Hydrological Responses from Low Impact Development comparing with Conventional Development

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ABSTRACT

In November of 2000, Prince George's County, Maryland initiated a field monitoring program to compare the stormwater hydrologic and water quality responses between a Low Impact Development (LID) design and the conventional development design at Somerset Heights Subdivision. In the Subdivision, two small watersheds are located side-by side: one was developed using a few LID concepts (grassed swales, bioretention areas, etc) with drainage area of 11.84 acres and another was developed entirely using a conventional stormwater conveyance system (a curb, gutter and pipe stormwater conveyance system) with drain area of 8.43 acres. The monitoring program, including one rain gage, two stream gages and two water quality automatic samplers, is capable of collecting continuous data in a 2-minute time interval. So far, more than two years of continuous flow and water quality data have been collected at both sites. The program is now moving into the third year of operation. This paper presents a data summary and analysis for the first two years of the monitoring program.

Although there are only two years of data, analysis of this data seems to reach a few general conclusions. When compared to the conventional site, the LID site had considerably lower event runoff volumes and peak flow rates as well as lower annual flow. In addition, most event runoff hydrographs started later, including peak time, in the LID site. The LID site showed a higher frequency of smaller flow rates while the conventional site showed a higher frequency of larger flow rates. As expected, the peak flow rate or runoff volume reduction at the LID site decrease as the event rainfall depth increased because the ground is saturated after certain rainfall depth. The annual pollutant loads for the LID site were lower for most constituents measured but not significant. The major reason is that the LID site is just recently completed and the soil conditions are still not stabilized yet. It is expected that, after the site is stabilized, the better water quality benefits will show-up.

Keywords: Stormwater, Runoff, Bioretention, BMP, Low Impact Development (LID)

INTRODUCTION

Urban stormwater runoff has been identified as a significant source of pollution for many water bodies. Washing off road surfaces, parking areas, vehicles, and building materials, this precipitation and surface runoff contain a broad spectrum of pollutants. Proper control and management of runoff from impervious urban sources can provide for significant improvements to the quality of water entering local waterways. Concern for urban water quality improvements has spawned interest in natural-based treatment processes, such as bioretention and vegetated swales. These practices are part of an integrated paradigm known as Low Impact Development (LID—Department of Environmental Resources, 1999), which employs vegetated techniques to hold and treat run off water at the source, maximize infiltration, and reduce both quality and quantity impacts on local ecology.

Bioretention facilities are an integral part of stormwater management in the Prince George's County (Maryland) low-impact development program. Several systems have been designed and constructed in the county. However, not much performance data has been collected on their treatment efficiency, especially their advantage comparing to the conventional piping system; this paper represents the work in this regard. Detailed monitoring of the characteristics and performance of bioretention systems have been performed. The removals of several heavy metals and nutrients from both LID development and conventional development were evaluated.

The Somerset Heights monitoring program was developed to quantify the storm water hydrology and water quality benefits of LID. This evaluation is based on a comparison of the hydrologic and water quality differences between a watershed developed using LID practices and another watershed developed entirely using a conventional stormwater conveyance system. The two watersheds selected for the study are completely developed small, urban watersheds with uniform land uses and stormwater conveyance systems. Construction in the LID watershed was completed during 1999-2000. The stormwater management system for the LID watershed consists of grassed swales, Bioretention areas and disconnected impervious areas. Only a few LID techniques were used since the site was designed three years prior to the release of the County's LID design manual and very early in the County's development of the technologies. The conventional watershed was developed in 1990 and uses a curb, gutter and pipe stormwater conveyance system. The monitoring program was started in November of 2000 when the LID site was just completed and has been in continuous operation since that time.

It should be noted that the LID site is not developed in a typical and full-scale LID manner and is County's first attempt of using non-conventional approaches to reduce stormwater flows. This LID-like development includes grass swales, disconnection of impervious areas, and non-typical bioretention facilities. Although the site did not follow the LID sizing and design criteria and was not stabilized during the monitoring period, the sampling results are very encouraging because it works better than what was expected.

METHODOLOGY

Watershed Characteristics

Landscape features for the two watersheds, while not identical, are in almost all respects similar. Land use within each watershed is comprised entirely of single family detached housing (1/4 acre lot size). The watersheds are geographically located adjacent to each other and drain approximately the same area. Housing and road density are different slightly (Table 1). Figure 1 shows the geographic location of the two sites.

Figure 1. Project site

Table 1. Watershed Features

Watershed	Drainage Area (acres)	Number of Houses	Houses/acre	Road Length (ft/acre)	Road Width (ft)	Percent Impervious
Low Impact Development (S2 LID)	11.84	40	3.37 houses per acre	187	36	36 %
Conventional Development (S3 CONV)	8.43	28	3.33 houses per acre	189	24	30 %

The conventional site's stormwater conveyance system consists entirely of a curb, gutter and pipe system. The LID site consists of a curb-less road drained by a grassed swale network; but did not follow today's LID sizing and design criteria. It was County's first attempt of using non-conventional approaches to reduce stormwater flow. Bioretention areas are located both on individual lots and along grassed swales. Typically, pipes are used only to convey stormwater under driveways and roads, however, when flows become too concentrated drop inlet structures and pipes are used to convey stormwater flows to an outfall point. In some cases, inverts for the drop inlets are slightly higher then the inverts for the bioretention area or swale and provide additional stormwater flow attenuation (see Figure 2).

Figure 2. Drop Inlet Structure Located in Bioretention Area

Monitoring Program

In addition to the careful selection of the two watersheds, a well-designed monitored program is also essential to the evaluation of differences in hydrology and water quality. Each watershed's outfall was instrumented with automated level and water quality sampling equipment. A rain gage was also located at the outfall point for the conventional watershed. A second rain gage, located about 0.5 miles from the monitored watersheds and maintained as part of county's flood warning system, was used as a data quality check.

A 2-foot H flume is used at each site to determine the flow rate and volume at each watershed's outfall point (Figure 3). The water levels in each flume are continuously monitored using an ISCO water level sensor, with level data recorded every two minutes. Conversion of water levels to flow rate is based on standard rating curves for H type flumes. Rainfall data are also collected using a two-minute interval.

Water quality sampling at each site is based on volume-weighted composite sampling procedure. This sampling method results in a 250-ml storm water sample being collected for each 250 cf (cubic feet) of runoff for small storms (less than 1.0 inches).

While for larger storms, the programming is changed to collect a water sample for each 500 cf. of runoff. These 250-ml samples are combined into a single water quality sample that is then sub-sampled and submitted to a laboratory for chemical analyses. This sample represents a volume-weighted event mean concentration for each sampled storm. The chemical analyses completed include measurements for lead, zinc, copper, total nitrogen, total phosphorus and total suspended solids. The sampling equipment is also illustrated graphically in Figure 3.

Figure 3. Flow and Water Quality Sampling Equipment at the Project sites

RESULTS AND DISCUSSIONS

General Climate

The results of any monitoring program are always affected by the large-scale weather patterns that occur during the course of monitoring. On an annual basis, rainfalls during the first and the second years of monitoring were slightly less than the long-term average of 42.3 inches reported by National Resources Conservation Service for Upper Marlboro (NRCS, 1995). Using a combined rainfall data set based from the Somerset monitoring station and County's rain gage, a rainfall total of 35.5 inches was measured from November 1, 2000 to October 31, 2001. For the period from November 1, 2001 to October 31, 2002, the total rainfall was 26.4 inches which is only 75% of the first year's value and only about 63% of the long term average. Figure 4 shows a comparison of monthly rainfall for these two years.

Hydrology

The flow sampling devices used in this project automatically record information at a two-minute interval. When measured on an annual basis, significant differences between the two watersheds were observed in the number of runoff events, the total runoff volumes and in peak event flow rates (Table 2). For the period, the LID watershed had 20% fewer runoff events. The LID watershed also had 20% less runoff volume per acre than did the conventional watershed. Peak flow rates during the period also had a tremendous reduction in flow rates on a per acre basis of about 44%. A change in the distribution of peak event flow rates was also observed and is illustrated in Figure 5. As shown in Figure 5 the event peak flow rates are generally lower and less frequent for LID sites than those observed at the conventional site. These results appear very encouraging. Even better, because of the location of the LID outfall (about 30 feet below the ground surface), the measured flow volume include both surface runoff and groundwater. Therefore, the actual annual surface runoff volume is even much smaller than the sampling results show.

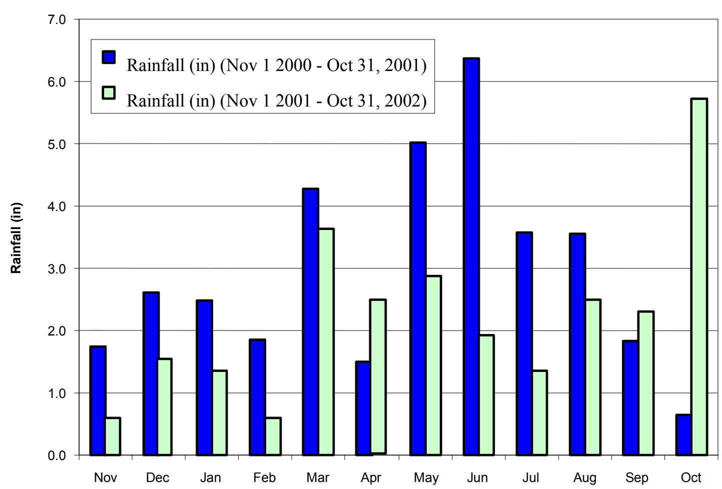

Figure 4. Month Rainfall Totals Nov 2000 to Oct 2002

Table 2. 2-Year Hydrologic Summary

Measurement	**Watershed**	
	Conventional	**LID**
Number of Events with Measurable Runoff > 100 cubic feet*	104	83
Total Runoff Volume (cubic feet/acre)*	41,403	33,391
Percent of Rainfall converted to Total Runoff*	19.0%	15.3%

* Difference is significant at the 95% confidence interval

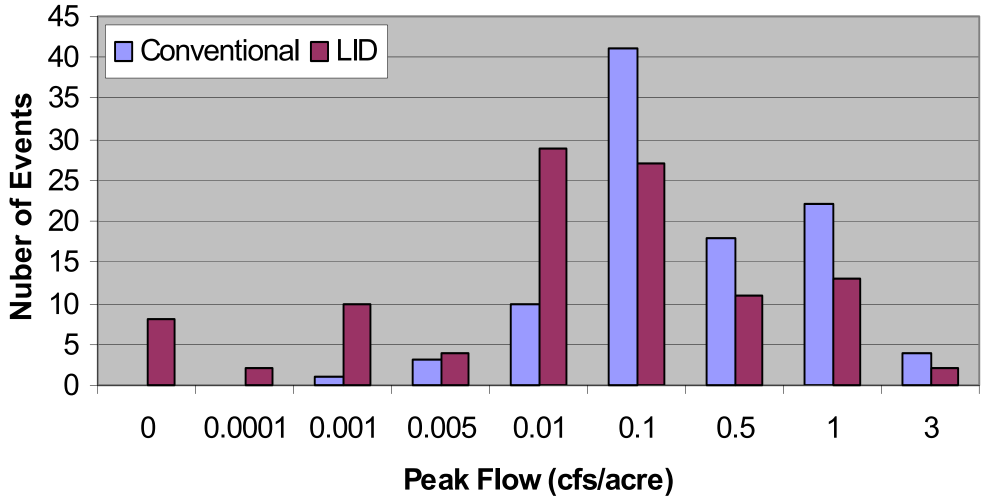

Figure 5. Comparison of Peak Event Flows at Conventional and LID Sites (November 2000 – October 2002)

On an event basis, reductions in an event's peak flow rate were also observed to increase in proportion to the inter-event time period between storms. Conversely, for very short inter-event time periods, a much smaller reduction in event peak flow rates was observed. A minimum inter-event period of about 24 hours appeared to be sufficient for the recovery of the LID watershed's storage and infiltration capacity. This recovery period is longer in duration during the non-growing season or nonexistent in the case of frozen soils. The responses of the LID and conventional site to a short event time period are illustrated in Figure 6. While the LID site effectively reduces the peak flow rate and volume for the first event, the following storm is not as effectively managed. In total thirty-six percent or 1/3 of the storms monitored at Somerset had a prior storm event that occurred within the previous 24- hour period. The main reason for this result is because of the location of the storm drain outfalls. For the conventional site, the storm drain outfall is located only a couple feet from the ground surface; while the outfall for the LID site is approximately 30 feet below the ground surface. Consequently, the measured peak and flow volume at LID site includes not only the surface runoff but also the ground water flow. This situation is very obvious because the outfall at LID site still releases flows even days after the storm events.

This annual groundwater volume needs to be estimated. A similar monitoring station, with a drainage area of 50 acres, is located a few miles away from this site. 38% of the total flow volume is measured to be groundwater. By carefully examining the flow data, the groundwater contribution is estimated at 25.5%. This separation between surface runoff and groundwater is estimated based on the storm hydrograph at a point which the flow is 150% of the pre-storm event.

It is also difficult to accurately measure runoff volume from short and intense storms at the conventional site. These storms produced rapid changes in flow that, even with the use of a 2-minute interval sampling, from which it was difficult to get accurate runoff volume estimates. Conversely, the slow and more gradual response of the LID site resulted in more accurate volume estimates for these types of storms.

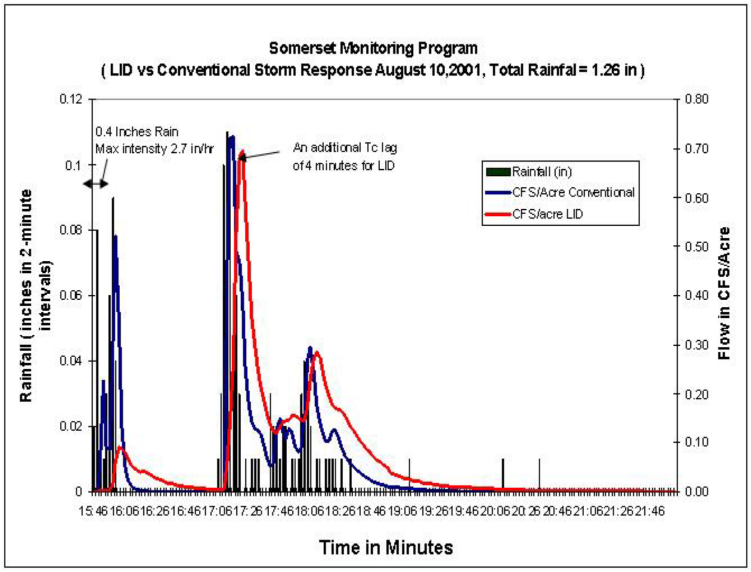

Figure 6. Peak flows comparison for Consecutive Storm Events

Even with these two disadvantages, the overall hydrological performance at the LID is still very impressive. The average peak flow rate for the two-year period at LID site is only 56% of the conventional site. The total flow volume, including groundwater / interflow volume at LID site is approximately 80 % of the conventional site. Since groundwater / interflow is 25.5% of the measured flow volume, the surface runoff volume at LID site is only approximately 60% of the conventional site. (see Figure 7).

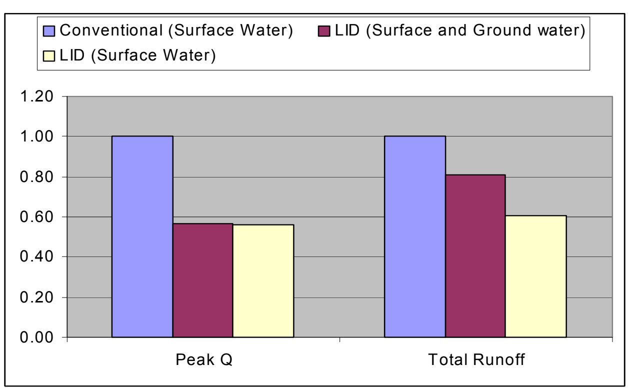

Figure 7. Two Years Hydrologic Performance Chart

Water Quality

The sampling program to compare the water quality benefits of the two stormwater conveyance systems consisted of a monthly sampling program for subset of the parameters normally monitored as part of the County's NPDES permit (Table 3). All the samples collected were volume-weighted composite samples. A total of ten storms were monitored every year.

Table 3. Water Quality Sampling Parameters

Parameters	Method	Reporting Limit (mg/L)
Nitrate/Nitrite	EPA 353.2	0.05
Total Kjeldahl Nitrogen	EPA 351.3	1.00
Total Phosphorus	SM 4500 P B+E	0.01
Total Suspended Solids	EPA 160.2	2.5
Total Copper	EPA 200.8	0.002
Total Lead	EPA 200.8	0.005
Total Zinc	EPA 200.8	0.020

For comparative purposes, water quality samples were required from both sites for the same storm. Since runoff from the LID watershed occurred less frequently then at the conventional site, the sizes of storms from which water quality samples were submitted were mostly larger storms (>0.5 inches). Overall, this resulted in a large percent of the total annual runoff volume from both sites being sampled for water quality (Table 3). For the conventional site, 66% of the annual runoff volume was sampled for water quality while 69% of the annual runoff volume was sampled for water quality measured at the LID site.

Event mean concentrations (EMC) and loading values were measured for both watersheds. The annual EMCs are calculated based on the total measured load for all ten storms divided by the total runoff for these storms. From the two-year average annual EMC values the LID site had lower loading rates for nitrate, total suspended solids (TSS) and zinc, and slightly higher loading rates for total Kjeldahl nitrogen and total phosphorus (see Table 4 and Figure 8).

This is a very in-consistent sampling result. After a careful reviewing of the site conditions, it is concluded that the major reason for this in-consistency is that the LID site is just recently completed and the vegetation and soil conditions are still not stabilized yet; while the conventional site was constructed in early 1990's. It is therefore expected that, after the site is stabilized, the better water quality benefits will show-up.

Table 4. Two-Year Average Loading

Parameter	Conventional Loading (lb./acre)	LID Loading (lb./acre)	% Difference
Total N	6.57	6.39	2.74%
Nitrate/Nitrite	1.64	1.07	34.76%
TKN	4.92	5.33	-8.33%
Total P	1.11	1.55	-39.64%
TSS	121.86	104.45	14.29%
Copper	0.0184	0.0117	36.41%
Lead	0.0057	0.0045	21.05%
Zinc	0.0682	0.0433	36.51%

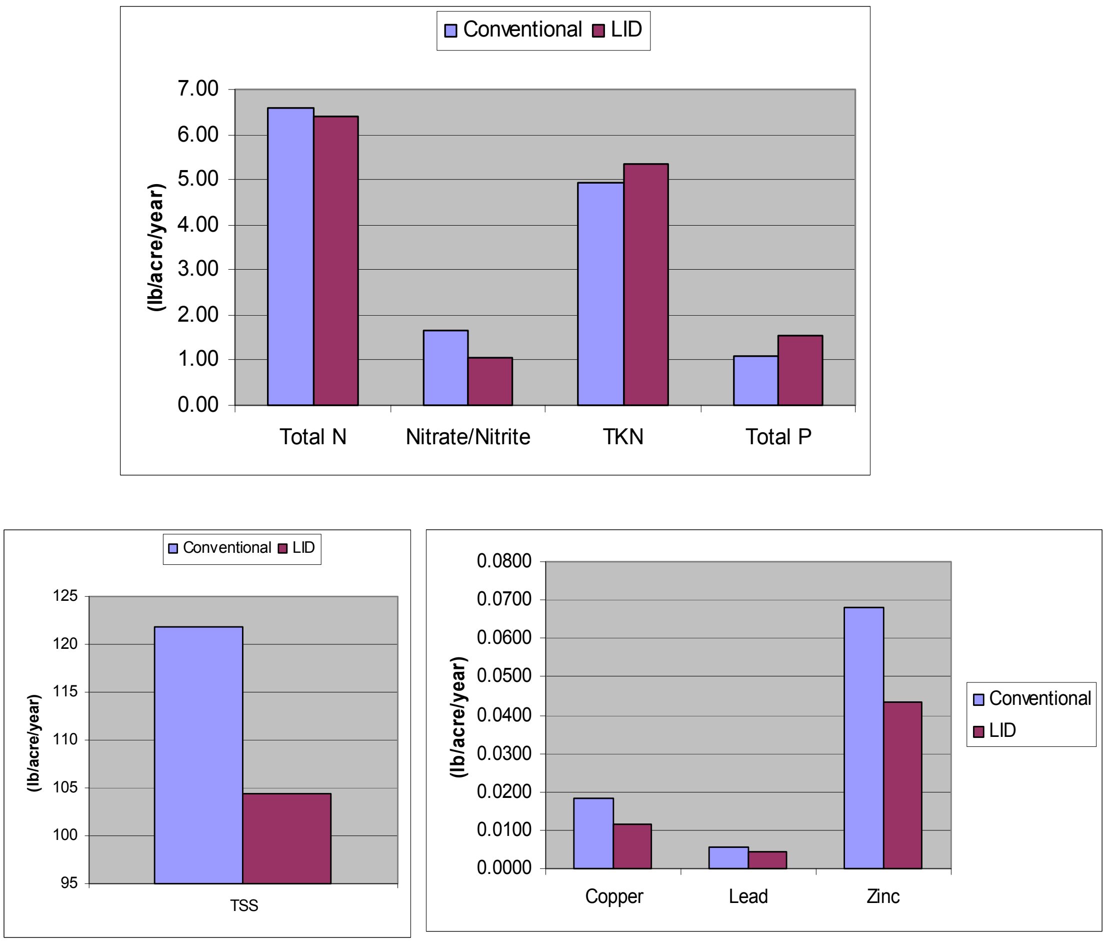

Figure 8. Comparison of Annual Pollutant Loadings between Two Sites.

SUMMARY AND CONCLUSIONS

Although the LID site did not utilize the typical and full-scaled LID approaches and was simply a first attempt of using non-conventional approaches to reduce stormwater flows, when compared to the conventional site, the LID site had considerably lower runoff volumes and event peak flow rates per unit area. The LID site also had fewer runoff producing events. Over the two years, percent of rainfall converted to runoff was 19% for the conventional site and 15% for the LID site. Accordingly, the average annual runoff volume per unit area was smaller at the LID site by 20%. Event runoff hydrographs started later in the LID site. The LID site showed a higher frequency of smaller flow rates (including no runoff events) while the conventional site showed a higher frequency of larger flow rates.

LID site also had a smaller peak flow per unit area. The ratio of the LID to Conventional peak flow per unit areas showed a general positive trend with event rainfall depth. Any peak flow rate or runoff volume saving of the LID practices seem to decrease as the event rainfall depth increases. The magnitude of the differences between the two sites did not appear to be affected by seasonal differences in rainfall intensity and infiltration rates. However, it is impacted by the time period between rainfall events.

The Total Nitrogen loading per unit area was similar at the two sites while the Total Phosphorus loadings were higher by about 40% at the LID site. The average annual loading per unit area for suspended sediment was lower at the LID site by 14.3%. For copper, lead, and zinc, the LID site had lower EMCs and annual loadings. The annual loadings per unit area were 36%, 21%, and 37% lower for Copper, Lead, and Zinc respectively at the LID site than the conventional site. This difference is a result of removal mechanisms in the grassed channels and/or bioretention areas. Another factor to remember is that the LID site is just recently completed and the site and soil conditions are still not stabilized yet. It is expected that, after the site is stabilized, the better water quality benefits will show-up.

It is beneficial to keep in mind that this monitoring period was a rather dry period when the annual rainfall was only about 84% of the long-term average for the first year, and 63% for the second year. Data from dry years may not be a good representative of normal or average years. Two other issues are also important to remember. For a drainage area as small as 10 acres, two-minute sampling time interval may not short enough for a conventional development site. One-minute time interval is more appropriate. To address the issue of consecutive storm events, more storage for the LID measures is recommended.

Finally, because the LID site was not developed according to today's LID sizing and design criteria, an EPA 319 grant was provided to the County to retrofit this residential development. When the project is completed, a better performance is expected.

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