Hydrol. Earth Syst. Sci. Discuss., 11, 5487–5513, 2014
www.hydrol-earth-syst-sci-discuss.net/11/5487/2014/
doi:10.5194/hessd-11-5487-2014

Hydrology and Earth System Sciences
Discussions
Open Access

Infiltration well to reduce the impact of land use changes on flood peaks: a case study of Way Kuala Garuntang catchment, Bandar Lampung, Indonesia

D. I. Kusumastuti[1], **D. Jokowinarno**[1], **S. N. Khotimah**[1], **C. Dewi**[2], **and F. Yuniarti**[3]

[1]Civil Engineerring Department, Engineering Faculty, University of Lampung, Lampung, Indonesia
[2]Study Program of Survey and Mapping, Engineering Faculty, University of Lampung, Lampung, Indonesia
[3]Magister of Civil Engineering, University of Lampung, Lampung, Indonesia

Received: 6 May 2014 – Accepted: 13 May 2014 – Published: 26 May 2014

Correspondence to: D. I. Kusumastuti (kusumast@gmail.com)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Significant land use changes due to rapid development, a central issue in Bandar Lampung and high rainfall intensity are the main triggers for frequent flooding. This study was carried out to define design rainfall intensity based on analysis of hourly temporal rainfall pattern for calculating design discharge, predict the impact of land use changes on flood peaks, and predict the impact of infiltration well on flood peak reduction. The results showed that rainfall distribution pattern for storm duration of 4 h are 40, 35, 20 and 5 % for the first, second, third and fourth hour, respectively. Analysis on land use changes underlined that if 30 % of the catchment area is maintained for green land then flood peaks can be decreased. However, with city development, land conversions are intended for settlements, industries and trading areas which will increase flood peaks significantly. Application of infiltration well in the catchment can reduce surface runoff depends on the density and dimension of the well. The results suggest that using infiltration well with diameters between 0.8 to 1.4 m which are applied each in every 4000 m^2 of land area will reduce flood peaks from 6.9 to 12.6 %. While the application of infiltration well with density of 500 m^2 will reduce flood peaks from 55.21 to 99.8 %. Commitment and relevant government policies and community participation will encourage to undertake flood reduction measures.

1 Introduction

Flooding often occurs in several locations in Indonesia during wet season, that include Bandar Lampung, the capital city and economic hub of Lampung Province and the entry point to Sumatra. The province is located on Southeast Sumatera island. The city's area is about 169.21 km^2, with a population of approximately 881 801 people (Bappeda, 2010). Over the last two decades the city has shown significant increase in population and economic growth. Recently several flooding events in the city had caused inundation. In one instance several patients were evacuated from a public hospital located near a river. Landslide in a canal within the Bumi Kedaton National Park caused severe damage on road and bridge, the central town was inundated for few hours and caused massive traffic jam and some casualties.

The most common causes of flooding are high rainfall intensity, land use changes, reduced infiltrated area, insufficient drainage system and reduced river capacity. Significant land use changes due to rapid development in most part of Indonesia's larger cities are considered as one of the major cause of flooding. The land use changes include urbanisation, deforestation and industralisation. The changes in land use associated with urban development contribute to flooding in terms of the peak discharge, volume, and frequency of floods.

The effect of land use changes on hydrologic response has gathered interest among researchers recently due to intensified developments in developing countries (Ashagrie et al., 2006; Doe et al., 1996). Numbers of researches use GIS based model to evaluate the impacts of land use changes on hydrologic response (Gumindoga, 2010; Hacket, 2009; He and Hogue, 2012; Juahir et.al., 2010; Koch et al., 2012; Camorani et al., 2005; Nobert and Jeremiah, 2012). Beside surface hydrology responses, the effect of land use changes on groundwater hydrology is also becoming a research interest (DeSmedt and Batelan, 2001). This study investigates the impact of land use changes on surface runoff that contribute flood discharge.Information about streamflow and the impact of land use changes to the flow can help communities reduce their current and future vulnerability to floods.

Flood peak is influenced by many factors, including the intensity and duration of storms. In common engineering practice there is the specification of a rainfall event as *design rainfall* which must reflect required levels of protection, local climate, and catchment conditions as well as to ensure safe, economical and standardised design. Design rainfall temporal patterns are used to represent the typical variation of design rainfall intensities during a typical storm burst. A number of hydrology analyses in Indonesia used van Breen method to determine design rainfall intensity, a method which considers temporal distribution of rainfall within the design rainfall (Ilmiaty et al., 2012;

HESSD
11, 5487–5513, 2014

Kusumastuti, 2009). Van Breen method was developed in the early twentieth century using rainfall data of Java Island, Indonesia. The temporal distribution of rainfall within the design storm is an important factor that affects the runoff volume and magnitude and timing of the peak discharge.

Increase in settlements, industries, trading and roads due to rapid development of Bandar Lampung city has a dire consequence on flooding. To reduce the impact of flooding, use of infiltration wells was investigated. Infiltration well is one of water conservation techniques which help reducing surface runoff and peak flow. Study about infiltration well in indonesia was initiated by Sunjoto (1988). It was based on the concept of natural water balance as a part of hydrological cycle (Sunjoto, 1993, 1994). When the ground surface is permeable, some precipitation will infiltrate naturally and the rest as runoff along the ground surfaces. However, massive land use changes in recent times promote more runoff because much of ground area is covered by impervious layers such as roofs and pavements which prohibit water infiltration process. Infiltration well will be ideal in this situation because collected water from roof and channels can be directed to the wells for infiltration (Fig. 1). Some researches on infiltration well found that with appropriate well dimensions and numbers, it can reduce surface runoff significantly. Furthermore, the application of infiltration well support the policy of zero delta discharge which limits water discharge to drainage system (Arafat, 2008; Iriani et al., 2013; Indriatmoko, 2013).

Study area for this research is Way Kuala Garuntang catchment, one of the two major catchments in Bandar Lampung, has an area of 63.9 km^2 and lies across the centre of the city (Fig. 2). The catchment experienced frequent flooding due to significant land use changes. This research will focus on how land use changes in the Way Kuala Garuntang catchment influence the hydrologic responses. The hydrologic analysis using rational method was applied on some land use change scenarios to see the changes of peak flow of Way Kuala Garuntang catchment. Design rainfall intensity analysis was also carried out to support the rational method calculation in the beginning of hydrologic analysis. Finally, analysis of the impact of infiltration well in the Way

HESSD
11, 5487–5513, 2014

Kuala Garuntang catchment to reduce flood discharge was carried out. The aim of this study is (1) to define design rainfall intensity based on analysis of hourly temporal rainfall pattern, (2) to predict the impact of land use changes on flood peaks, and (3) to predict the impact of infiltration well on flood peak reduction.

2 Methodology

Four scenarios of land use changes were applied on a simple rainfall–runoff model, using rational method to see the pattern of flood peak generated by the catchment. The study also concerns to the effort for flood reduction in Way Kuala Garuntang catchment by using infiltration well. Land slope, the depth of shallow ground water and infiltration rate are important considerations for determining the area for infiltration well. Quantum GIS was used in the study Way Kuala Garuntang catchment in order it fulfill the requirement for the application of infiltration well.

2.1 Rainfall–runoff model of land use change scenarios

This study focuses on peak discharge rather than the hydrograph, hence a simple rainfall–runoff method was utilized. The rational method is widely used to calculate runoff producing potential of a catchment and form as the basis for many small structure designs. The application of rational method is valid for predicting runoff in a small catchment (ASCE, 1992). The area of the catchment is larger than specified in ASCE (1992), but rational method was adopted in this study not to predict runoff precisely, rather the method occupied to get insight of the effect of land use changes on runoff.

Application of the rational method is based on a simple formula that relates runoff producing potential of the watershed, rainfall intensity for a particular length of time (the time of concentration), and the watershed drainage area. The formula is

$$Q = C_{\mathrm{u}} \cdot C \cdot I \cdot A \quad (1)$$

HESSD
11, 5487–5513, 2014

where, Q = design discharge ($m^3 s^{-1}$), C_u = unit conversion coefficient, C = runoff coefficient (dimensionless), I = design rainfall intensity ($mm\,h^{-1}$), A = catchment area (km^2).

2.1.1 Design rainfall intensity

Design rainfall intensity, I, varies according to geographic location and design exceedence frequency or return period. The longer the return interval (hence, the lower the exceedence frequency), the greater the precipitation intensity for a given storm duration. Series of hourly rainfall data 2001–2012 were obtained from the Meteorological and Climatology Berueu Panjang, Lampung Province. The data was not complete, no data for year 2002 and some missing months for others. The average annual rainfall was between 1500–2500 mm, with wet season occurs beween October to April and dry season occurs between April to October.

The series of hourly rainfall data was grouped according to storm durations, with the shortest and longest durations are 3 and 8 h, respectively. Minimum storm depth considered in the analysis is 20 mm. Analysis of rainfall intensity pattern for each storm duration initially was done by calculating the percentage of storm depth occurs in a particular storm event compared to total storm depth occurs during that day (within 24 h). Next, the percentage of hourly rainfall pattern is calculated by comparing hourly rainfall to storm depth. Design rainfall intensity was selected as the highest percentage of hourly rainfall pattern. Flood frequency analyses were used to estimate the probability of the occurrence of a given hydrologic event. Once design rainfall intensity for particular return period was estimated, flood peaks can be calculated using rational method.

2.1.2 Runoff coefficient

Runoff coefficient plays an important role in catchment management as it can be used as surface runoff indicator in a catchment and flood estimation. To estimate runoff

HESSD
11, 5487–5513, 2014

coefficient for Way Kuala Garuntang catchment, it requires runoff coefficient for each land use in Way Kuala Garuntang catchment. Land uses in Way Kuala Garuntang catchment (Bappeda, 2010) and corresponding runoff coefficients (Triatmojo, 2008) are mining area (0.95), residential (0.65), industry purposes (0.55), vacant land (0.4), trading area (0.8), government office (0.75), tourism area (0.8), industry area (0.85), preserved area (0.3), agriculture (0.35), public service area (0.75), road (0.9) and double track railway (0.35). Industry purpose area differs from industry area as industry purpose area is an area reserved for future development, while industry area is an area that has already been occupied with industries.

2.1.3 Scenarios for sensitivity analysis of land use

Figure 3 presents the existing distribution of land uses in Way Kuala Garuntang catchment: mining area (0.4 %), settlement (54.14 %), industry purpose(4.1 %), vacant land (31.22 %), trading and service area (1.79 %), government office area (0.23 %), tourism area (0.04 %), industry area (0.38 %), preserved area (0.46 %), agriculture area (4.72 %), public service area (1.28 %), road area (1.16 %) and double track railway (0.07 %) (Bappeda, 2010).

To understand the impact of land use on flood peak, this study considers four scenarios in the sensitivity analysis of land use. In Scenario 1, all vacant land is converted into green land. Based on Regional Spatial Plan of Bandar Lampung 2010–2030 approximately 30 % of the area is reserved for green land. In Scenario 2, all vacant land is converted into green land (as in Scenario 1) and half of the agriculture area is converted into settlement and industry purpose.

Scenarios 3 and 4 consider different land use changes from Scenarios 1 and 2. In Scenario 3 all vacant land is converted into industry area and half of the settlement into trading and service. Nowadays there is tendency in Bandar Lampung to build *ruko*, a term in Indonesia meaning home and store which being used for living as well as trading and services. A *ruko* usually consists of three or more storeys, where the first storey is used as store and second and third storeys are used as home. Scenario 4 considers

HESSD
11, 5487–5513, 2014

the convertion of all vacant land into industry area and a quarter of the settlement area into trading and services. Scenarios 3 and 4 assume that despite the projection of very high population by 2030, it will not require more land for settlement as more people will live in appartment and *ruko*. Significant growth of industries requires more space and hence the policy to preserve 30 % of the area for green land cannot be maintained. Description about land use and corresponding percentage of the catchment area for each scenario above is presented in Table 1.

2.2 Infiltration well application

In its application, the natural condition of the area should be checked whether the area fulfill the requirement of National Standard such as (1) land permeability should be more than 2 cm h^{-1}, (2) shallow ground water level is greater than 3 m below ground level in wet season and (3) land slope is less than 30°. In this study the conditions of Way Kuala Garuntang catchment were established by using maps of land permeability, shallow groundwater level and land slope of Way Kuala Garuntang catchment with existing land use map to determine suitable areas for the application.The number of infiltration well can be calculated as follows (Suripin, 2004).

$$\text{The number of wells} = \frac{Q_{\text{runoff}}}{Q_{\text{well}}} = \frac{Q_{\text{runoff}}}{(A_{\text{well base}} \times V) + (A_{\text{well wall}} \times V)} = \frac{Q_{\text{runoff}}}{\left(\pi \cdot \Phi_{\text{design}}^2 \times K\right) + (2 \cdot \pi \cdot \Phi_{\text{design}} \cdot \text{h}_{\text{design}} \times K)} \quad (2)$$

where Q_{runoff} is daily peak flow in 1 day (m^3 day^{-1}), Q_{well} is total runoff collected in a well within 1 day (m^3 day^{-1}), Q_{well} is calculated based on infiltration well discharge (m^3 day^{-1}) and wall infiltration well discharge (m^3 day^{-1}), K is land permeability

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |
HESSD
11, 5487–5513, 2014
Infiltration well to reduce the impact of land use changes on flood peaks
D. I. Kusumastuti et al.
Title Page
Abstract Introduction
Conclusions References
Tables Figures
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

coefficient (m day^{-1}), Φ_{design} is well radius (m), $A_{\text{well base}}$ is well base area (m^2), $A_{\text{well wall}}$ is well wall area (m^2) and h_{design} is well depth (m).

3 Result and discussion

The characteristics of the storm data analysed in this study are presented in Fig. 4. For storm duration 3 to 8 h the average of total storm depths is between of 38.98 to 62.47 mm (Fig. 4a), standard deviation is between 12.19–36.02 mm (Fig. 4b), minimum storm depth is between 20 to 40.5 mm and maximum storm depth is between 57.8 to 145 mm (Fig. 4c). From the available hourly rainfall data, there were 34.15, 26.83, 13.41, 14.63, 4.88 and 6.10 % storm events for storm duration of 3, 4, 5, 6, 7 and 8 h, respectively (Fig. 4d). Figure 4 shows that the trend of average storm depth, standard deviation and minimum storm depth increase as storm duration increases. However, maximum storm depth tends to decrease as storm duration increases.

The result shows that the most common storm event has 3 h duration, followed by 4 h duration. Storm event with duration of 5 and 6 h have similar percentage of occurrences, but have less significant percentage of event compared to the event with 3 and 4 h duration. The percentage of occurrences for storm duration of 7 and 8 h are similar but they have the least percentage of occurrences compared to others. Storm depth of the event compared to storm depth within 24 h shows that the percentage is between 87 to 97 %.

Storm event with the duration of one and two hours are not taken into account as the duration is too short and in most events, they are followed by another storm event which have longer storm duration and higher storm depth.

Further investigation on hourly storm distribution is done to understand the distribution pattern. Figure 5 shows the percentage of hourly storm distribution for storm duration 3 to 8 h. There are similar trend for all storm duration that the percentage of storm distribution at early hours are relatively high compared to that toward the end

HESSD
11, 5487–5513, 2014

hours. For storm duration of 3 h (Fig. 5a), the percentage of storm depth distribution is 40, 50 and 10 % for the first, second and third hour, respectively. For storm duration 4 h (Fig. 5b), the percentage of hourly storm distribution is 40, 35, 20 and 5 % for the first, second, third and fourth hour, respectively. It can be seen that the highest percentage of storm depth distribution occurs at second and first hour at storm duration 3 and 4 h, respectively. While for storm duration of 5 h (Fig. 5c), the first and second hours have the same percentage, i.e. 30 % and for storm duration 7 h (Fig. 5e) have the same percentage, i.e. 20 %. For storm durations 6 and 8 h (Fig. 5d and 5f), the highest percentage of storm duration distribution occurs at second hour.

Relating the result of this study with van Breen method, there are some similarity and differences. The similarity is the comparison between depth of storm event compared to that of storm fall in 24 h. Van Breen defined that 90 % of the rain in one day fell in four hours. This study shows that approximately 90 % of the rain in one day falls in one storm event. Furthermore, for storm duration of 4 h, the highest percentage of storm depth distribution defined in the method was 40 %. The difference between result of this study and van Breen method is in the distribution patterns. Van Breen illustrated that distribution of storm depth was low in first hour, and significantly high in the second and third hours and considerably decreases in the fourth hour. While the results of the study show that the distribution pattern was high in beginning hours and significantly low toward the end (Fig. 6).

Using the finding, design rainfall intensity for Way Kuala Garuntang catchment can be calculated as 40 of 90 % of design rainfall (in one day). Calculated design rainfall intensity for 2, 5 and 10 year return periods are 24.67, 27.71 and 29.20 mm h^{-1}, respectively.

3.1 Land use

Simulations on land uses in Way Garuntang catchment was done using Quantum GIS as presented in Fig. 7. Based on runoff coefficient for various land uses in Way Garuntang catchment as well as proportion of catchment area associated with particular land

HESSD
11, 5487–5513, 2014

use as presented in Table 1, the composite runoff coefficient for existing condition, Scenario 1 (Fig. 7a), Scenario 2 (Fig. 7b), Scenario 3 (Fig. 7c) and Scenario 4 (Fig. 4d) are 0.56, 0.45, 0.47, 0.74 and 0.72, respectively. For the existing condition, using calculated design rainfall intensity and composite runoff coefficient for the catchment, design flood for 5 year return period is 260.95 $m^3 s^{-1}$.

Simulation on land use impact as presented in Fig. 8 shows that the results can be categorised into two groups. Simulation results using Scenarios 1 and 2 has an impact in reducing peak discharge, while Scenarios 3 and 4 effect in increasing peak discharge. Those ratios are the comparison between the peak discharge resulted from the scenario and that resulted from existing condition. The reduction of peak discharge ratios are 19.48 and 16.01 % for simulation results using Scenarios 1 and 2, respectively. The decrease in peak discharge is an impact of applying around 30 % of the catchment area into green land. A preliminary work on the impact of land use changes in this catchment has been done by Yuniarti et al. (2013) and found the importance of green land. Green land is required to give sufficient space for infiltration, which is good for groundwater recharge as well as flood control. Scenario 2 includes green land in the simulation, but also converts some of agriculture area into settlement. This means increasing semi impervious area, increasing runoff coefficient and consequently increasing flood peak. As a result, the reduction of peak discharge is less significant as land use conversion tend to change recharge potential area into semi impervious area.

In contrast to simulation results on the first two scenarios, Scenarios 3 and 4 cause significant increase of peak discharges. Scenario 3 aggravates land use change situation which converts all vacant land into industry area and half of settlement area into trading and service. Therefore, the impervious area increases significantly which reflects in the increase of peak discharge to 32.28 %. Compare to that Scenario, Scenario 4 alleviates land use change situation as in addition to the conversion of vacant land into industry area, only a quarter of the existing settlement is converted into trading and service area. Scenario 4 causes the increase of peak runoff to 28.66 %.

3.2 Analysis of the number of infiltration well applied in the catchment

Understanding possible impact of land use changes presented above, there should be an effort to reduce the impact of land use changes on flooding. From the analysis using Geographic Information System which overlays the existing land use map with land permeability, shallow ground water level and land slope maps, it is found that 52.06 km^2 or 81.47 % of the catchment area is the effective area for applying infiltration well. Figure 9 presents the map of suitable area for infiltration well application. Based on the effective area, an analysis of the density of infiltration well application was done with the assumption that the depth of the well is 3 m, and diameters of the wells are 0.8, 1.0, 1.2 and 1.4 m. Equation (2) was used in this analysis.

The average land area for applying infiltration well related to flood peak reduction is presented in Fig. 8. It can be seen that the average land area and well diameter have significant impact on reducing flood peaks. Applying an infiltration well per 4000 m^2 in the whole catchment will reduce flood peaks to 6.9, 8.76, 10.68 and 12.6 % using diameters of 0.8, 1.0, 1.2 and 1.4 m, respectively. Applying an infiltration well per 4000 m^2 means that there will be about 13 015 wells applied in the catchment. Using average density area of 2000 m^2, infiltration wells may reduce flood peaks to 13.8, 17.52, 21.3 and 25.29 % for diameters of 0.8, 1.0, 1.2 and 1.4 m, respectively. Considerable increase of flood peak reduction showed when applying infiltration well each in the average of 1000 and 500 m^2 land area. The ranges of flood peak reductions are between 27.61 to 50.57 % and 55.21 to 99.8 % using designated diameters for average applying land area of 1000 and 500 m^2, respectively.

The results suggest that using infiltration well with diameter 1.4 m which are appliedeach in every 500 m^2 of land area nearly reduce all runoff. However, applying an infiltration well per 4000 m^2 means implementing 104 116 wells in the catchment. It requires a lot of financial commitments not only from the government but also from the people. It also requires willingness of people to allow their land for the implementation. Relating the result with possible land use changes, implementation of infiltration well in every 2000 m^2 is considered sufficient as flood peak reductions correspond to flood peak increases with land use changes. In addition, the number of wells required will only be 26 029 wells, far less compared to applying an infiltration well each in every 500 m^2.

4 Implication and conclusion

Rainfall data, especially in fine time scale, is less available in developing country such as Indonesia. In practice design rainfall intensity is significant for determining design flood. With limitation of fine scale rainfall data, design rainfall intensity is usually estimated from a 24 h design rainfall. Design of hourly rainfall distribution consequently control design rainfall intensity. There is different hourly rainfall pattern between the method that commonly used and result from this study. For selected runoff method used in this study, as its simplicity, flood peak is only influenced by the highest hourly rainfall intensity distribution and not by the whole rainfall intensity pattern. Therefore, design rainfall intensity resulted in this study is similar with that of the common used method. However, for runoff calculation method which also considers rainfall intensity pattern, flood peak will be different if using rainfall intensity distribution resulted from this study compared to that of commonly used method.

Rainfall intensity pattern resulted from this study was carried out by simple analysis of hourly rainfall data. To have a more accurate result, a thorough statistical analysis needs to be done. Result indicated by this study is expected to provoke further analysis as in a case of limited fine time scale of rainfall data, rainfall intensity pattern will influence not only flood peaks, but also flood hydrographs and intensity duration curves which are vital in hydrology design.

Urbanisation, population growth and economic increase require more settlements, trading area and industries which may cause some land use changes. Bandar Lampung as a developing city will experience some land use changes due to the factors mentioned above. Analysis on some possible land use changes emphasize the

HESSD
11, 5487–5513, 2014

importance of open green space related to flooding, and particularly flood peaks. In fact there is spatial plan act for this city to maintain 30 % of the area for open green space. However, in practice people may not comply with the rule. This study indicates if conversion of land use to get space for more settlement, industries and trading areas will increase flood peaks significantly.

Application of infiltration wells have been considered in several places in Indonesia including Bandar Lampung, but not widely applied. Most possible places to apply infiltration wells are at the area of government offices or public facilities. Although there are few individuals who had applied infiltration wells at their house. This study does not examine the locations to implement infiltration wells. Instead, it considers the density of infiltration well within the catchment and how it may reduce flood peaks.

Infiltration well is one of the techniques to reduce flood, beside some other techniques such as rain barrel, porous trench, retention pond and bio-retention. Implementation of these techniques simultaneously will have significant impact on flood reduction. Require commitment and relevant policies from the government to encourage use of these applications as well as community participation to tackle flood reduction.

Acknowledgements. This work was financially supported by National Strategic Research Funding under Department of Research and Community Service, Department of Higher Education Indonesia (DIKTI). This support is gratefully acknowledged.

References

Arafat, Y.: Reduksi Beban Aliran Drainase Permukaan Menggunakan Sumur Resapan, SMARTek, 6, 144–153, 2008.

ASCE – American Society of Civil Engineers: Design and Construction of Urban Stormwater Management Systems, ASCE Manuals and Reports on Engineering Practice No. 77 and Water Pollut. Control Fed. Manual of Practice RD-20, New York, NT, 1992.

Ashagrie, A. G., de Laat, P. J., de Wit, M. J., Tu, M., and Uhlenbrook, S.: Detecting the influence of land use changes on discharges and floods in the Meuse River Basin – the predictive power of a ninety-year rainfall–runoff relation, Hydrol. Earth Syst. Sci., 10, 691–701, doi:10.5194/hess-10-691-2006, 2006.
Bappeda Bandar Lampung: Bandar Lampung Spatial Plan, Bandar Lampung, 2010.
Camorani, G., Castellarin, A., and Brath, A.: Effects of land use changes on the hidrologic respons of reclamation system, Phys. Chem. Earth, 30, 561–574, 2005.
DeSmedt, F. and Batelan, O.: The impact of land use changes on the groundwater in the Grote Nete River Basin, Belgium, in: Proceeding of the Conference Future of Groundwater Resources, edited by: Ribeiro, L., Lisbon, 151–158, 2001.
Doe, W. W., Saghafian, B., and Julien, P. Y.: Land use impacts on watershed respon: the integration of two dimensional hydrologic model and geographical information system, Hydrol. Process., 10, 1503–1511, 1996.
Gumindoga, W.: Hydrology Impact of Landuse Change in the Upper Gilgel Abay River Basin, Ethiopia, TOP MODEL Application, Thesis, International Institute for Geo-Information Science and Earth Observation, Enschede, the Netherlands, 2010.
Hacket, W. R.: Changing Land Use, Climate, and Hydrology in the Winooski River Basin, Vermont, M.S. thesis, The University of Vermont, Vermont, 2009.
He, M. and Hogue, T. S.: Integrating hydrologic modeling and land use projections for evaluation of hydrologic response and regional water supply impact in semi arid environments, Environ. Earth Sci., 65, 1671–1685, doi:10.1007/s12665-011-1144-3, 2012.
Ilmiaty, R. S., Susanto, R. H., Setiawan, B., Suryadi, F. X., and Bonar, G.: Drainage effects of Sangkuriang Indah residential area on condition existing drainage system in watershed Borang River Palembang City, Int. J. Biol. Ecol. Environ. Sci., 1, 154–158, 2012.
Indriatmoko, R. H.: Penerapan Prinsip Zero Delta Q dalam Pembangunan Wilayah, J. Air Indonesia, 6, 77–83, 2010.
Iriani, K., Gunawan, A., and Besperi, B.: Perencanaan Sumur Resapan Air Hujan untuk Konservasi Air Tanah di Daerah Permukan (Studi Kasus di Perumahan RT II, III, dan IV Perumahan Lingkar Timur Bengkulu), Inersia, 5, 9–22, 2013.
Juahir, H., Zain, S. M., Aris, A. Z., Yusof, M. K., Samah, M. A. A., and Mokhtar, M.: Hydrological trend analysis due to land use changes at Langat River Basin, Environ. Asia, 3, 20–31, 2010.

HESSD
11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

Koch, F. J., Griensven, A. V., Uhlenbrook, S., Tekleab, S., and Teferi, E.: The effects of land use change on hydrological response in the Choke Mountain range (Ethiopia) – a new approach addressing land use dynamics in the model SWAT, in: Proceedings of the International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany, 2012.

Kusumastuti, D. I.: Hydrology analysis to define design flood of the Johor River using synthetic unit hydrograph gama I, Rekayasa, 13, 219–228, 2009.

Nobert, J. and Jeremiah, J.: Hydrological response of watershed systems to land use/cover change, a case study of Wami River Basin, Open Hydrol. J., 6, 78–87, 2012.

Sunjoto, S.: Optimization of infiltration well to avoid salted water intrusion in coast areas, in: Proc. Sent. IUC-UGM, Yogyakarta, 1988.

Sunjoto, S.: Sustainable urban drainage, in: Proc. Intl. Conf. On Environmental Management, Geo-Water and Engineering Aspects, 8–11 February 1993, Wollongong, 1993.

Sunjoto, S.: Infiltration well and urban drainage concept, in: Proceedings of the Conference on Future Groundwater Resources at Risk, IAHS Publ. no. 222, June 1994, Helsinki, 527–532, 1994.

Suripin, S.: Drainase Perkotaan, Andi Offset, Yogyakarta, 2004.

Triatmodjo, B.: Hidrologi Terapan, Beta Offset, Yogyakarta, 2008.

Yuniarti, F., Kusumastuti, D. I., and Jokowinarno, D.: Geospatial analysis of land use and land cover changes for discharge at Way Kuala Garuntang watershed in Bandar Lampung, in: Proceedings of the 2nd International Conference on Engineering and Technology Development, 27–29 August, Bandar Lampung, 2013.

HESSD

11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

Table 1. Percentage of land use of the catchment area for four scenarios.

Land Use	Percentage of Land Use of The Catchment Area				
	Existing	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mining Area	0.40	0.40	0.40	0.40	0.40
Residential	54.14	54.14	56.50	27.07	40.60
Industry Purpose	4.11	4.11	–	4.11	4.11
Vacant Land	31.23	–	–	–	–
Trading and Service	1.79	1.79	1.79	28.86	15.33
Government Office	0.23	0.23	0.23	0.23	0.23
Tourism Area	0.05	0.05	0.05	0.05	0.05
Industry Area	0.38	0.38	4.49	31.60	31.60
Preserved Area	0.46	0.46	0.46	0.46	0.46
Agriculture	4.72	4.72	2.35	4.72	4.72
Public Service Area	1.27	1.27	1.27	1.27	1.27
Road	1.16	1.16	1.16	1.16	1.16
Double Track Railway	0.07	0.07	0.07	0.07	0.07
Green Land	–	31.23	31.23	–	–

HESSD
11, 5487–5513, 2014

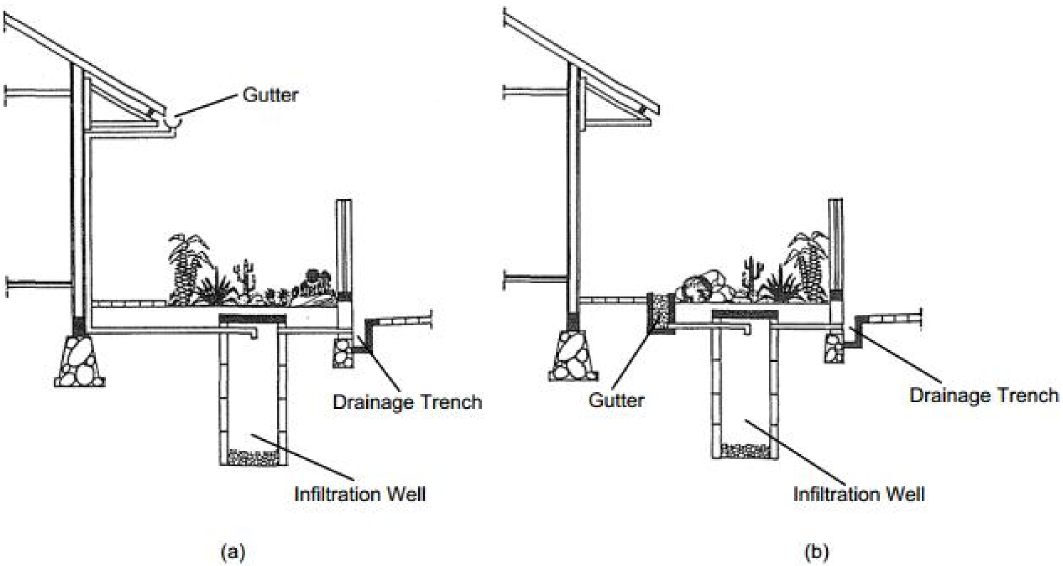

Figure 1. Illustration of infiltration well applications **(a)** house with gutter at the eaves and **(b)** house with gutter at the ground (source: Sunjoto, 1994).

HESSD
11, 5487–5513, 2014

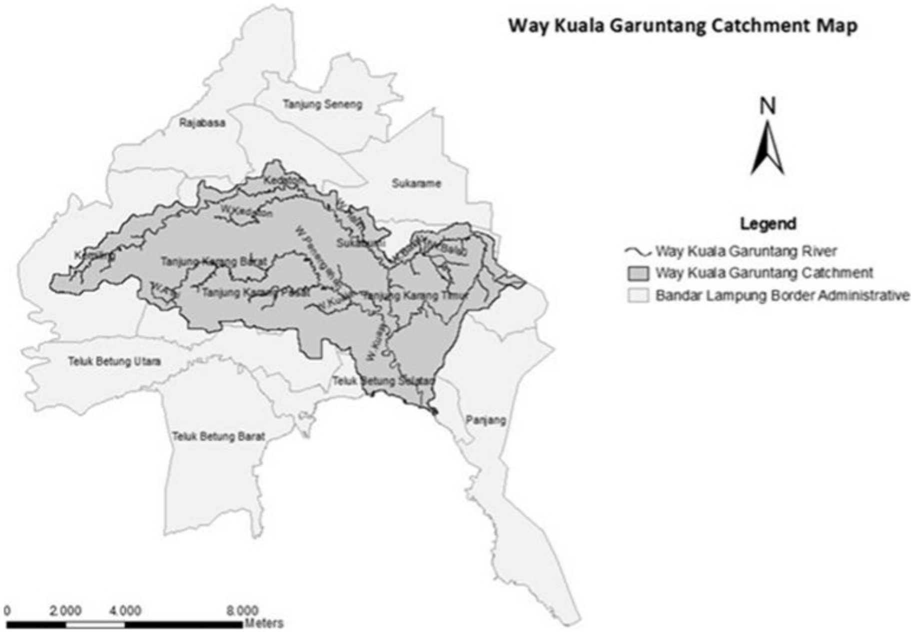

Figure 2. Way Kuala Garuntang catchment within the city of Bandar Lampung.

HESSD
11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

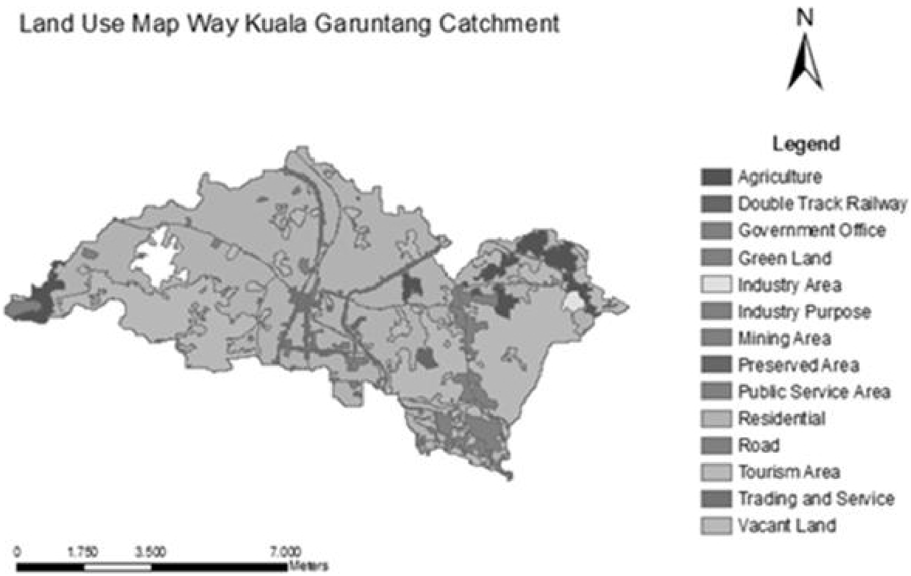

Figure 3. Land use map of Way Kuala Garuntang at existing condition (source: Bappeda, 2010).

HESSD
11, 5487–5513, 2014

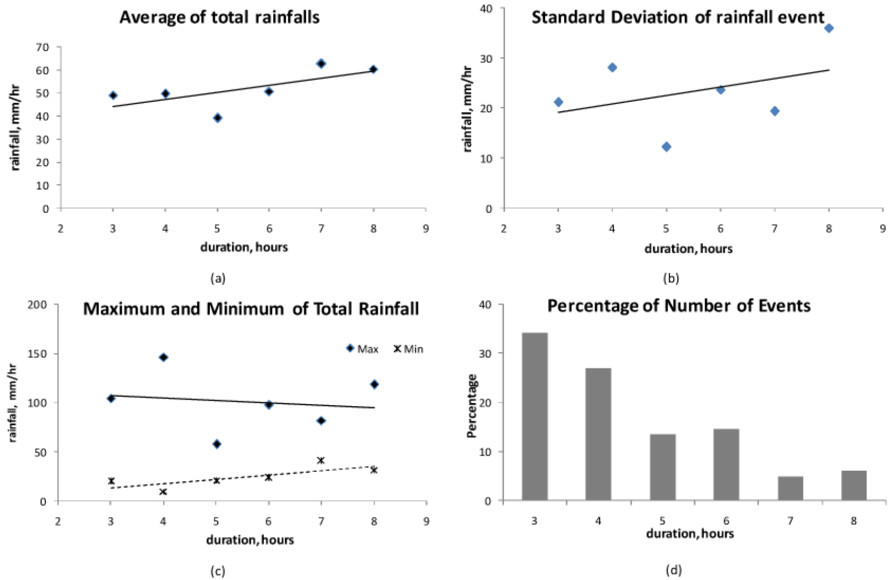

Figure 4. Characteristics of rainfall data.

HESSD
11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

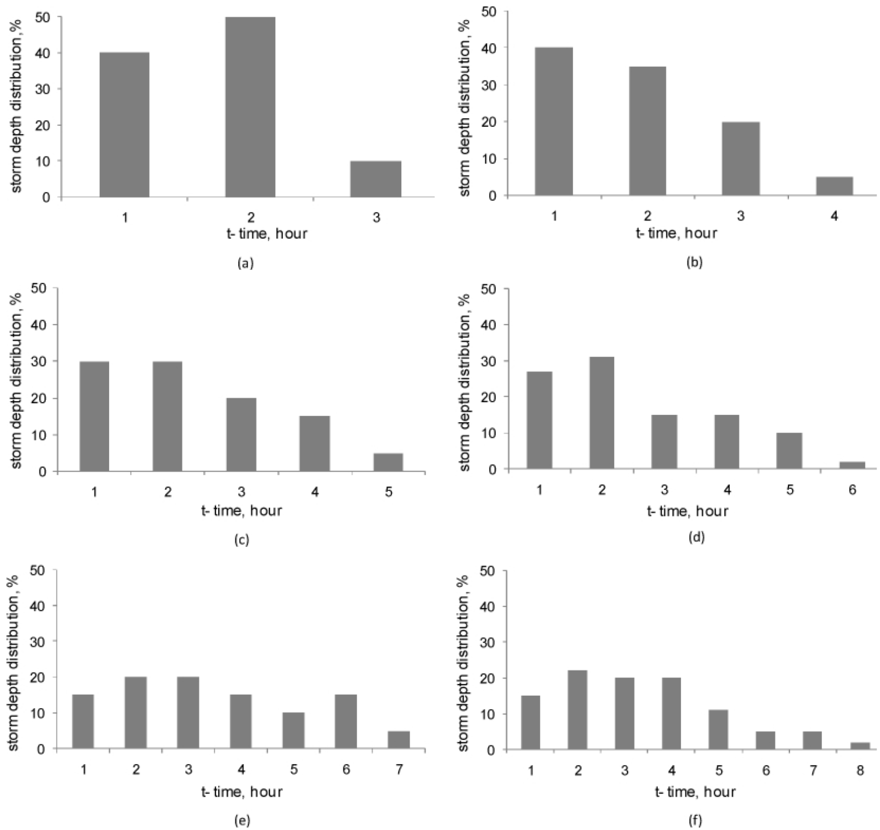

Figure 5. Storm depth distribution for storm durations 3 to 8 h.

HESSD
11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

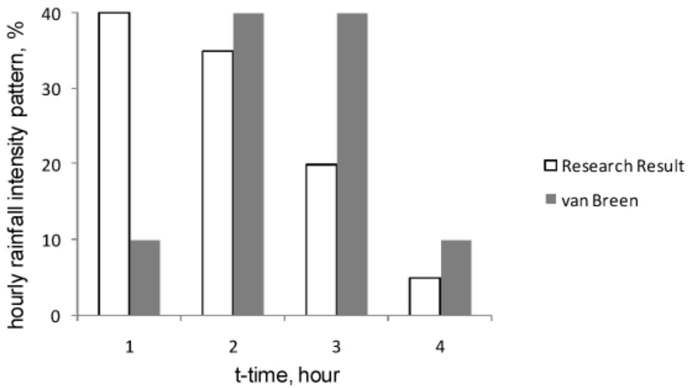

Figure 6. Hourly rainfall distribution pattern.

HESSD
11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

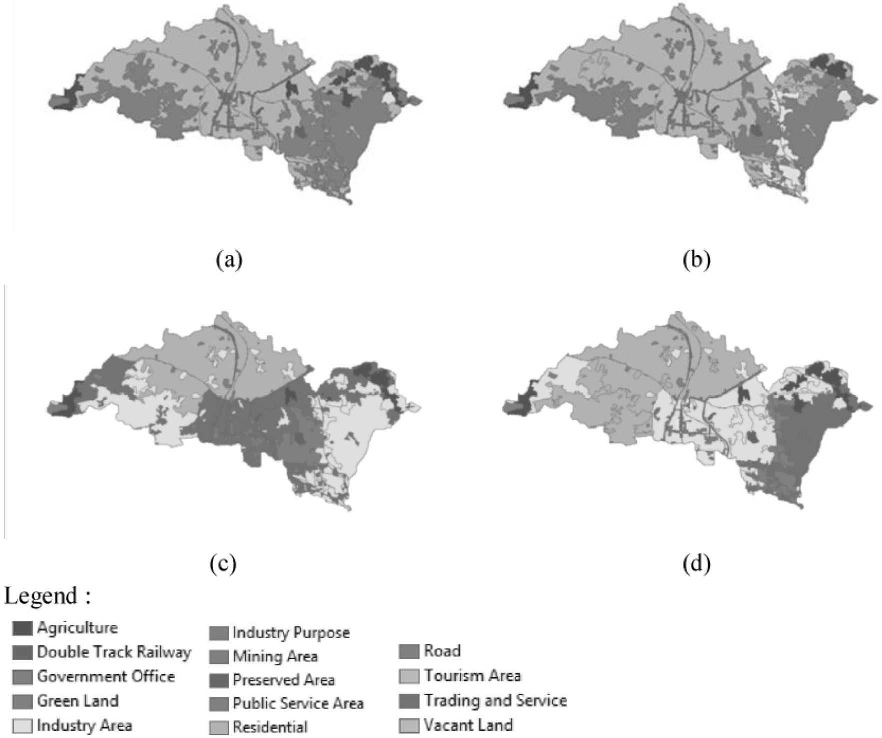

Figure 7. Land use on the four land use change scenarios.

HESSD
11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

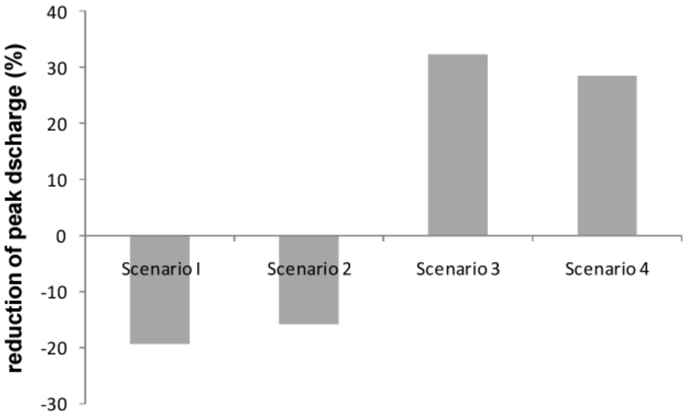

Figure 8. Impact of land use changes on peak discharge compared to existing condition.

HESSD
11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

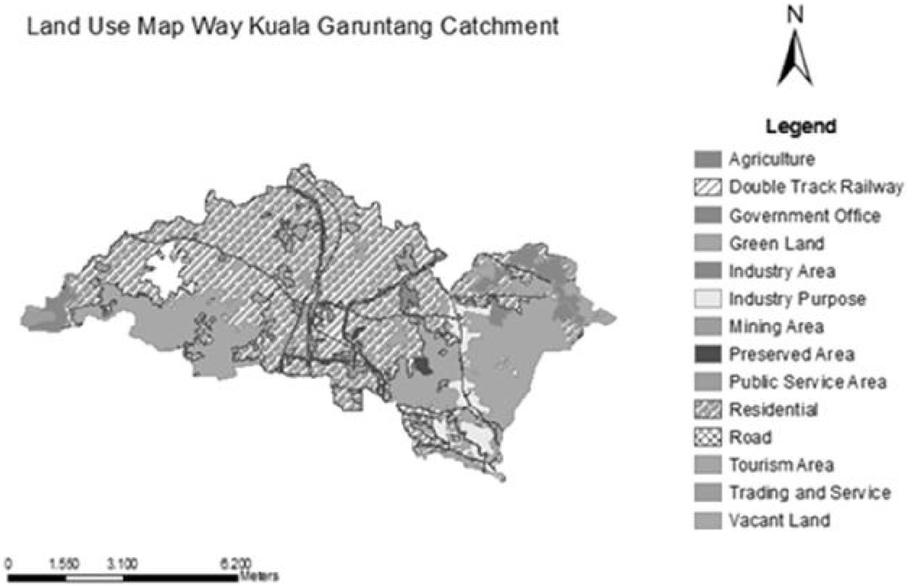

Figure 9. Suitable area for infiltration well application.

HESSD
11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

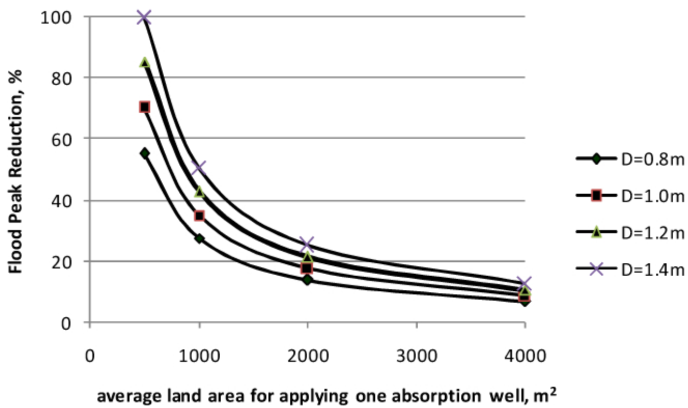

Figure 10. Average land area for applying an infiltration well vs. flood peak reduction.

HESSD
11, 5487–5513, 2014

Infiltration well to reduce the impact of land use changes on flood peaks

D. I. Kusumastuti et al.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◂◂ | ▸▸
◂ | ▸
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion