Integrating GIS and Drainage Modelling to Better Manage Stormwater Runoff in Urban Catchments

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Introduction

In urban and suburban communities, a high level of stormwater runoff can cause significant adverse environmental effects, such as residential damages, degrading of local water quality, and destruction of creek channels [1]. Due to the impacts of climate change and human activities on the hydrological cycle, the frequency of extreme meteorological and hydrological events (e.g. floods) is expected to rise [2]. This change has added urgency to the need to improve our capability to manage stormwater and control their environmental effects in urban/suburban catchments. Older developments with impervious surfaces have adopted Low Impact Development (LID) controls as a retrofit option to limit storm water runoff by increasing infiltration rate [3]. The SWMM drainage modelling helps to assess the LID performance based on the runoff volume and suggest a better planning and design for the long [3]. The urban drainage modelling when integrated with GIS layers and/or remote sensing imagery, creates opportunity for diagnosis and troubleshooting of drainage issues.

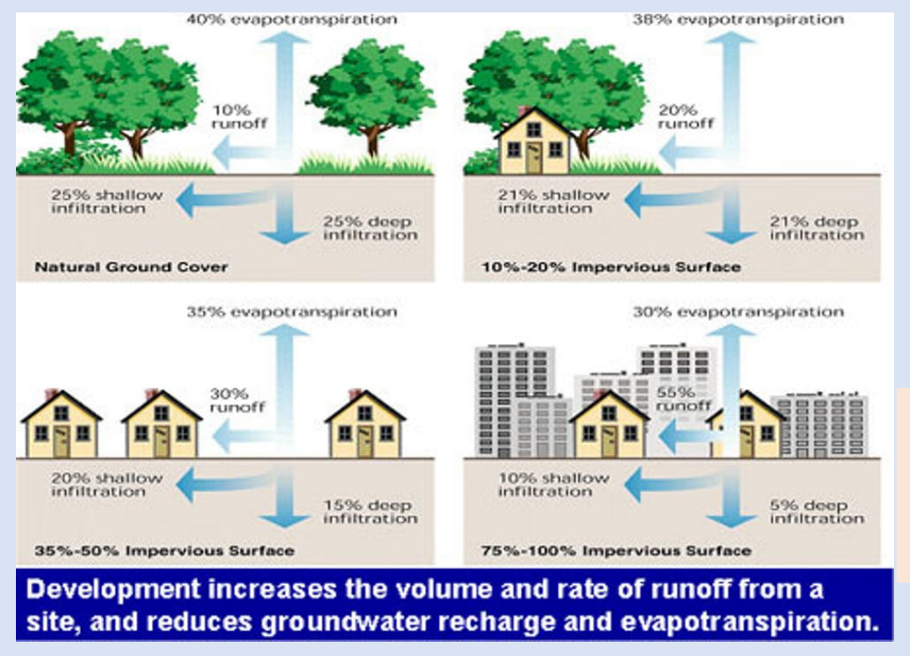


Fig 2: Dependence of runoff rate on development [4].

Fig 1: Storm water runoff at Taylor Creek Park.

Objective

In this study, the proposed research will test more exhaustively whether we can better manage urban/suburban stormwater runoff and mitigate their effects on urban environments by integrating GIS database and urban drainage models. The objective of this research is to explore the adverse effects caused by storm water on urban/suburban drainage system with and without LID controls.

Methodology

Study Area

- The study urban catchments are located within the City of Mississauga, Ontario, especially the neighborhoods that are close to the Lake Ontario. The parameters of the drainage area were averaged for lumped modelling.

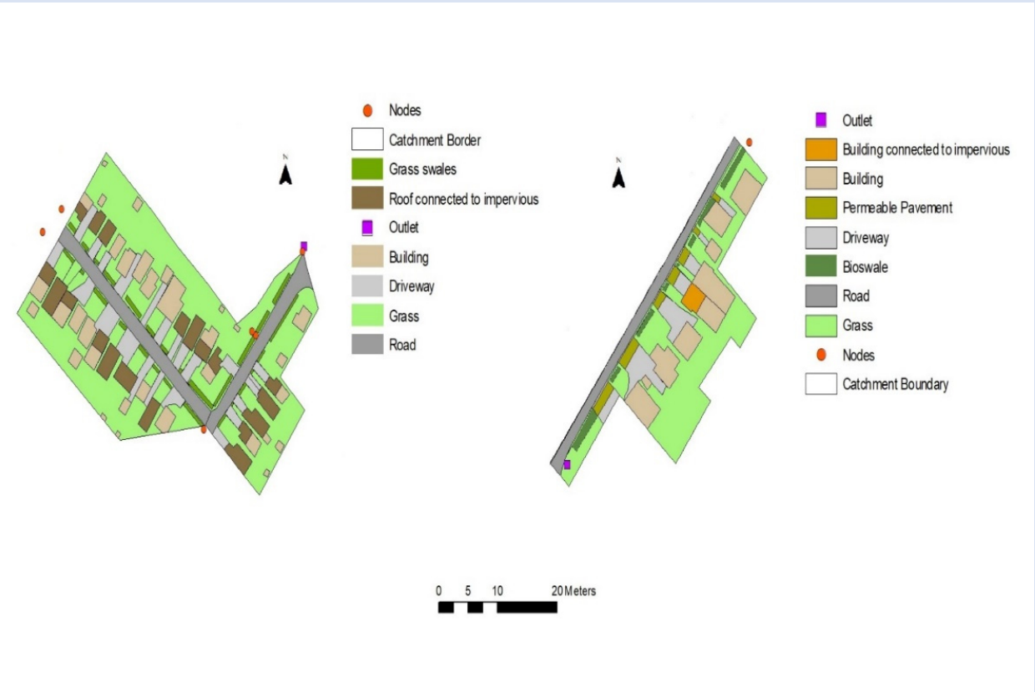


Fig 3: LV2 (left) and LV4 (right) catchments

Analysis

- Suggested SWMM parameters were used to run Green-Ampt Infiltration model for sandy loam soil type [3].
- CVC precipitation data were used for continuous simulation over a period of one year (2014) for LV2 and two years (2014 - 2015) for LV4. The precipitation monitoring data are at 10 min intervals. Evaporation was considered, but its impact is insignificant for our case.
- The flow unit is in cubic meter per second (CMS).

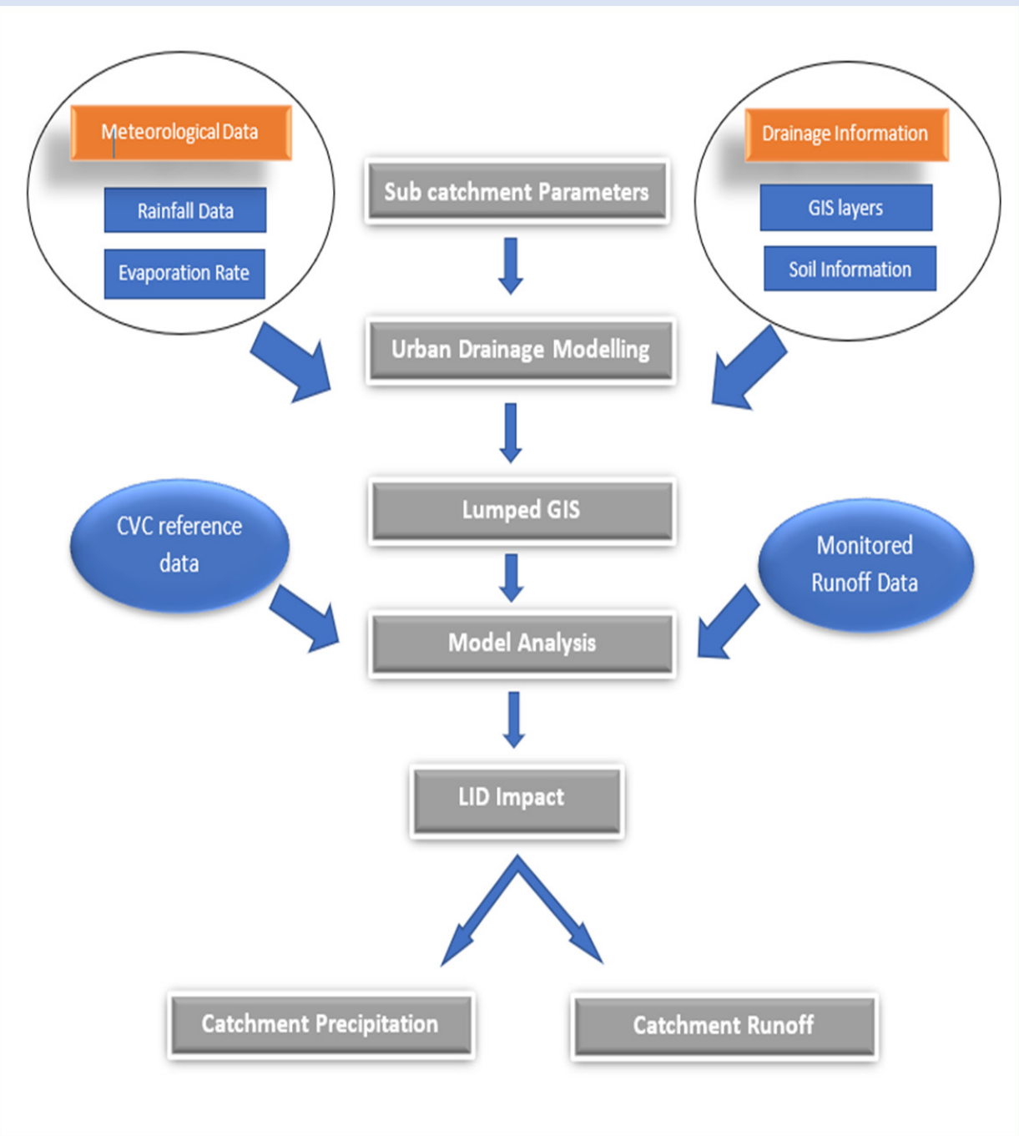


Fig 4: Flow chart for this work

LID controls

- The grass swales in LV2 (541 m^2) are shallow vegetative waterways whereas bioswales in LV4 (163 m^2) have soil engineered beneath the channel to infiltrate, retain and filter the storm water runoff [5]. Permeable Pavement in LV4 (173 m^2) are porous pavements designed with paving stones and enough space for filtration of stormwater [5].

Fig 5: Green swale at a residential area [6].

Fig 6: Multipurpose bioswale in the neighborhood Source [7].

Fig 7: Different types of porous pavements [8].

LV2 Results with LID control

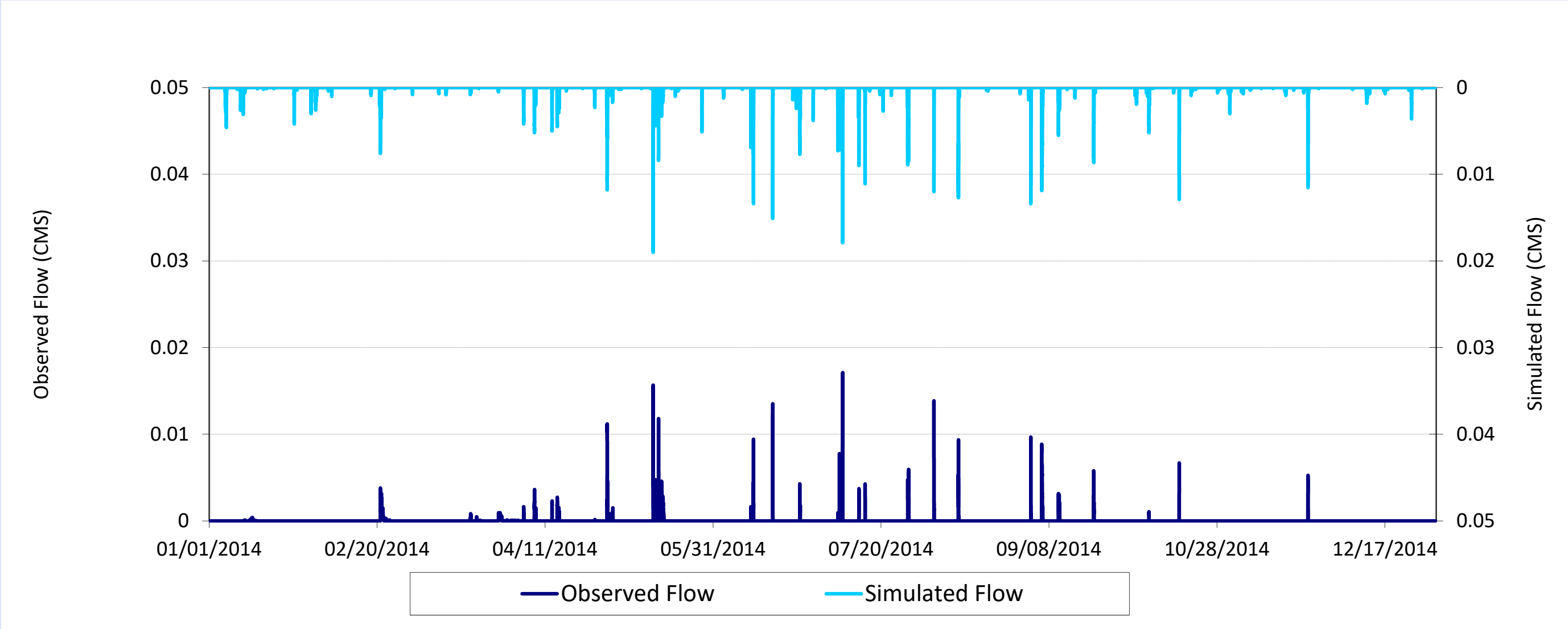


Fig 8: Simulated outflow vs observed outflow for LV2 catchment

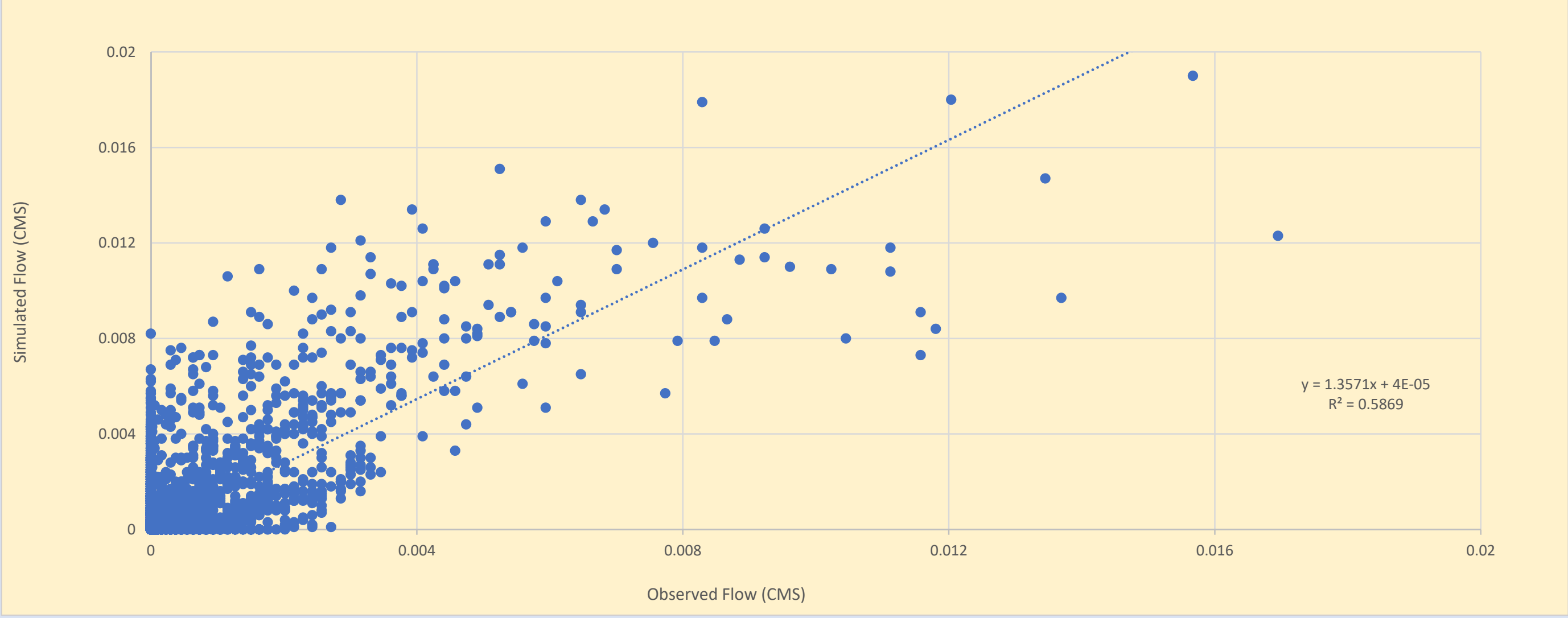


Fig 9: Linear regression between observed and simulated outflow for LV2 catchment

LV2 Results without LID Control

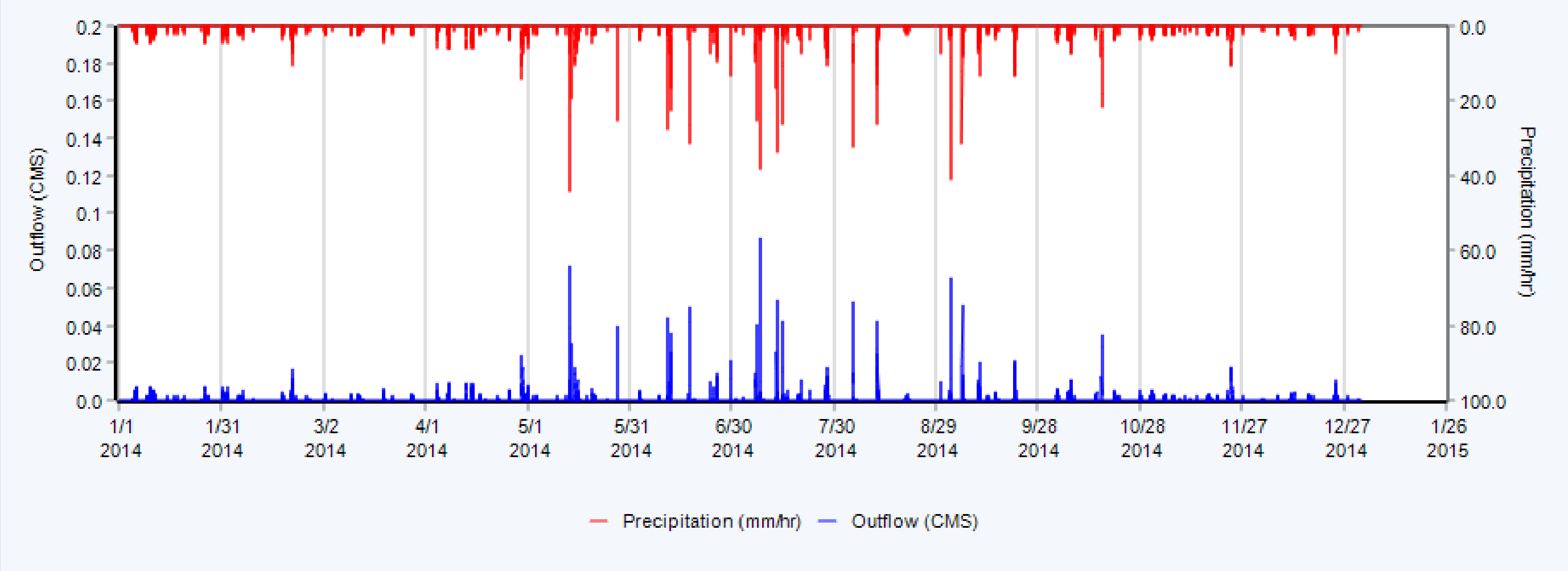


Fig10: Rate of precipitation and outflow without LID controls.

LV4 Results without LID control

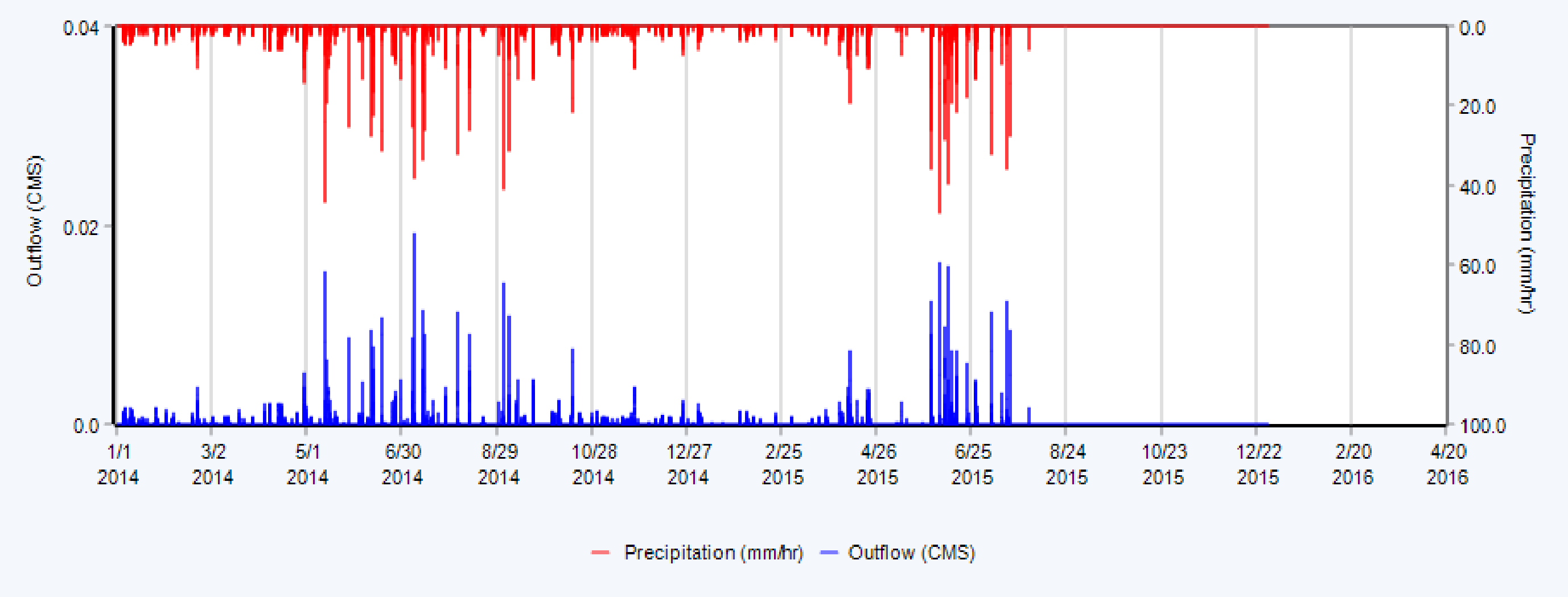


Fig11: Rate of precipitation and outflow without LID controls.

LV4 Results with LID Control

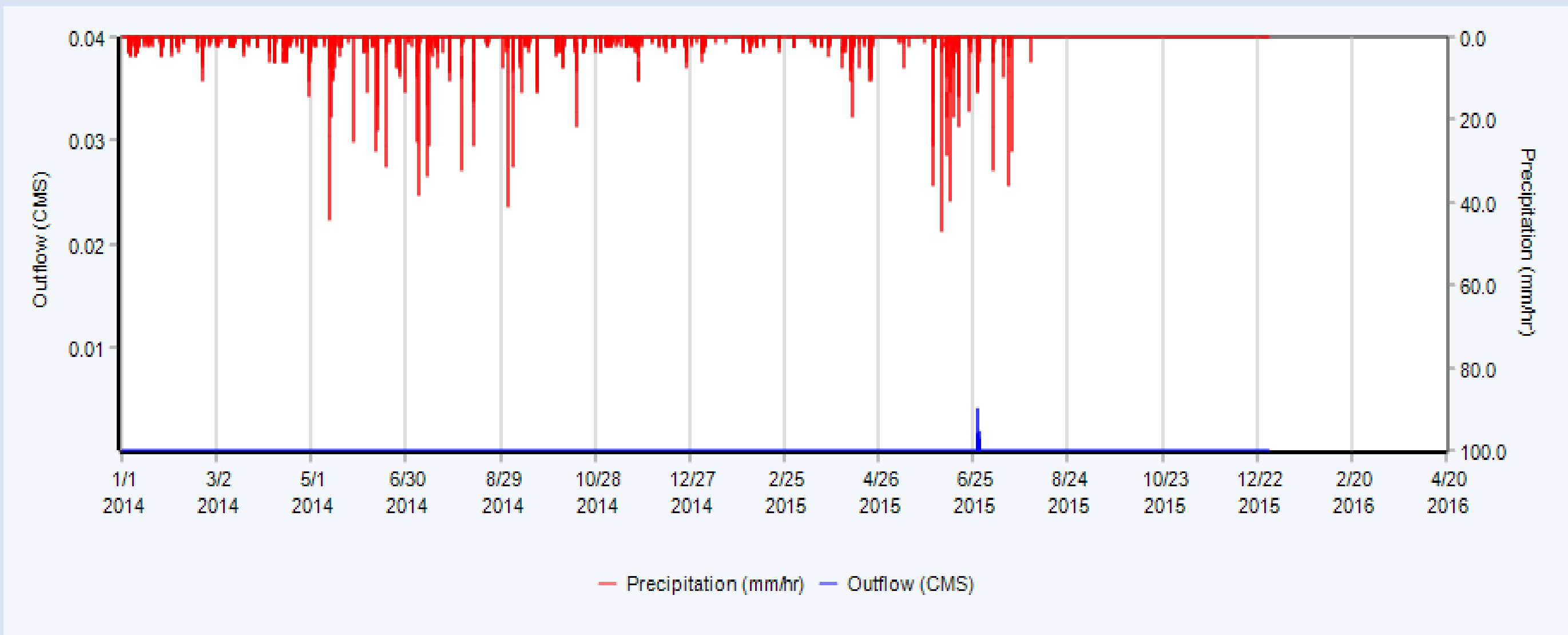
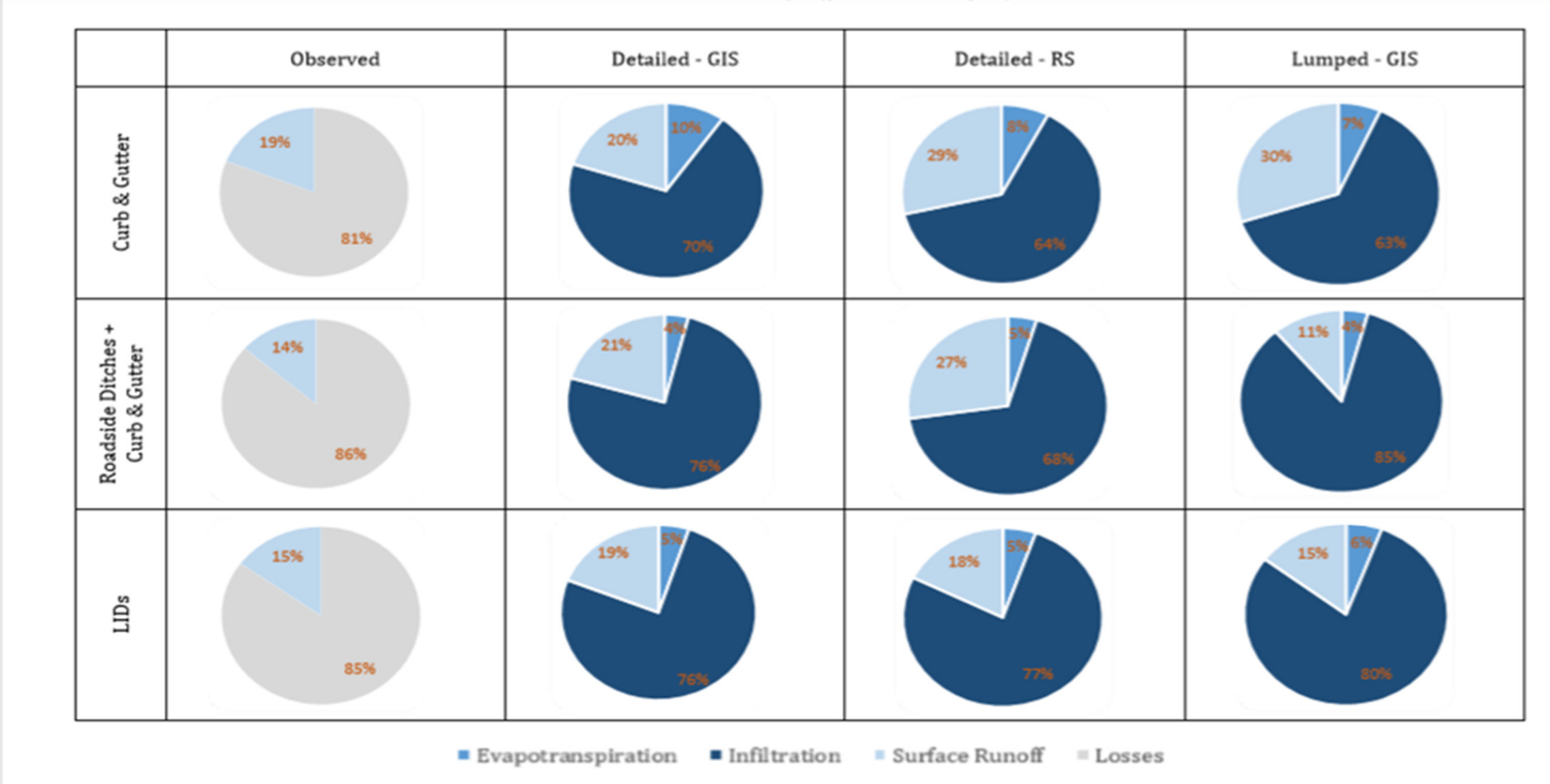


Fig12: Rate of precipitation and outflow with LID controls.

Research Approaches



The approach taken in this research is lumped data collection. Results vary depending on different methods. High resolution Quick bird image can be classified to generate land cover data or GIS layers can be incorporated to find the value of each land cover. Results are enhanced when the parameters are specific and updated.

Fig 13: Different research approach for drainage modelling [3].

Results

In Fig 8, the simulated outflows are compared with observed data from CVC. With lumped modelling and average parameters, the simulated outflow had similar peak outflows as the observed outflow around mid April, late May and mid July. The simulated flow considered more details of the outflows between 0.00 – 0.004 CMS whereas the observed outflow mostly accounted for significant peaks only.

As indicated in the scatterplot of Fig 9, there is a strong correlation between the simulated and observed outflows, with a correlation coefficient *R* of 0.77.

In Fig 8 & 10, a significant difference is observed between the simulated outflows with LID controls and without LID controls. The peak of the simulated outflow with LID controls is 0.0185 CMS whereas the same peak of the simulated outflow without LID controls is 0.09 CMS. The difference is 0.0715 CMS, which clearly reflects the ability of LID to reduce runoff volumes.

In Fig 11 & 12, stark difference in LV4 simulated outflows can be observed due to presence/absence of LID controls. The LV4 precipitation flow is mimicked by the outflow but with LID it drastically changes the outflow rate. Only the precipitation flow in June 2015 has generated an outflow rate of 0.004 CMS.

Discussion and Conclusion

The simulated data in Fig. 8 accounts for all details as opposed to the observed data provided by CVC which only highlights the peak flow. The detailed outflow data from the simulation has a possibility of changing the R^2 value in Fig 9. The R^2 value of 58.6% denotes that the variance in one variable accounts for the variance in other variable but as observed in the graph, an over estimation has been made for the simulated outflow. The over estimation is recognized from most of the values in linear regression being above the line of best fit. But in general, the r square value shows there is dependence between the two variables and room for more accuracy. Moreover, lumped modelling only provides average value for the sub catchment parameters which might be another reason for the R^2 value. For more specific parameters, classifying landcover with remote sensing imagery or accumulating data from GIS layers is integral.
Crucial to this research are the types and impacts of LID controls on each sub catchment's runoff volume. Urban areas have increasing amount of impervious surfaces and grey infrastructure which hinders water infiltration in to the soil and results in water accumulating over the surface, causing runoff and flooding. The water pipelines fall short when attempting to withhold adverse effects of heavy rainfall events. That is why, it is important for individual lots within a sub catchment to have LID controls installed to prevent runoff. The LV2 sub catchment have old fashioned LID controls (grass swale and ditches) which prevents storm water from running off but not to a significant degree. LV2 has decreased the peak flow by 0.0715 CMS. But water retention abilities of LV4 LID controls (bioswale and permeable pavement) surpasses LV2 LID controls . As seen is fig 11, the precipitation results is emulated by the outflow results when no LID control is in effect. But a drastic change is observed when LID controls are incorporated where only a very small portion of outflow around June 2015 is observed from the precipitation event. In the year 2014, LV4 sub catchment, with the more improved and effective LID controls, have been able to prevent nearly all outflows from the precipitation events. This sheds light to the importance of having LID controls for storm water runoff management.

LID controls not only help to retain water but is pollutant resistant and aesthetic [3]. This research has capability of having in-depth and more precise results when incorporated with remote sensing as it will allow to cross check the results. Urban drainage planning require upgradation with the changing urban infrastructure and this research is a substructure to the bigger picture.

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