# FINAL REALIGNMENT SAN ANTONIO RIVER, DESIGN. STRUCTURES ON THE RIVER BED AND BANKS.

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## ABSTRACT

In all open-pit mining activities show different alterations of the natural conditions of the system intervened, therefore, it is necessary to implement mitigation plans for the preserving the environment and the dynamics of rivers. In particular, the Drummond's Ltd. company developing a mining operation in the south of the department of Cesar. The San Antonio river is a natural stream that discharge through the exploitation area. It is necessary study, define and design the realignment of a section of the stream to give continuity to the drainage system and as part of the environmental management plan proposed by Drummond Ltd.

These activities had been designed to preserve the morphological, hydrological, hydrographic and geometric characteristics of the natural stream and the realignment the San Antonio river. Its meandriform conception allows to hold the natural conditions of the stream maintain the fluvial processes. The studies, designs and works on the slope and banks of the new realignment channel allowing its stability in the time.

## INTRODUCTION

Drummond Ltd. is engaged in open pit mining in the area that receives the name PRIBBENOW. For the development of this exploitation, it has been necessary to modify the natural discharge of the zone and design channel of the temporary realignment of the San Antonio Stream to lead the waters of the basin to a point of delivery again in the same stream. For the proposed mining progress, it is necessary to define a realignment of the main drainage channel towards the south of the zone. For this engineering project called Realignment No. 4, the hydrological, morphological and fluvial hydraulics studies take into account the confluence of the "Embalse Paujil" with the upper part of the San Antonio creek basin, the Caño Piedras, the Caño Melanquez and others dynamic elements of the system.

For the development of this engineering project, the hydro-climatological information was analyzed, different hietograms were constructed with the purpose of estimating the maximum flows and the hydrographs produced in the sub-basins of the study area, information necessary for the hydraulic flow through the new channel, as well as for the designs of different hydraulic sructure proposed to improve the stability in the plant and profile of the new realignment and of the area. The investigation take into account of different channels to this new realignment No. 4 and therefore, the necessary works to ensure proper management of flow.

At the schematic level, the general model, which search to reproduce the current flow conditions in the drainage network, considers a hydrological transit in the middle and upper part of the San Antonio Creek basin, located in the "Serrania del Perijá" area, up to the start of the new realignment channel; a hydraulic transit from the starting points of this diversion channel to the delivery point downstream and finally a hydrological transit from the delivery point of the realignment channel to the San Antonio Stream to the floodplain area in its discharge to the Cesar River.

The general scope of this work also includes the design of the realignment channel and works for the runoff handling according to the alignment established by Drummond Ltd.

## TOPOGRAPHIC AND ZONE INFORMATION. PARAMETERS

The natural and anthropic topography of the channels of interest on the San Antonio Creek basin is available, useful information for the delimitation of the watersheds and for obtaining the morphometric parameters required in the hydrological transit. In the plains areas, the topographic information provided by Drummond Ltd. corresponding to sections 250 meters wide every 500 meters on the layout of the new realignment which has been defined on properties owned by Drummond.

This information is necessary taking into account that the hydrograms generated with the HMS model used for the hydraulic transit of floods through the projected channel. From the information available, it is possible to implement a model that combines a hydrological transit in some sections of the drainage network, especially the initial and final points and a hydraulic transit in the realignment section.

As such, it's been an integrated geographic model of basins and drainage systems including realignment. The available information of the digital terrain models from NASA used with the reconditioning of the terrain carried out with the photointerpretation of channels carried out by Drummond Ltd.

## INFORMATION OF PHOTO RESTITUTED THE CANALS IN NATURAL STATE

According to the work carried out in the previous studies in which the water supply in the natural state was determined for the San Antonio Creek Basin, the drainage network consisted of 81 sections with an approximate length of 249 kilometers. In the Figure 1 shows a map of the general drainage of the area and the delimitation of the river basin.

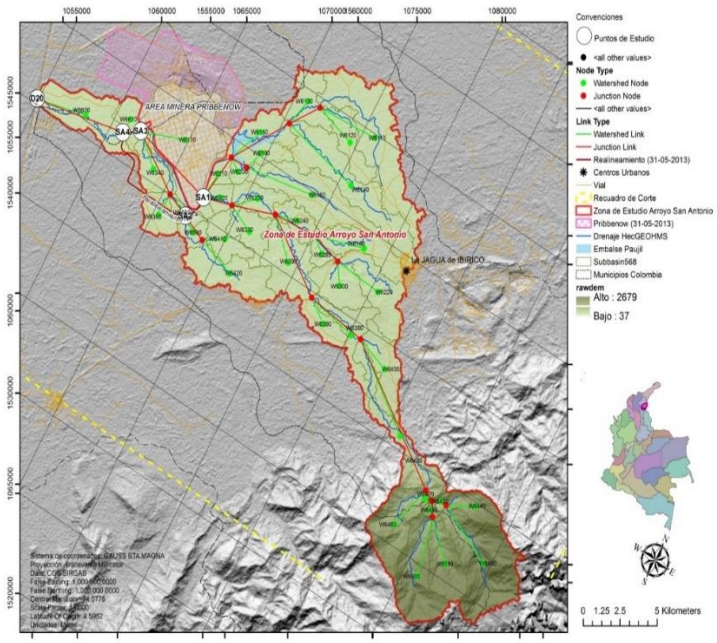


**Figure 1. Natural Drainage Network with HydroID identifier.**

## ANALYSIS OF ALTERNATIVES FOR THE AXES OF THE REALIGNMENT AND FEASIBILITY OF THE CHANNEL AND TRANSVERSAL SECTIONS. PLOTING AND PROFILE

The different hydraulic characteristics of the new realignment channel were studied and defined in accordance with the topographic, geological, geotechnical and morphological conditions to ensure its stability, due to other aspects, to the forced change in the conditions of runoff in the exploitation area mining. To carry out these analyzes and taking into account the information available and supplied by Drummond Ltd., it was very important to have a detailed visit to the exploitation area, especially at the start and discharge points of the new channel. As a result of the studies and designs proposed for the new channel, it has been necessary to implement bed stabilization and structures edge protection.

With the layout defined for the realignment channel, conditions have been established that allow the advance of mining towards the south west of the current mining front. The construction of this canal is necessary to divert the waters of the Paujil Canal and the upper basin of the San Antonio Creek to the south, to intercept the channel of the Caño Piedras (tributary of the current channel of the realignment). Additionally,

the new channel of realignment deviates in east-west direction and intercepts the channel of Caño Melanquez that discharge in a northwesterly direction, which later tributes its waters to Caño Piedras.

The intervention on the Caño Melanquez is presented in front of an existing box culvert and therefore its new download must be made in the new channel of realignment. From this point, the channel of realignment continues towards the west and its alignment takes direction northwest, to connect with the natural channel of the San Antonio Creek. From this point of delivery, the channel of the Arroyo San Antonio maintains its natural condition, that is to say it transports the runoff flows of the entire basin that come from the channels of the Paujil reservoir, San Antonio high basin, Caño Piedras and Caño Melanquez.

With the design of the realignment that includes its outline in plan and in profile and a series of works of control, management and protection of the bed, the current conditions of runoff in the current area of influence of the mining operation are modified. To visualize the detail of these modifications. In the Table 1 presents a comparison between the current conditions and the conditions after the intervention, product of the realignment. The new realignment has a length 22.3% greater than the current one; the speeds for the new channel are between 0.63 m/s and 1.13 m/s, speeds lower than those of the current realignments. It can be noticed that the slope of the new realignment is 23.16% less than the average of the slope of the current realignment, in order to achieve a slope similar to that of the San Antonio creek bed in this area.

The comparison of the cross sections allows observing that for the dominant flow (Tr = 2.33 years) the base, the height and the slopes of the channel are smaller than the current realignment (25 m and 35 m for the base, 1.5 m and 3 m for the height, 1: 1 and 2: 1 for the slopes, respectively) situation that is compensated with a more generous section for the flood flows that are transported through the valley, even though the designs correspond to different return periods.

**Table 1. Comparison between the channels of Realignment No. 2 and No. 3 (current) and Realignment No. 4.**

| Stream | Lengh (m) | Typical Section | Average Speed Max. Tr: 2.33 (m / s) | Average Speed Tr: 2.33 (m / s) | Average Longitudinal Slope (m / m) |
|---|---|---|---|---|---|
| Realignment No. 4 | 8990.1 | Main Channel: Trapezoidal Section, Base minor 25m, Base Major 28m, Slope 1: 1, Height 1.5m<br><br>Flow Tr: 50 years: Trapezoidal Section, Base smaller 80m, Base Major 88m, Slope 2: 1, Height 2.0m | 1.13 | 0.11 | 0.00133537 |
| Old realigment ** | 7379.38 | Existing Realignment ** 7379.38 Main Channel: Trapezoidal Section, Base smaller 25m, Base Major 28m, Slope 1: 1, Height 1.5m.<br><br>Flow Tr: 50 años: Trapezoidal Section, Base smaller 80m, Base Major 88m, Slope 2: 1, Height 2.0m | 2.00 | 0.41 | 0.001754286 |
| * Information measured on design plans and hydraulic models of ECI | | | | | |
| *Information taken from the study "Arroyo San Antonio deviación final" Channel No. 2 DRUMMOND | | | | | |

## HYDRAULIC DESIGN OF THE REALIGNMENT CHANNEL

Multiple hydrological modeling carried out at different points along the canal in order to obtain the input hydrograph (for different return periods) that used as an initial condition of the hydraulic modeling of the future realignment channel. The results of the San Antonio runoff hydrographs presented in Figure 2.

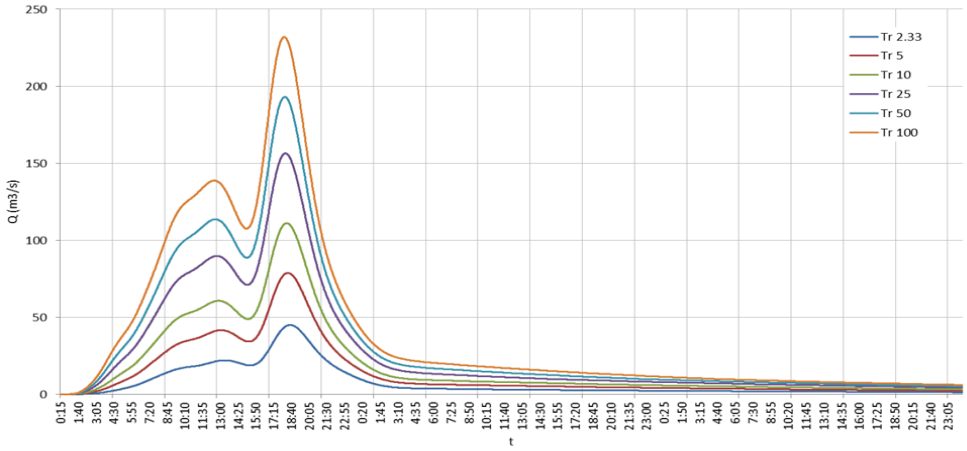


**Figure 2. Hydrogram of River San Antonio.**

The regional geology of the Valle del Cesar River in the area of influence of the project shows that superficially there is an alluvial plain with a succession of terraces resulting from the alluvial processes developed during the quaternary period. In general, the upper layers of the soil are formed by fine silty sands or sandy silts with a certain plasticity, materials that have angles of rest around 30 ° and with the possibility that this value increases considerably as the content of clay material increases. Based on the field observations it has been determined that, in order to guarantee the stability of the channel slopes, in the absence of flow, the lateral slopes for the section up to the dominant flow can be adopted between 2: 1 with an angle of 25.56 ° and 3: 1 with an angle of 18.43 °. It's values lower than the angle of repose of the material and assuming an unfavorable condition of without vegetal cover.

The material that forms the banks and that carries the Arroyo San Antonio, as observed during one of the technical visits made to the area, has plasticity and cohesion, a condition that considerably increases the angle of repose and the stability of the material of the banks, which reflected in more vertical slopes. Based on these considerations, the possibilities for using resting angles of the material expanded, that with a good margin of safety give the possibility of using side slopes in the channel and for the dominant flow of 1 to 1 or 0.75 to 1.

**Figure 3. Photograph of the Realignment Channel No. 4 of Arroyo San Antonio (1).**

These considerations and the temporary conditions of the runoff, for the design of the cross section of the realignment, it was proposed a made-up cross section of a natural channel. The main channel was designed (average waters and dominant flow, flow with return period of 2.33 years) with a trapezoidal section and lateral slopes 1: 1, so that these flows are transported properly and ensure the geotechnical stability of said section. The flood channel designed with a wider section with side slopes of 2: 1 for flows with return period of 50 years.

The longitudinal slope of the axis of the realignment must ensure the stability of the bed and achieve adequate cutting speeds and shear, consistent with the existing material, to prevent processes of deepening the channel bed and erosion of the walls thereof. Equally, possibly, it is necessary to reduce the costs generated by earth movements during the construction phase. Analyzes carried out related to the dynamic equilibrium of the system suggest an average slope of 0.00105 m / m. For the definition of the average slope the field visit was basic, the evaluation of the mechanical and granulometric characteristics of the material of the zone and the analysis of the existing geomorphological conditions in the Paujil channel and in the Arroyo San Antonioin natural and anthropogenic conditions, related to the length of the channels and their sinuosity.

To adjust the designs of the realignment to the current initial level at the confluence of the Paujil canal and the Arroyo San Antonio in the called upper basin and to the elevation of the new delivery over the San Antonio stream downstream of the mining exploitation area, it was necessary build twelve small structures, between K6 + 738.72 and K7 + 288.83. The location of these has been define with the possibility of improving and optimizing costs and construction processes. It is also important to mention that these structures, in spite of being staggered, do not interfere with the development and reproduction of the fauna existing in the streams, mainly the Blanquillo and Bocachico, species reported in the available information.

**Figure 4. Photograph of Realignment Channel # 4 of Arroyo San Antonio (2).**

The longitudinal profile of the canal was established based on the depths of the current channel, at the beginning and end of the channel, after the confluence of the Paujil Canal and the San Antonio Arroyo basin. According to the characteristics of the material on which the canal should be built, a speed of about 0.6 m / s for a flow with a return period of Tr = 2.33 years, recommended value according to the material available for the bed of the Chanel. Also according to these characteristics, it were established a Manning roughness coefficient of 0.02, depths of the water surface between 0.4 m and 1.3 m and slopes of 1: 1. For the design process to establish the appropriate cross section were used the methods of the permissible speed and the tractive force implemented in

HEC-RAS From the analyzes carried out, it is concluded that, for the parameters adopted, the shear stress must be less than 15 Pa.

For the flow of 55.2 m³/s, corresponding to a return period of 2.33 years, the depths of the water sheet, for a 1: 1 slope, are between 1 m and 1.5 m. As shown in Figure 2, a maximum section at the base of 16.7 m in width and 1.5 meters in height was obtained with a bottom armor with particles of maximum size 18.2 mm and in 10 mm slopes.

Based on the previous calculations, the natural conditions observed and the need for the channel to develop its sinuosity for medium and dominant flow conditions was used a trapezoidal channel 25 m wide for the conditions corresponding to the dominant flow and lateral slopes of 11, coinciding with the natural conditions of the river in this sector and the channel of previous realignment in the area that stable. This width of the base, higher than that obtained for the dominant flow, also ensures speeds and lower shear stress when this flow is transported.

Defined the section to transport flows until return period 2.33 years it evaluated the conditions for the transportation of the upper flows. Based on the existing natural conditions,a trapezoidal composite section was created, consisting of a lower trapezoidal section, 25 m in the base, slopes of 1:1 and 1.5 m high and a trapezoidal upper section of 80 m of base and 2 m height with slopes of 2:1, to ensure shear forces compatible with the available material and allow easy revegetation of the floodplain. This section for uniform flow conditions with a depth of water of 2.16 m. This section allows to safely transport flows with returns less than or equal to 50 years. The section was evaluated up to a flow rate of 248 m³/s.

Once the composite section was established, a verification of these dimensions was carried out using the HEC-RAS tool. According to the above, for a roughness coefficient of 0.02, a flow rate of 248 m³/s (return period of 50 years), the tool calculates the width of the flood plain at the height of the free surface. In Figure 3 it observes that for a width of the floodplain of 70 m the free surface of the water reaches a height of 3.25 m, leaving a free edge of 0.25 m. These dimensions have the disadvantage of transporting the flow with a height of the depth of water and relatively high shear stresses. The modeling was made with a depth of water similar to the one proposed, a width is obtained for the floodplain similar to the one initially proposed, as 80 m.

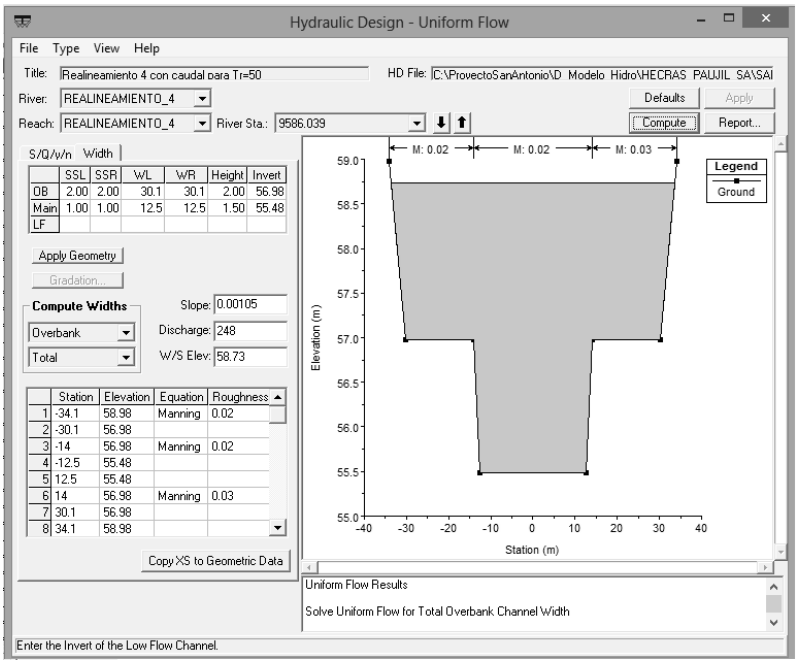


**Figure 5. Hydraulic simulation with Hec-Ras of realignment channel of the Arroyo San Antonio.**

In accordance with the considerations and analyzes carried out, the section established for the realignment of the Arroyo San Antonio, with the purpose of allowing the expansion of the mining front to the south, is presented in Figure 4. A composite trapezoidal section was adopted whose base is 25 m, height of 1.5 m and slopes 1: 1 and an upper section of 80 m of base and 2 m of height with slopes of 2: 1.

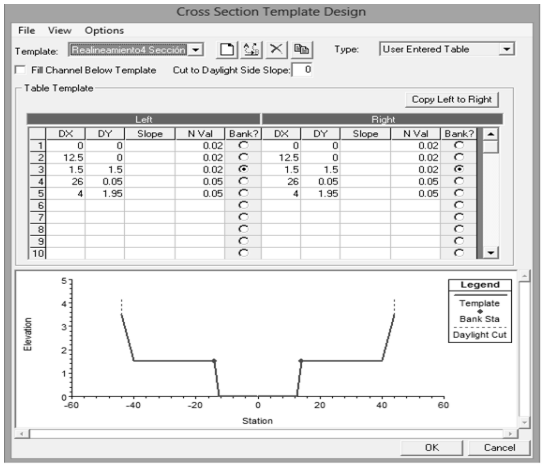


**Figure 6. Composite cross section adopted for realignment.**

To evaluate the hydraulic conditions of the canal and verify its dimensions, a modeling carried out under permanent flow conditions for medium, dominant and maximum flow. The results of the flow profile throughout the realignment are shown in Figure 7.

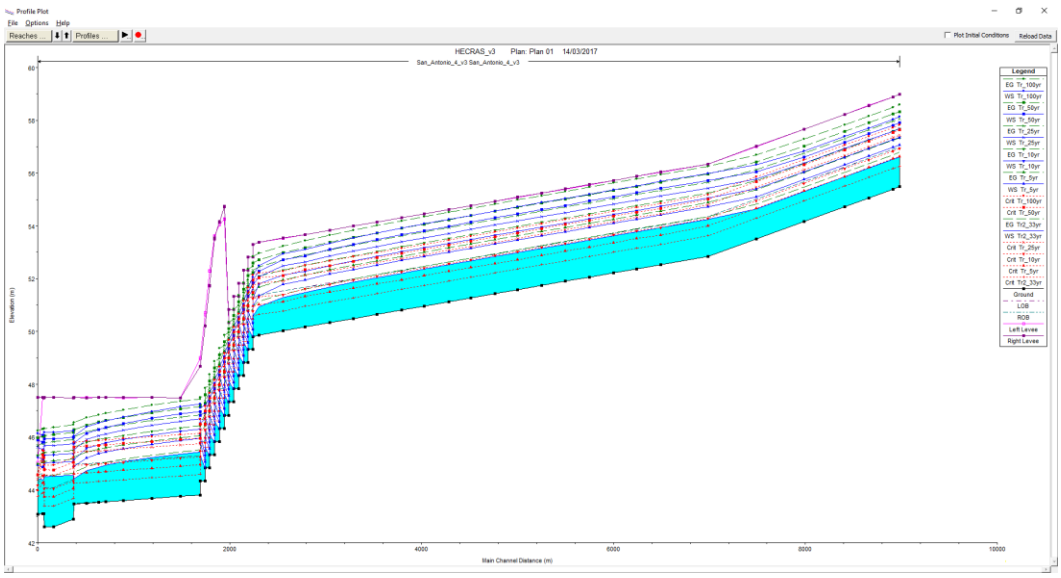


**Figure 7. Flow profile in Realignment No.4 of Arroyo San Antonio for uniform flow conditions.**

## CONCLUSIONS

According to the research carried out, the axis of the definitive channel proposed by Drummond Ltd. is posible from the geomorphological point of view and the fluvial dynamics.

The zone projected for the construction of the realignment in general corresponds to that of the basin of the stream before the mining exploitation; the average slope of the bed is very similar to that of the Arroyo San Antonio before the intervention, so that the length of its layout is adequate.

The analyzes have made it possible to define for the cross section of the realignment channel a composite section very similar to the natural channel, that is, a section corresponding to the dominant flow and a section for the flood plain in such a way that it is possible to dampen considerably the crescent of the Arroyo. The width projected for the floodplain is sufficiently generous and the final dimensions must be adjusted and defined at the design stage.

The bed will be built on a landfill formed by material that was excavated during the mining and in order to control the processes on the channel derived from its dynamics mainly in medium and low waters (change in the sinuosity, braids, deposition, accretion and erosion of the banks) control works along the rive are planned that are very low cost and that can be easily maintained since they have been projected using materials available in the area.

To ensure the stability and impermeability of the projected channel it is very convenient, from now on, in the stage of the definitive designs, to take into account the general geotechnical recommendations indicated in the present investigation.

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