Hydrol. Earth Syst. Sci. Discuss.,
doi:10.5194/hess-2016-362-AC2, 2016

Hydrology and Earth System Sciences Discussions
Open Access

Interactive comment on "Urban sewershed overflow analysis using super-resolution weather radar rainfall" *by* J. Y. Hyun et al.

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Received and published: 16 October 2016

Reply RC2(Anonymous Referee #2) on October 6th 2016

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This document provided detailed response to referee comments (RC2) from Anonymous Referee #2. The authors recognize and thank this reviewer for the effort and suggestions to improve this manuscript.

1. Could the authors define the "overflow depth"? Do the author mean the overflow water depth from CSO? Or the runoff depth on the surface? If it is the caused overflow from CSO, it should be a volume divided by an area. How is the area defined? If it is the runoff depth on the surface, would "runoff depth" be more appropriate? However,

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the runoff depth is spatial varied and what is the location the authors are referring to? Also, the runoff depends on the terrain (slope, catchment area, etc.) and the drainage capacity, how did the author determine the depth? Also, in most cases, the overflow from CSO is unlikely to be linear relationship to rainfall depth when considering the rainfall pattern, topography, catchment area and concentration time, drainage network and capacity. The ratio of "overflow depth" to "rainfall depth" is over-simplified and misleading.

Answer. Yes, each of these questions can be answered here. The "overflow depth" means the volume of water that is not captured by the sewer pipe and transmitted to the waste water treatment plant, and the volume is expressed as a depth (relative to the sewershed area size) as is commonly done in hydrologic applications. In general, for hydrologic studies, the water volume (rainfall or runoff or evaporation), and in this case the sewer overflow volume, can be defined or mathematically expressed as depth by dividing volume by watershed area. Yes, the overflow water depth is from the CSO outlet pipe measurement records from a gauge mounted at the discharge pipe. Yes, the overflow depth is expressed as a runoff depth using the definition noted earlier. During rainfall-runoff, stormwater runoff and sewage water mix together in the combined sewer system (CSS) and flow through the discharge pipe. As the sewer pipe begins to fill with this combined flow, the pipe capacity may be exceeded since in CSS pipes are typically not capable of conveying the rainfall-runoff and sewage flow. The result is an overflow event or combined sewer overflow. To prevent sewage backup into streets, residences, businesses, an overflow structure is used to divert excess capacity flow (volume) directly into surface waters. To accomplish this, the CSS pipe has a weir structure to divert water to the waste water treatment plant, and if flow depth exceeds the weir height, all overflow from the weir goes into a nearby surface water stream – and a Combined Sewer Overflow (CSO) event is recorded. As in many urban areas of the USA with CSS, these CSO events must be monitored – and now regulatory agencies such as the US Environmental Protection Agency (EPA) require municipal governments to eliminate all CSO events. The flow record for the overflow event includes measurement of the overflow volume since the overflow volume (not the portion transmitted to the waste water treatment plant) is the portion of interest since this runoff water (combined with sewer water) results in a public health issue and environmental pollution of surface waters. In this manuscript the term “overflow” is used in order to distinguish it from the portion of flow associated with stormwater only or sewage only. The CSO discharge is a mixture of these two water sources.

Yes, the drainage area is defined by topography of the land surface as the region draining or area contributing surface water runoff flow to the sewer pipe network draining to the most downstream pipe where the CSO diversion or overflow weir is located. Similarly, the drainage area also includes all “sanitary” sewer connections from area residential and business customers that contribute sanitary flow to the same pipe network draining to this common downstream CSO diversion point. If useful for clarification, the authors can add a figure or figures illustrating both the diversion weir and the specific catchment location. Surface runoff and sanitary sewage flows to this common downstream point and is the location where CSO measurement is recorded. The local sewer agency, Metropolitan Sewer District (MSD), Louisville, KY, identified the sewershed area after multiple surveys (The details uploaded in the supplement ‘CSO 130: Combined Sewer Overflow Fact Sheet’).

Yes, generally runoff depth is spatially varied in any catchment, however that is a not an aspect explicitly addressed in this work. Yes, runoff depth does depend on surface characteristics of the area as mentioned in this comment. However, the focus of this work is only on rainfall-runoff events that result in an overflow event – meaning the stormwater runoff combined with the sanitary sewer flow exceeds the CSS capacity. In cases where no CSO event occurs, all runoff (combined stormwater and sewage) flows to the waste water treatment plant and there is no public health or pollution issue. The runoff is measured at the sewershed drainage area outlet point (most downstream point) and since this area is entirely drained by a CSS, all runoff and sewer water flows past a common point in the pipe system. The CSO flow amount diverted to the surface water stream is measured at the downstream (pipe) at the weir chamber. The volumetric overflow is then converted to depth for comparison in magnitude to rainfall depth for the storm causing the CSO event. It is common in hydrology to show both rainfall and runoff in a common unit such as volume or depth in order to visualize a relationship and evaluate quantities on a common scale. Again the volume of overflow water is converted to depth units by dividing by the drainage area.

The authors agree that in a typical rainfall-runoff study, one might attempt to identify a relationship to define a rainfall to runoff depth ratio in order to determine land-use runoff coefficients or develop a means to estimate surface runoff from rainfall. However that is not why the overflow depth was utilized here. Instead, the overflow depth was compared to rainfall depth as a direct means to evaluate the quality and significance of the CSO event. The goal of this study was to identify the type of rainfall events in terms of amount (volume, intensity, duration) associated with a CSO event. If one can identify such rainfall event characteristics, then municipal agencies can develop strategies to mitigate CSO occurrence. The EPA strongly prohibits the overflow of the combined sewer water into the aquatic environment, thus, it is valuable to investigate the overflow trend and pattern according to the extreme rainfall event. In most CSO sewersheds there is limited or no understanding of the specific rainfall patterns leading to CSO events in that particular location (downstream discharge point from the sewershed). Instead, agencies view the entire region and simple develop a relationship between regional rain depth and number of CSO occurrences across the areal region of responsibility such as a large urban area, a county, or other multiple watershed region. That type of view cannot provide optimized and most economical planning of mitigation approaches. In summary, as the reviewer states, earlier non-site-specific studies are oversimplified in some cases. That is the impetus for this work – here the authors propose and illustrate a non-simplistic, high-resolution, location-specific identification of rainfall characteristics that produce CSO events in a given sewershed. The framework developed and illustrated in this manuscript is universally applicable to CSS urban regions (give radar availability). With this approach, the results can be

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used to assist with efforts to eliminate CSO events through the use of mitigation measures. Due to the variety of mitigation strategies available, and consideration of local hydrologic climate and regulations, specific measures are not proposed in this work – however the capacity of a mitigation strategy can be identified as outlined in the final summary table of results.

2. The authors only discussed the relationship between the "rainfall depth" and "overflow depth" without considering the hydrology and hydraulics in the whole process. This is the major weakness of the paper. The author said "a search to understand the contributing factors causing overflow events is warranted", but the paper does not cover those critical contributing factors.

Answer. The authors agree with this point, however, the direction of this work did not include development or identification of details of surface runoff characteristics or pipe flow hydraulics in the sewershed. The study applied a lumped-hydrology concept to identify rainfall event characteristics producing CSO events. This small-scale urban sewershed has high imperviousness. The study area is located in an urban residential and commercial area of the city of Louisville, KY, and according to MSD documentation the percent impervious is 71% with land-use estimated as [residential 24%, commercial 25%, industrial 32%, vacant 6%, undefined 13%]. Due to the relatively large percent imperviousness, the expectation is that rainfall volume governs overflow occurrence with limited influence from sewershed characteristics such as slope, antecedent condition, and other terrain features. As indicated in the runoff records, the short lag time (rainfall to runoff flow) and the high imperviousness, the influence of terrain is low for heavy rainfall (rainfall events identified according to EPA definition). In support of the short response time, the CSO event analysis was developed using sub-hourly temporal resolution to identify the 52 strongest storm events considered during the study period (Jan. 2011 to Dec. 2013). As stated in response to review question 1, this work proposes and illustrates a non-simplistic, high-resolution, location-specific identification of rainfall characteristics that produce CSO events in a given sewershed. The methods are universally applicable to CSS urban regions (give radar availability), and results can be used to optimize CSO mitigation measures. Due to the variety of mitigation strategies available, and consideration of local hydrologic climate and regulations, specific measures are not proposed.

3. Line 352: The authors identified 95 rain events with coupled CSO occurrence in the sewershed. Is this a correct statement? Are those events selected according to EPA definition without considering CSO?

Answer. Yes, there are 95 overflow-producing rainfall events identified. Additionally, the events are screened as shown and explained in figure 8 to evaluate data quality. The EPA rainfall definition is specific for urban hydrology applications and yes, all these event are selected according to EPA but also encompass all overflow occurrences. The EPA rainfall events means the runoff-producing rainfall, 0.1 inch of rainfall for urbanized area – and is an independent evaluation of rainfall occurrence regardless of CSO occurrence. The specific consideration and selection of CSO occurrence is independent of the EPA rainfall definition.

4. Line 370: Why it is not possible to determine the flow in sewer network and the overflow? Using sewer model can easily provide the answer. Otherwise, how did the authors get the overflow depth? If the rainfall-runoff index is a ratio of overflow depth to GAUGE rainfall depth, what's the point to estimate radar rainfall?

Answer. The overflow was measured at the downstream point in the pipe at the diversion chamber overflow weir. This study did not address or evaluate the details of stormwater runoff in the sense of modeling or forecasting. The intent of this study, in brief, is to identify the specific characteristics of rainfall leading to a CSO occurrence in a specific sewershed. While the authors agree that a hydrologic model might be useful for other types of rainfall-runoff study, in this case it was not a necessary component since total runoff was not of interest. Since regulatory agencies such as the EPA, and the local agency responsible for sewage collection and treatment (MSD) have interest only in the elimination of CSO events and that is the focus of this study. During rainfall-runoff events in which all water in the sewer flows to the waste water treatment plant (no CSO) – there is no need for consideration of the runoff amount. As stated in earlier responses above, the overflow amount is recorded at the downstream point in the sewershed discharge pipe. The specific location of the measurement is at the overflow weir where sewage flow combined with stormwater runoff is diverted into the surface stream. The EPA requires all sewer agencies in the US to identify and monitor all CSO locations, occurrences, and flow amounts. One impetus of this study is optimization of radar-rainfall for urban hydrologic applications. The reason for two rainfall sources in the screening of rainfall events is to minimize uncertainty. The multiple rainfall sources, both the locally-optimized radar and the nearest rain gauge were used. However, the ground-based rainfall measurement, rain gauge, was only used in evaluation of radar-rainfall estimation, and the filtering section. Rain gauge amounts were not used for the CSO runoff depth comparison – the rainfall depth for this part of the study was solely sourced from optimal radar-rainfall.

5. Line 441: How to determine the convective radar pixels and the total number of rain pixels? Are those only the pixels covering the sewershed? If yes, the sewershed is 13 ha and a radar pixel is about 5ha. So only up to 3 pixels area considered? If not, how will the rainfall outside the sewershed affect the flow in the sewershed?

Answer. The authors thank the reviewer for this comment. Yes, the spatial variation of rainfall was investigated and considered for this study. The results are summarize in the rainfall structure study by Hyun et al. (2016), where the spatial variation of the rainfall at quarter-hourly temporal resolution is found to be limited across this small-scale area. Additionally, the radar reflectivity data (radar pixels) and resulting rainfall values over the area do not vary relative to the immediate surrounding region. For this reason, as mentioned in the response to Anonymous Referee #1 (AC1: Reply on RC1 (comments from Referee #1) – question #10), the usefulness of the radar-rainfall spatial resolution is limited at this sewershed scale. However, for a sewershed of greater extent (several square kilometers), the rainfall variation becomes apparent and must be incorporated. Since the authors did not know if the CSO associated rainfall spatial variability was significant, it was evaluated and considered. Again, due to the limited spatial extent of this sewershed the rainfall spatial variation is not an issue. The spatially-averaged radar reflectivity pixel data which falls across the study area (approximately three pixels) is used without areal weighting. This aligns with the evaluation of radar-rainfall over the sewershed using the nearest MSD rain gauge. The nearest rain gauge, TR05 which is 700 meters away from the study area, was used in the radar optimization component of this work. Implying that the radar data were optimized to provide ground level rainfall verified using this rain gauge. The radar reflectivity data were then transformed into rainfall using the optimal Z-R relationship and the spatial variation within this range was negligible. For this work the authors found limited variation for the rainfall events within the sub-kilometer range. Lastly, any rainfall outside the sewershed boundary will not directly influence the runoff in the sewershed of CSO130. Neighboring watersheds and sewersheds flow into other drainage networks whether it be natural streams, combined sewer systems (potentially with a CSO outlet), or into separate sanitary and storm sewer pipes. This sewershed is not connected on the surface and does not share any sewer pipe connection with adjacent catchments. The drainage region for this CSO is field-verified by the local sewer company.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-362/hess-2016-362-AC2-supplement.pdf

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-362, 2016.