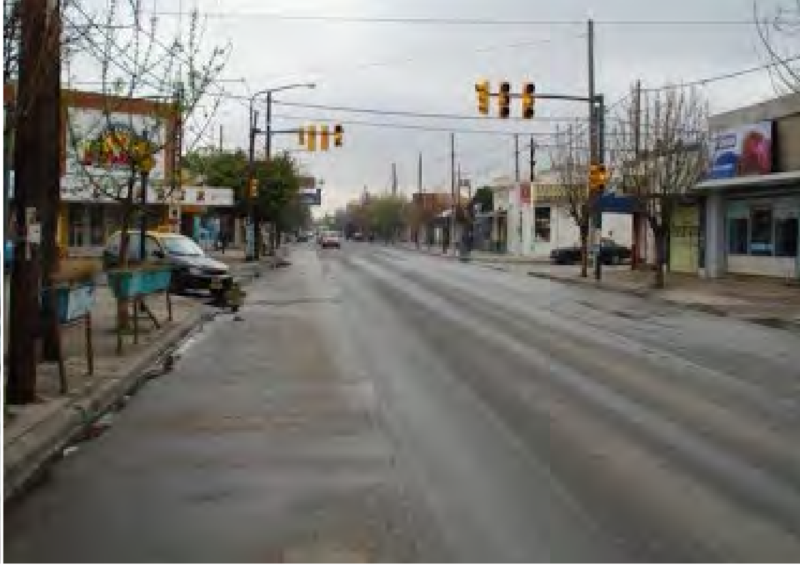

Guideline 1: Methodological guidelines for monitoring of runoff and infiltration of storm water

Monitoring impacts of urban and peri-urban agriculture and forestry on climate change mitigation and adaptation

Francisco Escobedo and Marielle Dubbeling
With inputs from: Laura Bracalenti and Erik Zimmermann

RUAF

CONTENT

1. INTRODUCTION

Cities and climate change are virtually inseparable. Cities are mayor contributors to Green House Gas (GHG) emissions and thus climate change. Cities, and their sheer number of inhabitants, are also directly and indirectly affected by climate change, with the urban poor being most at risk. Cities have an important role to play in climate change mitigation and adaptation, while at the same time they need to ensure adequate access to basic urban services such as water, food and energy to their growing populations.

The IPCC Fifth Assessment Report (University of Cambridge and ICLEI, 2014) presents amongst its key findings that:

1. Many emerging climate change risks are concentrated in urban areas,
2. Rapid urbanisation will increase the number of highly vulnerable urban communities,
3. Key climate risks faced by cities include storm surges, sea level rise, droughts and water scarcity, excessive rainfall, floods and landslides, heat waves and urban food insecurity amongst others.

As a result of urbanisation, many cities are characterised by a reduction in open spaces and green areas and increases in impervious surfaces such as buildings and concrete. This reduces soil infiltration and increases surface runoff during rainstorms, especially in areas experiencing more or more intense rainfall. Flooding is increasingly reported in cities as a result of overloaded or inadequate urban infrastructure and drainage systems and lack of infiltration areas.

Techniques that promote infiltration and storage of water in the soil, such as permeable pavements, uncompacted soils and increasing the green and vegetation cover in urban areas can be incorporated into new and existing residential and commercial developments to increase infiltration and reduce the volume of storm-water runoff from urban and peri-urban areas (Cohen and Wijsman, 2014).

Urban and Peri-urban Agriculture and Forestry (UPAF) may be one of the strategies to be promoted to increase or maintain the amount of pervious surfaces. Such urban productive green spaces at the same time offer opportunities for recreation and leisure, for income generation, and may contribute to the food security and well- being of citizens.

Several cities that are increasingly confronted with floods are considering the role of urban agriculture and forestry as alternative options for flood risk management. In Sri Lanka, rehabilitation of former paddy fields and drainage channels has proven to be an effective strategy for the reduction of flood risks (Dubbeling 2014). The city of Freetown (Sierra Leone) has zoned all wetlands and low-lying valleys for urban agriculture. Next to promoting local food production, this measure is expected to help keep flood-zones free from construction and improve water infiltration, resulting in reduced flooding incidences and related damage (Dubbeling 2013). The city of Rosario (Argentina) promotes the preservation and protection of green and productive areas on stream banks to reduce flood risks (Hardoy and Ruete 2013). Agricultural use of lowlands in Antananarivo (Madagascar) is reported to prevent flooding as the lowland rice and watercress systems can store large amounts of water. It has been calculated that one of the city's low-lying valleys with a total area of 287 ha can store up to 850,000 m3 of water, corresponding to three successive days of heavy rains (Aubry et al. 2012).

The lack of an adequate monitoring framework and guidelines for scenario development on UPAF however hampers data collection efforts at local level regarding the presence and actual/potential impacts of (various types of) UPAF on flood risks and their integration in storm water management and climate change policies, action plans and planning instruments.

To monitor the impact of different forms and distribution of land uses and ground cover (including UPAF ground cover) on flooding, storm water run-off volumes are often used as indicator of measurement. Reduced storm water runoff not only reduces flood risks, it may also extend the lifetime of the city's drainage system, whose infrastructure is expensive to maintain.

A simple method for estimating the runoff indicator is based on the rational runoff coefficient method that is used to quantify the impact of different ground covers on storm water runoff from an urban watershed.

Scenario building can be used to simulate hypothetical "future" states or ground covers of selected urban catchment areas. A scenario study in this respect can be used to compare runoff and related flood risk in catchment areas without and without UPAF. It can also be used to estimate impacts of further urbanisation and ground sealing (replacing current agricultural and green areas with built-up areas) or alternatively estimate what the larger benefits would be if decision-makers would up-scale and increase UPAF areas.

In this manual, a methodology is proposed to relate different future scenarios of land use to changes in the runoff indicator and in flood risk. An example will be given for Rosario (Argentina), where increase of green areas in urban and suburban areas, such as green sidewalks, green roofs, agriculture and forestry, is included in the scenarios.

2. QUANTIFYING RUNOFF

Urban storm water runoff occurs at the catchment, or the area of land where all of the water that drains off it, goes into the same place or outlet. Catchments are also referred to as "watersheds" or "basins" ((http://en.wikipedia.org/wiki/Drainage_basin). In particular, urbanised catchments have higher and more intense "flows" and "peak flows" that occur earlier in time, and frequently less "normal or base" flows"[1]. It is these intense peak flows that occur earlier in time that increase the risk of flooding in urban and peri-urban areas.

This methodological guideline will provide measurement, quantification and monitoring methods to assess the hypothesis that increased UPAF area in urban and peri-urban catchments will reduce storm water runoff. This can be measured by quantifying and monitoring catchment characteristics affecting the peak flows, specifically the reduction in an indicator referred to as "change in runoff coefficient (ΔC)".

Specifically, this manual will provide the methods to:

- Identify and map representative urban and peri-urban catchments and the amount of UPAF- and built-up, impervious, area
- Quantify the runoff coefficient and flood risk for these representative catchments
- Integrate policy objectives and existing and proposed land uses ordinances to better assess the effects of different land use scenarios (such as increasing UPAF in these catchments) on reduction of storm water runoff.

These methods are based on the Rational Formula that is regularly used in small urban catchments to estimate the peak rate of runoff in a drainage area as a function of 3 variables: runoff coefficient, rainfall intensity, and catchment area (http://rational.sdsu.edu/). The Rational method was introduced by Kuichling in 1880 for determining peak discharges from drainage areas. Although the method simplifies the relation between rainfall, infiltration and runoff, this same simplicity has made the Rational Method one of the most widely used techniques today. The method is generally used for catchments less than 80 Ha. and occasionally humid, rainy areas. There are other methods and models available (e.g. http://www.toolkit.net.au/Tools/; http://en.wikipedia.org/wiki/Runoff_curve_number; Soil and Water Assessment Tools- http://swat.tamu.edu/) but these are more complex in use and require more data, thus also making them more costly.

The Rational Method outlined in this manual can also facilitate future assessment of reducing flood risk by changes in land use cover, by quantifying the "peak flow" (m^3/s) at the outlet of these catchments. Peak flow is used for the engineering design specifications of irrigation, drainage and flooding structures, and in general the larger the structure, the greater its construction cost (http://rational.sdsu.edu/)

The runoff indicator

In this guideline, the change in runoff coefficient will be used as indicator for monitoring impacts at the level of a catchment or sub-catchment (http://drdbthompson.net/writings/rational.pdf). The runoff coefficient can be defined as the proportion (%) of the rainfall that appears as storm water runoff from a certain surface. Negative changes in the runoff coefficient (negative ΔC values) for any time period will indicate a net decrease in runoff (which subsequently reduces the risk of floods) and an increase in infiltration/storage of the storm water within a given surface area. The use of the runoff coefficient 'C' or more specifically the changes in runoff coefficient (Δ C) can be directly linked to changes in land cover (such as increased or decreased UPAF surfaces). There is a direct relation between ΔC and flood risk reduction, thus the implications of different changes in land cover on flood risks can be made without having to calculate intensity of rainfall ('i') or flow (Q), which present greater difficulties (http://drdbthompson.net/writings/rational.pdf).

1 For definitions of these hydrologic terms see: http://webworld.unesco.org/water/ihp/db/glossary/glu/aglu.htm

The runoff coefficient varies with slope, surface conditions, vegetation cover type and hydrological soil type (http://drdbthompson.net/writings/rational.pdf). Surfaces that are impervious like streets and parking lots have runoff coefficients approaching 1 (see appendix 1). Also black roofs and other (close to) impermeable surfaces have high run off coefficients. Surfaces with vegetation can intercept surface runoff and allow for infiltration of rainfall and have runoff coefficients less than 1. All other factors being equal, an area with a greater slope will have more storm water runoff and thus a higher runoff coefficient than an area with a lower slope. Soils that have high clay contents generally reduce infiltration and thus have relatively high runoff coefficients, while soils with high sand content have higher infiltration rates and thus low runoff coefficients.

Given the objectives of this manual and the relative ease of using the rational method and its runoff coefficient, the monitoring method provided will outline the means to quantify and monitor impacts of UPAF on the runoff coefficient at the catchment scale. Urbanisation does affect land use and cover and as such their effect on the runoff coefficient will be the main indicator for assessing the positive impacts of UPAF on storm water runoff.

As previously mentioned, climate change will affect rainfall intensity (i). Information on 'i' and the rational method can be used to quantify flood risk and peak flow at the outlet of each catchment (http://drdbthompson.net/writings/rational.pdf). However and in most bioclimatic zones, the impact of land use changes on 'C' will be greater than the impact of climate change on 'i'. Additionally quantifying the effect of climate change on 'i' also requires city-specific rain gauge information that is costly in terms of equipment and labour, while modelling peak flows is more technically difficult. Therefore developing a simple methodology that precisely assesses peak flows is difficult and will not be described in detail in this chapter, but additional information for calculating 'i' and peak flows is provided in Appendix 2.

Selection/establishment of monitoring areas

For analysis purposes, it will be necessary to initially select representative catchments with a different range of UPAFs in terms of types and areas in the city. Each city will need to use and adapt a UPAF typology that accounts for its socioeconomic and biophysical conditions. These UPAF types can be selected based on either specific policy objectives (promoting productive green ways, gardens or reforestation projects) or more quantitative criteria such as the total area or proportion of specific UPAF types in the city, relative to other land use and cover types. Some basic UPAF types are presented below in Table 1 and can be used as a starting point, but need to be adjusted to reflect specific UPAFs found in the area of interest.

Table 1. Proposed Urban and Peri-urban Agriculture and Forest (UPAF) typology based on land use/cover types in Rosario, Argentina and Kesbewa, Sri Lanka.

City Zone (A = Inner city; B= Sub urban - less densely built up; C= Peri-urban -mainly open spaces)	UPAF type
A-B-C	1. Non-UPAF; Urban Core, densely built up: Impervious, high density residential, industrial, commercial, transportation, buildings
A	2. Backyard and community gardens
A-B-C	3. Green productive rooftops

A-B	4.Flood zones and other urban open spaces for conservation or food and biomass production: Inner city parks, wetlands, rice fields, pervious vacant areas, public green spaces, urban "greenways"
B-C	5. Urban, peri-urban and agro-forests: parks, low density residential areas with high tree cover, forest reserves, wooded hills and mountain slopes
B-C	6. Agriculture areas in city fringes/peri-urban areas, including wetlands
A-B-C	7. Street trees, street-side gardens

The number of selected catchments in each city can vary, but a minimum of 2 catchments is recommended, including one highly urbanised catchment and another with a high area of UPAF. The different areas (hectares) of UPAFs in the catchments will also be used to develop the scenarios that can characterise the effect of different surface areas of UPAF on the runoff coefficient. Alternatively, in the case where multiple catchments cannot be identified, 1 catchment can be selected and used to develop different scenarios by modifying the amount of UPAF land use/cover in the catchment given certain scenario objectives.

Identifying catchments and their characteristics

The study catchments should be selected based primarily on hydrological criteria (drainage flow areas) and the impact of existing or proposed UPAFs on storm water runoff. Storm water runoff monitoring criteria should therefore consider other socio-political realities in the catchment and the potential of actual or proposed UPAFs on reducing hydrological flood risks by reducing runoff coefficients. For example, a catchment with existing areas of UPAFs that reduce runoff coefficients by 10% (compared to a highly urbanised catchment) could be considered a "UPAF catchment". Or a catchment comprised of built up, impervious areas but with a potential for establishing increased UPAF area that could reduce the runoff coefficient by 10%, could be considered a "catchment with potential UPAF land use/cover". Quantifying a numerical value (i.e. 10%) in reducing the runoff coefficient implies a reduction of flood risk, and thus a direct and positive effect of UPAF land use/cover in reducing the runoff coefficient (http://drdbthompson.net/writings/rational.pdf).

Land uses

As indicated above, existing and potential future land uses in each catchment will determine which catchments are selected for monitoring. The terms "land use" and "land cover" are often confused. Land cover is "the observed physical and biological cover of the earth's land, as vegetation or man-made features", while land use is "the total of arrangements, activities, and inputs that people undertake in a certain land cover type".
(http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/land_use/045.htm).

In this manual, land use will refer to politically defined uses of the land and their role as support for green and grey infrastructure, buildings and related activities in urban and peri-urban areas. These uses are defined in existing regulations according to appropriateness for different uses or the "carrying capacity of an urban area for performing certain urban functions, defined by the relevant legislation if it exists, or effective use of that area" (Calvimontes Rojas, 2001.) For example, a basic classification defines the following land uses in urbanised areas: urbanised, buildable, urban reserve or transition and not buildable. The latter class includes rural land, ecological reserves, areas of flood risk and landslides, the sides of roads and highways, etc. There are also various classifications for land in undeveloped areas, based on production capacity, human activities and land tenure. Other possible classifications include those of the UN-FAO (http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/land_use/045.htm) and others such as: Land suitable for intensive cultivation and other uses; Land suitable for permanent crops, pasture and forestry; marginal lands for agricultural use; Land not suitable for agricultural or forestry purposes (OAS, 1978).

Land covers

Land covers in addition to land uses are another factor that will be used in selecting catchments and eventually the runoff coefficient. Land cover in this manual refers to physical-material characteristics of the earth surface and specifically the type of surface material. A possible general classification of soil or ground cover could be: built and paved (impermeable and semipermeable); green (grass, grassland, shrub land, forest, agriculture), degraded (dumps, landfills, caves, etc.); bare soil (disturbed earth, ploughed soil, compacted soil by human activities or movement of animals, etc.)

Land use however, is associated with different land covers as previously explained. For example, urban built areas -either of high or low density- with residential, industrial, commercial or mixed activities, have a wide variety of land covers. On the other hand, a soil with UPAF, either classified as urban, buildable, urban reserve or not buildable land use, may be covered by tree cover or horticultural crops, depending on the specific UPAF type found.

Although generalised and universal classes of land use and cover can be developed (see: http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/land_use/045.htm), given the complexity explained previously, in reality each city must establish its own spatial typology according to existing land cover and soil characteristics, activities and regulations. This will require spatial information of the study areas. Some cities have classified their urban and peri-urban areas into classes that integrate land use, function, activities, ordinances and morphological characteristics. But, few standard typologies are available in the international literature that integrate all the variables that need to be considered in order to quantify and monitor the effects of different UPAFs on flood risk.

Classifying and mapping UPAFs and land use/cover

There are a few classifications that have been developed and can be used for calculating the runoff coefficient 'C' based on land use/cover and the soil characteristics of the area of interest (see: http://water.me.vccs.edu/courses/civ246/table2.htm; http://geoinfo.mrt.ac.lk/waterresources/publications/B052.pdf;
http://www.ems-i.com/wmshelp/Hydrologic_Models/Models/Rational/Equation/Runoff_Coefficient_Table.htm).

These tables classify urban land use/cover according to existing activities, building densities, surface cover types, and construction material types. Peri-urban and rural classes are primarily based on different vegetation cover types and can incorporate soil characteristics and topography. These tables on runoff coefficients will therefore be used as a basis for defining the runoff indicator for the different land use classes identified in the study catchments.

The following are some approaches that are often used for defining classes of urban, potentially urban, non-urban, and conservation land uses in the catchments. The first approach is using general classifications that take into account soil type and slopes based on existing inventories or other cadastral mapping in each study catchment or sub-catchment. The second approach is to use remote sensing or aerial photograph and satellites at an appropriate resolution sufficient to detect and classify land uses/cover according to the proportion of impervious (built and paved) and pervious (UPAF and other) surfaces. Predetermined scales (see Appendix 3) can then be used to proportion the existing surface covers. For example, land use and covers can be analysed and classified according to different spatial typologies that take into account: predominant human activities; materials, density and ground covers.

These two approaches, in particular the second, can identify: 1. Existing and predetermined classes from the international literature that can be used to calculate storm water runoff through runoff coefficient (C) and 2. Specific land uses and covers or areas can be defined and mapped using existing spatial polygons, remotely sensed imagery, or other maps using GIS or AUTOCAD software. Both approaches will facilitate the definition of relatively homogeneous areas that can then be used to calculate their area and corresponding runoff coefficients. In cases where GIS spatial data or satellite images with an adequate resolution and spectral information exist, this task can also be performed directly using software for image interpretation.

3. DEVELOPMENT OF SCENARIOS FOR RUNOFF AND FLOOD RISK

Scenario development and quantification of expected impacts can be used as basis for decision making and planning. Policy-makers should interact intensively with researchers and other stakeholders in order to arrive at scenarios that are highly relevant to the local context. Once land use/cover scenarios have been designed, their potential impacts on storm water runoff and flood risk can be quantified, making use of field data, and proxies based on research literature for those variables where no local measurements are available.

Different land use/cover scenarios

Potential future land use/cover scenarios can incorporate policies, land uses, ordinances, and the urban morphology specific to each city. Hypothetical future changes using these scenarios can be taken into account to better model and quantify the impact of UPAF on runoff coefficients.

A single study catchment can be selected and using existing and hypothetical land use and UPAF areas, the rational method can quantify the existing and potential effect of UPAF on both the runoff coefficient and flood risk.

Alternatively, and to take into given sociopolitical realties and to facilitate development of specific UPAF and land use planning and policy objectives that reduce storm water runoff, several existing catchments that represent "with and without UPAF" scenarios can be studied to quantify and monitor land use/cover impacts, specifically selecting one highly urbanised catchment and another with a large area of UPAF.

Another alternative is to select a third "catchment with potential UPAF" that is characterised by areas of non-built surfaces that could potentially be converted into UPAFs, in addition to the "highly urbanised catchment" and "catchment with a large area of existing UPAF". Including this third category in the scenarios would facilitate incorporation of site-specific realties and the role of policies and community preferences in creating UPAFs and subsequent reductions in runoff coefficients and flood risk.

A general guideline for selecting catchments can be based on proportion of land uses/covers: catchments with less than 25%, 26-74%, more than 75% impervious cover can be considered "with UPAF", "potential for UPAF" and "Highly urbanised", respectively.

Apart from differentiation in UPAF and non-UPAF land use/cover, also some general and specific policy objectives can be used to develop the scenarios. For example, a research team in Rosario, Argentina defined the following general policy objectives for "highly urbanised catchments": 1. Reduce flood risk and increase soil-water infiltration by integrating optimal urban vegetation strategies and 2. Increase the area of UPAF in existing non-built up areas. Specific objectives include: 1. Increase the area of green roofs in new and existing buildings and 2. Integrate UPAF in all policies affecting public parks, squares, walks, side of motorways, railways, institutional green spaces, and public woodland.

Similarly, other public policy objectives in Rosario for catchments "with UPAFs" and with "potential for UPAFs" include general ones such as: 1. Reduce flood risk and storm water runoff caused by pavement and urban development in flood-prone areas using UPAF strategies and 2. Integrate UPAF in non-urbanised peri-urban and rural areas. Specific ones include: 1. Increase UPAF area in flood-prone zones through land use ordinances and inter-sectoral strategies, 2. Promote UPAF in rural areas where traditional intensive agriculture is implemented, 3. Integrate UPAF strategies in public parks, squares, walks, transportation rights of way, railways, institutional green spaces, and public woodlands in existing and potential urbanised areas, and 4. Preserve existing UPAFs in peri-urban areas. In Rosario, four scenarios are proposed for the each catchment area (in case the catchments are already fully urbanised, only three scenarios will remain, leaving out the second scenario):

First Scenario: Current situation
Current land use/cover as determined through the interpretation of aerial photographs and / or satellite imagery, and field work.

Second scenario: Urbanisation of buildable land according to the legislation in force
Applies a hypothetical future land use/cover characterisation according to current regulations, considering that all buildable soil is urbanised to the maximum allowed densities.

Third scenario: Urbanisation of buildable and non-buildable land
Hypothetical land use/cover characterisation considering that all buildable and non-buildable land is urbanised to the allowed densities according to current regulations.

Fourth scenario: UPAF areas increased and optimised
Hypothetical land use/cover characterisation considering that UPAF is promoted on all non-buildable land as well as introducing UPAF in urbanised (buildable) areas.

Data collection

Once study catchments/sub-catchments have been identified and mapped and the scenarios selected, different methods and data sources can be used to determine the area (hectares) under UPAF and other land use/covers, soil types, urban morphology, etc. When determining soil types, it is important to use the soil classes that are given in the reference tables for runoff coefficients.

It is also recommended to analyse road surfaces sidewalks and driveways in detail, determining the percentages of paved and unpaved soil, as the latter can have a significant impact on reducing runoff. Also, sidewalks and driveways may constitute areas where future UPAF can be promoted to improve infiltration in urbanised areas.

Cadastral and satellite/aerial photo data should be verified with field data. Site-specific data can also be obtained using monitoring plots to verify UPAF classification and selection as well as to collect data necessary for runoff and peak flow calculations. There should be at least 1 monitoring plot per UPAF type (see Table 1) and if an increased number of plots are used they should be well distributed throughout the catchment. The monitoring plots should measure/verify soil and surface characteristics (necessary for peak flow calculation) and vegetation types, covers and densities (see Appendix 1).

Measuring catchment area and slope

The estimated drainage area for each catchment and types of land use and covers present needs to be quantified for estimating the runoff coefficient. The drainage area of a catchment is determined using spatial data and GIS or from topographic maps and field surveys. For large drainage areas, it might be necessary to divide the area into sub-catchments to account for major land use changes, obtain analysis results at different points within the drainage area, combine hydrographs from different sub-catchments as applicable, and/or route flows to points of interest. Where topographic map information is missing, this data can be obtained from SRTM Topographic Mission that provides elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth (see http://www2.jpl.nasa.gov/srtm/cbanddataproducts.html).

Another factor that affects the runoff coefficient is the average slope of the catchment. The slope can be determined using GIS or topographic maps using three classes of slope: 1= < 2 %, 2= 2-6 %, 3= > 6 %.

Hydrologic soil types

As discussed earlier, soil characteristics also strongly influence runoff. Four types of soil are generally considered for this application (A, B, C and D):

- Group A: Deep sand; deep loess; minimum infiltration rate 0.30 - 0.45 inches/hr[2].
- Group B: Shallow loess; sandy loam; minimum infiltration rate 0.15 - 0.30 inches/hr.
- Group C: Clay loams; shallow sandy loam; soils low in organic content; soils usually high in clay; minimum infiltration rate: 0.05 - 0.15 inches/hr.
- Group D: Soils that swell significantly when wet; heavy plastic clays; certain saline soils. Minimum infiltration rate: 0 - 0.05 inches/hr.

With use of GIS, use or earlier studies on soil types and field observations, the research team must identify the major hydrological soil types of the catchment area. The total surface area for each soil type in each specific land use and UPAF type used in the scenarios must be calculated and ideally mapped for each catchment.

Assigning runoff coefficients to different land uses/covers

Land use/covers and site characteristics such as slope and soils have together a high influence on the portion of rainfall that will not infiltrate or stored in the soil and will become runoff. Once the data mentioned are collected, runoff coefficients can then be assigned to each land use/cover type representing both UPAF and non UPAF areas in the catchment. In cases where there are several runoff coefficients for areas that are relatively homogenous, an average runoff coefficient can be used.

4. DETERMINING THE WEIGHTED RUNOFF COEFFICIENT

Runoff coefficients determined for each type of land use and ground cover, based on field and/or internationally available data, can then be used to calculate the reduction in runoff indicator for each of the selected scenarios by using the coefficients for both the existing and potential land uses/covers. The following formula can be used to calculate the weighted runoff coefficient (C) for all ground covers in the catchment area:

$$C = \Delta A_i C_i / \Delta A$$

Where C= weighted run-off coefficient and Ci the runoff coefficient of ground cover, soil

2 Note, inches can be converted to centimetres by multiplying them by a factor 2.54

type and slope, and Ai is the area of specific ground cover type (hectares) and A is the total catchment area (hectares).
This can then be used to calculate the percentage in reduction or change (Δ) in runoff using the equation:

$$\Delta C = 200 \cdot (C_{t+1} - C_t)/(C_{t+1} + C_t)$$

where:, C_{t+1} is the runoff coefficient for the hypothetical scenarios and C_t = runoff coefficient for the current situation (scenario 1).

The following provides a simple example of how weighted averages of runoff coefficients for 2 scenarios can be used to assess the effect of UPAF on each catchment. For example if a catchment is 50% industrial, 25% residential, 25% parks; then the average runoff coefficient for that catchment is: 0.8*0.5+0.5*0.25+0.1*0.25 or C = 0.55 runoff coefficient

However if industrial areas were converted to agriculture: 50% Agriculture, 25% residential, 25% parks, the weighted average would be calculated as: 0.2*0.5+0.5*0.25+0.1*0.25, resulting in a runoff coefficient for that same catchment of C= 0.25 runoff coefficient.
Using this example, the reduction or change (%) in runoff will be:

$$\Delta C = 200 \cdot (0.25 - 0.55)/(0.25 + 0.55) = -75\%$$

5. CALCULATION OF CHANGES IN FLOOD RISK

Using a rational equation to obtain the design flow and the equation of Kieffer and Chu empirical model, the relationship between runoff coefficients under different scenarios of land use and the probability of excess or return period (that is used for the design of drainage infrastructure) can be expressed as (Zimmermann and Bracalenti 2014):

$$\left(\frac{C_{t+1}}{C_t}\right)^{1/m} = \frac{T_t}{T_{t+1}} = \frac{P_{t+1}}{P_t} \qquad \text{(A.1)}$$

Where C_t and C_{t+1}; T_t and T_{t+1}; P_t and P_{t+1} are the coefficients of runoff, return periods and probabilities of excess of rainfall intensity at time t and t + 1, respectively; m is an empirical regional parameter, exponent of the return period in the equation of Kieffer and Chu. M has to be defined locally based on local rainfall data.

Return time and probability of excess respectively (P_t and P_{t+1}), with P being precipitation of design associated with the return time can be used to define flood risks and required expansion of the urban drainage infrastructure. For example given a probability of excess of 20% (which equals a return time for heavy storm events of every 5 years), in a scenario where the runoff coefficient increases with x%, the new probability of excess and new return time can be calculated. Using rainfall statistics for the study city, the volume of precipitation for design of drainage infrastructure corresponding to a probability of excess of 20% can be determined. Higher probabilities of excess, and thus lower volumes of rainfall that can be handled by the current urban drainage system, imply the required expansion of the urban storm water drainage infrastructure to return to the current security/safety conditions.

A more elaborate example of such calculations and analysis as developed in the Rosario, Argentina, is given in Appendix 4.

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Appendix 1. Runoff coefficients (proxies)

From: R. H. McCuen 2004. Hydrological Analysis and Design. 3d Edition, Prentice Hall, NJ USA.

Land use / vegetation cover	Peak **run off coefficients C** (range)	**C suggested Default value** (soil class B, Slope class 1: max 2%)	For Soil type classes C and D	For Slope classes 2 and 3 (1= < 2 %, 2= 2-6 %, 3= > 6 %)
Agricultural land				
Cultivated cropland	0.10 – 0.40	0.15	Add 25% for each higher class	Add 30% for each higher class
Pasture/ meadow	0.10 – 0.60	0.25	Add 25% for each higher class	Add 30 % for each higher class
Rice fields	0.9	0.9	-	-
Undisturbed natural vegetation				
Mainly shrubs/ scrubs	0.10 – 0.40	0.15	Add 25% for each higher class	Add 30 % for each higher class
Mainly grasses	0.10 – 0.60	0.25	Add 25% for each higher class	Add 30 % for each higher class
Sparsely vegetated	0.20 - 0.60	0.35	Add 25% for each higher class	Add 30 % for each higher class
Wetlands	0.9	0.9	-	-
Forested	0.05 – 0.25	0.10	Add 25% for each higher class	Add 30 % for each higher class
Pavement				
Asphalt/cement	0.75 - 0.95	0.85	-	-
Brick/ flagstone/ gravel	0.70 - 0.85	0.80	-	-
Compacted non- vegetated land	0.30 – 0.75	0.50	Add 25% for each higher class	Add 30 % for each higher class
Black roofs	0.75 – 0.95	0.85	-	-
Water bodies	1	1	-	-

Appendix 2. Peak discharge calculations

The rational method can be used in smaller and medium sized watersheds (1000 hectares or less). Assessing the costs of infrastructure needed to reduce peak discharges will be specific to each situation, and will be based on available materials and technologies, land use codes, building infrastructure, population density, local costs, etc. Hence this analysis can be time consuming and requires further resources and methods that are beyond the scope of this manual.

Peak discharge (m^3/s) can be calculated using the following equation Qp = 0.0028 CiA (S.I. unit) where (C) is the runoff coefficient, (i; mm/hr) the rainfall intensity, A the area of the catchment in ha and 0.00028 is the factor that converts to English metric units (http://rational.sdsu.edu/).

The time of concentration needed to calculate 'I' or the "Intensity/ Duration/ Frequency[3]" curves for rainfall events in the geographical region of interest is used to establish acceptable levels of risk. Duration (hours) is equivalent to the time of concentration of the catchment's area, or the time when the furthest point in the catchment contributes to runoff and peak flow (often 1 hr rainfall event) and can be calculated using several formulas. One method accounts for the channel characteristics: straight concrete channel versus, sinuous wide channel with vegetation. It can also be determined using the length of longest channel (m), slope (%), and channel type (roughness coefficient) for representative catchments. These in turn can be estimated using GIS and ARC HYDRO to delineate catchments and also compute the time of concentration.

Arc Hydro Tools Overview – v2.0

H&H Modeling/Time of Concentration

Tool	Description	Requires ArcInfo or ArcEditor	Requires Spatial Analyst
Compute Time of Concentration	Compute Time of Concentration and associated Longest Flow Path for each input Drainage Area feature. The time of concentration (Tc) is defined as the time for runoff to travel from the hydraulically most distant point of the drainage area to the outlet of the drainage area.		x

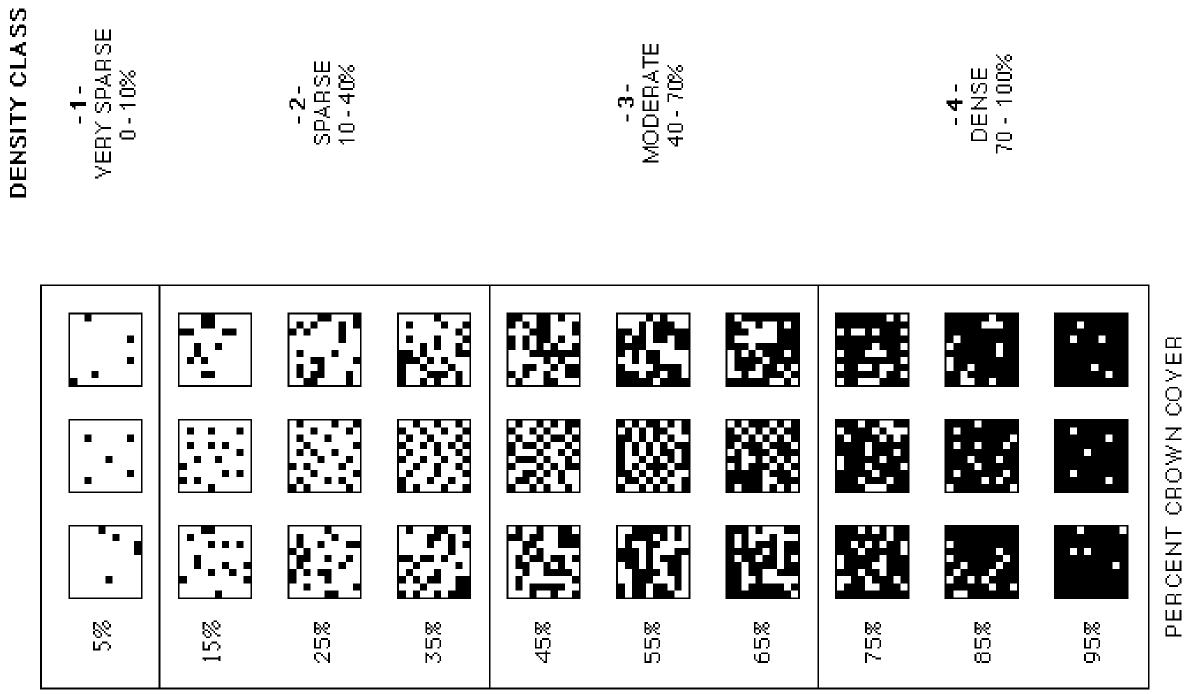
Table 9-Rainfall Intensities and Corresponding Peak Flow

Watershed	Area (ha)	Tc (min)	Rainfall Intensity (mm/hr) Corresponding to Time of Concentration (Tc)			
			2Yr	5Yr	10Yr	25Yr
A	4	15.35	124	148	163	183
B	4.22	9.90	136	160	175	197
C	1.63	7.88	141	165	180	202

3 "Frequency" is typically stated by local authorities depending on the impact of the development as 10-yr, 25-yr, or 50-yr storms.

Appendix 3. Example of ground cover scales

The following scale can be used to estimate the ground covers: black areas on the scale represent the specific cover type that you want to estimate (see categories below), while the white areas represent the sum of other covers in the study area. Make a sketch of the parts of the area under the specific cover type that you want to estimate and then compare to the scale below to arrive at a certain percentage.



Estimate, with help of the scale above, the percentage of the catchment area (rounded off to the nearest 5%) that is covered by each of the following vegetation, or other locally relevant UPAF types, or materials (The sum of all covers should be 100%):

- **Buildings, asphalt and cement:** % of study area covered by buildings and pavements of asphalt and cement
- **Other pavements:** % of study area covered by pavements made of brick, flagstone, gravel, etcetera
- **Compacted bare soil:** % of study area covered by soil that is heavily compacted due to human or animal activity (e.g. used for parking, markets, walking area, grazing area etcetera).
- **Cultivated cropland:** % of study area in use for cultivation of crops other than wet rice. Land planted with non-woody trees (banana, papaya, etcetera) is included in this category
- **Pasture/meadow/lawn:** % of study area used as pasture, meadow or lawn
- **(wet) Rice fields:** % of study area
- **Forested area:** % of study area that is forested (trees with dbh above 2,5 cm; density is such that no cultivation underneath is possible)
- **Area with young woody trees** (under 2.5 cm diameter at breast height)
- **Undisturbed natural vegetation: % of plot under natural vegetation:**
    a. mainly shrubs/scrubs
    b. mainly grasses/herbaceous
    c. sparsely vegetated (but not compacted due to human activity)
- **Water:** % of study area: water bodies, including pools, ponds and wetlands with surface water

Appendix 4. Scenario development and analysis for a catchment in Rosario, Argentina

The methodology proposed in this manual was applied in the Watershed Conduit 10, that is located in the central-west area of the city of Rosario (Fig. A.1). Four scenarios have been defined and applied: (1) the current situation; (2) one possible future scenario taking into account development of all urban areas in accordance with current regulations; (3) a hypothetical scenario in which all buildable and non- buildable land would be urbanised; and (4) a fourth scenario increasing the amount of green areas, with alternative proposals for land use such as UPAF, green streets and green sidewalks, green roofs, etc.

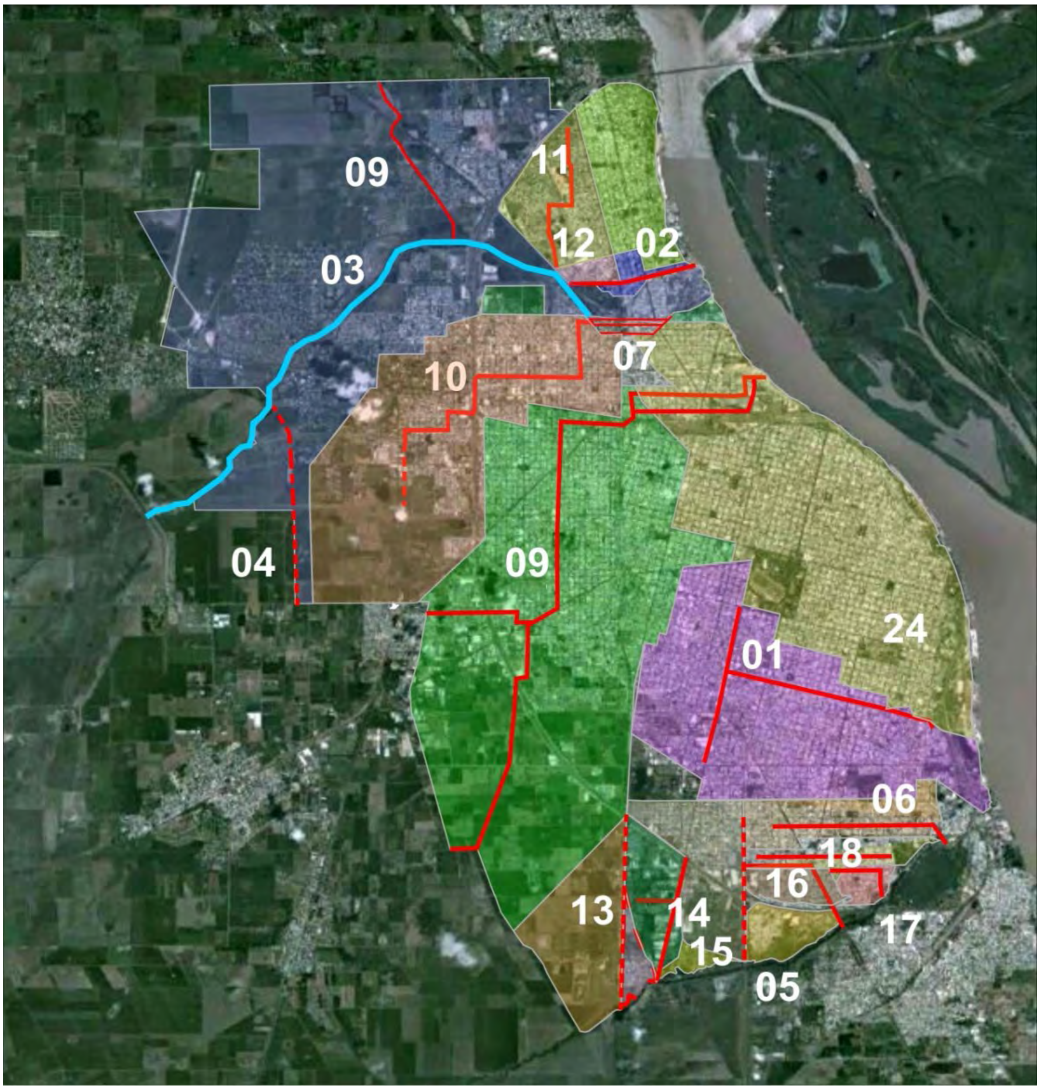


Figure A.1. Hydrological Sub-basin of Rosario City.

<u>Location and general features</u>

The area corresponding to the Sub-Watershed Conduit 10 (SW10) of Rosario, is part of Ludueña's stream basin. It is located in the central-west part of the town, and its west-side limit coincide with the borders of a rural township. This sub-basin number 10 covers an area of about 23 km2 (2,282 ha). The area belongs for a major part to the Municipal Northwest District (Distrito Noroeste), with only the southern sector belonging to the West District- Distrito Oeste (Fig. A.1 and A.2). The Northwest District has a population of 144,461 inhabitants (15.23% of the total municipal population) and covers a total area of 44.14 km ² (24.7% of the municipality). It has a density of 3,273 inhabitants/km ² and a total of 41,740 homes. The West District has a population of 106,356 inhabitants (11.22% of total) and covers an area of 40.21 km² (22,5% of the municipality). It has a density of 2,645 inhabitants/km ² and a total of 31,625 homes.

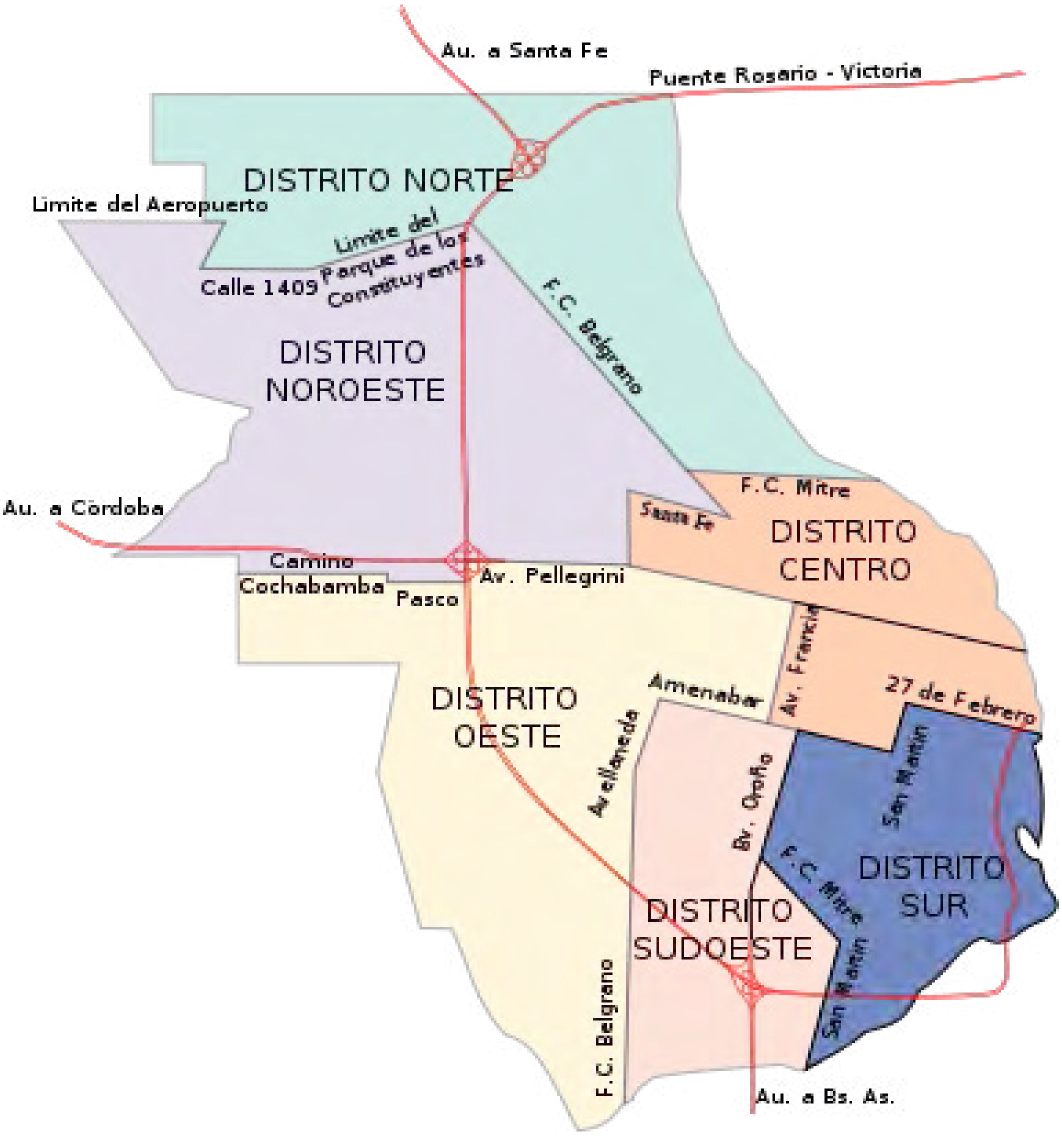


Figure A.2. Districts of Rosario city.

Features of SW10

Rural Areas

Both the Northwest and the West District integrated areas that correspond to the category of non-built up land (rural areas and large non-built areas). These areas are used for horticultural activities, intensive farming, production of bricks and as vacant areas (see Fig. A.3 and following photographs).

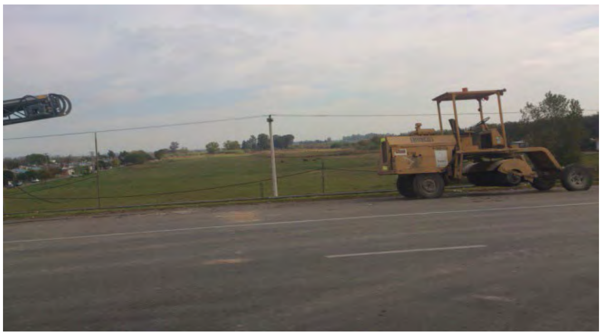
Figure A.3. Rural area Southwestern sector.

PICTURES OF NON-BUILD UP AREAS IN SW10










Urbanised Areas

The urbanised area corresponding to the SW10 is characterised by a wide variety of uses and activities as well as urban fabric. Infrastructure services and urban facilities are of better standard in the more consolidated and well-off sectors, while in other sectors, the equipment is inadequate and infrastructure is incomplete, sometimes non-existent (in peri-urban areas with irregular settlements). In the Northeast Sector, east of Circumvallation Avenue, (Fig. A.4 and photographs), and north of Córdoba Avenue, industry is found. Industrial areas alternate with residential sectors, irregular settlements, traditional neighbourhoods and commercial sectors located on important avenues like Córdoba and United Provinces.

Figure A.4 Urbanised area. North-east Sector.

PICTURES OF URBANISED AREAS. NE CIRCUMVALLATION AVENUE

At Northwestern of Av. Circumvallation, the Fisherton district is located, created as a residential area for Railway employees, which is now a high-class residential area (Fig. A.5 and photographs).

Figure A.5. NW Sector
This sector has low building density and a high percentage of ground vegetation and forestation. Notwithstanding, the area was recently flooded as a result of overflow of storm water in Ludueña stream basis, due to heavy rainfall.

PICTURES OF URBANISED SECTORS. NW CIRCUMVALLATION AVENUE






The West Sector, located south of Av. Córdoba, north of Rosario-Córdoba Highway, and west of Av Circumvallation represents a consolidated residential middle-class area, near to the private Jockey Club of Rosario. The west zone of this sector has a large of vacant land for a future industrial park and large-scale residence.

PICTURES OF URBANISED SECTORS. WEST SECTORS

Scenarios considered

Based on land use classes and soil coverage in the study area, four scenarios were analysed:

Scenario 0. Baseline: Current status of land uses (Figure A.6.)

Scenario 1. Urbanisation simulated based on planning regulations. This scenario shows the potential coverage of buildable land considering actual government plans and development regulations. When determining building densities and other elements for this scenario, current trends in land occupation were taken as the standards (Fig. A.7).

Scenario 2. This scenario shows the hypothetical coverage and urbanisation of un-buildable areas in accordance with current trends in land occupation. For the determination of the building densities and other elements, the current trends in land occupation were taken as standards (Fig. A.8).

Scenario 3. Future urbanization, but considering the maximum land use allowed by current regulations for different vegetative ground covers (gardens, trees, green streets and sidewalks, green roofs). UPAF activities in non-urbanised areas (public parks, floodplains, side road and rail) are optimised (Fig. A.9.).

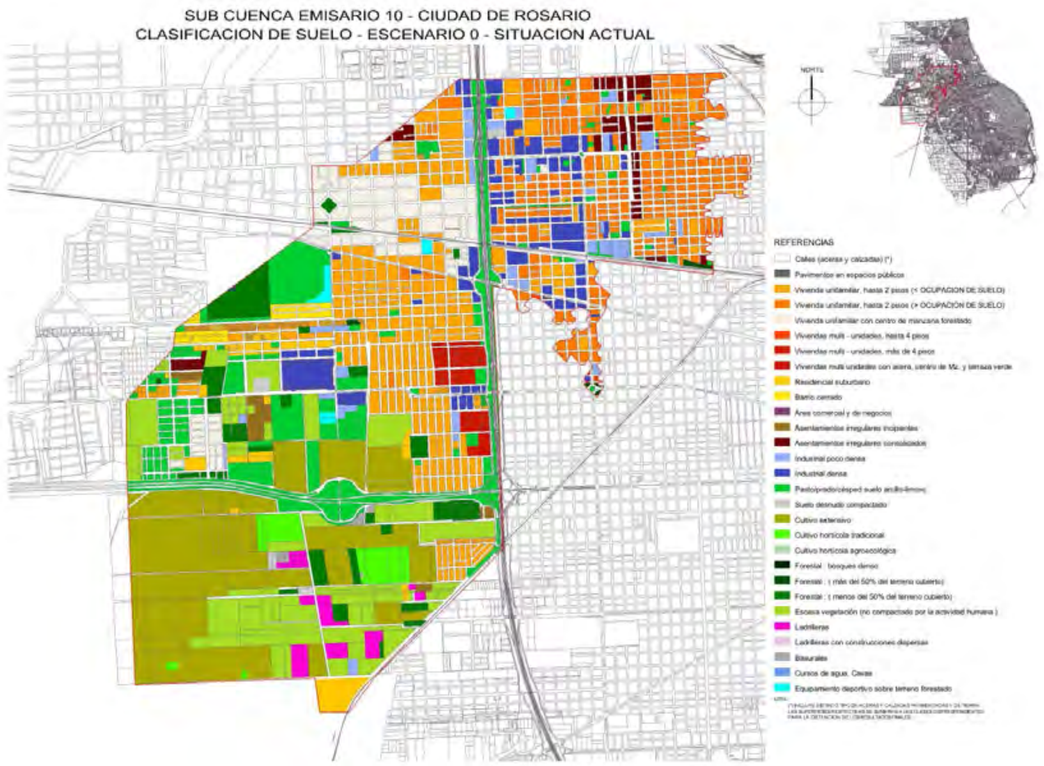


Figure A.6. Land use for Scenario 0 (current).

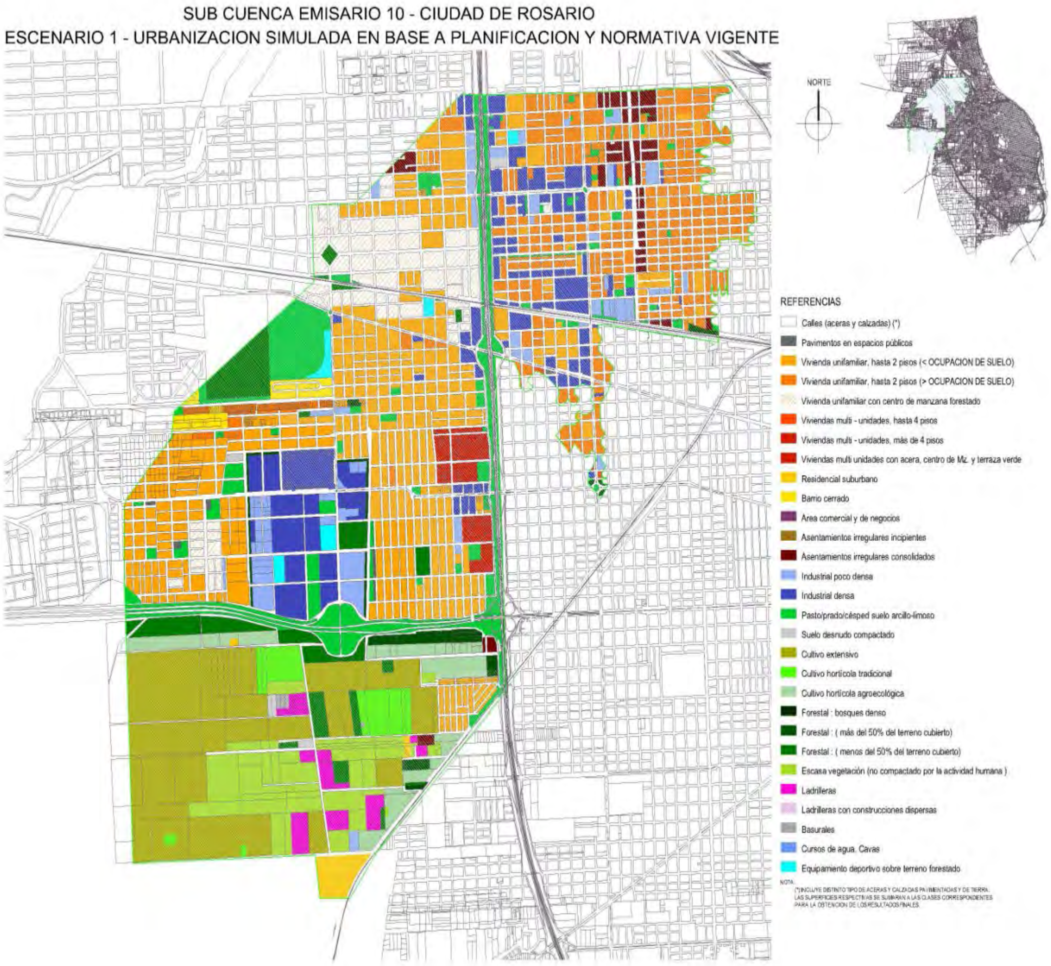


Figure A.7. Land use for Scenario 1 (current planning).

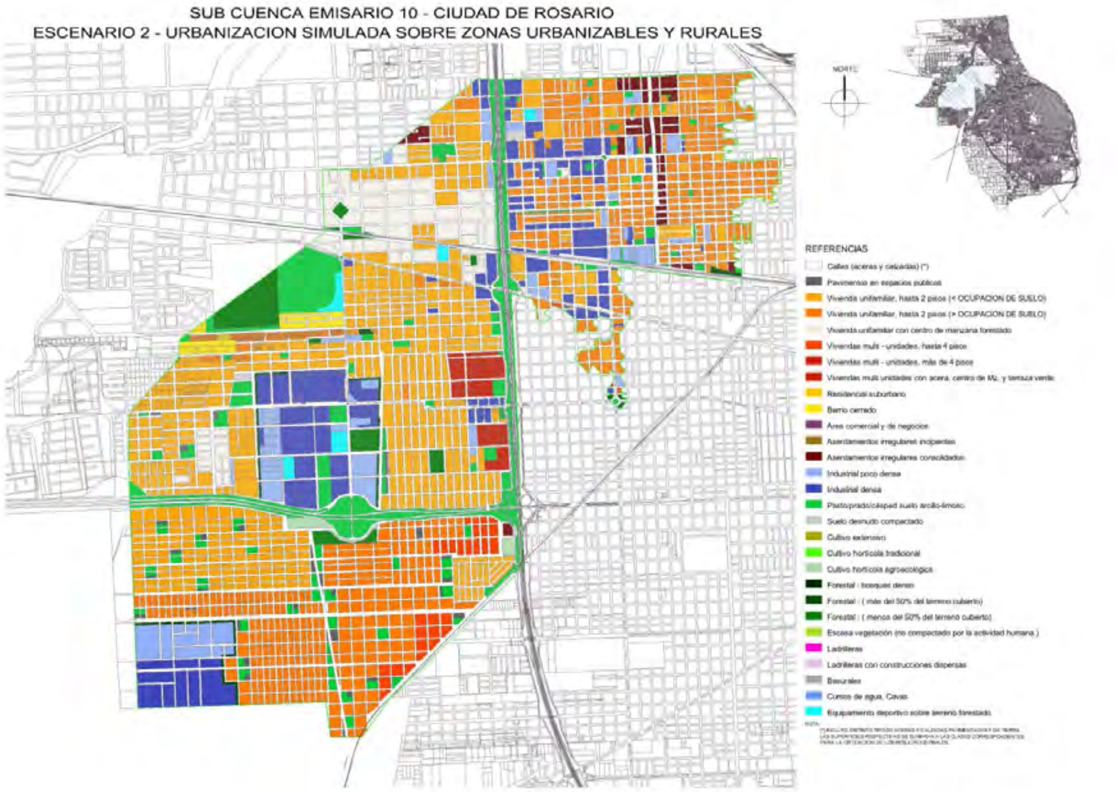


Figure A.8. Land use for Scenario 2.

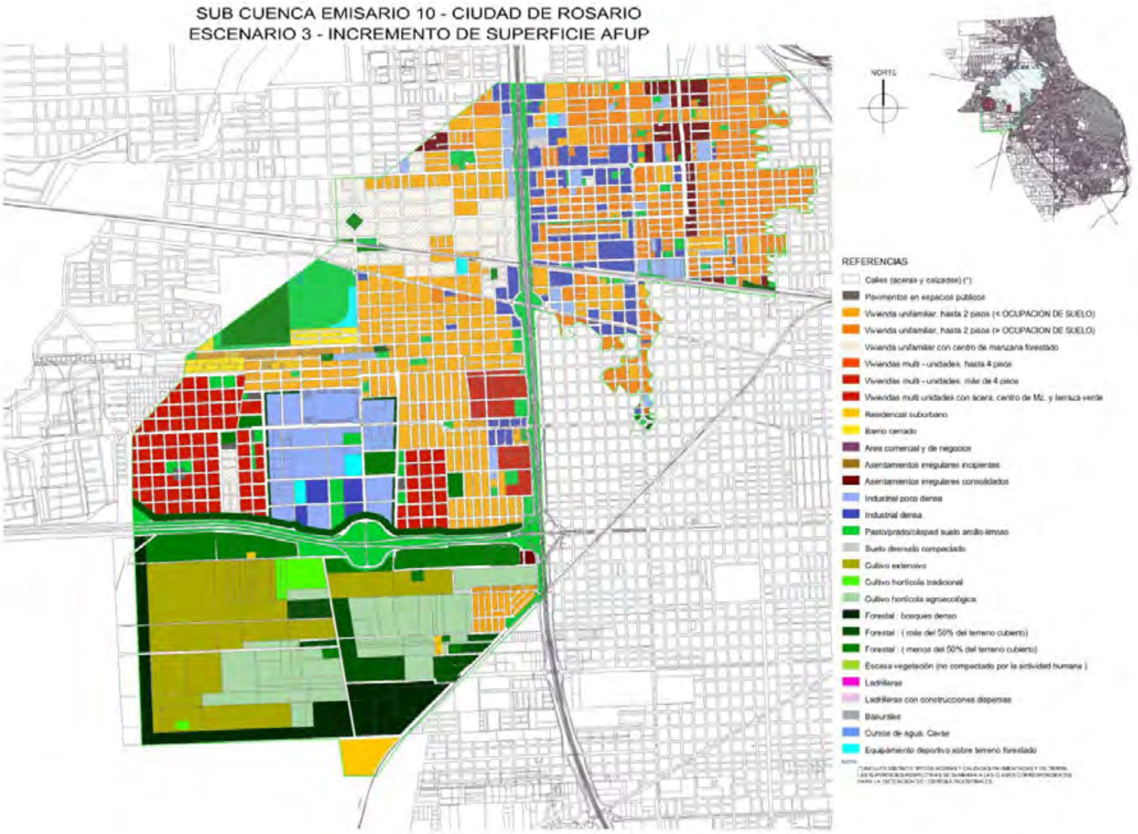


Figure A.9. Land use for Scenario 3 (UPAF activities).

Calculation of runoff indicator for the proposed scenarios

Changes in runoff due to changes in land use were calculated as follows:

(a) Estimation, using Tables 1 and 2, of runoff coefficients for each soil type and slope coverage.

(b) Calculation of the composite runoff coefficient for all land covers in the catchment area, on the basis of additional information using satellite imagery (Google Earth). Details for estimating runoff coefficients are described in Table A.1 for scenario 0. In Table A.2 land use areas and runoff coefficients for scenario 0 are given.

(c) Calculation of the change in runoff due to changes in land use, Δ C. Negative values for any period of time in Δ C indicate a net decline in runoff (and consequent reduction of flood risk) caused by an increase in infiltration / storage of precipitation in the urban area.

Results are shown in Tables A.3, A.4 and A.5 corresponding to scenarios 1, 2 and 3, respectively.

Table A.1. Estimated runoff coefficients

	Coverage	C	**Observations**
1	Streets (sidewalks and driveways) (*)	**0.90**	Range 0.70-0.95
2	Pavement in public spaces	**0.90**	Range: 0.70-0.95
3	Single-family home, up to 2 floors (<occupation of land)	**0.60**	Weighted: 50%*0.90+50%*0.30, 50% grass and roofing
4	Single-family home, up to 2 floors (>occupation of land)	**0.65**	Weighted: 70%*0.90+30%*0.30, 30% grass and roofing
5	Single family home with central forested block	**0.57**	Weighted: 45%*0.90+55%*0.30, 55% grass and roofing
6	Multi-housing units, up to 4 floors	**0.70**	Considered as a compact family housing
7	Multi-housing units, more than 4 floors	**0.75**	Considered as a more compact family housing
8	Multi-housing units with green sidewalk and green roofs	**0.48**	Weighted: 12%pavement*0.90+24%roof*0.95+24%green roof*0.30+28%forest*0.23+12% organic garden*0.10.
9	Residential or suburban	**0.59**	Considered intermediate between Classes 3 and 5
10	Cottages	**0.48**	Weighted: 30%*0.90+70%*0.30, 70% grass and roofing
11	Commercial and business areas	**0.60**	Range: 0.50-0.70
12	Incipient and irregular settlements	**0.56**	Considered as a compact family housing less compacted
13	Consolidated and irregular settlements	**0.70**	Considered as a compact family housing
14	Industrial not very dense	**0.70**	Range: 0.50-0.80
15	Industrial dense	**0.80**	Range: 0.60-0.90
16	Pasture / meadow / lawn clay loam soil	**0.30**	Considered as grass (C=0,25) + 25% soil type C
17	Bare soil compacted	**0.63**	Considered according Table (C=0,50) + 25% Soil type C
18	Extensive crop production	**0.21**	Considered according Table (C=0,15) +25% Soil type C+10% compacted
19	Traditional horticultural crops	**0.20**	Considered according Table (C=0,15) + 25% Soil type C +5% because of lower organic matter content
20	Ecological horticultural crops	**0.10**	Considered as traditional crop + soil with high organic matter
21	Forestry: Dense forests	**0.13**	Considered according Table (C=0,10) + 25% Soil type C

22	Forest (more than 50% of the land covered)	**0.23**	Considered according Table (C=0,18) + 25% Soil type C
23	Forest (less than 50% of the land covered)	**0.33**	Considered according Table (C=0,25) + 25% Soil type C
24	Sparse vegetation (not compacted by human activity)	**0.44**	Considered according Table (C=0,35) + 25% Soil type C
25	Brick factory	**0.63**	Considered according Table (C=0,50) + 25% Soil type C
26	Brick factory with scattered buildings	**0.74**	Considered according Table (C=0,50) + 25% Soil type C+ 40% roofing (C=0,90)
27	Landfills	**0.63**	Considered as bare soil compacted
28	Watercourses, land deposits	**0.00**	Considered as storage areas of rain
29	Sports equipment on forested land	**0.30**	Range (parks): 0.20-0.35

Table A.2. Land uses, areas and runoff coefficients for Scenario 0.

	SCENARIO 0	areas en m2	C	% Area
1	Streets (sidewalks and driveways) (*)	**3,997,899.43**		
2	Pavement in public spaces	2,187,217.67	**0.90**	11.5
3	Single-family home, up to 2 floors (<occupation of land)	2,296,804.16	**0.60**	12.1
4	Single-family home, up to 2 floors (>occupation of land)	1,579,613.31	**0.65**	8.3
5	Single family home with central forested block	810,390.67	**0.57**	4.3
6	Multi-housing units, up to 4 floors	5,355.96	**0.70**	0.0
7	Multi-housing units, more than 4 floors	566.04	**0.65**	0.0
8	Multi-housing units with green sidewalk and grenn roofs	244,904.84	**0.48**	1.3
9	Residential or suburban	339,961.14	**0.59**	1.8
10	Cottages	137,203.53	**0.48**	0.7
11	Commercial and business areas	0.00	**0.60**	0.0
12	Incipient and irregular settlements	118,357.77	**0.56**	0.6
13	Consolidated and irregular settlements	269,923.67	**0.70**	1.4
14	Industrial not very dense	346,599.51	**0.70**	1.8
15	Industrial dense	841,016.63	**0.80**	4.4
16	Pasture / meadow / lawn clay loam soil	2,035,547.84	**0.30**	10.7
17	Bare soil compacted	754,772.50	**0.63**	4.0
18	Extensive crop production	2,938,434.23	**0.21**	15.4
19	Traditional horticultural crops	297,929.14	**0.20**	1.6
20	Ecological horticultural crop	0.00	**0.10**	0.0
21	Forestry: Dense forests	0.00	**0.13**	0.0
22	Forest (more than 50% of the land covered)	633,127.51	**0.23**	3.3
23	Forest (less than 50% of the land covered)	1,044,096.14	**0.33**	5.5
24	Sparse vegetation (not compacted by human activity)	1,830,273.75	**0.44**	9.6
25	Brick factory	234,080.62	**0.63**	1.2
26	Brick factory with scattered buildings	0.00	**0.74**	0.0
27	Landfills	30,273.60	**0.63**	0.2
28	Watercourses, land deposits	0.00	**0.00**	0.0
29	Sports equipment on forested land	72,062.02	**0.30**	0.4
	SUBTOTAL	**19,048,512.26**		
		C average	**0.51**	

Table A.3. Land uses, areas and runoff coefficients for Scenario 1.

	SCENARIO 1	areas en m2	C	% Area
1	Streets (sidewalks and driveways) (*)	**4,229,480.73**		
2	Pavement in public spaces	2,303,472.17	**0.90**	12.1
3	Single-family home, up to 2 floors (<occupation of land)	3,215,338.44	**0.60**	16.9
4	Single-family home, up to 2 floors (>occupation of land)	1,579,613.31	**0.65**	8.3
5	Single family home with central forested block	920,185.75	**0.57**	4.8
6	Multi-housing units, up to 4 floors	5,355.96	**0.70**	0.0
7	Multi-housing units, more than 4 floors	566.04	**0.65**	0.0
8	Multi-housing units with green sidewalk and grenn roofs	244,904.84	**0.48**	1.3
9	Residential or suburban	130,597.57	**0.59**	0.7
10	Cottages	137,203.53	**0.48**	0.7
11	Commercial and business areas	0.00	**0.60**	0.0
12	Incipient and irregular settlements	0.00	**0.56**	0.0
13	Consolidated and irregular settlements	257,039.41	**0.70**	1.3
14	Industrial not very dense	575,154.11	**0.70**	3.0
15	Industrial dense	1,279,223.24	**0.80**	6.7
16	Pasture / meadow / lawn clay loam soil	1,460,704.10	**0.30**	7.7
17	Bare soil compacted	804,157.14	**0.63**	4.2
18	Extensive crop production	2,204,590.94	**0.21**	11.6
19	Traditional horticultural crops	297,929.14	**0.20**	1.6
20	Ecological horticultural crop production	456,857.07	**0.10**	2.4
21	Forestry: Dense forests	0.00	**0.13**	0.0
22	Forest (more than 50% of the land covered)	853,546.10	**0.23**	4.5
23	Forest (less than 50% of the land covered)	1,049,988.74	**0.33**	5.5
24	Sparse vegetation (not compacted by human activity)	920,757.06	**0.44**	4.8
25	Brick factory	234,080.62	**0.63**	1.2
26	Brick factory with scattered buildings	0.00	**0.74**	0.0
27	Landfills	13,759.62	**0.63**	0.1
28	Watercourses, land deposits	0.00	**0.00**	0.0
29	Sports equipment on forested land	103,487.37	**0.30**	0.5
	SUBTOTAL	**19,048,512.26**		
		C average	**0.53**	

Table A.4. Land uses, areas and runoff coefficients for Scenario 2.

	SCENARIO 2			
		areas en m2	C	% Area
1	Streets (sidewalks and driveways) (*)	**5,283,511.36**		
2	Pavement in public spaces	2,829,513.05	**0.90**	14.9
3	Single-family home, up to 2 floors (<occupation of land)	4,182,563.31	**0.60**	22.0
4	Single-family home, up to 2 floors (>occupation of land)	3,136,644.15	**0.65**	16.5
5	Single family home with central forested block	920,185.75	**0.57**	4.8
6	Multi-housing units, up to 4 floors	224,077.41	**0.70**	1.2
7	Multi-housing units, more than 4 floors	566.04	**0.65**	0.0
8	Multi-housing units with green sidewalk and grenn roofs	244,904.84	**0.48**	1.3
9	Residential or suburban	0.00	**0.59**	0.0
10	Cottages	137,203.53	**0.48**	0.7
11	Commercial and business areas	0.00	**0.60**	0.0
12	Incipient and irregular settlements	0.00	**0.56**	0.0
13	Consolidated and irregular settlements	243,019.74	**0.70**	1.3
14	Industrial not very dense	796,349.17	**0.70**	4.2
15	Industrial dense	1,585,568.73	**0.80**	8.3
16	Pasture / meadow / lawn clay loam soil	1,749,728.35	**0.30**	9.2
17	Bare soil compacted	1,256,387.45	**0.63**	6.6
18	Extensive crop production	0.00	**0.21**	0.0
19	Traditional horticultural crops	0.00	**0.20**	0.0
20	Ecological horticultural crop production	60,612.86	**0.10**	0.3
21	Forestry: Dense forests	0.00	**0.13**	0.0
22	Forest (more than 50% of the land covered)	899,441.20	**0.23**	4.7
23	Forest (less than 50% of the land covered)	678,259.31	**0.33**	3.6
24	Sparse vegetation (not compacted by human activity)	0.00	**0.44**	0.0
25	Brick factory	0.00	**0.63**	0.0
26	Brick factory with scattered buildings	0.00	**0.74**	0.0
27	Landfills	0.00	**0.63**	0.0
28	Watercourses, land deposits	0.00	**0.00**	0.0
29	Sports equipment on forested land	103,487.37	**0.30**	0.5
	SUBTOTAL	**19,048,512.26**		
		C average	**0.62**	

Table A.5. Land uses, areas and runoff coefficients for Scenario 3.

	SCENARIO 3			
		areas en m2	C	% Area
1	Streets (sidewalks and driveways) (*)	**4,391,084.50**		
2	Pavement in public spaces	2,361,514.54	**0.90**	12.4
3	Single-family home, up to 2 floors (<occupation of land)	2,259,205.14	**0.60**	11.9
4	Single-family home, up to 2 floors (>occupation of land)	1,579,613.31	**0.65**	8.3
5	Single family home with central forested block	763,088.26	**0.57**	4.0
6	Multi-housing units, up to 4 floors	5,355.96	**0.70**	0.0
7	Multi-housing units, more than 4 floors	566.04	**0.65**	0.0
8	Multi-housing units with green sidewalk and grenn roofs	1,124,775.78	**0.48**	5.9
9	Residential or suburban	161,502.07	**0.59**	0.8
10	Cottages	137,203.53	**0.48**	0.7
11	Commercial and business areas	0.00	**0.60**	0.0
12	Incipient and irregular settlements	0.00	**0.56**	0.0
13	Consolidated and irregular settlements	245,408.35	**0.70**	1.3
14	Industrial not very dense	1,005,499.67	**0.70**	5.3
15	Industrial dense	735,511.67	**0.80**	3.9
16	Pasture / meadow / lawn clay loam soil	1,290,340.33	**0.30**	6.8
17	Bare soil compacted	619,232.30	**0.63**	3.3
18	Extensive crop production	1,584,778.45	**0.21**	8.3
19	Traditional horticultural crops	127,383.32	**0.20**	0.7
20	Ecological horticultural crop production	1,236,989.79	**0.10**	6.5
21	Forestry: Dense forests	698,042.61	**0.13**	3.7
22	Forest (more than 50% of the land covered)	1,858,932.59	**0.23**	9.8
23	Forest (less than 50% of the land covered)	1,100,277.80	**0.33**	5.8
24	Sparse vegetation (not compacted by human activity)	0.00	**0.44**	0.0
25	Brick factory	0.00	**0.63**	0.0
26	Brick factory with scattered buildings	0.00	**0.74**	0.0
27	Landfills	0.00	**0.63**	0.0
28	Watercourses, land deposits	49,803.37	**0.00**	0.3
29	Sports equipment on forested land	103,487.37	**0.30**	0.5
	SUBTOTAL	**19,048,512.26**		
		C average	**0.49**	

CALCULATION OF CHANGES IN FLOOD RISK

Using a rational equation to obtain the design flow and the equation of Kieffer and Chu empirical model, the relationship between runoff coefficients under different scenarios of land use and the probability of excess or return period (that is used for the design of drainage infrastructure) can be expressed as (Zimmermann and Bracalenti 2014):

$$\left(\frac{C_{t+1}}{C_t}\right)^{1/m} = \frac{T_t}{T_{t+1}} = \frac{P_{t+1}}{P_t} \qquad \text{(A.1)}$$

Where C_t and C_{t+1}; T_t and T_{t+1}; P_t and P_{t+1} are the coefficients of runoff, return periods and probabilities of excess of rainfall intensity at time t and t + 1, respectively; m is an empirical regional parameter, exponent of the return period in the equation of Kieffer and Chu.

For calibration of this equation with rainfall data from the city of Rosario (Argentina, 32° 57'S, 60° 41'W), m = 0.122. The regional average of parameter m is 0.18 (Zimmermann 2013).

RESULTS

The tables provided above show the difference in average C when comparing scenarios with and without development of UPAF areas.

For the current land use (scenario 0), the average runoff coefficient is 0.51 for the study area.

For the future urbanisation of buildable land according to the current regulations of land use (scenario 1), the runoff coefficient reaches a value of 0.53, which implies an increase of about 4% in Δ C:

$$\Delta C = 200\frac{C_{t+1} - C_t}{C_{t+1} + C_t} = 200\frac{0.53 - 0.51}{0.53 + 0.51} \approx 3.8\%$$

Considering the value of m = 0.122 adjusted for Rosario, applying equation (A.1) we can calculate that for an increased runoff coefficient of 4%, Ct + 1 / Ct = 1.039, flood risks would increase by Pt + 1 / Pt = 1.37 times. Using this same example, in urban drainage design, given a probability of excess of 20% (which equals a return time for heavy storm events of every 5 years), in the scenario where the runoff coefficient increases with 4%, the new probability of excess reaches the value 1.37 * 20% = 27% (a new return time of 3.6 years). Using rainfall statistics for Rosario, under current conditions (scenario 0), the volume of precipitation for design of drainage infrastructure corresponding to a probability of excess of 20% is 135.6 mm. For the future scenario (scenario 1), the current urban drainage system would only be able to discharge a precipitation of 125 mm (corresponding to a probability of excess of 27%). These values indicate that scenario 1 would require an expansion of the urban storm water drainage infrastructure to return to the current security/safety conditions.

For scenario 2 (extreme conversion to impervious land covers and sealing), the runoff coefficient reaches a value of 0.62, which represents approximately an increase of 20% from its current value, and a positive ΔC indicator value of 19.5%. Considering the value of m = 0.122 adjusted for Rosario, applying equation (A.1), we find that Ct + 1 / Ct = 1.22, which would lead to an equivalent ratio of Pt + 1 / Pt = 4.96. Given a probability of excess of 20% (return time of 5 years), for scenario 2, the new probability of excess reaches the value of 99% and a new return time of about 1 year. For this future scenario, the urban drainage system would only be able to cope with a rainfall of 48 mm. These values indicate that the current drainage infrastructure would become totally inadequate, and that major reinvestment in urban drainage infrastructure is needed to restore the status of protection as prevalent under current conditions.

For future use of the land with increased green area (scenario 3), the average runoff coefficient reaches a value of 0.49, which represents an approximate 4% decrease compared to its current value and an indicator Δ C of -4%. Considering the value of m = 0.122 adjusted for Rosario, applying equation (A.1), Ct + 1 / Ct = 0.96 and the ratio Pt + 1 / Pt = 0.72. Again, given a probability of excess of 20% (return time of 5 years), for scenario 3 the new probability of excess reaches a value of 14% and the new return time will be 6.9 years. For this future scenario, the urban drainage system would be able to cope with a rainfall of 146 mm. These values imply that no further expansion of drainage infrastructure is needed in the foreseen future, significantly improving the situation of the population.

Table A.6 summarizes these results.

Table A.6. Synthesis of the results found for SW10

Sub-basin 10					
Sc.	C	Δ C %	Tt+1	Pt+1	P mm
# 0	0.51		**5.0**	**20%**	**135.6**
# 1	0.53	**3.8**	**3.6**	**27%**	**125.2**
# 2	0.62	**19.5**	**1.0**	**99%**	**48.5**
# 3	0.49	**-4.0**	**6.9**	**14%**	**145.9**

C= runoff coefficient; Δ C = percentage change in the runoff coefficient; Tt + 1 and Pt + 1 return time and probability of excess respectively; P precipitation of design associated with the return time.

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