GEO-PUMMA: Urban and periurban landscape representation for distributed hydrological modelling

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Geo-PUMMA: Urban and Peri-urban Landscape Representation Toolbox for Hydrological Distributed Modeling

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1 Introduction and Objectives

- **Geo-PUMMA** is a **GIS toolbox** to represent the terrain used in distributed hydrological modeling in urban and peri-urban areas, which preserves the hydrological connectivity and extracts a realistic drainage network.
- **Geo-PUMMA** uses a vectorial approach that generates a polygonal mesh composed of physiographic units. Urban areas are represented using **Urban Hydrological Elements (UHE)** (Rodríguez et al., 2008). Rural and peri-urban areas are depicted using **Hydrological Response Units (HRU)** (Flüguel, 1995). (*Figure 1*)
- Geo-PUMMA improves the ***numerical stability*** of hydrological models as it considers several segmentation processes to address the following issues in mesh representation: thin units, elements extremely non-convex, too large elements and homogeneous properties within an HRU (slope, aspect, etc).

2 Study site, available data

- The Mercier sub-catchment, France (7 km^2, 10% urban) is covered with forests and crops.
- The peri-urban basin Estero El Guindo, Chile (6.5 km^2, 50% urban) is covered by native vegetation (Figure 2).

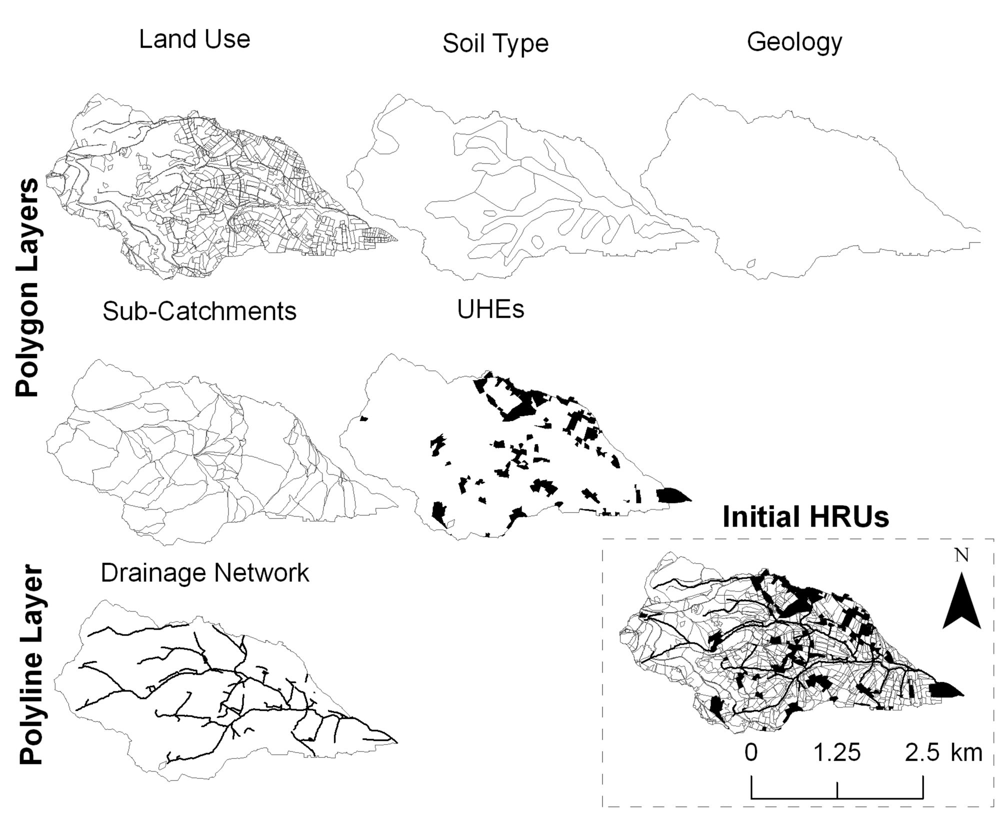

Figure 1.- Polygonal Mesh composed of HRUs and UHEs

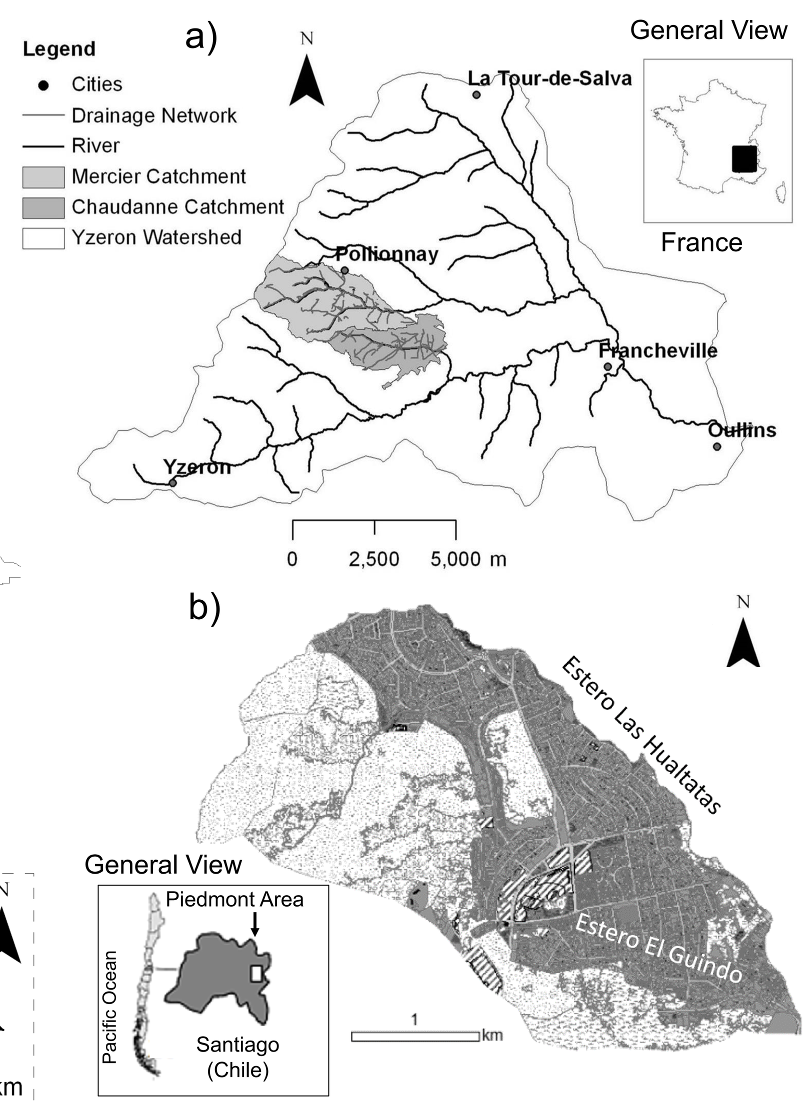

Figure 2.- Catchments Mercier (a) and El Guindo (b)

The initial HRUs were obtained using
- ***Land use map*** (Jacqueminet et al., 2011; Guzmán 2014)
- ***Pedology map*** (SIRA, 2011; DGA-AC, 2000)
- ***Geology map*** (BRGM, 2011; DGA-AC, 2000)
- ***Subcatchments*** (Jankowfsky et al., 2013; Sanzana et al., 2015)
- ***Ditch*** network (Jankowfsky et al., 2011; DOH-EIC, 2004)
- **Sewer systems** (SIAHVY, DOH-EIC, 2004).
- A ***DEM*** (Lidar, 2 m; Sarrazin, 2012) and contour lines 1: 5.000 (2,5 m) (DOH-EIC, 2004).

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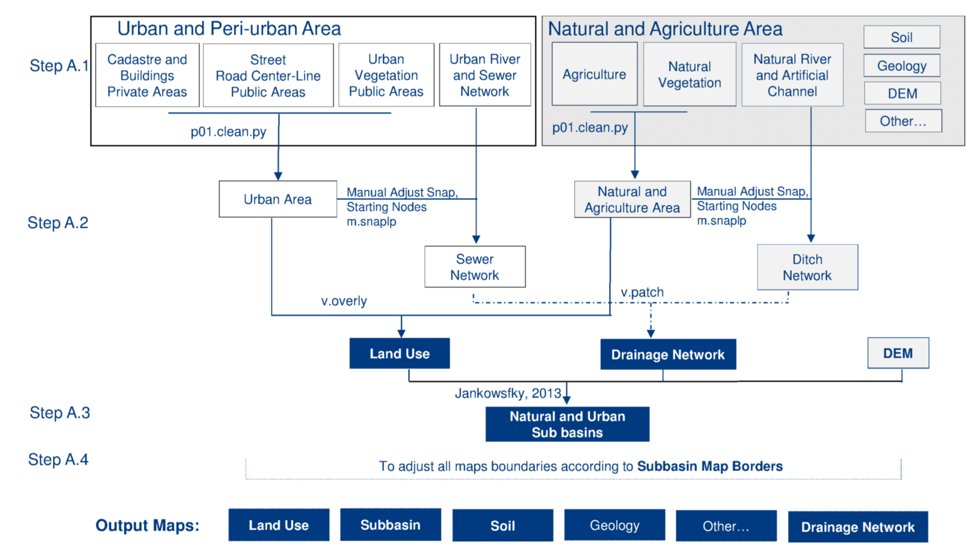
3 Geo-PUMMA

The proposed methodology has four steps.
Step 1 (A): data collection, digitalization and quality improvement of all the maps (Figure 3)

Step 2 (B-UHE) : representation of the urban area: all UHEs delineated and characterized using attributes such as average height, area, imperviousness, green area, and distance to the closest sewer or street.

Step 3 (B-HRU): improvement of initial HRUs segmentation to address geometric constraints

Figure 3.- Step A



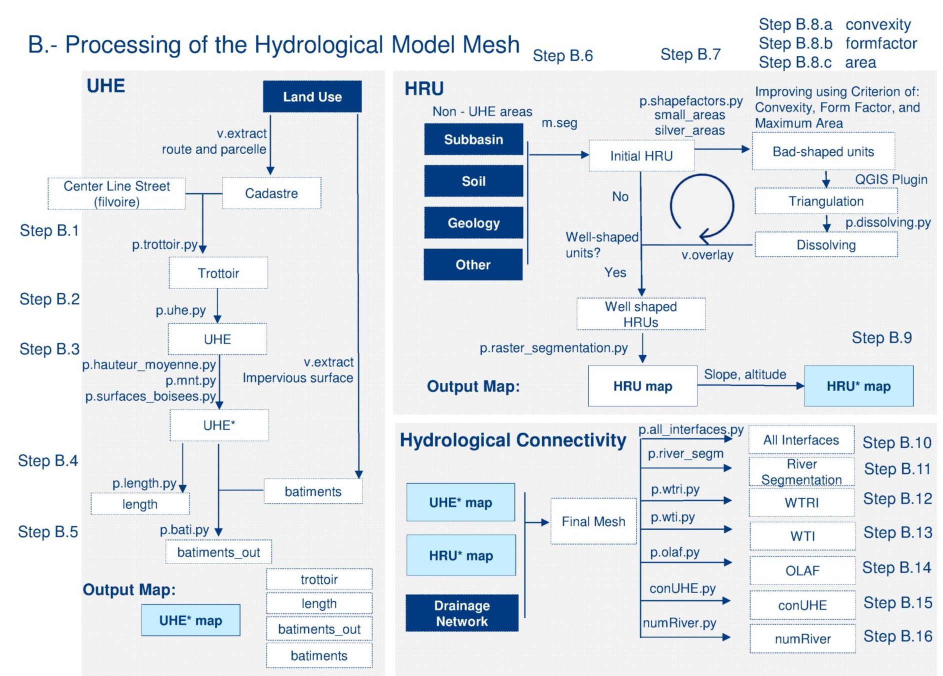


Figure 4.- Step B-UHE; Step B-HRU; Step B-Hydrological Connectivity

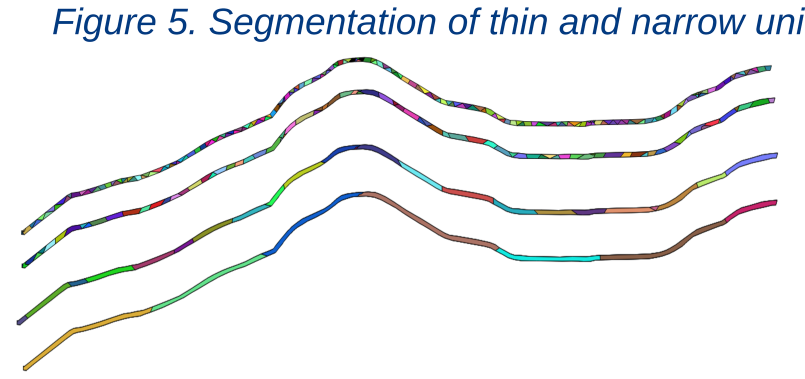
To do this we use a triangulation and dissolution process based on geometrical indicators for which we propose values ensuring a compromise between quality and number of elements (**recommended mesh**).

In this step, HRUs can be processed to obtain more homogeneous properties such as slope, topographic index, aspect derived from high resolution DTMs (Sanzana et al, 2013).

Step 4 (B-Hydrological Connectivity): extract the hydrological connectivity between the different units, using a recursive algorithm for identifying surface flow directions.
This drainage network is composed of channelized and non-channelized elements.

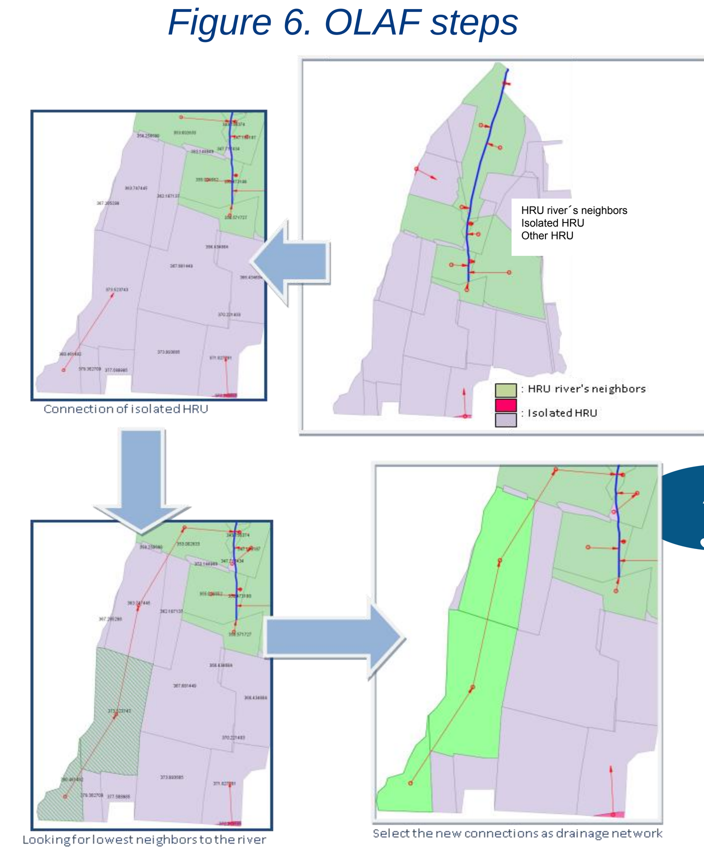
Figure 5 illustrates the main task of Step 3, showing the effect of the segmentation of a street, represented by a narrow and thin polygon. Figure 6 shows sevrral steps of OLAF routine (main task of Step 4).

Figure 5. Segmentation of thin and narrow units



Form Factor Threshold	Initial HRU	HRU Triangulated	HRU Dissolved FFT	Satisfactory
0.75	1	259	185	No
0.50	1	259	84	No
0.20	1	259	23	No
0.10	1	259	7	OK

Figure 6. OLAF steps



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This work was developed within the framework of Project MAPA (IDRC 107081-001) and Project ECOS-CONICITY C14U02. We would also like to thank IRSTEA-Lyon for their financing, as well as the contribution of Projects FONDECYT Nº1131131 and CEDEUS (FONDAP 15110020).

4 Results

Sensitivity of the drainage network to various options in GEO-PUMMA (Figure 7): illustration for the El Guindo catchment
Three meshes presented:
- the recommended mesh defined in section 3 (2057 HRUs).
- The initial mesh (without applying STEP B3 on HRUs) (2016 HRUs)
- a reference mesh (with high values of geometric criteria) and large number of elements (3749 HRUs)

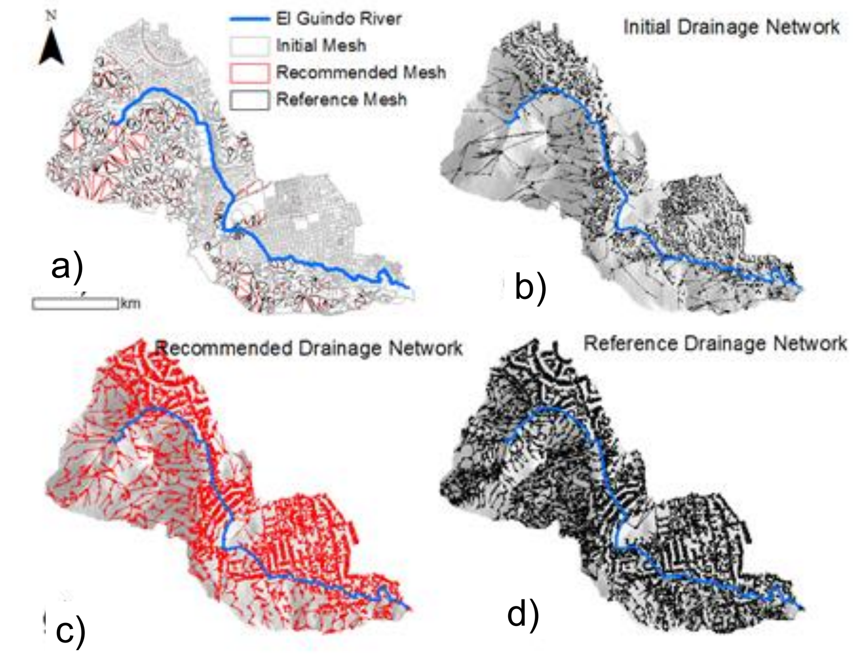
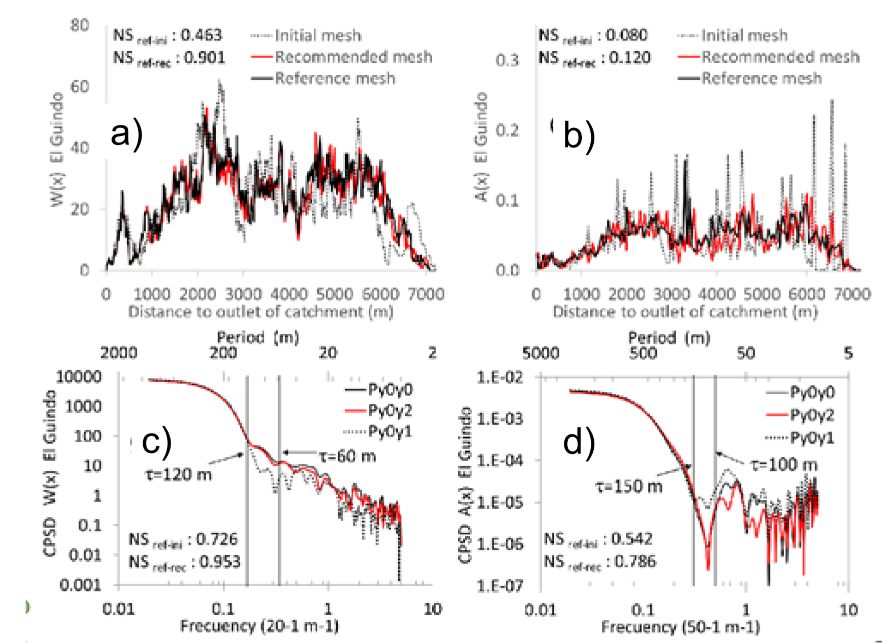


Figure 7, Initial, Reference and Recommended Mesh for El Guindo (a). Drainage Network from Initial (b), Recommended (c) and Reference (d) Mesh for Mercier.



Evaluation of the mesh improvement using the width and area functions and spectral analysis (Figure 8)
- Improvement visible at the largest distance from the outlet where initial mesh is coarser.
- Nash value (NS) between the reference mesh and the others is larger for the width function than for the area function.
- Cross Spectral Analysis (CPSD) shows improvement from 120 m to 60 m for CPSD of W(x) and from 150 m to 100 m for CPSD of A(x) (vertical bars in Figures c) and d))

Figure 8, (a) Width-Function, W(x), and (b) Area-Function, A(x), of three meshes of El Guindo. In both drainage networks came from initial mesh (segmented gray line), recommended mesh (red) and reference (black). (c) CPSD of Width-Function and (d) CPSD of Area-Function of El Guindo. In both cases, comparing reference vs reference (Py0y0, black line), reference vs initial (Py0y1, gray segmented line) and reference vs recommended (Py0y2, red line).

Illustration of the improvement led by the GEO-PUMMA vectorial approach, as compared to standard raster approaches (HRU_Delin derived from Grass-HRU, Schwartze, 2008)
- Necessity to use high resolution (2 m cell size and minimum area threshold of 10 m^2) with the raster approach.
- Large number of HRUs (more than 30,000 units) as compared to about 2400 for GEO-PUMMA
- But some land use features such as streets and irregular boundaries between lots are lost. (Figure 9)

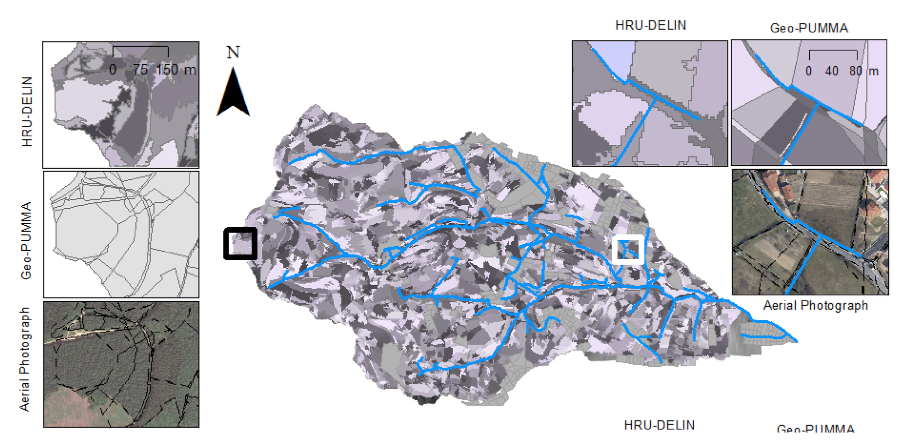


Figure 9. Middle: HRU generation by HRU-DELIN (raster approach). Zooms comparing HRU-DELIN (raster) and Geo-PUMMA (vectorial approach)

5 Conclusions

- **Geo-PUMMA** was successfully tested in the Mercier and El Guindo catchment.
- This toolbox **allows getting the drainage network** from a polygonal mesh, with a novel approach that extracts the hydrological connectivity from a terrain represented only by HRUs and UHEs elements, considering hydraulic infrastructures present in the urban and peri-urban catchment.
- Hydraulics features are **not limited by a cell size**.
- The **recommended mesh** allows preserving the physiographic units and improving the drainage representation **without increasing** significantly the final number of elements.