AN AUTOMATIC PROCEDURE TO DETERMINE MAGNITUDE AND LOCATION OF ERODED SOIL VOLUMES FROM A PIPELINE TRACK

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ABSTRACT

A procedure is described, which constitutes a first step in the direction of automatizing the determination of location, size, and strength of soil retention structures for pipeline tracks, for a first stage design. Based on topographic data, and using RUSLE for a design event, the procedure provides a series of eroded soil volumes, and identifies the locations at which sedimentation of each one of them will take place.

The procedure is programmed within a GIS environment. A Digital Elevation Model (DEM), such as SRTM, is used as the basic topographic data. The trace of the track is introduced, as a series of *x, y* coordinates. As a result of crossing the DEM and the trace, the software generates, by interpolation, new points (nodes) to define the trace, coincident with the DEM grid sides. Additional nodes are also introduced to avoid lengths between nodes larger than the maximum slope length (taken as 130 m). Elevation values are next assigned to the trace nodes, by interpolating within the DEM. After that, each segment is characterized as an erosion or sedimentation segment, depending on its steepness being above or below a critical value (taken as 5%). Each erosion segment is interpreted as a slope, and the corresponding eroded volume for the design event calculated using RUSLE. Consecutive erosion segments are grouped, and the corresponding sedimentation segments, where the eroded soil will move, identified. In this way, the total eroded volume that reaches each sedimentation segment group is obtained.

As an illustration, the developed software, named *DUCTO*, is applied to the Macueta-Piquirenda gas pipeline track, where INMAC participated as the Contractor to open the track for pipeline construction, and closing it for restoration.

Key words: pipeline track; track erosion; eroded volumes; deposited volumes

1. INTRODUCTION

The construction of longitudinal works, such as oils and gas pipelines, requires the temporary uncover of a long strip of land. This track is then subject to increased erosion. To minimize soil exportation from the track to the surroundings, it is necessary to build a series of temporary soil retention structures. Determining the location, size, and strength of such structures is not a minor task. This is usually undertaken manually, based on expert criteria.

In this paper a procedure is described, which constitutes a first step in the direction of automatizing this task for a first stage design. Based on topographic data, and using RUSLE for a design event, the procedure provides a series of eroded soil volumes, and identifies the locations at which sedimentation of each one of them will take place. The procedure is programmed within a GIS environment.

The developed software, named *DUCTO*, is applied to the Macueta-Piquirenda gas pipeline track, where INMAC participated as the Contractor to open the track for pipeline construction, and closing it for restoration. The pipeline (Figure 1) starts at Piquirenda Plant (altitude 522 m) and ends at Macueta mountains (1142 m), crossing mountains and valleys along its 60 km length. About 50.5 km (86% of the total lenght) has longitudinal slopes between 0 and 15%; 7.4 km (12.6%) between 15 and 30%; 760 m (1.3%) between 30 and 45%, and 60 m (0.1%) between 45 y 60%. The mean slope is 7.5%.

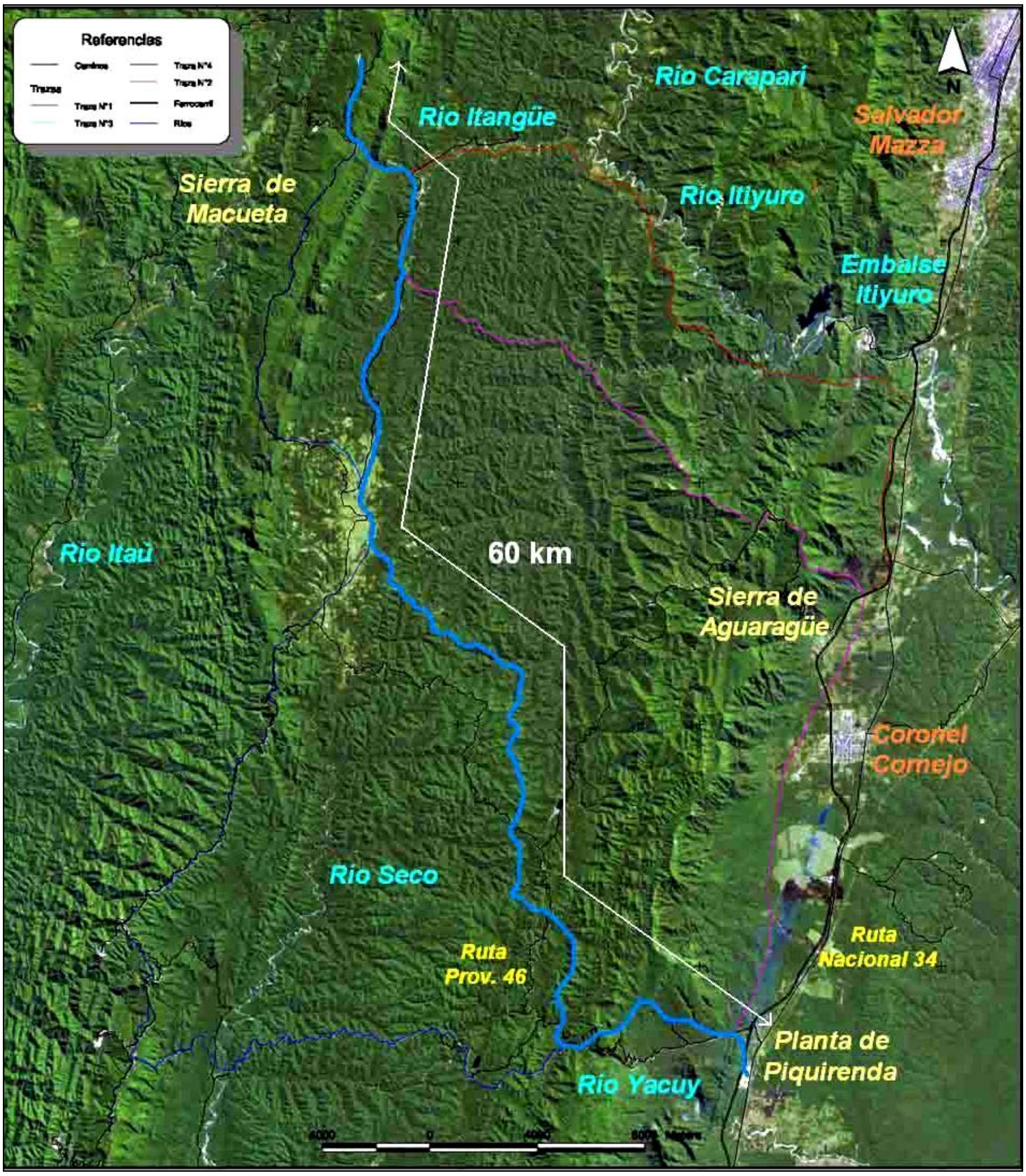


Figure 1. Macueta pipeline track

2. METHODOLOGY

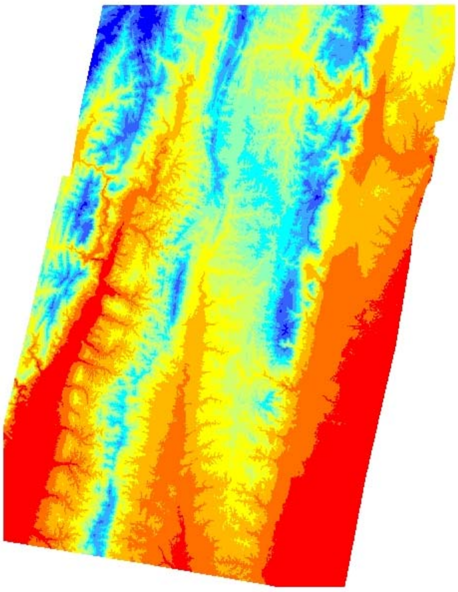
Starting from the input data, the methodology proceeds through the following four procedures:

- Segmentation of trackline
- Topographic characterization of track segments
- Determination of erosion and deposition zones
- Calculation of eroded and deposited volumes

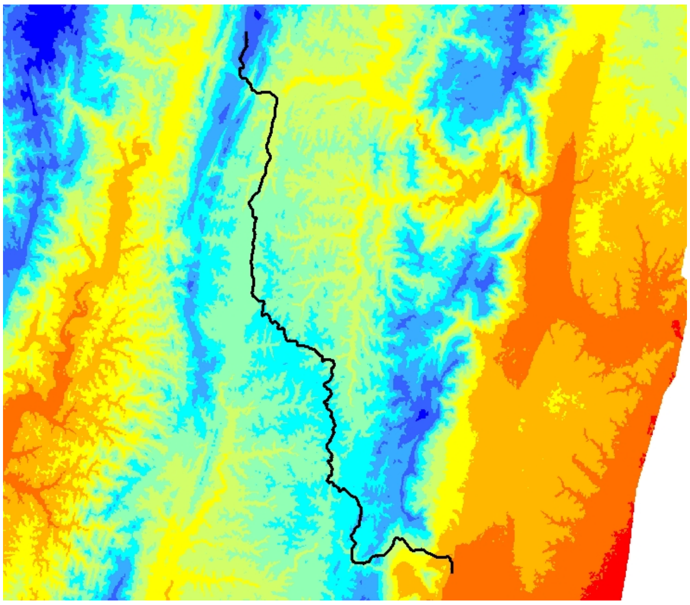
2.1 Input

The topography of the intervention zone must be provided as a quadrangular Digital Elevation Model (DEM). Figure 2a shows the DEM for the Macueta-Piquirenda project (MPP), corresponding to NASA SRTM (downloaded form the Web page of the USGS), with a resolution of 90 m. It is supposed that the resolution of the DEM is never lower than 90 m.

On top of the DEM, the trackline is introduced as a set of points, as illustrated in Figure 2b for MPP. For each point, information on the track width must be provided.



a) DEM



b) Trackline

Figure 2. Geometric data for Macueta-Piquirenda project

Calculations with RUSLE (Wischmeier & Smith 1965, 1978) require the knowledge of the associated parameters, namely, *R* (rainfall-runoff erosivity factor), *K* (soil erodibility factor), *LS* (topographic factor), *C* (cover-management factor) and *P* (support practice factor). Zoning information must be provided for parameters *R*, *K*, *C*, and *P*. In the case of *R*, it should represent the rainfall-runoff erosivity factor for a design rainfall event (Menéndez et. al., 2005). The topographic factor is calculated from the DEM, as explained below.

2.2 Segmentation of trackline

Starting with the set of points defining the trackline (Figure 3a), named 'original nodes', an interpolation algorithm is applied in order to include points so that distances between consecutive points are no longer than about 130 m (the extension of the DEM grid cell diagonal), a value considered as maximum for a slope length (Figure 3b). The algorithm proceeds as follows:

a) Two consecutive nodes of the trackline are analyzed.

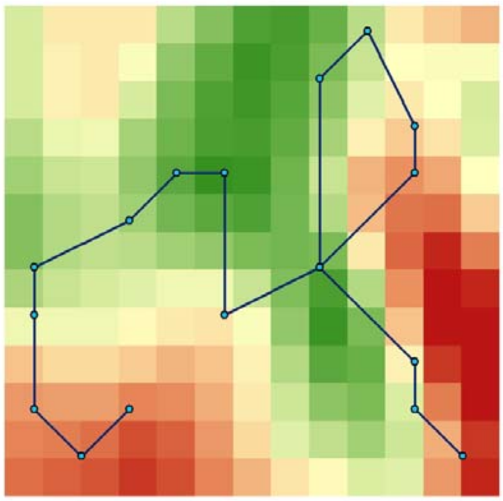
b) The DEM cells to which those nodes belong are identified.

c) If the DEM cells are neighbours (the eight neighbours surrounding a cell are considered, i.e., the diagonal neighbours are included), no node is added. Go back to step a).

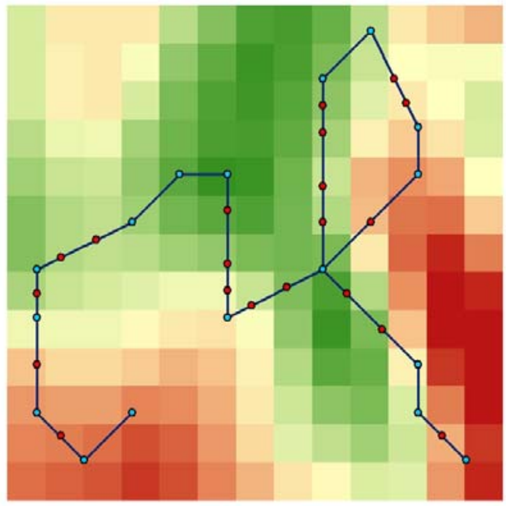
d) If the DEM cells are not neighbours, then the location of the middle point between the two nodes is calculated, and the DEM cell to which it belongs is identified.

e) If the cell of the middle point is a neighbour of the one where the first node lies, then the middle point is accepted as a new node of the trackline (‘interpolated node’). The analysis is repeated for the pair constituted by the new node and the second original node. Go back to b).

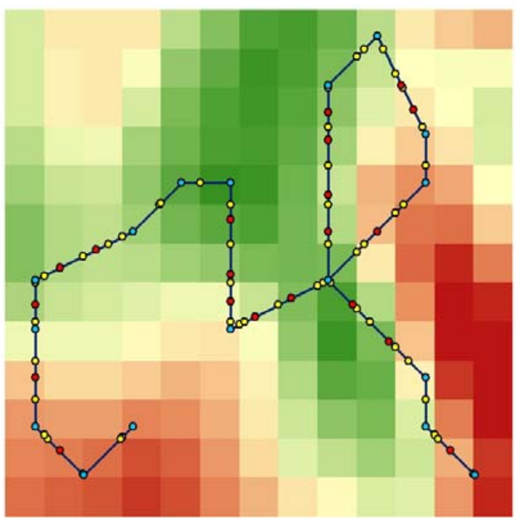
f) If the cell of the middle point is not a neighbour of the one where the first node lies, then the location of a second middle point, between the first node and the first middle point, is calculated, and the DEM cell to which it belongs is identified. Go back to e).



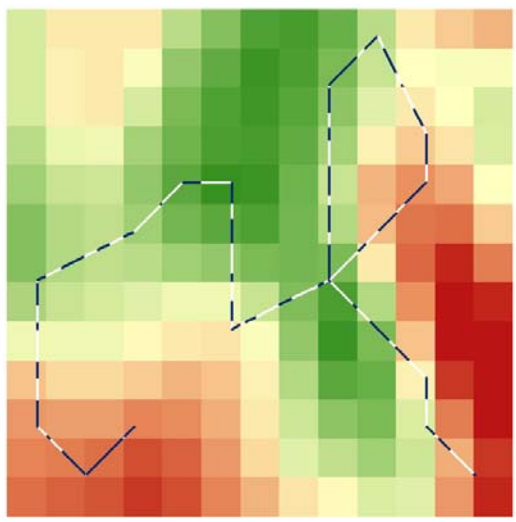
a) Trackline, with original nodes (in blue).



b) Trackline including interpolated nodes (in red)



c) Trackline including intersection nodes (in yellow)



d) Segments of the trackline

Figure 3. Steps of trackline segmentation procedure.

Next, based on the extended set of nodes, the intersection points between the trackline and the cell sides are found, where 'intersection nodes' are defined (Figure 3c). 'Segments' of the trackline are considered the ones between consecutive nodes (Figure 3d).

2.3 Topographic characterization of track segments

Elevation values are assigned to the trackline nodes. They are obtained by Lagrange interpolation of DEM values corresponding to the nearest 8 grid cells, as schematized in Figure 4.

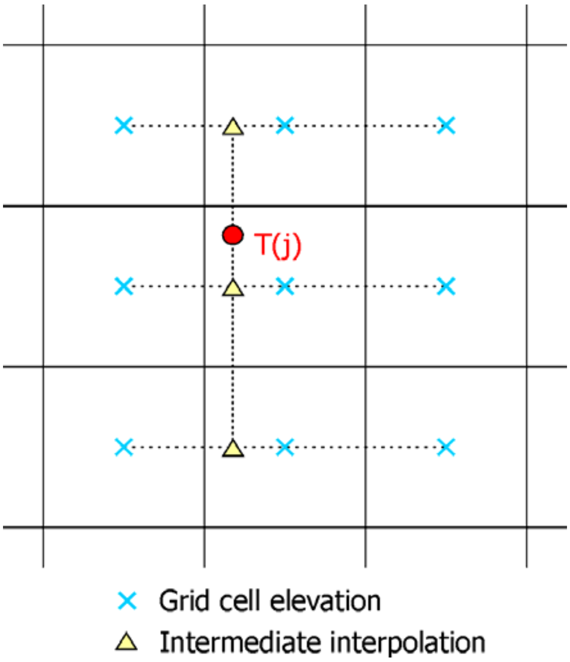


Figure 4. DEM grid cells used for interpolation of trackline nodes elevations.

Using the difference between elevation values at the extreme nodes of each track segment, and the horizontal distance between them, the slope of the segment is obtained.

2.4 Determination of erosion and deposition zones

A critical slope is defined, above which soil erosion occurs. A value of 5% is assumed by default. Track segments with slope above the critical value are considered as 'erosive' segments; the remaining ones are 'non erosive'. The latter ones are identified as 'type 0'; erosive segments with a positive slope (in relation to the trackline direction) are considered as 'type +1', while erosive segments with a negative slope are 'type -1'.

Moving along the trackline, consecutive segments are grouped by type. Three group categories are considered, namely:

- E: Erosive group; constituted by erosive segments (types +1 or -1), where no deposition occurs.
- D: Depositional group; constituted either by erosive (types +1 or -1) or by non erosive (type 0) segments, where deposition can occur.
- N: Non-erosive group ; constituted by non erosive (type 0) segments, where no deposition occurs.

Each group is analyzed according to the group located before and after it, as follows (see Figure 5):

- If a type 0 group follows a type -1 group, or is followed by a type +1 group, then the group is considered as category D. If that is not the case, the group is category N.
- If a type +1 group follows a type -1 group, then the group is considered as category D. In that is not the case, the group is category E.
- If a type -1 group is followed by a type +1 group, then the group is considered as category D. In that is not the case, the group is category E.

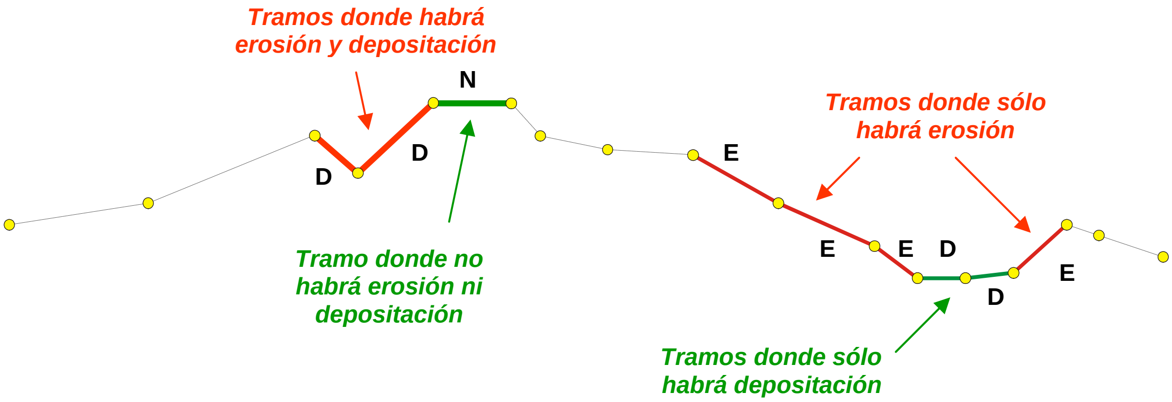


Figure 5. Classification of track segments.

2.5 Calculation of eroded and deposited volumes

In erosive segments erosion occurs. The erosion rate for each segment is calculated using RUSLE. Factor *LS* is obtained from the segment slope and the horizontal distance between extreme points. The values of the remaining RUSLE factors are the ones corresponding to the zones where each segment lies. The erosion rate times the segment area (obtained from its length and the width at the segment nodes) is the eroded volume for that segment, associated to the design event.

The eroded volumes are distributed in category D groups, according to the following rule:

- For a type 0 group, the first segment of the group receives the total eroded volume coming from the erosive segments belonging to the previous group, while the last segment of the group stores the total eroded volume coming from the erosive segments belonging to the next group.
- For a type +1 group, the first segment of the group receives the total eroded volume coming from all the segments of the group.
- For a type -1 group, the last segment of the group receives the total eroded volume coming from all the segments of the group.

As an illustration, Figure 6 shows eroded and deposited volumes for the example of Figure 3.

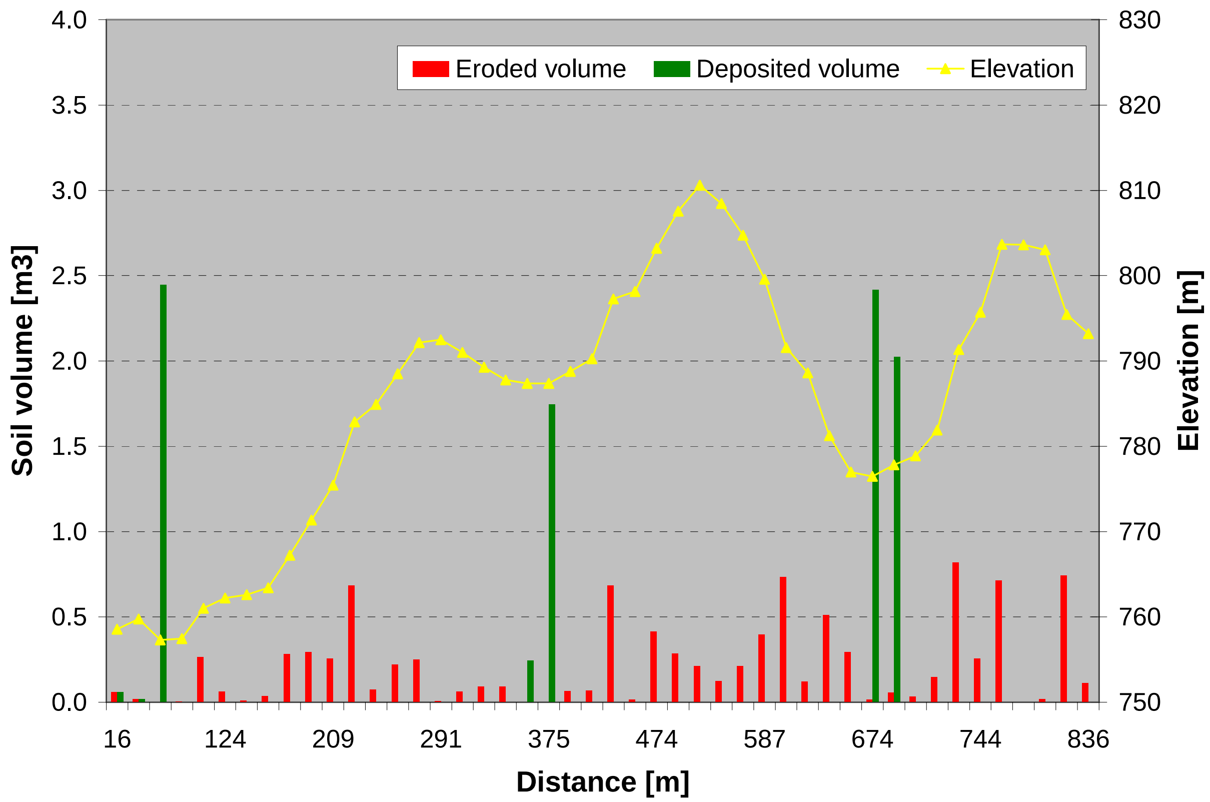
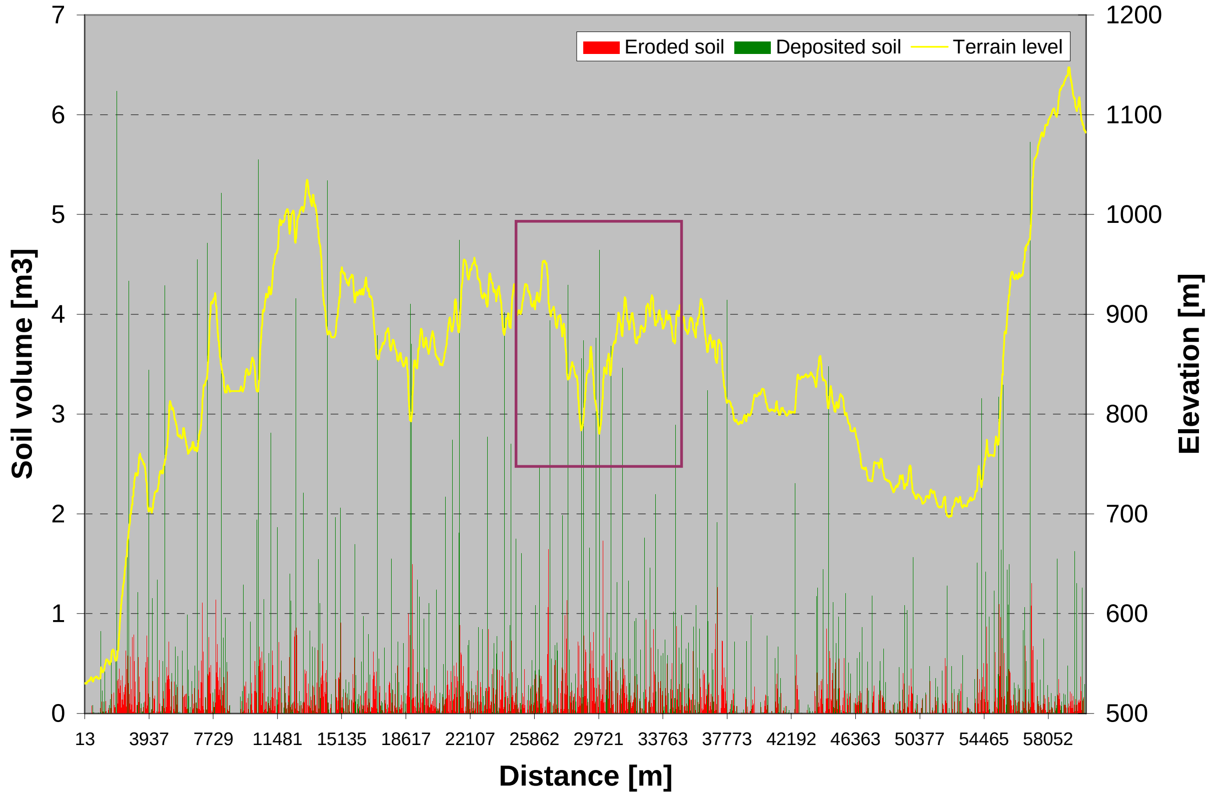


Figura 6 Eroded and deposited volumes along a track.

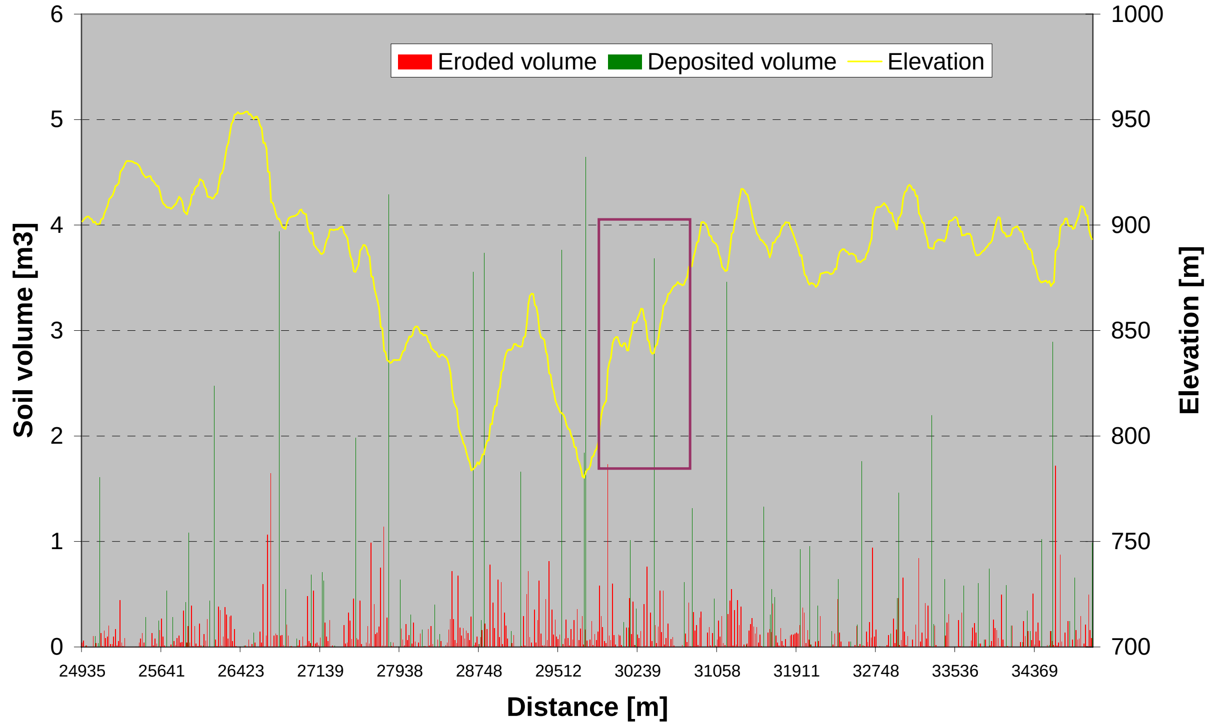
3. APPLICATION

Software DUCTO was applied to MPP. Constant values were assumed for RUSLE parameters throughout the study zone. A typical high-intensity event, with, R = 5700 MJ/ha·mm/h, was considered. A value of K = 0.003 ton/MJ/(mm/h) was taken, typical for some of the regional soils. The cover-management factor was fixed at C = 0.45, representative of a roadway (naked soil with some significant roughness). No support practice was taken into account, i.e., P = 1. The track width was assumed as uniformly equal to 11 m, and the soil specific weigth was considered as 1700 kg/m^3.

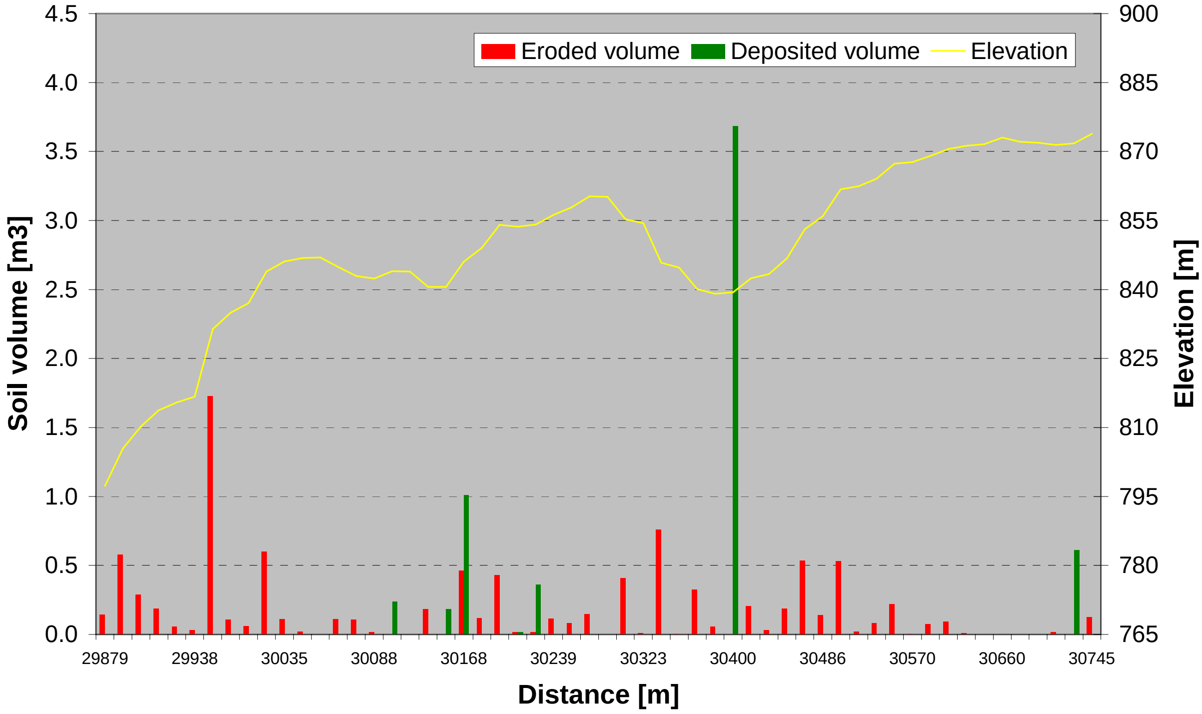
The results for the eroded and deposited volumes are presented in Figure 7, where zooms are taken in order to have a closer view of their distribution at some stretches. The total eroded volume (equal to the deposited volume) is 334 m^3. The highest deposition, of about 6.2 m^3, occurs at the trackline segment located in km 2.0. Within the stretch shown in the expanded view of Figure 7c, a maximum of 3.7 m^3 accumulates at km 30.4; taking into account the slopes of that valley, this would require a retention structure 0.5 m high.



a) Complete track extension



b) Expanded view of sub-zone indicated in a)



c) Expanded view of sub-zone indicated in b)

Figura 7. Distribution of eroded and deposited volumes for MPP.

4. CONCLUSIONS

Modern technologies allow the automatization of a procedure to estimate soil erosion from a pipeline track for specific rainfall events, and determine the accumulated deposited volumes and their locations. One such procedure has been implemented in software DUCTO, running within a GIS environment, which constitutes a useful help for a first stage design of sediment retention structures.

5. REFERENCES

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