Hydrol. Earth Syst. Sci. Discuss., 8, C2745–C2762, 2011
www.hydrol-earth-syst-sci-discuss.net/8/C2745/2011/

Hydrology and
Earth System
Sciences
Discussions

Interactive comment on "Exploration of land-use scenarios for flood hazard modeling – the case of Santiago de Chile" *by* A. Müller and F. Reinstorf

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Received and published: 14 July 2011

First of all, the authors would like to thank the two reviewers for their interest and their valuable questions and comments. We would like to reply as follows:

Question: Precipitation forcing. Using precipitation observations from a single site to force the model over the whole study area (elevation varies in a large range) might be problematic. Apparently, the impact of precipitation could be more significantly than that of land-use changes. With that said, using precipitation data with higher spatial resolution likely leads to more dramatic changes in peak flows than the land-use scenarios considered in the study.

Response: The study was carried out in a data-scarce region, thus a major issue is limited data availability. Using precipitation data of just one station thus is a trade-off between data reliability and the existence of the study. The spatial interpolation with other stations in the city is not feasible as the relief is very heterogeneous and consequently leads to small-scale precipitation patterns. However, the specific catchment hydrology needs to be considered as well. The San Ramón basin is located at the western slopes of the Andean mountains, i.e. on the windward side of the mountain range. Luv effects frequently lead to a decreasing amount of rainfall with elevation. In addition to that, the upper subbasins within the catchment are during winter precipitation events frequently covered in snow. Thus if precipitation reaches the uppermost areas it does only to a small part contribute to the direct surface runoff. This phenomenon is accounted for by the assignment of high values for the initial abstraction ratio in the upper subbasins. Using the only available station for that study consequently remains an admissible choice. The focus of this study is clearly on exploring the influence of land-use changes on runoff. Assessing the additional impact of other factors is difficult though as respective data are not available for this study. Nevertheless, modelling the same precipitation events with different LULC scenarios shows the clear impact of LULC changes on the runoff volume (mentioned in the conclusions section 8). It will be added to the text on page 3996, after line 9: The focus of this study is clearly on exploring the influence of land-use changes on runoff. Assessing the additional impact of other factors is difficult though as respective data are not available for this study. It will be added to the text on page 3998, after line 15: The San Ramón basin is located at the western slopes of the Andean mountains, i.e. on the windward side of the mountain range. Luv effects frequently lead to a decreasing amount of rainfall with elevation. In addition to that, the upper subbasins within the catchment are during winter precipitation events frequently covered in snow. Thus if precipitation reaches the uppermost areas it does only to a small part contribute to the direct surface runoff. This phenomenon is accounted for by the assignment of high values for the initial abstraction ratio in the upper subbasins. Using the only available station for that study consequently remains an admissible choice.

Question: Sensitivity analysis. Except for precipitation, model parameters could also overrule land-use change in terms of altering flow peaks. Therefore, parameter sensitivity should be evaluated comprehensively. There are several shortcomings of the current sensitivity analysis: a) no credible flow observations available; Response: As mentioned in the text, the study area is a data-scarce region in terms of runoff volumes. The best way to work around this obvious deficit is to analyze other studies on the same topic which was done in this research with the result that our simulated results are very much in line with previous studies carried out by local researchers (Perez 2009, AC Ingenieros 2008).

Question b) analysis focuses on individual parameters only, the combined effects of multiple parameters are not investigated; Response: From our point of view, the analysis of combined effects of multiple parameters should be carried out to i) validate a model to new local conditions, where the model was applied never before or ii) in case the model is over-parameterized. As the applied model is neither over-parameterized nor it is a novel model ("...standard application...") that needs to be verified analyzing the combined effects of multiple parameters is in this case not necessary. As a consequence this study investigates the sensitivity of the simulation with respect to single parameters in detail. First, to analyze the plausibility of the effects of their changes on the simulation result and second, to determine the stability of the simulation within physically reasonable limits. Both could be completed successfully as single effects could be shown.

Question c) no detailed results presented (e.g., model results with and without Ia optimized). Response: A detailed sensitivity analysis was carried out in the scope of the research but was not meant to be the focus of this paper (Müller 2011) and a detailed description would exceed the extent (see below). We would prefer to insert the reference of the project report in the paper on page 4003, line 12.

The results are presented in the attachted table (supplement). The numbers of the 11 subbasins in the first row refer to the numbers of the subbasins.

The parameters in up to three subbasins were altered in combination if the subbasins showed similar characteristics. The first block of the table shows the analysis for the two highest-lying subbasins 90 and 91 which have only little vegetation coverage and cover an area of around 11 km^2. The higher the value for Ia the higher the retention in the subbasin and the lower the total and peak outflow. The values for the total outflow reach from 26.25 m^3/s to 27.58 m^3/s, the peak values vary between 21.7 m^3/s and 22.8 m^3/s. High retention (Ia = 0.4) could for example result from snow coverage or precipitation falling as snow instead of rain. Low retention (Ia = 0.01) is assumed to represent the natural conditions of the subbasins. Changing the parameter values in subbasin 84, the south-central subbasin with predominantly sparse vegetation coverage in the same value range showed a stronger impact on the resulting runoff even though the subbasin has a smaller size (7 km^2). The resulting peak runoff values lay between 20.4 and 21.9 m^3/s. Applying a high value for subbasin 84 would imply that retention basins are installed in that area or that the snow line is very low. A low value for the initial abstraction ratio would imply a sparse vegetation coverage which seems to be realistic with respect to the exposition of the basin. The analysis of the parameter values in the south-facing subbasin 79 with a size of 7.5 km^2 and denser vegetation coverage resulted in peak flow values between 21.2 and 21.9 m^3/s. Like in the previous example, assigning a high value (0.4) presumes the availability of retention basins or a low-lying snow line. With an average elevation in the subbasin of 1,900 m that might be the case under present climate conditions. However, it does not seem to be realistic under climate change conditions. A low value again represents low vegetation coverage which might be the case if the climate gets dryer and less water is available for the plants. The parameters for the small subbasins 78 and 75 located in the central part of the basin did not show a very high influence on the resulting runoff. The two basins cover an area of less than 1 km^2, have a flat slope, and have comparably dense vegetation coverage as they form large parts of the river bed. Changing the values in the same range as in the subbasins before brought total runoff values between 25.98 and 26.29 m^3/s and peak flow values between 21.6 and 21.7 m^3/s. As the three north-lying subbasins 69, 74, and 66 in the central and lower part of the catchment show similar vegetation coverage and slopes they were analyzed as a group. The subbasins cover an area of about 5.6 km^2 and are covered by shrub and bush vegetation. Based on the same reasoning for the parameter selection as in the previous subbasins, peak runoff values between 20.7 and 21.8 m^3/s result. The total runoff volume ranges from 25.22 to 26.39 m^3/s. Subbasin 68 is located in the central eastern part of the basin and has a size of about 1.1 km^2. With its small size it does not show a significant impact on the resulting runoff volumes. Values for the total runoff between 25.97 and 26.27 m^3/s and for the peak runoff between 21.4 and 21.7 m^3/s support that assumption. To finish, subbasin 72 was analyzed. It covers the westernmost 5.2 km^2 in the catchment and contains the gaging station San Ramón. Changing its parameter values has a comparably high impact on the resulting total and peak outflow values. Assuming a high retention potential, e.g. as a result of newly constructed retention basins, would lead to total runoff volumes of 24.68 m^3/s and a peak flow of 20.3 m^3/s. With a low initial abstraction value of 0.01 the total runoff volume rises to 26.25 m^3/s and the peak flow is 21.7 m^3/s.

Question: Scenario definition. The scenario development section is not self-explanatory. Particularly, it is unclear how scenario I relates to climate change. Does climate change result in the transferring of vegetation to barren land (as told from the table in Fig.3) and long drought periods (L21, P3994)? Response: Yes, the average high temperatures in summer time today are between 29 and 30°C. The minimum temperatures in winter time are around 0 to 5°C. Climate change scenarios predict that both minimum and maximum temperatures are going to rise by approximately 1.5 to 2°C between 2045 and 2065 which results in an increase of days with temperatures above 30°C by 30% (McPhee et al. 2011). The average rainfall at the station "Terraza Oficinas Centrales DGA" located at 560 m was 332.3 mm compared to 442.9 mm at the station "Antupiren" located in the eastern part of the city at 920 m asl (own calculations of rainfall statistics between 1979 and 2007). The total amount of precipitation will decrease by 20 to 100 mm per year in future while the intensity of extreme precipitation events is going to increase slightly (McPhee et al. 2011). The developments for the existing IPCC scenarios are to a large degree parallel until 2030 and do only differ from that period onwards. The assumption is that due to the effects of climate change, i.e. less precipitation in average and rising temperatures, the amount of vegetation decreases. These interrelations could be observed in the past when several years with low amounts of precipitation succeeded.

Page 3994, line 21: as the amount of valuable biomass is clearly smaller in those cases. Page 4005, line 9: The assumption is that due to the effects of climate change, i.e. less precipitation in average and rising temperatures, the amount of vegetation decreases. These interrelations could be observed in the past when several years with low amounts of precipitation succeeded.

Question: Also, comparing to 2009 land use, scenario III has more intermediate built-up areas (0.81 kmËĘ2, which accounts for 2.2% of the total area of the study basin). Physically speaking, this 2.2% change in land-use very unlikely leads to such changes in peak flows as presented in Table 7 (for example, for 10-year event, there is 7.3% increase in flow peak). Response: Scenario III does not only show changes in built-up area but also shows smaller changes in the amount of vegetation. It was shown in the sensitivity analysis that subbasin 84 in the southern part of the basin has a higher influence on the runoff than the majority of the remaining basins. Such an increase of runoff seems rather plausible.

Add on page 4005, line 16: Scenario III does not only show changes in built-up area but also shows smaller changes in the amount of vegetation due to climate change. These changes predominantly affect the most sensitive subbasins in terms of runoff generation in the southern part of the subbasin.

Question: Those changes in Table 7 are caused by different parameters (which not appropriately reflect the land-use change) applied, which is a main science flaw of the study (also refer to comment # 2). Response: After having discussed that question thoroughly, the authors would like to clarify that the curve number grid and the initial abstraction ratio both representing the land-use conditions are the only parameters that were changed in the models. Columns 4 to 7 of Table 7 show the runoff values of the same precipitation events under the original and under changing land-use conditions reflected in the three scenarios.

Question: Flood hazard. The description on flood hazard is quite thin (section 6.3). Response: It will be added to the text on page 3998, after line 24: Perez (2009) derived flood hazard maps in the scope of a Master's thesis at the Universidad de Chile. These maps are used as input for the flood hazard and risk calculations in this study. In a first step, runoff volumes for the present area of interest (Quebrada San Ramón) were delineated using a synthetic unit hydrograph (Linsley) and assuming conditions of climate change. Therefore, estimations about the future development of temperature, maximum daily precipitation, and the location of the 0°C isotherm were formed using the IPCC scenarios A2 and B2. The hydraulic model HEC-RAS was in a second step applied to process the runoff volumes estimated from the climate change scenarios. Hydraulic transversal profiles available every 50 m enabled in a third step the preliminary estimation of points of overflow from the channel. The overflow from the channel was then used to calculate a flow pattern in the street network. Simulating the movement of the water through the street network though was not possible using HEC-RAS, thus the hydraulic model MOUSE was applied for this part of the modeling process. A methodological drawback still is that the transversal street profiles need to be simplified to a rectangular shape. As a consequence the water does not pass over the sidewalk as it would be in reality. However, as the simulations indicate, the amount of runoff overflowing into the street network is three to seven times as high as the runoff remaining in the channel indicating the highly insufficient capacity of the water courses. The precipitation that is falling on the street during a storm is thereby not even included in the modeling process and would thus additionally add to the street runoff. Page 4015:

Table 1: add line: column 1: Flood hazard maps, column 2: Outline and water depths for different flood hazard levels for San Ramon channel (Perez, 2009)

Question: The physical connection between peak runoff and flood hazard needs more clarification. The interpolation in section 6.3 is confusing and not convincing. It will be added/replaced to the text on page 4006, line 13 onwards: The goal of this research is to closely approximate which spatial impact the quantitative changes in runoff volume have on the flood hazard zones. Perez (2009) calculated the flood hazard maps of the urban part of the San Ramón river based on peak runoff volumes derived using a synthetic unit hydrograph. These flood hazard maps are in the present article first analyzed in terms of the relation of runoff and flooded area and in terms of changes of runoff and changes of the flooded area (and flood depth). Based on these first analyses the runoff volumes derived from the modelling with HEC-HMS are now related to the hazard maps by approximating the runoff volume with the flooded area extent. The six flood hazard maps available from the study of Perez (2009) were generated based on the following runoff volumes: 27.3 m^3/s, 47.4 m^3/s (baseline scenario), 38.2 m^3/s, 64.6 m^3/s (IPCC scenario B2), 35.1 m^3/s, and 50.9 m^3/s (IPCC scenario A2). While these different runoff volumes result from changes in precipitation intensity and frequency, the different runoff volumes calculated in the scope of this research result from changing land-use and land-cover pattern. Leaving the precipitation probability out at this stage allows for a combination of existing hazard maps and newly calculated runoff volumes. As a matter of fact, the new runoff values do not exactly match the runoff values on which the calculations of Perez (2009) were based. Nevertheless, a combination of both data sets delivers an insightful output. With an increase of the runoff values from 27.3 to 35.1 to 38.2 m^3/s the affected area changes from 188 to 214 ha (runoff + 7.8 m^3/s) and from 214 to 217 ha (runoff + 3.1 m^3/s). Assuming higher discharge values the changes are accordingly: With an increase from 47.4 to 50.9 to 64.6 m^3/s the flooded areas (only outlines) would increase from 230 to 243 (runoff + 3.5 m^3/s) and from 243 to 396 ha (runoff + 13.7 m^3/s). In addition, the water depth changes with an increasing amount of overflow. The changes are not linear but indicate that in that dense urban environment the damage would increase notably. The higher the absolute peak discharge values the higher the absolute changes in the spatial extent of the hazard zones with the same absolute increase in discharge. That means that the absolute changes are higher for high runoff values, i.e. low frequency events. The runoff volumes calculated for a changing land-used pattern are shown in Table 7. Taking the rainfall event from August 2005 as an example shows that the runoff would increase from 45.6 m^3/s to 49.2 m^3/s in Scenario I. That means an absolute increase of approximately 3.6 m^3/s. Comparing these numbers with the ones presented above (i.e. 100 year return period for baseline scenario and scenario A2) shows that the areas affected only by the San Ramón channel would increase by approximately 13 ha.

Question: Nothing from section 6.3 is presented in the conclusion section. Response: It will be added to the conclusion section 8 on page 4010, line 23: The research highlighted that the urban fringe plays a major role in protecting the urban built-up areas from flood risk. The study showed that potential future land-use changes have a clear impact on the generation of urban floods and lead to a critical increase of the number of affected population, buildings, and urban infrastructure.

Question: In addition, the authors mess up the study area and the city. Evidently, the study area is largely undeveloped (with 0.02 kmËĘ2 built-up out of 36.72 kmËĘ2). There is no way that the peak flows derived from this study area can be extrapolated into other areas. As such, the title (“flflood hazard modeling”, ”Santiago de Chile”) largely overstates the work. Response: The study area for this research is the peri-urban watershed of the San Ramón river which is part of Santiago de Chile Metropolitan Area. The introduction section lines out that the focus of this work is to analyze the influence of peri-urban land-use changes both through urban expansion and climate change on urban flood risk. While the modelling work previous to Section 6.3 covers these peri-urban land-use changes in the study area Section 6.3 itself combines the obtained results with existing urban flood hazard maps of the very same San Ramón

river after entering the urban built-up body. Thus no peak flows are extrapolated to other areas.

It will be added to the text on page 4006, line 12: While the modelling work presented in the previous section covers the peri-urban land-use changes in the San Ramón basin, this part of the study combines the obtained model results with existing urban flood hazard maps of the very same San Ramón river after entering the urban built-up body. Thus, the final step. . .

The authors propose the alternative title: Exploration of land-use scenarios for high flood simulation in a data-scarce urban fringe region. The case of Santiago de Chile

Question: It is not clear from the paper what it is that the authors believe to be novel about their application of HMS to the study basin, except that it is in South America. Response: HEC-HMS is a software that can be used free of charge. That makes it for financial reasons very attractive for an application in developing countries especially as it also allows for a distributed modelling approach. So far no studies showed how the model can be parameterized even without readily available soil maps and associated Hydrologic Soil Group (HSG) classifications outside the USA. This study shows how the distributed modelling approach of HEC-HMS can be applied in a fairly data scarce region outside the conterminous US. The study shows how the HSG classifications can be derived from geomorphologic maps in regions with only little soil development and demonstrates the potential of the model application in new regions. Besides that the study develops land-use scenarios for the basin which is another novel aspect.

It will be added to the text on page 3995 after line 27: The first novel aspect of this study is the development of plausible future land-use scenarios for the catchment area to enable the analysis of their impact on the runoff volume entering the urban built-up body.

The following phrase will be replaced in the text on page 3996, line 3 onwards: “It is shown in the scope of this study that the hydrological model HEC-HMS with the standardized hydrological grid that was developed especially for the conterminous United States can also be transferred into other regions of the world." By: "The second novel aspect of this study is the application of the distributed modelling approach implemented in the hydrological model HEC-HMS in a South American country, i.e. outside the conterminous United States."

It will be added to the text on page 3999, after line 9: HEC-HMS is a software that can be used free of charge. That makes it for financial reasons very attractive for an application in developing countries especially as it also allows for a distributed modelling approach. So far no studies showed how the model can be parameterized even without readily available soil maps and associated Hydrologic Soil Group (HSG) classifications outside the USA. This study shows how the distributed modelling approach of HEC-HMS can be applied in a fairly data scarce region outside the conterminous US. The study shows how the HSG classifications can be derived from geomorphologic maps in regions with only little soil development and demonstrates the potential of the model application in new regions.

Question: HEC-HMS was used to model the runoff, but why was HEC-RAS not used to model the impact of the runoff on inundated areas? Some previous flood inundation maps were used, but new results were not generated. Response: The focus of this article is laid on the analysis of land-use changes on runoff and consequently on the flood hazard. Therefore, this study uses newly developed flood hazard maps for the San Ramón River. These maps were readily available from a study carried out at the University of Santiago in 2009.These maps are based on the application of the hydraulic model MOUSE and do exactly show the impact of different runoff volumes on the flood extent. However, the combination of HEC-HMS and HEC-RAS is a very interesting point for further research.

No results of the modeling are shown in the figures. Why not? It could be added to the text on page 4006, line 8: The following figures 6 and 7 show the modelling results from the three land-use scenarios and the conditions of the respective year (current, dashed

line) from the rainfall events in July 2001 and in September 2009. It becomes apparent that the runoff in 2002 was still lower than in the afforestation scenario for 2030. In 2009 the loss of vegetation in comparison to 2002 already shows an increase in runoff. Thus, the best scenario option in this case would be afforestation. Both dry conditions and construction activities show the highest peak flows whereby the construction scenario with irrigated private green spaces shows slightly lower runoff values than Scenario I with the dry conditions.

Question: In general, the paper is a good description of the modeling effort, but the presentation of the results is somewhat lacking in terms of detail and interpretation. For the most part, the paper does not provide new and interesting insights into the hydrology of the study area. Response: It will be added to the text on page 4005, after line 25: The following two Figures 4 and 5 give some more insight in the catchment hydrology during two rainfall events with a return period of 25 years at two different points in time. The total precipitation was 113.5 mm for the event in May 2002 and 148 mm in August 2005. The peak runoff was 31.9 m^3/s and 45.6 m^3/s respectively. The total runoff volume was 87.13 m^3/s in May 2002 and 121.02 m^3/s in August 2005.

The hydrographs exemplify how the runoff recedes as soon as the precipitation stops or significantly minimizes. That stands for a fast drainage of the rainwater and a direct response of the runoff on precipitation. The temporal delay, i.e. the response time of the watershed is thereby approximately eight to ten hours. The difference between the two events in May 2002 and August 2005 is the duration of the rainfall as well as a changing LULC pattern in the basin that could be observed during the three years that lay between both modelling time steps. The tendency of the proportional increase in the total amount of runoff at the gaging station becomes obvious in the two examples. The influence of land-use changes on the peak runoff is exemplified in the results of Table 7.

In addition to these insights, the responses to the previous questions showed the importance and effects of single subbasins for/on the runoff volume.

Further planned changes in the text: Page 3994: Line 5: in many urban and peri-urban regions Line 8: a watershed at the urban fringe of Santiago de Chile Line 9: delete: using the distributed hydrological model HEC-HMS. The study area for this research is a small peri-urban watershed in the eastern area of Santiago de Chile. Line 16: how the hydrological model HEC-HMS Page 3995: Line 19: replace “this” by “that” Line 20: replace “this” by “the study by Fuentes and Romero” Page 3997 Line 5: The protection of ecologically valuable areas of the urban fringe is legally being ignored in such cases. Page 3998: Line 16: delete: HEC-HMS requires input without data gaps. Line 18: delete: Thus event were selected both after amount of rainfall and data availability Page 3999: Move line 9 completely to page 4000 before line 13. Page 4002: Line 12: The HSG value for each LULC class with their specifications for a subtropical area were taken from literature. Page 4003: Line 6: important is the intensity of the rainfall rather than the duration of the rainfall. Page 4004: Line 22: Delete: Several interviews were conducted during field work to obtain expert knowledge from different perspectives about possible future urban development and relevant planning regulations were revised” Line 25: replace “is meant to be used” by “was used” Page 4005: Line 3: conversations with the local population, experts, and decision makers, and the analysis... Line 24: Replace “As a reference” by “for model calibration” Page 4006: Line 12: canalized and enters the city with the urban built-up body. Page 4007: Line 11: a high density of people, one-family homes, and values. Line 15: delete stronger Line 19: 1.6 m3 s-1 Line 20: Change last sentence to: “The projected increase in precipitation intensity for the extreme events and the rising amount of rainfall in higher elevations is in this analysis not yet incorporated.” Page 4009: Line 6: LULC types in Chile which is feasible because the climatic conditions are comparable for the applied classes. Page 4011: Line 6: replace “makes clear” by “proofs”

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/8/C2745/2011/hessd-8-C2745-2011-

supplement.zip

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 3993, 2011.

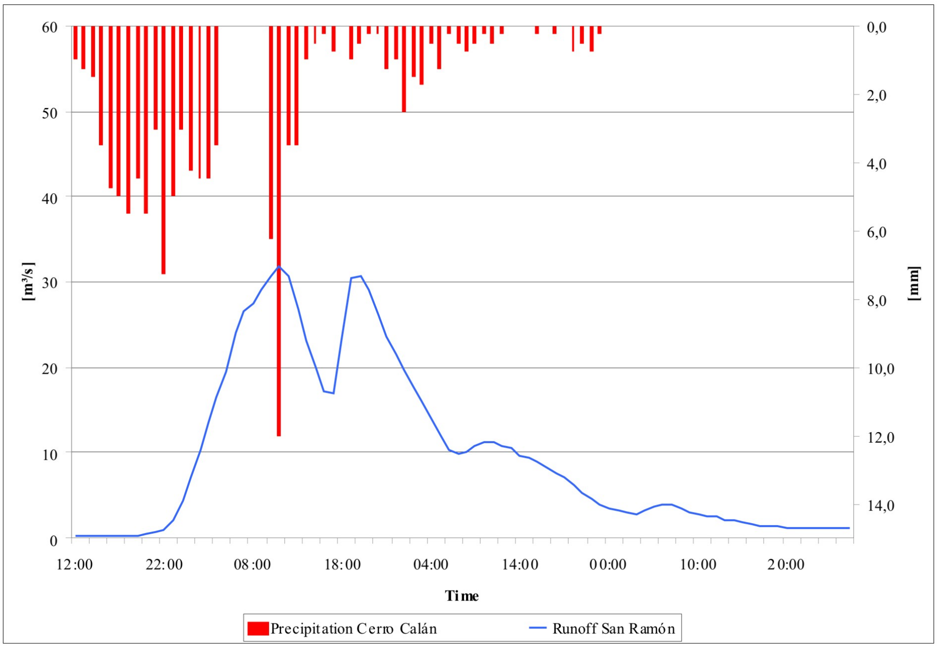

Fig. 1. Result of the hydrologic modeling using HEC-HMS: Precipitation data from Cerro Calán station and modeled hydrograph at San Ramón station for rainfall event in May 2002

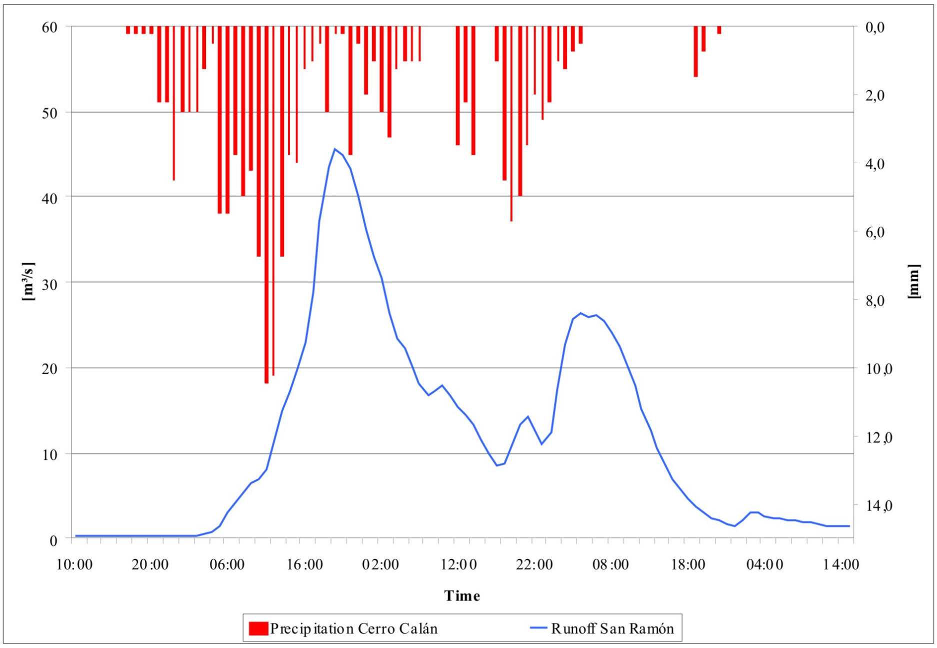

Fig. 2. Result of the hydrologic modelling using HEC-HMS: Precipitation data from Cerro Calán station and modelled hydrograph at San Ramón station for rainfall event in August 2005

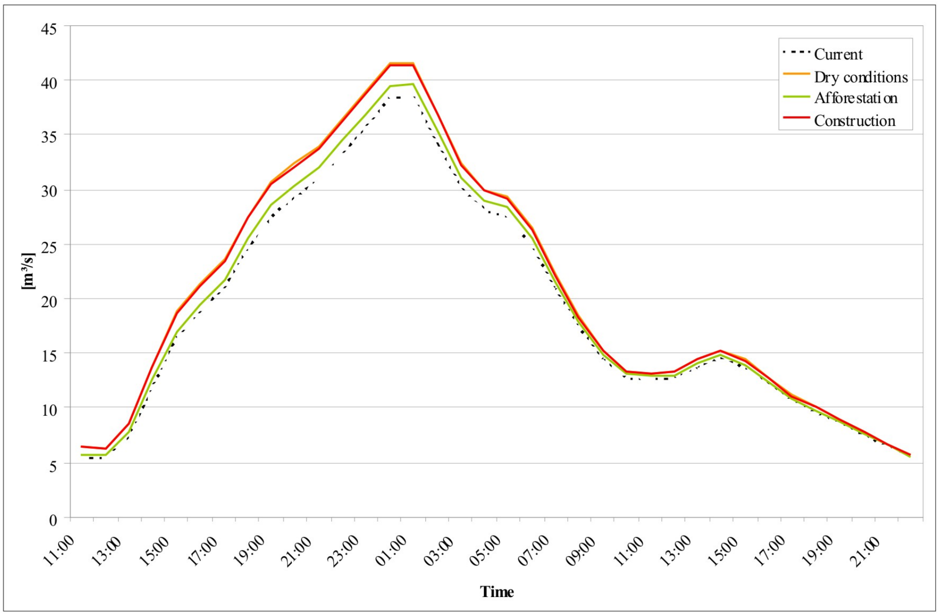

Fig. 3. Hydrograph for the different LULC patterns for the rainfall event in July 2001

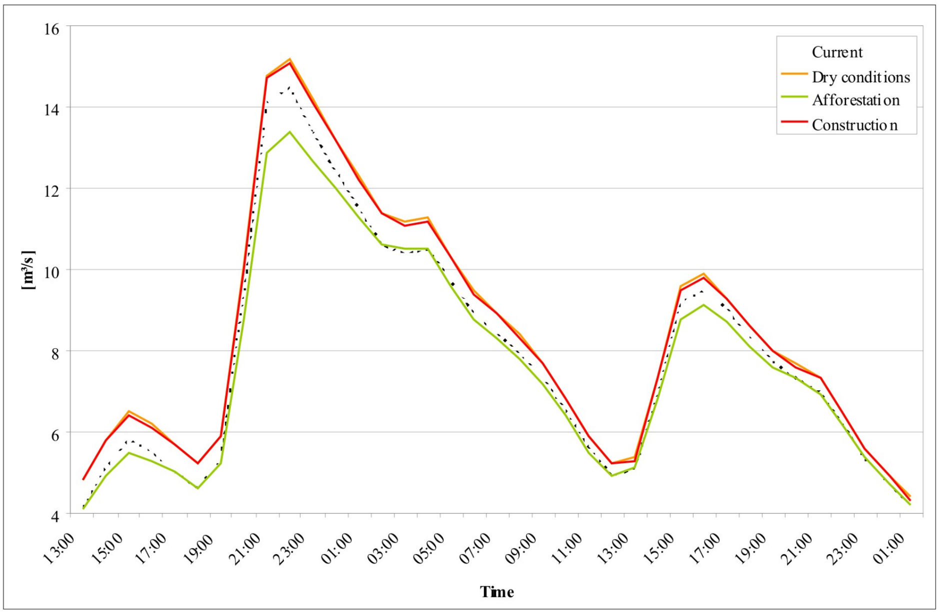

Fig. 4. Hydrograph for the different LULC patterns for the rainfall event in September 2009