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Proposals for Flashflood Management in Western Argentina. Case Study: The Metropolitan Area of Greater Mendoza

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Abstract

The watersheds located in west of Greater Mendoza (Argentina) are typical examples of areas directly or indirectly affected by flashfloods. Greater Mendoza is encroaching upon areas with a pronounced relief (eastern slope of the Precordillera, the piedmont and other minor units) with strong human pressures on a fragile environment. Nowadays, the western part of Greater Mendoza is covered with paved surfaces and buildings, jeopardizing the city located downstream. In order to mitigate the negative effects of the use and occupation of the piedmont, a set of structural and non-structural measures and an urban planning model, with new urban development and architecture proposals, have been devised. These measures involve flood control, erosion control, afforestation, habitat management, control of extraction practices (aggregates, wildlife, vegetation, etc.) and education. The new urban planning model is based on the preservation of the natural character of the land and on appropriate management of surplus water (runoff detection at the source area, drainage system retention, increasing drainage capacity while minimizing impacts on downstream environments, and creation of areas to buffer runoff). Many of these measures were developed and successfully demonstrated locally.

Keywords

Flashfloods; Flood Control; Urban Drainage; Arid Areas; Mendoza

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1. Introduction

Due to historical and geopolitical conditions, many towns and cultivated areas in the western and central parts of Argentina are located in regions directly or indirectly affected by flashfloods, i.e., areas with extensive piedmont, depressions, muddy areas, and mountains. On the other hand, the oases and cultivated areas benefit from rivers that rise in the Andes and are fed by snowmelt and glacier-melt.

The urban agglomerations most vulnerable to flooding are: San Salvador de Jujuy, Salta, San Fernando del Valle de Catamarca, San Juan, Greater Mendoza, Neuquén and many towns near the Sierras Subandinas, Sierras Pampeanas or Famatina (Bertoni et al., 2003). These cities and towns were founded in mountain and hilly valleys or at the foot of mountain ranges in the western part of Argentina. Due to population growth, people tend to settle in areas with more pronounced relief, so they are more exposed to natural water threats and higher risks.

In general, urban development processes, i.e., transformation of a natural ecosystem into an urban one, are responsible for the changes in the hydrological parameters of the watershed, in the geo-shapes and in the channel network. In turn, the urban system is highly dependent on the natural conditions and on the dynamics of the natural phenomena to which it is exposed (Dourojeanni, 1999).

The watersheds located in west of Greater Mendoza are typical examples of areas with frequent flashfloods that have been affecting the urban area since the end of the 16th century. To mitigate adverse effects, it is necessary to search for innovative action approaches, new forms of land use planning and an urban development model that helps reduce flashflood risks.

2. Study Area: Description and Diagnosis

The watersheds west of Greater Mendoza are typical examples of hazardous flood zones, where flashfloods cause serious damages. The watershed area comprises the eastern slope of the precordillera, the piedmont, Cerrillada de Mogotes and part of the plains. Cerrillada de Mogotes divides the flashflood area in two well-differentiated sectors: the piedmont proper and the eastern slope covered with debris and alluvial cones which reach the urban area (Vich & Pedrani, 1993).

The area extends from Cordón de las Peñas and Cordón de los Manantiales in the north to the Mendoza River in the south. To the west it borders with the Precordillera watershed and to the east with the Greater Mendoza urban area and the cultivated plain. With a total area of some 800 km^2, it comprises a series of watersheds that drain in a west-east direction. The urban agglomeration, which comprises the cities of Las Heras, Capital, Guaymallén, Godoy Cruz, Maipú and Luján de Cuyo, occupies an area of some 16,000 ha and has a population of about 1,000,000; despite the six independent political-administrative jurisdictions, it is a single functional unit.

The eastern boundary of the flashflood area—comprised by Regalado Olguín Street to the north, Caracoles de Chacras de Coria to the south, the eastern slope of the Cerrillada Pedemontana and Boulogne Sur Mer Avenue to the east—is the sector most at risk because of an ever-increasing uncontrolled urban development with no land use planning suitable to the natural characteristics of the site (**Figure 1**). The Cerrillada Pedemontana, a low mountainous area (1200 m.a.s.l, on average), separates the torrential flashflood watersheds from the urban and periurban areas. Usually, the main stream ends in a control structure, and the surplus water is conveyed by channels and canals through the urban area to the main collector, the Cacique Guaymallén canal (DIGID, 1973).

The natural processes that have affected the city of Mendoza the most are debris flows from the piedmont, known as flashfloods, and medium-high magnitude earthquakes with epicenters associated with active Quaternary faults. The intense seismic activity in Mendoza is due to sub-horizontal subduction of the Nazca Plate at 32˚ south latitude (Ramos, 1996). The orogenic front of the compression system, which began in the Miocene, migrated eastward elevating the Cordillera (8 to 12 million years ago) and the Precordillera (.7 million years ago) creating a stress zone in the piedmont, where the land has been elevated by Quaternary tectonic movements.

The climatology of the piedmont has been constructed using historical records from the Mendoza Aero (32.50˚S y 68.47˚W) and Observatorio Mendoza (32.53˚S y 68.51˚W) stations. Maximum rainfall occurs in the summer months. Rainfall declines in a south-west to north-east direction from some 400 mm per year to 130 mm (Fernández, 2010). No clear trend in the evolution of the amount of rainfall is observed in the last three decades of the 20th century. It seems that the average number of rainy days has decreased over the decades (Norte & Simonelli, 2010). According to Köeppen, the piedmont has a BWakw climate, i.e., arid (B), desert with very hot summers (BW), mean temperature in the hottest month above 22˚C (BWa), mean annual tempera-

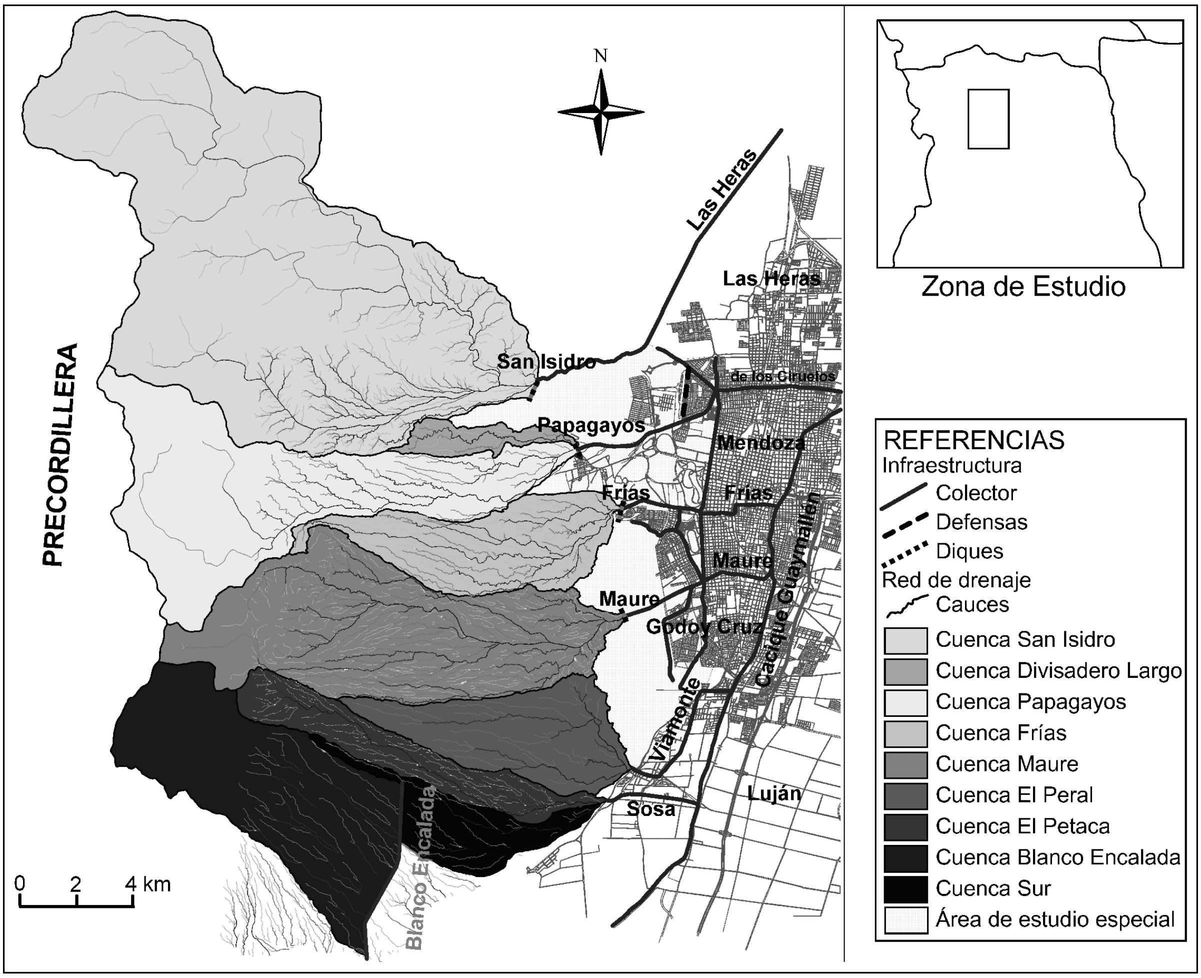

Figure 1. Greater Mendoza flashflood area.

ture below 18˚C, and mean annual temperature of 18˚C in the hottest month (BWak). Winters are dry and rainfall in the driest winter month is less than one-third the rainfall in the wettest summer month (BWakw) (Norte & Simonelli, 2010). Mean relative humidity is 52%, with mean monthly variations between 42% and 62%.

The vegetation grows in two large landscape units: Sierra de Uspallata and the piedmont, each with its own vegetation communities and associations. The vegetation belongs to the Monte Phytographic Province, Andean Piedmont District, with two sub-districts: Larrea divaricata and Fabiana denudate, and Larrea cuneifolia and Lycium tenuispinosum (Roig, 1976). The Larrea divaricata community grows above the 1200 m in the upper, semiarid part of the piedmont up to 1600 m along ravine slopes with southern exposure; at a lower altitude, it behaves as riparian vegetation. It grows in loose soils, with abundant gravel and pebbles. The Larrea cuneifolia community grows in the lower arid part of the piedmont, between 1200 and 750 m, on fine textured soils, with 50% to 55% coverage. The Zuccagnia punctata community grows as shrubs with a mean coverage of 50%. It develops best on Quaternary deposits or where erosion products accumulate at an altitude of 1200 - 1300 m. There are other smaller communities in rocky environments and in temporary rivers (Roig, 1976; Martínez Carretero, 1999).

Concerning floods in Greater Mendoza, two aspects should be taken into consideration. One is the Mendoza River summer flashfloods that affect areas in Luján de Cuyo, San Martín and Maipú directly, and the Greater Mendoza urban area indirectly—as they jeopardize basic infrastructure works, such as the Luján de Cuyo water treatment plant and the irrigation distribution system. The other relates to the flashfloods caused by rainfall in the western Cerilladas (low hills), in the piedmont and in urban areas, which is the subject of this paper. Their effects are interdependent, though they are treated differently.

Different types of flood protection structures have been constructed to prevent flashflood damage. One of them directs the flood from the west, and channels surface runoff along collector canals or deep ditches, which cut across the city from west to east up to the Cacique Guaymallén main canal, located in the lowest part of the city. It is the only drainage collector for all flows from the west because of its southwest-northeast direction. The second type of structures controls flashflood runoff through the city by retaining surplus water in reservoirs and then releasing that same amount of water in a controlled manner. This is the retention or mitigation effect of the dams in the western part of the city of Mendoza. Eventually, flood waters began to be diverted to outlying areas or to other main channels by means of drainage canals that intercept runoff from the west.

Current operation of the flood control system is strictly restricted to flashflood hydrograph attenuation for a predetermined time to recurrence, sediment retention, and to directing reservoir discharges and water surpluses along channels and drainage canals through the urban area to the Cacique Guaymallén Canal. The flood control system was conceived to protect urban and suburban areas and to reduce flood losses. The system, however, has some critical aspects: in the case of an extraordinary rainfall event, discharges from dam control structures would exceed the conveyance capacity of channels and canals and flood nearby areas. The dams would not be affected but they would not fulfill their intended use. Even in the case of a moderate rainfall event, the capacity of the Cacique Guaymallén Canal would not suffice to discharge the surplus water and the overflows would flood neighboring areas, as is usually the case.

The current system does not reduce flashfloods, which cannot be prevented, but it could and should mitigate them. It does not control or decrease degradation processes in the watershed such as: increased erosion processes, landslides, increased surface runoff, etc. Another problem, still unsolved, is the progressive silting of storage reservoirs, which involves significant cleaning and silt removal expenses. Also, current watershed degradation increases risks to infrastructure.

The use of new marginal lands for urban development has accelerated the degradation process. Buildings increase the runoff-formation process and strongly affect the natural system of surplus water discharge.

Urbanization is one of the most significant examples of human activity. In the province of Mendoza, 79% of the population lives in cities and the remaining population (21%) is scattered in irrigation oases, rainfed and mountain areas. These figures are below the national mean, 89%, and above the South American mean, which is 77% (World Bank, 1999). The human population has settled and farmed in the oases, habitats created by man to help him cope with arid conditions and which account for 3% of the provincial territory, of which .25% corresponds to urban areas. There are three oases in the province: the Northern Oasis, the Central Oasis and the Southern Oasis, and some other small ones in Malargüe and in mountain areas. The fact that 53.6% of the population in Greater Mendoza is concentrated in only .16% of the land area shows a lack of balance in land occupation and the huge relative power of the oases compared to other provincial territories.

Greater Mendoza is expanding west to environmentally fragile areas, where the population is exposed to risks characteristic of piedmont regions. In the recent past, the piedmont was considered to be a constraint to expansion given its little water availability, seismic hazard and increasing flashflood occurrence and magnitude. On the other hand, real-estate speculation and lack of State involvement in the design of land use planning policies have resulted in a city with the characteristics of a regional, scattered and fragmented metropolis with gated communities, state-subsidized housing and precarious settlements. Also, but to a lesser degree, Greater Mendoza is expanding east towards fertile lands.

3. Measures and Strategies for Flashflood Risk Mitigation

3.1. Natural Area

Random occupation of the piedmont area is increasingly affecting the environment and its dynamics. The piedmont provides a number of ecological goods and services, such as regulation of runoff generated in its watersheds. Flashfloods are random events, like the rains that cause them, and pose a threat; as such, they are likely to occur, but the time of their occurrence is unpredictable. Besides, such a threat to a fragile territory under strong human pressure renders it highly vulnerable and affects areas that extend beyond.

In order to deal with the complex conservation and development situation of piedmont watersheds, a decision was made to adopt a watershed management approach: a set of integrated actions aimed at regulating the operation of the ecosystem and at minimizing the negative effects of human activities. Management actions should seek to preserve, restore and rehabilitate piedmont ecosystems and to maintain biological and functional diversity. In other words, the entire ecosystem must be protected and managed by correcting, improving and restoring its capacity to produce goods and services in a sustainable development context. To this end, two types of measures are used: structural and non-structural.

Structural measures are designed to retain and slow down runoff and to reduce erosion. This can be achieved with small hydraulic structures (gabion structures, water traps, infiltration terraces, etc.), slope terracing, etc., or through more extensive measures at watershed level, such as improved vegetation cover and habitat. Structural measures modify the system and usually entail high costs. They are feasible when reduction in losses is higher than the cost of the works. Non-structural interventions aim at ensuring conditions for effective and natural control of flashfloods. Actions include the design and use of regulatory instruments (flood-prone area zoning, insurance, etc.), individual protection (flood proofing), and especially education of the population through formal and informal learning. Non-structural measures, which can coexist with the natural system, are more appropriate for sustainable development and costs are low. The difficulty in implementing non-structural measures resides in the lobbying power of corporations.

Several measures and techniques are used for torrent correction. Consolidation dams along the channel help regulate water and sediment production. A number of operations and actions are also involved, such as:

- Consolidation dams
- Fascines to stabilize hillsides or riverbanks
- Interceptor ditches or hillside runoff infiltration terraces
- Anchored wire mesh on steep slopes to prevent rockfall
- Hillside terracing
- Hillside stabilization with anchored mesh
- Stone walls or wooden fences to intercept surface runoff, retain soil and prevent erosion
- Masonry, stone or timber sleepers or a combination of them to control rill erosion
- Stream bank protection
- Stream channelization

The above are some of the most commonly used measures to control flows and water erosion, but the list is by no means exhaustive. It should be noted that these structural measures are highly expensive, require skilled labor, and not all of them are fit for the environmental conditions of this flashflood area. This is the reason why efficient, low-cost technologies have been developed.

In order to improve the habitat and achieve system sustainability, water traps are used to control concentrated surface runoff that produces flashfloods and mudflows. These water traps have been developed to help reduce water and sediment production in a watershed and to take advantage of flashflood waters. This novel technology is based on the jessours, an ancient water harvesting technique from the arid areas of Tunisia, where it is used for olive tree and date palm improvement and development (Alaya et al., 1993).

Water traps are earthen dams of variable height (1 to 3 m) made of locally available material. Their position makes it possible to segment the watershed so that the catchment area of each trap comprises only the hillsides associated with the streambed segment determined by two consecutive traps, which generates an independent hydrographic unit. The dams have no weirs or spillways and they have a trapezoidal cross-section, an upstream slope of 2.5:1, a downstream slope of 2:1, and a crest width of 2.5 m. Dam volumes range from 100 to 150 m^3 of earth (Mariani et al., 1998).

Separation between water traps is variable and depends on their respective storage capacity and catchment area. The dams are built only in the first 1000 m of first- and second-order streams because most solid flow originates there. They are constructed from 70 to 100 m apart so that the catchment area for each of them is less than 2 ha. Reservoir storage capacity ranges from 250 to 400 m^3—maintenance is required—, and service life is estimated at 25 years. Water traps can be adapted for use in all piedmont environments (slopes less than 20%) in arid and semiarid regions. Their design is simple and can be easily adopted.

The traps are built with material borrowed from the future reservoir and compacted with a bulldozer in 20 cm-thick layers. The use of water traps as a watershed correction technique makes it possible not only to accumulate and retain sediments and runoff from the catchment area, which would otherwise cause great damage downstream, but also to make good use of such a scarce resource like water by allowing it to seep into the ground as soil moisture. This contributes to improved soil formation for natural or cultivated vegetation in the runoff retention areas.

The level of information generated so far makes it possible to assert that the risk of technological failure is negligible. An experimental watershed has been in operation for 40 years with total runoff control. Erosion, and sediment transport and buildup processes are now restricted to the watershed.

Gabion structures wire mesh filled with rocks or rubble are built downstream from the water trap sector. The gabion modules are rectangular parallelepipeds (2 × 1 × 1 m) made of 12-mm iron, lined with woven galvanized rhomboid wire mesh (5-cm openings) and 4.4-mm wire. Also used are sack gabions, cylindrical baskets which are extremely versatile because of the way they are filled with local materials.

The advantage of this type of structure is flexibility because it is not affected by soil settlement in its foundation and there is no loss of effectiveness and structural function. This is very important when structures are built on soils with little load-bearing capacity. They are highly permeable monolithic structures that allow water to flow through. This means that a smaller sized structure can withstand great stress. The cost of gabion structures is very low when compared to concrete masonry. Their construction is simple and fast, does not require skilled labor, and may be undertaken in places of difficult access or under unfavorable climate conditions. Gabions are made of inert materials and can be adapted to any ecosystem.

Gabions are meant to retain sediments and, should the water traps upstream fail, to provide protection against the mudflow. The ultimate objective of this type of structures is to establish a continuous process of changes to reach a dynamic equilibrium profile in the channels. This is produced by gradual silting of variable speed, depending on the torrential characteristics of the stream.

Infiltration terraces are small canals or trenches (with or without bottom slope) built on hillsides to capture and store runoff from higher ground and to reduce erosion by increasing water infiltration into the soil. These soil recovery works can be built manually or mechanically (Pizarro Tapia et al., 2004). Infiltration trenches store runoff water as soil moisture. In arid areas, the terraces are suitable for reforestation because their hydrological conditions are better than in the rest of the hillside. Besides, when irrigation water is available, the trenches are used for water conveyance and distribution.

Modification of the environment is the prevailing factor affecting wildlife populations and their habitats. Habitat management seeks to maintain habitat quality just as it is in the natural ecosystem and, if it is deteriorated or if a specific component of the original habitat is missing e.g. water, vegetation and/or shelter, it helps correct the situation. All such actions favor conditions for habitat improvement and for structural reinforcement.

The actions that were outlined included: recovery of natural vegetation through afforestation of sites under appropriate conditions (e.g. water trap reservoir); use of wildlife recovery techniques (closures, installation of artificial nests, scrublands, perches, etc.) and cattle management (WWF, 1987).

Regulatory instruments relate to management standards, regulation of human activities, control of extraction practices (aggregates, wildlife and vegetation), use of off-road vehicles, protected areas management plan, etc. Many of these aspects fall outside the scope of this report because they are or should be provided for in the new Land Use Planning Law.

The environmental degradation of the area is not due to the inhabitants' explicit decision to harm the environment but to the unwanted effect of a specific form of natural resources appropriation or space use. Therefore the only effective way of guaranteeing the results of any habitat improvement undertaking is by strengthening education in these critical areas. In order to raise community awareness of its biological environment, it is necessary to implement a number of actions in the informal education sector that will serve as a forum for reflection. These actions include guided visits, audiovisual presentations, development of library collections and museums, special school activities, workshops, production of educational materials, etc.

A real-time warning system is of the utmost importance to predict flashflood events. Unlike the rest of the country, Mendoza has made significant progress in the use of this type of technology. With forecasts provided by the Servicio Meteorológico Nacional or by the Dirección de Agricultura y Contingencias Climáticas of the Province of Mendoza, specialists at the Dirección de Hidráulica—on-call 24/7—can predict the daily occurrence of convective events and the risk of flashfloods (Fernández et al., 1999).

3.2. Urban and Periurban Areas

In its quest for clean air, nature and a noise-free environment, over the last decades Greater Mendoza has been encroaching upon the flashflood area. Real estate speculation and lack of land use regulations have inevitably led to uncontrolled expansion of the urban area and to increasing pressures on fragile ecosystems. As already mentioned, relentless and uncontrolled urbanization is expanding west.

Instead of reflecting the natural physical characteristics of the flashflood area, the urban development model uses the same checkerboard layout as the one used in the urban area, which is situated on a gently sloping plain. New urban and architectural intervention proposals are needed for new developments and unconsolidated areas that take into account natural and environmental characteristics. This is crucial to improve the quality of life and protect the environment.

The advantages of periurban development include healthier or cleaner air, panoramic views from the hillsides, closeness to nature and proximity to the city of Mendoza. But it also has some disadvantages: construction and extension of infrastructure services uphill involve higher costs. But most importantly, the preservation of the natural character of the land should be prioritized as much as possible by defining recreational green areas for protection of visuals and by lending identity to the site so as to deepen residents' appreciation and concern for the land. It also involves protecting the channel network for proper drainage of water surpluses, and adapting and maintaining the existing flood protection and drainage works.

Urban design criteria need to be changed. It is not possible to keep encroaching upon the piedmont with the same parameters as in the plains (e.g. the checkerboard layout) and not take into consideration the natural conditions of the land. At present, the consolidated zone of Greater Mendoza is located in the plains, where slopes are less than 5%. As the city is expanding to the west to areas with 5% to 15% gradient slopes, it is necessary to impose land use restrictions. Slopes with gradients ranging from 15% to 30% are found in low hills in the piedmont area where urban development is practically impossible.

Sound urban design in sloping areas should modify the natural shape of the land the least in order to avoid disrupting the visual quality of the landscape and, more importantly, avoid creating hazardous conditions for the residents due to erosion (Olshansky, 1990; APA, 2009). The optimal situation would be that housing should adapt to the slope of the land with no land leveling required; in other words, urban design should adapt to the shape of the land.

Most streets should be laid out parallel to contour lines, avoiding long streets perpendicular to the slope. Access roads and streets should be so designed to follow the natural contours of the landscape so as to minimize impervious surfaces and disruption of the natural topography (land clearing and land filling).

The steeper the slope, the less the allowed density of developments; therefore, occupancy parameters must be determined in relation to slope, a percentage of the area of each hillside should be kept in its natural state, and the impervious surface area should be reduced no more than 30 percent of the total, including accessory structures, courtyards, and pathways. As far as possible, no land movement or developments should be allowed on slopes with a gradient of more than 25 percent. The recommended maximum land occupancy percentage according to slope is shown in **Table 1** below.

Whenever possible, housing and services should concentrate in the more level areas, preserving steep areas and leaving more free space or land in its natural state. In a way, vegetation-covered areas represent some form of social equipment as they support amusement and recreation activities. They are privileged spaces for cultural reproduction and for enhancing urban identity. From an environmental point of view, urban green spaces contribute to regulate climate conditions, absorb contaminants, buffer noise, and allow rainwater capture for groundwater recharge. Above all, they offer environmental balance between soil, water and air, which is critical for urban areas. **Table 2** shows reference values of the minimum fraction of construction-free space according to the slope of the land.

In order to evaluate the quality of views and identify the best location for developments without disrupting the natural landscape, it is important to observe the following recommendations:

Table 1. Maximum percentage of land occupancy according to slope.

Slope %	Occupancy %
10.0 to 15.0	30
15.1 to 25.0	20
25.1 to 45.0	15
45.1 to 65.0	10
>65.0	2

a. Source: Olshansky, 1990; APA, 2009.

Table 2. Minimum percentages of open space according to the natural slope of the land.

Slope %	Open space %
>2	50
2 to 5	50
5 to 10	50
10 to 15	50
15 to 25	65
25 to 40	80
<40	100

a. Source: Olshansky, 1990; APA, 2009.

- As already stated, it is critical to devise a watershed action plan for new urban developments so as to control runoff volumes and water quality and prevent impacts on downstream sections.
- Urban developments shall be located in the least sensitive part of the site in order to preserve the natural and geological features and the vegetation.
- To protect the view of the mountains, the vertical distance of new structures should not be less than 30 to 50 m to the mountain top view. There must be quite enough separation between buildings so that the development looks less intrusive.
- Construction should follow the natural contour lines to enhance the natural characteristics of the slope avoiding excessively intrusive developments.
- Natural materials and colors should be used so that they do not clash with the scenery but allow for a smooth transition or blend of buildings and natural landscape.
- Afforestation with locally adapted species should be increased (Dalmasso, 2008; Dalmasso et al., 2009) to fix the soil, provide shade, enhance the landscape, prevent erosion, and promote recreation. On the other hand, the existence of large open spaces with no vegetation cover should be avoided.

Another important aspect to be taken into consideration is the use of stormwater or groundwater systems for drinking and irrigation purposes. As will be seen later, stormwater collection systems will be designed to facilitate water infiltration into each plot and, thus, prevent surplus stormwater from flowing out of the property. Wastewater treatment to produce irrigation water may also be feasible. In short, once the urban development project is completed, buildings should not dominate the landscape.

3.3. Urban Drainage

The uncontrolled expansion of the urban area and, hence, of impervious surfaces renders management of surplus stormwater difficult. That is why it is necessary to devise solutions at the planning stage for each of the urban components (streets, residential areas, sidewalks, parks, etc.) that will help not only retain, store and/or infiltrate surface runoff, but also improve runoff water quality through sedimentation, filtration and biological pretreatment.

A number of structural and non-structural measures or actions to prevent or minimize flood damages in cities have been devised. Such a set of measures or actions is known as urban drainage; stormwater refers to precipitation falling directly on urban areas and to precipitation falling on other areas but that drains through the city —whether this be along channels, canals or simply along its streets and sidewalks (Tucci, 2007). Thus, the following strategies should be implemented:

- In the case of unoccupied areas, develop non-structural measures such as urban drainage regulation and management by enforcing restrictions on use in flood-risk areas.
- In the case of occupied areas, conduct studies to identify the structural measures needed to control the quantity and quality of surplus stormwater and the non-structural measures needed to control future impacts.
- Control stormwater runoff at the source area and the drainage system. Avoid peak flow increases.
- Increase drainage capacity by minimizing impacts on downstream environments.
- Create conservation areas to buffer runoff.
- In areas with no sewer systems, provide for pollution control in the urban drainage system.

- In order to reduce the population's exposure to flooding, devise solutions that are both economically and environmentally feasible, that combine well with other actions on the urban environment (multipurpose works), and that are agreed with the community.

Low-impact urban developments, so named by the Centro de Aguas Urbanas (Fernández et al., 2010), fall under the urban drainage concept. The purpose is to avoid the negative externality of the stormwater-runoff process due to traditional urban development processes. Low-impact urban developments use runoff management techniques that are applied in small spatially distributed sites such as a roof, a street, a block or a neighborhood. There are three basic concepts associated with low-impact urban developments: protection of areas of great environmental value; reduction of impervious surfaces in urban design; and wise use of green spaces by turning them into hydrologically-effective landscapes. Conservancy areas can be used either as parks, ecological corridors and public recreation sites or for stormwater control and treatment. All of the above helps reduce floods, contamination and total water volumes.

Imperviousness can be reduced in two different ways. One consists in minimizing impervious surfaces by adjusting widths, following contour lines, etc. The other involves the use of permeable elements and materials and the redesign of green spaces.

While green spaces contribute to the landscape and to the community's quality of life, they can also be used hydrologically for infiltration, temporary stormwater retention, and water quality enhancement through filtration, sedimentation and biological pre-treatment. They should be strategically located according to the urban drainage system so as to ensure they capture runoff from small upstream impervious areas. This allows impervious areas to be disconnected and helps to achieve a significant reduction in watershed imperviousness and to maintain the hydrological conditions that prevailed before the urban development of the area. For urban runoff control, the following actions are required.

- Detention at the runoff source: infiltration trenches, permeable pavement.
- Runoff detention or retention in the drainage system.
- Increase of drainage capacity by minimizing impacts on downstream environments.
- Creation of runoff buffer areas.

Maximum reduction (literal or functional) of impervious areas can be achieved with proper treatment of parking lots and roofs. Many proposals have been developed by the Centro de Aguas Urbanas, a research and development unit of the Pontificia Universidad Católica de Chile (www.centrodeaguasurbanas.cl). There are different types of possible urban solutions:

- Retention/filtration ponds
- Bioretention gardens
- Permeable cobblestone pavement
- Grass swales
- Grass buffers
- Rain gardens
- Urban streams
- Wet vegetated swales
- Floodable parks
- Storage ponds
- Artificial wetlands
- Permeable concrete pavement
- Storage ponds
- Infiltration wells
- Energy dissipation devices

The effectiveness of the above measures will depend on whether the population can live with the threat (flashfloods), on the fairness of the solutions proposed, on the real and active participation of the social actors involved, and on understanding that it is an interdisciplinary and Intersectoral problem.

With regard to structural measures, the proposed intervention or strategies to minimize piedmont development risks are based on the experience of local and foreign experts. They seek to minimize negative impacts and to define parameters to encourage communities to settle in the eastern border of the flashflood area. The main recommendations, which are included in Amenazas naturales de origen hídrico en el centro-oeste árido. Diagnóstico y estrategias para su mitigación y control en el Gran San Juan y Gran Mendoza (Vich & Gudiño, 2010), are:

- Remove rubbish dumps and quarries (contamination foci) and use the sites as parks or runoff retention ponds, after slope restoration.
- Define recreational green areas, protect visuals, and lend identity to the piedmont area (Dalmasso et al., 2008).
- Protect the channel network for proper drainage of surplus water.
- Adapt and maintain flood protection works and stormwater systems.
- Provide regulations and advice on construction in piedmont areas (specific technical agencies and Dirección Provincial de Hidráulica).
- Prioritize the preservation of the natural character of the land as much as possible.
- Assess the advantages and disadvantages of residing in piedmont areas: advantages include healthier or cleaner air, panoramic views from the slopes, closeness to nature and proximity to the city of Mendoza; the disadvantages are the flashflood and seismic hazards that raise the costs of constructing and extending infrastructure services uphill.
- Fill in the urban "gaps" and take advantage of areas with infrastructure and services.
- Adapt the urban layout to the shape of the land. Ideally, housing should adapt to the slope of the land with no land leveling required.
- Lay out most streets parallel to contour lines, avoiding long streets perpendicular to the slope.
- Avoid building in areas with potentially unstable slopes or close to seismic faults.
- Specify a larger minimum size for plots on steeper slopes.
- Use stormwater or groundwater systems for human consumption and irrigation purposes.
- Design stormwater collection systems to facilitate water infiltration into each plot and, thus, prevent directing the surplus stormwater outside the property.
- Treat sewage for use as irrigation water.
- Increase afforestation with locally adapted species in order to fix soils, provide shade, enhance the landscape, prevent erosion, and promote recreation.
- Avoid large open spaces with no vegetation cover.
- Change urban design criteria. It is not possible to keep encroaching upon the piedmont with the same parameters as in the plains (e.g., the checkerboard layout) and not take into consideration the natural conditions of the land.
- Avoid modification of geomorphological features as much as possible so as not to impair the visual quality of the landscape and, more importantly, create erosion hazards.
- Minimize land leveling by following the natural shape of the land; there must be quite enough separation between buildings so that the development looks less intrusive into the landscape and erosion processes are reduced.
- Determine occupancy parameters in relation to slope keeping a percentage of each hillside in its natural state, and reduce the impervious area no more than 30 percent of the total, including accessory structures, courtyards, and pathways.
- Allow no land movement and developments on slopes with a gradient of more than 25 percent.
- Build green spaces because they represent some form of social equipment as they support amusement and recreation activities. They are privileged spaces for cultural reproduction and for reinforcing urban identity. From an environmental point of view, urban green spaces contribute to regulate climate conditions, absorb contaminants, buffer noise, and allow rainwater capture for groundwater recharge. Above all, they offer environmental balance between soil, water and air, which is critical for urban areas.
- Define minimum percentages of open space according to the natural slope of the land. In the case of a 15% slope, natural areas should account for 50% of the land; for a 25% slope, 80 percent.

4. Conclusions

The environmental problems of piedmont ecosystems should be a matter of serious concern as torrential rains, whose more visible effects are regular flashfloods, have severe economic and social impacts.

Historically, flashfloods have always caused considerable damages and in the 1970s the need arose to seek a permanent solution for Mendoza's watersheds. Unfortunately, the solution found was to build large flood control dams, water diversion works, and large runoff collection systems across the urban area, without any environmental protection action. Simply mitigating the effects of flashfloods with civil works a short distance away from the city is a critical and a reckless action.

A broader and deeper vision is needed when selecting steep slope development options. Zoning is not enough: specific technical parameters must be defined based on the natural and physical characteristics of the land. Urban design adapted to natural environmental conditions that helps mitigate degradation and erosion effects on the population is of the essence. It is necessary not only to optimize the design of urban developments but also to prioritize large open spaces where runoff is retained and reduced and where locally adapted species help preserve the natural vegetation in still non-degraded sites.

References

Alaya, K., Viertmann, W., & Waibel, T. (1993). *Les Tabias.* Tunis: Direction Générale des Forests, Ministere de l'Agricultures.

APA (2009). *Los fundamentos de planificación de sitios* (66 p). EEUU, American Planning Association. http://www.planning.org/CACes/Index.html

Bertoni, J., Maza, J., & Paoli, U. (2003). Inundações e drenagem urbana nos países da América do Sul. Argentina. In C. Tucci, & J. Bertoni (Eds.), *Inundações urbanas na América do Sul* (p. 471). Porto Alegre: GWP-ABRH-WMO.

Dalmasso, A. D. (2009). II. Arboles apropiados para la provincia de Mendoza. Silvicultura urbana. *Boletín de Extensión Científica* No. 7. IADIZA-CONICET-Gobierno de Mendoza.

Dalmasso, A. D., Candia, R., & Canci, C. (2008). Xerojardinería con especies nativas. *Boletín de Extensión Científica* No. 7. IADIZA-CONICET-Gobierno de Mendoza.

DIGID (1973). *Estudio de cuencas aluvionales en las provincias de San Juan y Mendoza*. Buenos Aires: Ministerio de Obras y Servicios Públicos. Subsecretaría de Recursos Hídricos.

Dourojeanni, A. (1999). *Gestión de cuencas y ríos vinculados con centros urbanos.* Santiago de Chile: División de Recursos Naturales e Infraestructura. Comisión Económica para América Latina y el Caribe (CEPAL).

Fernández, P. (2010). Capítulo 7: Hidrología del piedemonte del oeste del Gran Mendoza. In A. I. J. Vich, & M. E. Gudiño (Eds.), *Amenazas naturales de origen hídrico en el centro-oeste árido de Argentina. Diagnóstico y estrategias para su mitigación y control en el Gran San Juan y Gran Mendoza* (pp. 123-143). Mendoza: Zeta Editores. Editorial Fundación Nacional de San Juan.

Mariani, A., Pedrani, A., Vich, A. I. J., & Nave, M. (1998). Tecnología apropiada para la corrección de torrentes y mejoramiento de hábitat. In *Anales. XVII Congreso Nacional del Agua. II Simposio de los Recursos Hídricos del Cono Sur* (pp. 307-316). Santa Fe: Tomo III: Geomorfología, Erosión y Sedimentación Hídricas.

Martínez Carretero, E. (1999). Saxicolous and Riparian Vegetation of a Piedmont in Central Western Argentina. *Journal of Arid Environments, 42,* 305-317.

Norte, F. A., & Simonelli, S. C. (2010). Capítulo 5: Características climáticas del piedemonte precordillerano del norte de Mendoza y sur de San Juan. In A. I. J. Vich, & M. E. Gudiño (Eds.), *Amenazas naturales de origen hídrico en el centro-oeste árido de Argentina. Diagnóstico y estrategias para su mitigación y control en el Gran San Juan y Gran Mendoza* (pp. 91-110). Mendoza: Zeta Editores. Editorial Fundación Nacional de San Juan.

Olshansky, R. B. (1990). *Planning for Hillside Development, in American Planning Association*. Planning Advisory Service. Report Number 466.

Pizarro Tapia, R., Villanelo, J. P. F., Pool, C. S., & Araya, E. M. (2004). *Monografías: Zanjas de infiltración*. Proyecto FDI—CORFO. Talca: Sociedad Estándares de Ingeniería para Aguas y Suelos Ltda.

Ramos, V. (1996). Evolución tectónica de la Alta Cordillera de Mendoza y San Juan. In V. Ramos (Ed.), *Geología de la región Aconcagua, provincias de San Juan y Mendoza* (pp. 447-460). Buenos Aires: Subsecretaría de Minería de la Nación. Dirección Nacional del Servicio Geológico.

Roig, F. (1976). Las comunidades vegetales del piedemonte de la precordillera de Mendoza. *Ecosur, 3,* 1-45.

Tucci, C. (2007). *Urban Flooding Management.* World Meteorological Organization. Cap-Net International Network for Capacity Building in Integrated Water Resources Management. WMO/TD No. 1372.

Vich, A., & Pedrani, A. (Eds.) (1993). *Programa de Investigación y Desarrollo: Manejo Ecológico del Piedemonte*. Mendoza: Ministerio de Medio Ambiente Urbanismo y Vivienda—CRICYT. Unidad de Manejo Ecológico de Cuencas.

Vich, A. I. J., & Gudiño, M. E. (Eds.) (2010). *Amenazas naturales de origen hídrico en el centro-oeste árido de Argentina. Diagnóstico y estrategias para su mitigación y control en el Gran San Juan y Gran Mendoza*. *Mendoza*. Zeta Editores. Editorial Fundación Nacional de San Juan.

World Bank (1999). World Development Indicators. World Bank.

WWF (1987). *Manual de técnicas de gestión de vida silvestre*. Wildlife Society.