfall intensity is divided into time intervals, where rainfall intensity remains constant. To determine the size of each interval, first the time of concentration of the catchment was computed using the Kirpich equation:

$$t_c = 0{,}066 \times \frac{L^{0{,}77}}{S^{0{,}385}}$$

where,

t_c: is the time of concentration in hours

L: is the hydraulic length of the catchment (km), and corresponds to the largest flow path

S: is the average slope of the longest hydraulic path

The following table present the time of concentration of both catchments.

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[1] Formerly known as the Soil Conservation Service (SCS)

[2] Formerly known as National Water Directorate (DINAGUA, for its name in Spanish)

	Time of Concentration (hours)
Catchment 1	2.1
Catchment 2	5.5

Table 2–3 Time of concentration of Catchment 1 and Catchment 2

The numbers of blocks used to create the design storms were such that they cover at least twice the estimated time of concentration. We considered 25 blocks of 10 minutes each for Catchment 1 and 34 blocks of 20 minutes each for Catchment 2.

The precipitation intensity is the average rainfall rate, usually expressed in millimetres per unit of time. The value assumed is closely linked to the period of return of the storm (Tr) and the duration of the rainfall. The intensity – duration – frequency curves (IDF) and the Montana Law were used for the computation of the rainfall intensity. According to the Montana Law:

$$i = a \times t^b$$

where,

i: is the rainfall intensity in mm/h

t: is the duration of the storm in hours

a and b: are coefficients that depend of the duration and return period of the storm; they can be calculated using the following expressions:

- If the duration is smaller than 3.5 hours:

  $$a = P(3{,}10, p) \times (0{,}1241 \times ln\,(Tr)\; + 0{,}317)$$

  $$b = -0{,}547$$

- If the duration is bigger than 3.5 hours:

  $$a = P(3{,}10, p) \times (0{,}1567 \times ln\,(Tr)\; + 0{,}4017)$$

  $$b = -0{,}725$$

where,

Tr: is the return peridod in years

$P(3{,}10, p)$: is the height, in mm, of precipitation for a storm with duration of 3 hours and 10 years of return period. It is obtained from the map of isohyets of extreme rainfall in Uruguay. For the location of the catchments it takes a value of 88 mm.

The following table presents the coefficients a and b for this study.

Duration	a	b
Less than 3.5 hours	78.1881	-0.547
More than 3.5 hours	98.8531	-0.725

Table 2–4 Coefficients a and b to compute rainfall intensity

The following figure presents the design storms for 100 year return period for Catchments 1 and 2.

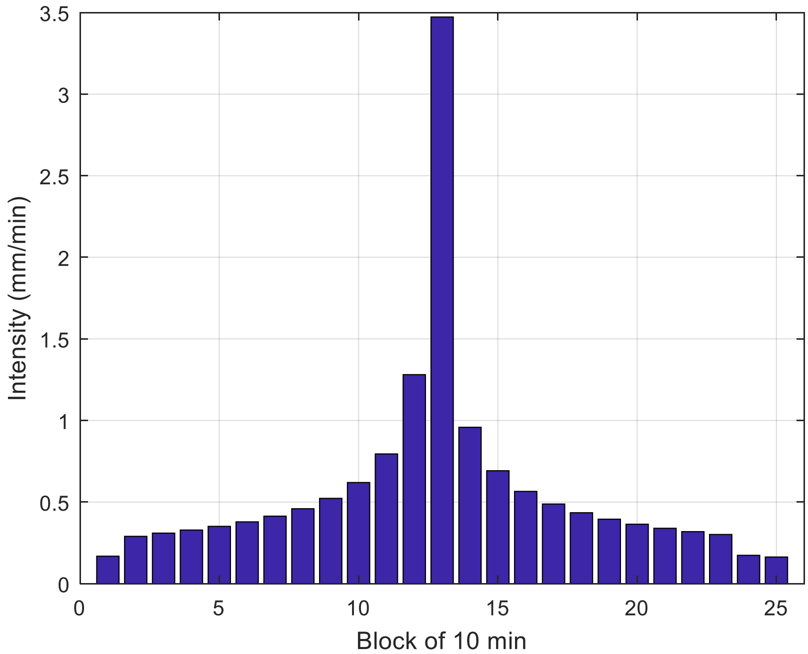

Figure 2–2 Synthetic design storm for 100 year return period for catchment 1

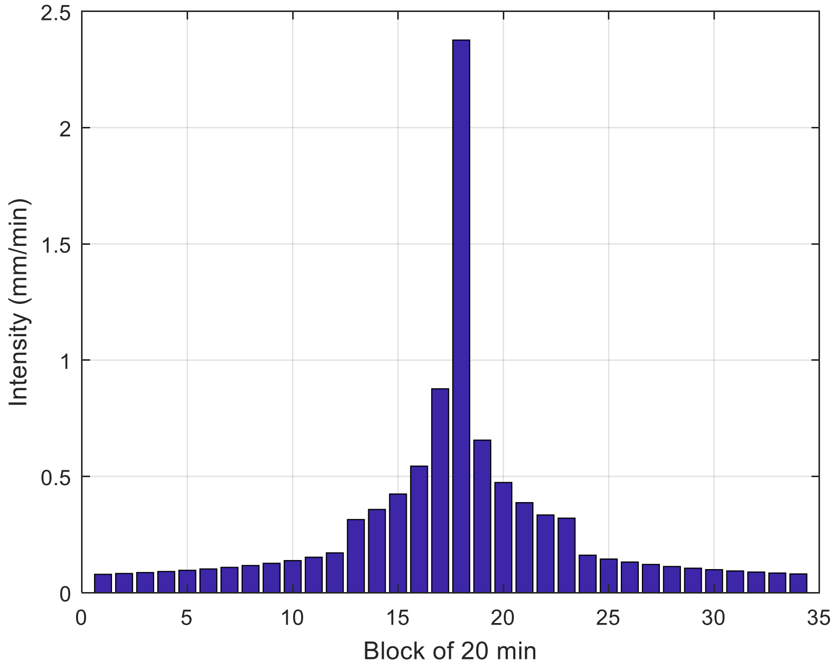

Figure 2–3 Synthetic design storm for 100 year return period for Catchment 2

2.2.2. Effective Rainfall

The effective rainfall is the part of the total rainfall that falls on a given area that generates direct runoff. It is computed from the design storm, already determined in the previous item, and the soil unit.

The effective rainfall is calculated for each interval of the design storm presented in item 2.2.1. From the cumulative volume of the storm, the runoff was calculated using the Curve Number Method (hereinafter CN), following the equations shown below.

- If P < 0,2 S

$$P_e = 0$$

- If P > 0,2 S

$$P_e = \frac{(P - 0{,}2S)^2}{(P + 0{,}8S)}$$

where,

P_e: is the effective rainfall

P: is the total rainfall

S: is the potential maximum retention of the soil, which depends on the CN, which in turn depends on the hydrological groups of the geological formations and their coverage. It is calculated as:

$$S = 25{,}4 \times (\frac{1000}{CN} - 10)$$

The CN have been tabulated by the NRCS based on the type of soil, its use, coverage and hydrological condition.

In order to define the soil type of the catchment, the Soil Recognition Map of Uruguay was used. The following table presents the soil type, its percentage and the associated hydrology group for each catchment.

	Soil type	Percentage (%)	Hydrology group
Catchment 1	Baygorria (By)	100	C
Catchment 2	Baygorria (By)	95	C
	Curtina (Cu)	5	D

The soil use was identified with the Land Used Map of the Ministry of Livestock, Agriculture and Fisheries of Uruguay. The following Tables present the Land Uses of each catchment and its area according to the hydrology group when needed.

Land Use	Area (km^2)
Dry crop > 2 ha	1.25
Watercourses	0.15
Natural meadow	7.36
Natural or improved meadow or arable crop	2.16
Uncovered soil associated to agriculture or forest plantation	0.85

Table 2–5 Land use of the Catchment 1

Type of soil	Land Use	Area (km^2)
C	Dry crop > 2 ha	1.06
	Watercourses	0.52
	Native forest	0.23
	Forest plantation > 5 ha,	0.04
	Natural meadow	29.49
	Natural or improved meadow or arable crop	14.02
	Uncovered soil associated to agriculture or forest plantation	3.18
D	Natural meadow	1.87
	Natural or improved meadow or arable crop	0.52

Table 2–6 Land use of the Catchment 2

This land uses were associated with the categories of land use presented in the Urban Storm Water Design Manual of DINASA, which have associated the NC. The following tables present the final land uses adopted and the associated area for each catchment.

Land use	NC	Area (km^2)
Crops cultivated in rows	84	1.25
Water bodies	100	0.15
Meadows	85	9.52
Low density grass and bushes	71	0.85

Table 2–7 Adopted land use of Catchment 1

Soil type	Land use	NC	Area (km^2)
C	Crops cultivated in rows	84	1.06
	Water bodies	100	0.52
	Forest	77	0.27
	Meadows	85	43.52
	Low density grass and bushes	71	3.18
D	Meadows	2.40	89

Table 2–8 Adopted land use of Catchment 2

The final NC of the catchments was computed by calculating the weighted average of the NC associated to the different land uses. The following table presents the NC adopted for each catchment.

	NC
Catchment 1	89
Catchment 2	84

Table 2–9 NC adopted for Catchment 1 and Catchment 2

2.2.3. Computed hydrograph

For each catchment, a Unit Hydrograph was constructed using the time of concentration and the area according to the NRCS methodology presented in the Urban Stormwater Design Manual of DINASA. The Unit Hydrograph consists of a triangle that has the following shape:

$$t_p = \frac{D}{2} + 0{,}6 \times t_c$$

$$t_b = 2{,}667 \times t_p$$

$$q_p = \frac{0{,}208 \times A}{t_p}$$

where,

t_p: is the time to peak of the hydrograph (hours)

D: is the duration of the block of rainfall (hours)

t_c: is the time of concentration (hours)

t_b: is the base time of the hydrograph (hours)

A: is the area of the catchment (km^2)

q_p: is the maximum discharge of the hydrograph (m^3/s)

Subsequently the properties of linearity and overlap were applied by multiplying the Unit Hydrograph by each increment of runoff and adding these hydrographs by displacing them over time. In this way, a hydrograph corresponding to the design storm is obtained, whose integral in time is equal to the water drained volume.

The following figure presents the obtained hydrographs for each catchment.

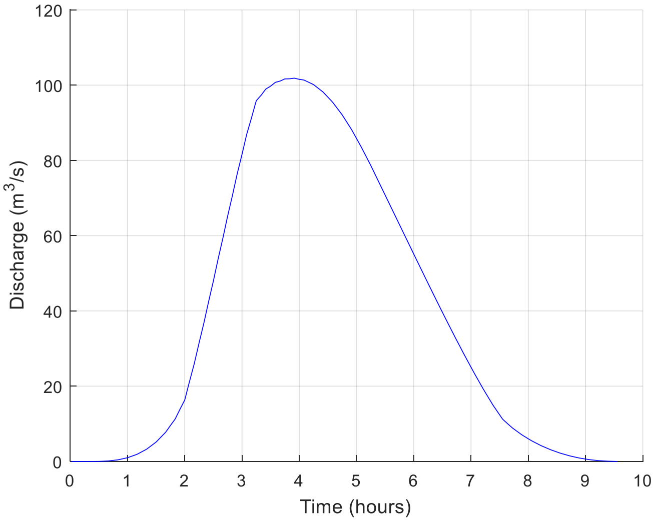

Figure 2–4 Computed hydrograph for Catchment 1

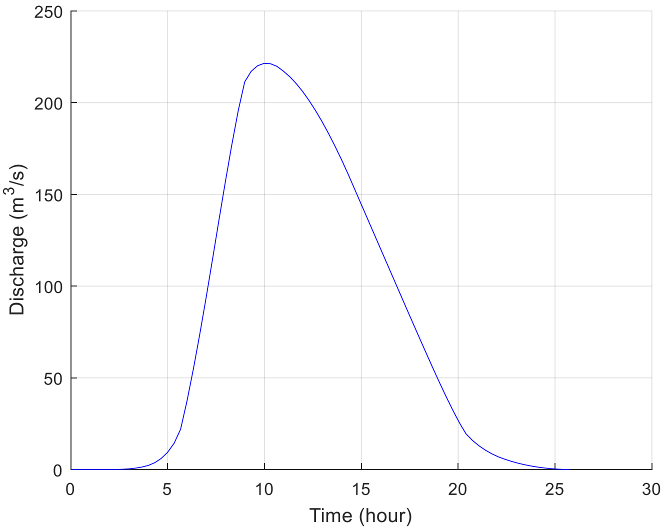

Figure 2–5 Computed hydrograph for Catchment 2

3. Hydraulic study

Two hydraulic models, one for each catchment, were created using the HEC-RAS modeling system to calculate the water level associated to the 100 year return period event for both catchments.

3.1. Description of the HEC-RAS modelling system

The HEC-RAS is a hydrodynamic modelling system designed to simulate one-dimensional free surface flow in networks and natural or artificial channels. The model is developed by the Hydrologic Engineering Centre of U.S. Army Corps of Engineers and has been extensively tested.

The system contains four main components for the hydraulic analysis of the pipes:

- Calculation of the free surface profile for steady flow.
- Non-stationary flow simulation.
- Calculation of sediment transport with moving bed.
- Analysis of water quality

The key element of the modelling system is that the four components use the same physical model and routines for the hydraulic and geometric calculation. In addition, the system contains several utilities for designing hydraulic structures, which can be invoked once the basic profiles of the free surface have been calculated.

3.2. Cross-sections

The bathymetry considered for the hydrodynamic models was obtained the Digital Terrain Model from the Ministry of Livestock, Agriculture and Fisheries of Uruguay (MGAP, for its name in Spanish)

The following image presents the location of the considered cross-sections.

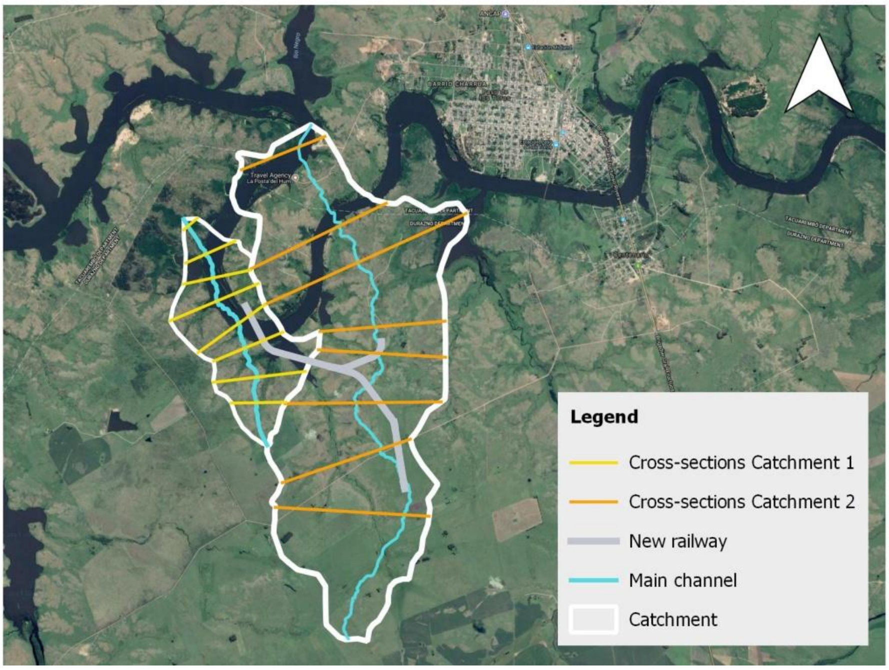

Figure 3–1 Cross-sections considered for the hydrodynamic model of Catchment 1 and Catchment 2

3.3. Boundary conditions and roughness

Each model presents the following boundary conditions:

- Upstream: hydrograph presented in item 2.2.3. corresponding to the Catchment 1 or Catchment 2 depending on the model
- Downstream: constant water level in the Negro river. The chosen water level corresponds to level in Paso de los Toros of the 100 year return period flood and it was computed in a previous study held by CSI Ingenieros in the Negro river basin for the state company Administración Nacional de Usinas y Trasmisiones Eléctricas (UTE). The computed water level is 59.11 m, referred to the Official zero.

The Urban Storm Water Design Manual of DINASA was considered for the selection of the roughness (Manning coefficient) of the models. This manual recommends a Manning coefficient of 0.15 for meadow of short grass and 0.24 for dense grass. To consider an intermediate situation, in this study was considered a Manning coefficient of 0.2 for both models. Although it is true that the roughness in the main channel of the creeks is smaller than in the flood plain, this study does not consider this difference and takes the same roughness for all cross-sections. As the objective of this study is to compute the maximum water level for each catchment in the new railway area, this consideration represents a worst case scenario for water levels.

3.4. Results

3.4.1. Catchment 1

The following figure presents the maximum water level profile. In green it is indicated the zone that corresponds to the area where the new railway is located.

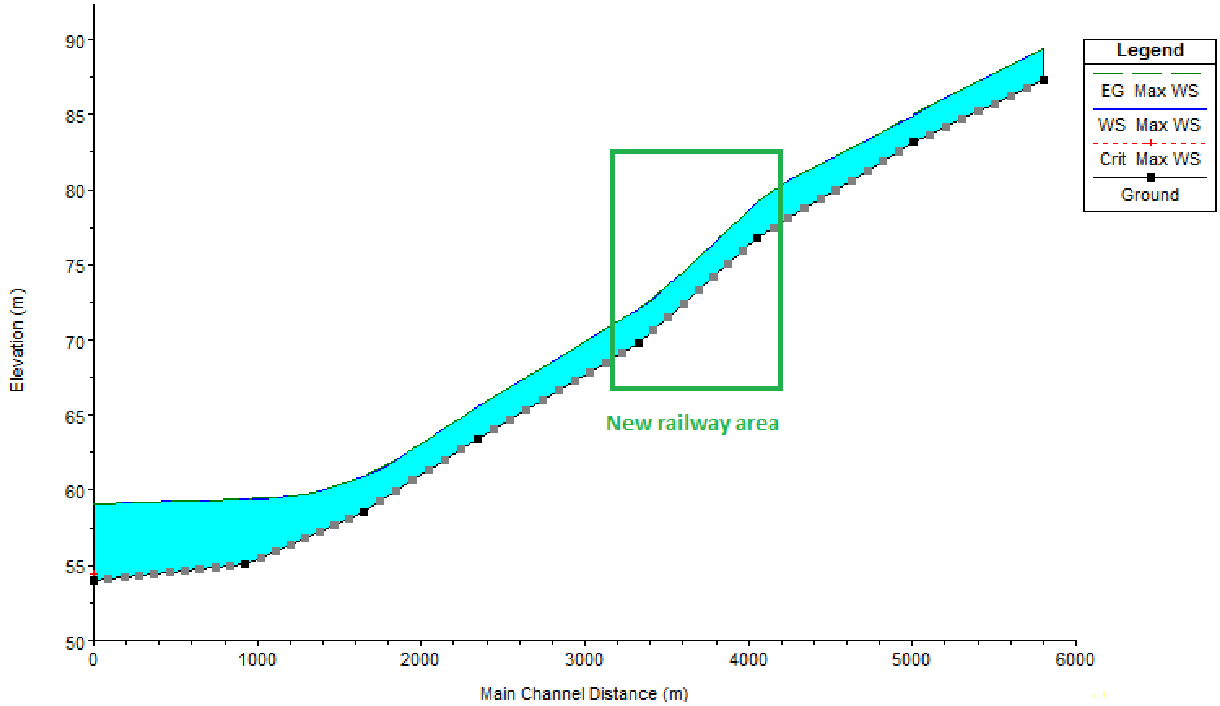

Figure 3–2 Maximum water level profile for Catchment 1

The following table presents the maximum water elevation and coordinates of two points in the area of interest. In the next figure is presented the location of these points

Point	E (referred to UTM84-21S)	S (referred to UTM84-21S)	Water elevation (m, Oficial zero)
1	542523.78	6363108.6	72.04
2	542702.25	6362453.53	79.17

Table 3–1 Water elevations in the area of the new railway for Catchment 1

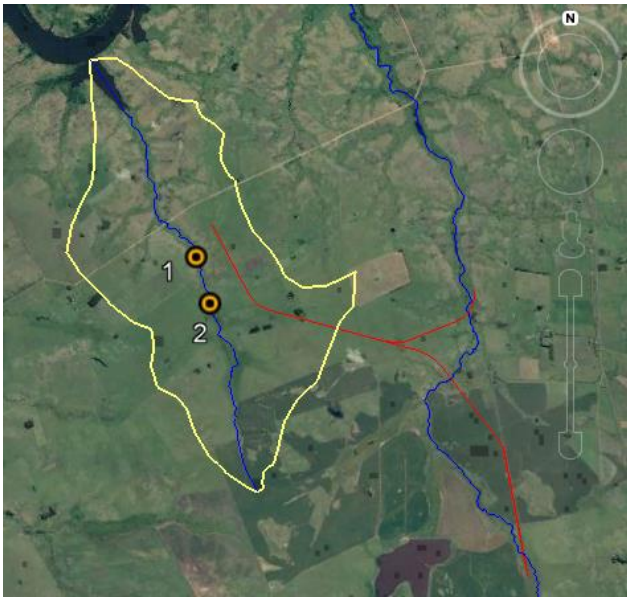

Figure 3–3 Location of the points where is given the water elevation in the area of the new railway for Catchment 1

According to the elevations presented in the DTM, the elevation where the railway is located in this catchment is over 83.5 m referred to the Official zero. Thus, it seems that there are no problems related to the water level of the creek in this area.

3.4.2. Catchment 2

The track of the projected train crosses the creek in two locations. In the following figure presents the location of these points.

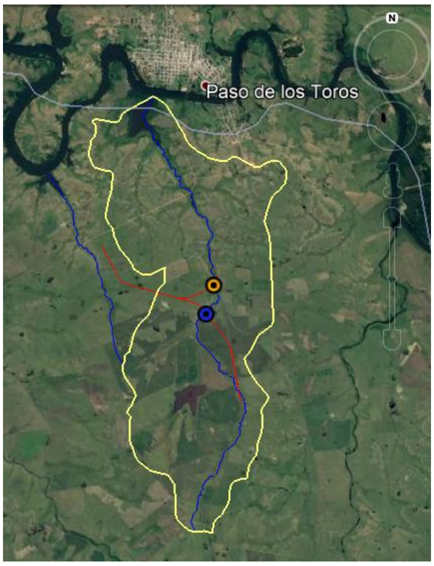

Figure 3–4 Location of the points where the projected railway crosses the creek of Catchment 2

The following figure presents the maximum water level profile. In green it is indicated the zone that corresponds to the area of the new railway.

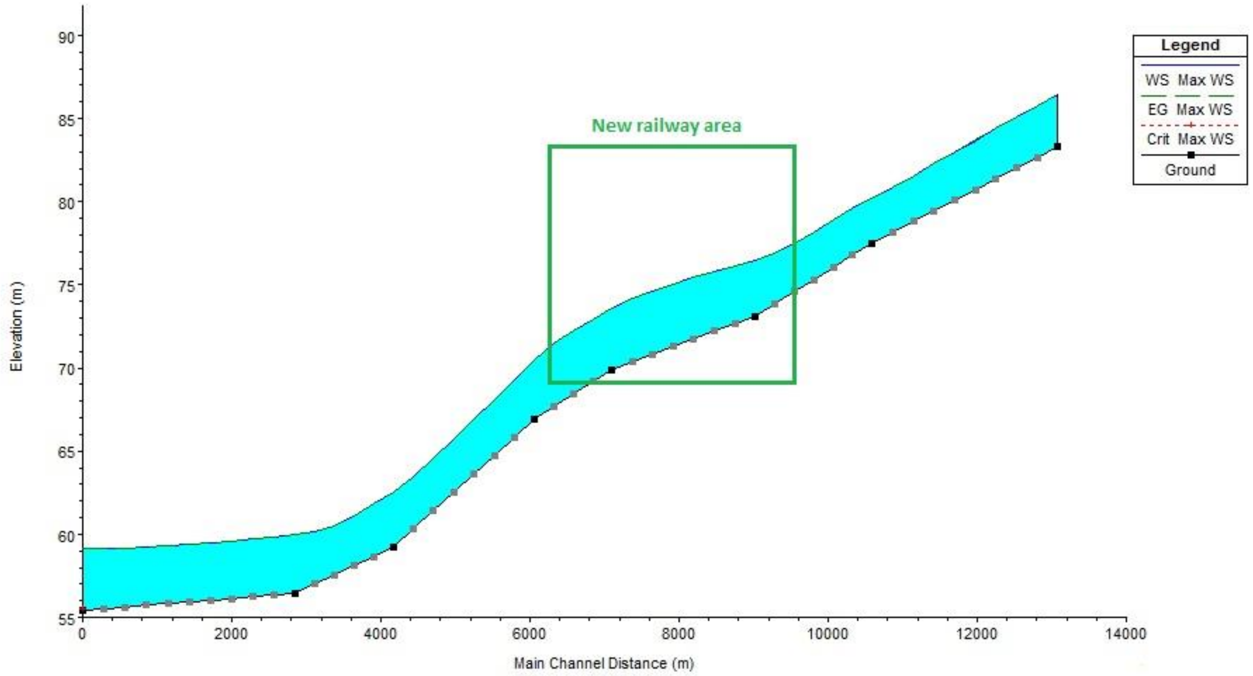

Figure 3–5 Maximum water level profile for Catchment 2

The following table presents the maximum water elevation in the area of interest. In colour blue and orange are highlighted the points were the railway of the train crosses the creek (the colours corresponds with the points presented in Figure 3-4).

E (referred to UTM84-21S)	S (referred to UTM84-21S)	Water elevation (m, Oficial zero)
546297.29	6362309.19	73.53
546356.00	6362046.00	74.19
546391.00	6361818.00	74.64
546230.00	6361743.00	75.04
546133.00	6361524.00	75.42
546032.00	6361383.00	75.78
545726.00	6361235.00	76.13
545695.00	6360967.00	76.48

Table 3–2 Water elevations in the area of the new railway for Catchment 2

4. Limitations and conclusions

4.1. Limitations

Some limitations of this study are worth to be mentioned:

- The cross-sections used to create the hydraulic model were obtained from a DTM. No survey cross-sections were used.
- The models were not calibrated. The selection of the roughness (Manning coefficient) of the hydraulic models was based on bibliography.

4.2. Conclusions

For Catchment 1, the maximum water level associated with the event with Tr equal to 100 years does not affect the track of the railway.

In relation with Catchment 2, the creek of this catchment crosses two times the projected railway track. For the nearest crossing point to the Negro river, the maximum water level for Tr equal to 100 years is 73.53 m. For the farthest crossing point, the maximum water level is 75.75 m.