JHA

FLOOD ASSESSMENT AND STORMWATER MANAGEMENT REPORT

Wee Hur Redfern Student Village, 13-23 Gibbons Street, Redfern, NSW 2016

REPORT FOR CITY OF SYDNEY COUNCIL AND NSW DEPARTMENT OF PLANNING & ENVIRONMENT

JHA

CONSULTING ENGINEERS

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1   EXECUTIVE SUMMARY

1.1   INTRODUCTION

JHA has been engaged by The Trust Company (Australia) Limited ATF WH Gibbons Trust to provide stormwater and drainage services, flood analysis and including preparing this report. This flood assessment and stormwater management report with attached stormwater concept plans form part of the submission of Development Application.

The proposed development is to construct a new student accommodation known as Wee Hur Redfern Student Village, located at 13-23 Gibbons Street, Redfern, NSW 2016. The site is identified as Lot SP60485 with an area of 1365 m2 (refer Survey and Strata Plan in Appendix B01). The existing site consists of a 4 to 5 Storey brick residential building with basement parking nearly covering the entire site. It is proposed the existing building will be demolished with the basement partly retained.

The adjacent site at the east of this development is a BP service station. Across Margaret Street to the south is a 3 to 5 storey residential flat building fronting Gibbons Street and a church building fronting Regent Street. At the west of the site across Gibbons Street is Gibbons Street Reserve. The adjacent site at the north is the former City of Sydney Council deport.

The approving authority for this development is City of Sydney Council and NSW Department of Planning & Environment. The proposed development is classified as State Significant Development as it has a project value of more than $10million. This stormwater report addresses the site stormwater and flood issues with reference to the following documents.

1) City of Sydney Council – Interim Floodplain Management Policy and Sydney Local Environmental Plan 2012 item 7.15 Flood planning.

2) Secretary's Environmental Assessment Requirements (SEARs Application Number SSD 9194 in Appendix B) item 14- Drainage and flooding.

Generally, this report intention is to determine that this development:

(a) is compatible with the flood hazard of the land, and

(b) is not likely to significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties, and

(c) incorporates appropriate measures to manage risk to life from flood, and

(d) is not likely to significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses, and

(e) is not likely to result in unsustainable social and economic costs to the community as a consequence of flooding.

Besides, this report also addresses the proposed stormwater quantity treatment (On-site Detention) and stormwater quality treatment (Water Sensitive Urban Design- WSUD).

This report together with attached certified stormwater concept plans and calculations are prepared by experience Chartered Professional Civil Engineer from JHA registered with NER.

1.2   LIMITATIONS OF THIS REPORT

This report only serves the purpose of what it was intended to address the stormwater, flood and drainage issues based on the information that is available at the time of preparing this report. This report is not intended for use as a scope of works for tender or other unrelated purposes. Data extracted from this report shall not be used for any construction work. This report may contain outdated drawings. Please refer to the relevant parties for their latest drawings.

2   THE ALEXANDRA CANAL CATCHMENT AND FLOOD CONDITIONS

The proposed development site is located within the Alexandra Canal catchment for which City of Sydney Council has conducted several flood studies as follows:

1)   Alexandra Canal Catchment Flood Study – Report Final, Project W4785 prepared by Cardno

2)   Alexandra Canal Floodplain Risk Management Study and Plan, Project W4948 prepared by Cardno

3)   11 Gibbons Street, Redfern Site Flood Assessment, prepared by WMA water Pty Ltd. This property is situated just north of this proposed development.

Stormwater management and flood assessment usually required us to examine the entire catchment which is much larger than the proposed development site area; with a focus on the site stormwater and drainage features. The Alexandra Canal catchment area is approximately 1,141 ha and includes the suburbs of Alexandria, Rosebery, Erskineville, Beaconsfield, Zetland, Waterloo, Redfern, Newtown, Eveleigh, Surry Hills and Moore Park. The majority of the catchment is fully developed (consist of housing, commercial and industrial) with some large open spaces. The trunk drainage system is mostly owned by Sydney Water Corporation, while the smaller feeding drainage systems owned by Councils. In this regard, Sydney Water has determined that this proposed development requires On-Site Detention (OSD) volume of 24 m3 and Permissible Site Discharge (PSD) of 48 l/s.

The extent of the flood study with the existing pits and pipe system is shown in Appendix A01 (an extract of Figure 4.3 from Alexandra Canal Flood Study). Wee Hur site is located near the upstream end of the Alexandra Catchment with Council's existing street drainage network of pits and pipes along Gibbons Street, Margaret Street and William Lane. The site elevation RL is between 20m to 30m as shown in Appendix A02.

During the major storm event 100 years ARI, the flood study results Appendix A03 indicate the site is not inundated. William lane at the northeast corner is flooded. Flood water is prevented to enter the premises due to the elevated courtyard at RL24.72 which is about 700mm higher than the street level of William Lane at approximately RL24.02 (Refer to Appendix B02 Survey drawing). Retaining wall was built across William Lane causing stormwater to be "tank" at this low point (Refer to photos at Appendix C04). There are two existing kerb lintel pits situated on both sides of William lane near the site's northeast corner with underground pipe sizes of 225mm diameter (Refer Appendix C04). The eastern kerb inlet pit diverts the trapped stormwater to a pit at Regent Street via underground pipe of 300mm diameter running eastward across the BP Station. The peak flood depth of this location shown in Appendix A04 is in the region 0.5m-0.69m (cyan colour). Due to the low velocity, this location is designated as Low Hazard as shown in Appendix A05.

During the extreme storm event of the probable maximum flood (PMF), the flood study results Appendix A06 indicate flood occur surrounding the buildings. The peak flood depth generally is in the region of 0.1m-0.3m (orange colour) as shown in Appendix A07. Gibbons Street, Margaret Street, William lane and part of the BP Station are inundated. Part of the retaining wall at the northeast corner has collapse (refer to photo at Appendix C05) and flood water could flow from William Lane into the compound of the BP Station. The flood water depth of the eastern kerb inlet pit could reach 0.7-0.99m. However due to the relatively low velocity of flow, the entire site is still designated as Low Hazard as shown in Appendix A08.

The NSW Floodplain Development Manual (2005) defines flood prone land to be one of the following 3 hydraulic categories:

a) **Floodway** – Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.

b) **Flood Storage** – Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10 percent.

c) **Flood Fringe** – Remaining area of flood prone land after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

The site is designated as flood fringe in the 100 years ARI event as shown in Appendix A09. During the PMF event, due to the relatively higher flow velocity of flood water on the street; Gibbons St, Margaret St and Willian Lane are designated as floodway (blue colour as shown in Appendix A10). As flood water have inundated the courtyard and part of the BP station compound; these areas are designated as flood storage (green colour).

The NSW Office of Environment and Heritage (formerly Department of Environment, Climate Change and Water (DECCW)) guideline, Practical Consideration of Climate Change (2007), provides advice for consideration of climate change in flood investigations. The guideline recommends sensitivity analysis is conducted for:

- Sea level rise – for low, medium, and high level impacts up to 0.9m

- Rainfall intensities – for 10%, 20%, and 30% increase in peak rainfall and storm volume

In the Alexandra report, models were run for 100 years ARI 90 minutes storm for the increased rainfall intensities of 10%, 20% and 30% with an elevated tailwater level of 2.9m AHD to Alexandra Canal. Appendix A11, A12 and A13 indicate the difference in peak water level compared to the base 100 years ARI 90 minutes event of rainfall increment of 10%, 20% and 30% respectively. For the 10% increment Appendix A11 indicates no rise in flood level. For the 20% (A12) and 30% (A13) increment indicates (pink region) an increase of 10mm to 20mm flood level. In this regard, with the appropriate adoption of the Council's policy of recommended 500mm freeboard above the flood level of 100 years ARI, climate change risk is deemed to be taken care of for this project.

3   THE PRE-DEVELOPMENT SITE AND FLOOD CONDITIONS

The existing site terrain generally slopes from north-west to southeast, refer to Appendix B02 (Survey drawings from LTS) and Appendix C. The existing site consists of a 5-storey brick building facing Gibbons Street, a 4-storey building facing Margaret Street, two 4-storey building facing the BP station and a paved courtyard at RL24.72 with 3 steps leading down to William Lane at the north. There is existing boundary fences (0.6m high brick wall with metal grille) at the boundary along the entire Gibbons Street, along Margaret St with an access driveway to underground car park and a retaining wall across William Lane. Existing building ground floor finished level is at approximately RL24.85, in which pedestrian generally required to walk up 6 concrete steps from the footpath level at approximately RL23.60 to enter the premises (Refer to Appendix C03).

Results derived from Alexandra Canal Flood study and Flood Assessment Report of 11 Gibbons Street (neighbour property situated at the north of this development) by WMA indicate that the existing building is not inundated during the Major Storm of 100 years ARI. From the Flood Assessment Report of 11 Gibbons Street, the flow along Gibbons Street is shallow with 150mm depth of water in the 1% AEP event and 200mm in the PMF event. The trapped low point of William lane could pond to a depth of 0.8m in the 1% AEP event. The dead end lane is drained via a 300mm underground pipe eastward toward Regent Street. When runoff exceeds the capacity of this pipe, stormwater ponds in William Lane until overflow via the compound of the BP Station toward Margaret Street (Refer Appendix C05). Given the depth of ponding, William Lane is considered as subject to "mainstream flooding". The 1% AEP Peak level (mAHD) of this low point of William Lane is estimated at RL24.82 from the report.

However, the flood level data derived from the above mentioned reports are insufficient to provide the determination of the design flood level for this development. As such, at a smaller scale flood analysis, focus on the site pre and post development condition was carried out with the similar modelling methodology and design procedure of those reports mentioned above. The Hec Ras Version 5.07 (Hydrologic Engineering Center – River Analysis System) has the 2D flood analysis capabilities and was used for flood analysis for this development. However, the previous flood study of Alexandra Canal utilized the SOBEK software. Similar to the previous flood study methodology, aerial laser scanning (ALS) ground levels surveyed in 2007 and 2008 was downloaded from NSW Government websites for this development area and encompassed all the upstream catchment areas. Generally, the accuracy of the ALS data is +/- 0.15m to one standard deviation on hard surfaces. We have also incorporated local survey data, particularly the existing kerb and gutter and footpath levels. We visit the site and took several photos to ensure the data correlate to the terrain on the ground.

Direct rainfall method was used similar to the report's modelling methodology. The critical duration of the major storm (100 years ARI) and PMF were taken from the reports as follows:

Average Recurrence Interval	Critical Durations
1 year to 100 year	60 to 180 minutes
PMF	15 to 45 minutes

Rainfall data for the 100 years ARI corresponding to various critical durations we generated from DRAINS software database (in mm/hr) and converted to format mm per 5 minutes as precipitation. As the upstream terrain is generally fully developed and we take a conservative approach of zero loss to infiltration and interception. For the PMF rainfall, we adopt the GSDM (Generalized Short-Duration Method) PMP estimation method based on Commonwealth Bureau of Meteorology guidebook "The Estimation of Probable Maximum Precipitation in Australia: Generalized Short-Duration Method). Due to the relatively small size of the site compare to the Alexandra Canal catchment, we adopt the point values which is very conservative. It is expected the flood analysis results for PMF will be more severe than values from the previous flood study's results.

The 2D flow areas consist of 20,520 cells cover the site area from Margaret St (lowest boundary) to Lawson St (highest boundary) as shown in Appendix D01. HEC RAS takes a very different approach from other software in 2D flow area

modelling. The cells can have 3, 4, and 5 up to 8 sides. Each cell is not a simple plane, but a detailed elevation and volume / area relationship that represents the details of the underlying terrain. Each cell face is a detailed cross section, which get processed into detailed elevation versus area, wetted perimeter and roughness. This approached allows the modeller to use larger cell size and still accurately represent the underlying terrain. As such, Hec Ras will "figure out" where the boundary of the catchment automatically during the direct rainfall analysis without the manual delineation that could be inaccurate.

Appendix D02 shows the contours of the ALS terrain at intervals of 0.2m; in which the North-West corner of the site at RL24.80 matching the ground level survey at the footpath at RL24.79 as shown in Appendix B02. The trapped low point at the Northeast corner of the site, with contour of 24.20 also matching the survey data.

Appendix D03, D04 and D05 show the results of maximum flood depth for the 100 Years ARI for the critical durations of 60min, 90min and 120min respectively. The highest flood depth is found to be 0.840m at the William Lane lowest point during the 100Y 90min duration storm which is consistent with the Alexandra Canal Flood Analysis results. Appendix D06, D07 and D08 show the results of the maximum flood water surface elevation for the 100 Years ARI for the critical durations of 60, 90 and 120 minutes. The highest flood surface level at the William Lane low point is found to be RL24.89 for the 100 Years ARI for the 90 minutes critical duration. This result is just 70mm higher than the results obtained by another consultant using a different software. The small increase in flood levels could be due to the following assumptions or methodology that may differ from the previous flood study:

i)   Existing pits and pipe are assumed to be fully blocked

ii)   No allowance for soil infiltration losses as the upstream catchment is fully developed.

In this regard, we are confident that the Hec Ras model is calibrated to match the results of those Flood Analysis that were formally accepted and approved by Council.

4 THE POST-DEVELOPMENT SITE AND FLOOD CONDITIONS

4.1 FLOOD ANALYSIS RESULTS

The proposed development is a tower of 18 storey high buildings with the roof, reaching RL85.75 (refer to Appendix E01). Appendix E02 shows the Architectural layout of the basement, ground floor and mezzanine floor. At the ground floor along the eastern boundary, there is a proposed public domain laneway that serves as a pass-thru for pedestrian and occasionally for vehicles. Between the proposed laneway and the building is a landscaped area with a gentle slope. The proposed laneway has a minimum clear width of approximately 4.72m between the eastern boundary and the landscaped area. The proposed laneway design contours are shown in Appendix J04 (Drawing C201).

The laneway is designed to provide access to the Substation room at FFL24.44 (with a 150mm step down to about RL24.29). As such, the laneway is designed to slope up gradually from William lane at the northern boundary with levels ranging from RL24.01 to RL24.14. The proposed laneway profile will have a crown near the entrance to the Substation and gradually slope down to Margaret St at the south boundary. At the North-East corner, there is an existing brick building with a 3m wall (3.5m high) along the eastern boundary effectively creates a trap low point. During the major storm event when the existing pits and pipes capacities are exceeded, the trap flood water will well up to the crown of the laneway before able to escape. Therefore it is necessary to create an escape route for flood water. We proposed an 800mm width concrete drain along the eastern boundary with a 200mm concrete kerb along the laneway. The concrete drain base is a straight profile of about 2% slope allow flood water to flow fast, providing an efficient escape route. The flood drain discharge stormwater into a 900x900 collection pit with a weir wall at top RL23.455. During the very frequent storm such as monthly storm, the runoff will be diverted to the Filterra tree/shrub pit for quality treatment. For larger storm event, runoff will overtop the weir inside the Filterra tree pit at RL23.095 and enter the OSD tank for quantity treatment. As the invert of orifice 150mm diameter is at IL 22.988, the outflow of the stormwater will be control within the PSD by the orifice. In the 1 in 100 years or extreme storm event, the flood water will overflow the weir and spread out onto Margaret Street.

The post development terrain of the site is modelled using 12D Model software and imported into HecRAS. HecRAS GIS tools (Ras Mapper) is capable to merge the site terrain into the ALS catchment terrain. Flood analysis was carried out with the same methodology and rainfall data as mentioned above within the same predevelopment model. Appendix F01 shows the contours of the post development terrain at 100mm interval.

During the major storm event of the 100 years ARI, the maximum depth of the flood at the low point of William Street is reduced from 0.835m to 0.411m for the 60min duration (refer Appendix F02), reduced to 0.417m for the 90min duration (Appendix F03) and reduced to 0.411 for the 120min duration (Appendix F04). The flood surface elevation is at RL24.424m for the 60min duration (refer Appendix F05), RL24.430 for the 90min duration (Appendix F06) and RL24.411 for the 120min duration (Appendix F07). Similarly, the maximum velocity for the same point at the laneway is found to be 0.758m/s for the 60min duration (Appendix F08), 0.821m/s for the 90min duration (Appendix F09) and 0.768m/s for the 120min duration (Appendix F10).

Since the 100 Years ARI 90min duration is found to be the critical storm event, profile of the flood surface water elevation is plotted along Gibbons St, Margaret St and William St with their layout as shown in Appendix F11. The corresponding profiles are plotted as shown in Appendix F12, F13 and F14 respectively. As shown in Appendix 12, the profile of flood water along Gibbons St has an average depth of 250mm at the north and gradually reduced to 150mm at the south. The profile of flood water along William lane as shown in Appendix F14 shows that the flood depth is 100mm at the north, gradually increase to a depth of 180mm at the south. The depth did not exceed the safe limit of 0.3m for the major storm. The velocity x safe depth is calculated as 0.821x0.18=0.15 which did not exceed the safe limit of 0.4 for the major storm. The profile of Margaret St of Appendix F13 shows the hydraulic jump at the confluence of the two flood stream resulting an abrupt increase of flood depth from 100mm to 180mm as expected.

During the 15min duration PMF storm event (refer Appendix G01), the maximum depth for the flood at the low point at the William Street increase to 0.858m. The flood surface water elevation is at RL24.490 as shown in Appendix G02. The maximum velocity reached 1.082 m/s at the same spot as shown in Appendix G03.

During the 30min duration PMF storm event (refer Appendix G04), the maximum depth for flood at the low point at the William Street increase to 1.069m. The flood surface water elevation is at RL25.137 as shown in Appendix G05. The maximum velocity reached 1.580 m/s at the same spot as shown in Appendix G06. As this is the critical PMF storm, both the depth and (velocity x depth) have exceeded the safe limits of a major storm. These situations are also consistent with the previous flood study that during PMF event, the road and the site are designated as floodway and flood storage respectively.

During the 45min duration PMF storm event (refer Appendix G07), the maximum depth for flood at the low point at the William Street increase to 1.075m. The flood surface water elevation is at RL25.132 as shown in Appendix G08. The maximum velocity reached 1.604 m/s at the same spot as shown in Appendix G09.

4.2 FLOOD PLANNING LEVELS

City of Sydney Council has a responsibility to manage flood affected properties to ensure that:

- Any new development will not experience undue flood risk; and

- Any existing development (neighbourhood) will not be adversely flood affected through increased damage or hazard as a result of the proposed new development.

The previous chapter flood analysis demonstrated that the proposed new development did not increase flood level or increase flood risk compared to its pre-development situations. In fact, flood level is reduced as much as 400mm due to the proposed removal of the "tanking" existing retaining wall at the northern William Lane and convert into a pass-thru public domain laneway. Due to such improvement, during the 100 years ARI flood situation of the post-development site, we could classify the Gibbons Street as "outside floodplain" and the Public Domain laneway at "local drainage flooding". However, these may be subject to the discretion of the local Authorities.

Nevertheless, the development shall comply with the floor level requirements as specified in the "City of Sydney Interim Floodplain Management Policy" as show in Appendix H01 and H02 (chapter 5-Flood Planning Levels). A flood planning level refers to the permissible minimum building floor levels. Below-ground basement/parking shall refer to the minimum level at each access point such as staircase, elevator or vehicle entrance.

We proposed the Flood planning levels (FPL) as shown below (Refer Appendix H03). The proposed floor planning levels are conservative in which we are proposing 500mm freeboard of the habitable areas above flooding from Gibbons Street (classified outside floodplain); 150mm freeboard for business areas and 50mm freeboard for non-habitable areas.

Appendix H03

PROPOSED MINIMUM FLOOD PLANNING LEVELS TO COUNCIL REQUIREMENTS

Item	GroundFloor Rooms / Entry Point	1% AEP Flood Surface Levels (m)	Classification	Freeboard (mm)	Minimum	Proposed FPL	Comment
1	Chamber Substation	24.35	Local Drainage	50	24.40	24.44	Meet requirement above flood level
2	Bike Repair/Storage	24.25	Local Drainage	50	24.30	24.36	Meet requirement above flood level
3	Fire Pumps/Control,Water Meter	24.35	Local Drainage	50	24.40	25.05	Meet requirement above flood level
4	Communal Kitchen	24.10	Local Drainage	500	24.60	24.70	Meet requirement above flood level
5	Lounge	23.95	Local Drainage	500	24.45	24.70	Meet requirement above flood level
6	Retail Unit	24.90	Outside Floodplain	150	25.05	25.11	Commercial Requirement
7	Office, Meeting and Manager	24.55	Outside Floodplain	500	25.05	25.05	Residential Requirement
8	Reception and Counsel	24.54	Outside Floodplain	500	25.04	25.05	Residential Requirement
9	Common Area	24.52	Outside Floodplain	500	25.02	25.05	Residential Requirement
10	Games Area	24.50	Outside Floodplain	500	25.00	25.05	Residential Requirement

5   STORMWATER DESIGN

5.1   STORMWATER QUANTITY TREATMENT

Sydney Water Corporation calculated the required Site Storage Requirement at 24m3 and Permissible Site Discharge at 48 litre/sec. A snapshot of Sydney Water email of SSR and PSD and the orifice calculation is shown in Appendix I01. The on-site detention tank (OSD) is situated approximately at the southeast corner of the building. The OSD tank layout is shown in drawing C202 (Appendix J05), C203 (Appendix J06) and cross-sections at C204 (Appendix J07). The shape of the OSD tank is rectangular with internal length 7.25m, width 4.7m and depth 2.75m. The bottom part of the tank with the twin submersible pumps and 40 m3 storage volume is used for irrigation. Above this compartment is the 26m3 OSD volume, which is more than the SSR of 24m3. The orifice is calculated to be 150mm diameter, which allow stormwater discharge at a maximum rate of 41.1 l/s (less than 48). The invert of the orifice is at RL 22.988m and top water level is at RL 23.83. The outlet UPVC pipe is 225mm diameter with invert level IL 22.95. The discharge from the OSD will be drained to a 900x600 overflow pit and eventually discharged into the existing Kerb Inlet Pit at Margaret Street. The longitudinal section of this drainage pits and pipes are shown in drawing C204 (Appendix J07).

The stormwater catchment areas are generally subdivided into 3 parts as shown in drawing C201 (Appendix J04). The first catchment (green colour) with an area of 330m2 consists of the public domain laneway and the landscaped batters. The second catchment (orange colour) with an area of 998m2 consists of the building roof and hardstand areas. The remainder catchment area of 37m2 will be the by-pass area. As shown in drawing C202 (Appendix J05), the first catchment runoff will be collected by the proposed trench drain and Filterra tree pit. The second catchment runoff mainly from the roof, will drain into the Filterra garden. During the minor storm event, stormwater runoff will undergo quality treatment and collected into the irrigation chamber of the OSD tank. During the major storm event, the first-flush component of the stormwater runoff is expected to fill up the irrigation chamber of the OSD tank. Subsequent stormwater runoff will be collected by the overflow chambers of the Filterra devices and drained into the OSD chamber. The 150mm diameter orifice will allow stormwater to flow out in a controlled manner without exceeding the PSD of 48 litre/sec.

The proposed floor FFL 24.70 is 870mm above the invert of the 300mm diameter overflow pipe (IL 23.38) as shown in Appendix J07; providing an airspace volume of 19m3. In the event of extreme storm greater than the 100 years ARI, the stormwater is expected to overflow from the "overflow pipe" and discharge out to Margaret Street safely without upwelling into the building's interior. Similarly, the flood water from the overland of this site will discharge directly toward Margaret Street, without draining into the OSD tank due to its relatively higher location.

5.2 STORMWATER QUALITY TREATMENT

We refer to the City of Sydney WSUD Technical Guidelines Oct 2014 for the design and MUSIC modelling (Model for Urban Stormwater Improvement Conceptualisation) for the stormwater quality treatment of this development. Based on Figure 1: "City of Sydney soils, with roads and suburb boundaries", the site is found to possess soil in category Tuggerah (code tg); the Aeolian soil with deep podzols on dunes and Humus Podzol intergrades on swales. Soil of this type is found to be suitable for infiltration. The soil type of "sandy soil" is selected for the MUSIC model.

Acid sulphate soils (ASS) must be taken into consideration in designing for stormwater quality treatment. The ASS mapping for City of Sydney is shown in Figure 2 of the Technical Guidelines. The site is found to be classified as Class 5 area that may be appropriate for infiltration.

In this project, we propose to use the Filterra bio-retention system (a product from Ocean Protect) for the stormwater quality treatment to satisfy the WSUD (Water Sensitive Urban Design) requirements. Filterra is a bioretention system in a concrete box. Contaminated stormwater runoff enters the filter box through the pit inlet or pipe spreading over the 75 mm layer of mulch on the surface of the filter media. As the water passes through the mulch layer, most of the larger sediment particles and pollutant are removed through sedimentation and chemical reactions with the organic material in the mulch.

Water passes through the soil media where the finer particles are removed, and other chemical reactions take place to immobilize and capture pollutants in the soil media. The cleansed water passes into an underdrain and flows to a pipe system or other appropriate discharge point such as a collection pit.

Once the pollutants are in the soil, the bacteria begin to break down and metabolize the materials and the plants begin to uptake and metabolize the pollutants. Some pollutants such as heavy metals, which are chemically bound to organic particles in the mulch, are released over time as the organic matter decomposes to release the metals to the feeder roots of the plants and the cells of the bacteria in the soil where they remain and are recycled.

Comparing to the standard bioretention cells, such as Raingarden, the Filterra garden typically required a much smaller footprint. Filterra filter media has been optimised to operate under high flow rates while maintaining high pollutant removal performance. They are simple to maintain and no specialist equipment is required.

Above ground, the system's plant species add aesthetics and value to the urban landscape, and are chosen for their aesthetic, functional and biodiversity-enhancing properties. While underground processes are at work effectively removing key pollutants such as Total Suspended Solids, Phosphorus, Nitrogen, Metals, Oil and Grease. They are designed to treat over 90% of the total annual runoff.

Appendix K provides the Filterra system brochure (6 pages). Appendix L (126 pages) provides a study to quantify the water treatment capabilities of a Filterra device by the North Carolina Department of Environmental and Natural Resources. Appendix M (13 pages) provides a peer review report in relation to the applicability of Filterra Bioretention System by the Western Sydney University, Sydney, Australia.

The public domain laneway is designed to serve several stormwater features. Along the eastern boundary there is an 800mm width overland by-pass drain. During the major storm event, flood water is allowed to flow out and spread to Margaret Street without the "tanking effect" during the pre-development stage cause by the existing retaining wall. During the minor storm event or the first-flush of the major storm event, stormwater runoff will be collected by the trench drain and diverted toward the Filterra tree pit for WSUD treatment. The roof and hardstand catchment runoff is collected and treated by the Filterra Garden as shown in C203 (Appendix J06).

City of Sydney Council provides the MUSIC link as a template for this WSUD design. Parameters for the storm event and pollutants data are prefilled within the template. Our designed MUSIC model is relatively straight forward and simple. The model with the treatment trains and the results are as shown below:

Percentage load reduction for the gross pollutant, total nitrogen, total phosphorus and total suspended solids are calculated and found to be compliant with City of Sydney requirements as shown above. The electronic version of MUSIC model shall be submitted together with this report for the City of Sydney Council approval.

5.3   STORMWATER MAINTENANCE SCHEDULE

Stormwater device requires maintenance to ensure they function as expected. The Filterra Bioretention system is usually package as a Plug and Play system. As such the installation and maintenance will be by the local supplier Ocean Protect.

The approximate schedule of stormwater maintenance is shown in Appendix N01. Maintenance and replacement of mulch and filter medium shall be carried out in accordance to the manufacturer's specification. The plants for the Filterra system are generally low maintenance with require no fertilizer or frequent watering. In the event of drought, temporary irrigation may be necessary.

6   DISCUSSION AND CONCLUSION

The flood studies done by other consultants such as Cardno and WMA provide preliminary information on the flood situation of the site. The site is classified as flood fringe and low hazard for the 1 % AEP storm event. The flood assessment of the neighbouring Northern properties indicates that during the 1% AEP storm event, the flood flow along Gibbons street is classified as "outside floodplain" and the flood flow along William Lane is classified as "mainstream" due to the depth of accumulated flood water from the retaining wall. However, the proposed development will remove the wall and replace with a pass-thru public domain laneway, allowing flood water to flow freely south toward the Margaret Street. We have analysed the flood situation using Hec Ras Version 5.07 and downloaded similar terrain data from NSW government websites. Results of predevelopment tally with previous flood study and hence calibrated.

The post development flood situation on William Lane is mitigated and depth of flood reduced by about 400mm. We could consider the 150-200mm depth flood flow along the laneway as "local drainage". The proposed flood planning is tabulated in the previous chapter, which compliance with the Authorities requirements. Due to the Architectural requirement that some of the floor slabs are in one piece without set-down, the proposed RL are set in accordance to the highest part of the slab. As such, the proposed flood planning levels are safe and compliant.

The site drainage and stormwater treatment system are also addressed in this report. The quantity treatment is via an on-site detention tank of volume 24m3 as calculated by Sydney Water. The tank is situated partly underneath the ground floor with the orifice control and overflow pipe. The quality treatment (WSUD) is via a Filterra Tree pit and a Filterra Garden. Together these treatment train as modelled using MUSIC are able to meet the stormwater pollution target stipulated by the City of Sydney Council. The MUSIC link model is included in this submission.

7   APPENDICES

WEE HUR SITE

Legend:
- Study Area
- Alexandra Canal
- Open Channel
- Surveyed Pipes
- Surveyed Pits

kilometres

0   0.5   1

ALEXANDRA CANAL CATCHMENT FLOOD STUDY

Final

Cardno

W4785

Figure 4.3

1D Network

LEGEND -
ELEVATION (m AHD)

■	<0.0m
■	1.5m
■	3.0m
■	4.5m
■	6.0m
■	10.0m
■	20.0m
■	30.0m
■	40.0m
■	50.0m
■	>60.0m

WEE HUR SITE

★Macconaldtown

★Erskineville

★Green Square

0   0.5   1
kilometres

ALEXANDRA CANAL CATCHMENT FLOOD STUDY

Final

Figure 4.6

2D Elevation Grid

WEE HUR SITE

Darcy St

Archur Street

Bourke St

Cleveland St

Buckland St

Hospital St

Bourke St

Pitt St

Phillip St

Wellington Street

Young St

Denks Street

Windmill St

Botany Rd

Larkier St

Mervon St

O'Dea Av

Prince St

Ashton Av

Newton St

★Macdonaldtown

Lawson St

St Marys St

Pemerville Rd

Errendale

★Erskineville

Park Street

Goodsland St

Belmont St

Union St

Victoria St

Ashmore St

Macdonald St

Bourton St

Botany Rd

Epsom Rd

Link Rd

Furton Rd

★Green Square

Gordon St

Sydney Park Rd

Mackey St

Huntley St

Euston Rd

Dapoy St

Bank St

Collins St

Bowden Street

Bowden St

Defreney Ave

Morley Ave

Bowden Rd

Hayes Road

Hordern Parade

Ricke y St

Tweedmouth Avenue

Gardeners Rd

Study Area

100yr ARI Flood Extents

Note: Results filtered to show areas where depth >=0.15m or velocity-depth product >=0.1m2/s (as described in Section 6.1).

0   0.5   1

kilometres

Figure 6.6

Cardno

ALEXANDRA CANAL CATCHMENT FLOOD STUDY

Flood Extents - 100yr ARI

W4785

Final
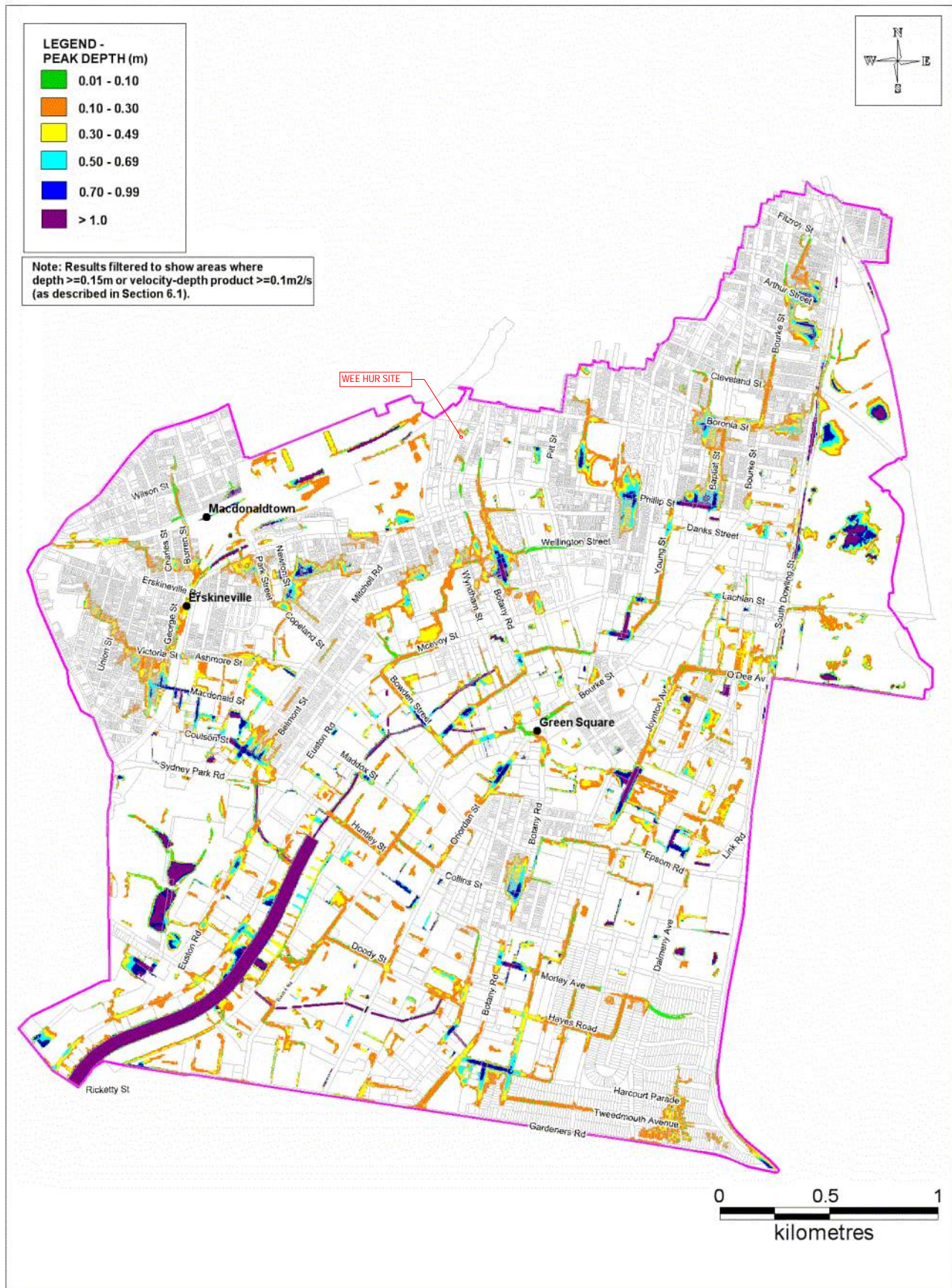
Figure 2-2   100 Year ARI Peak Flood Depths
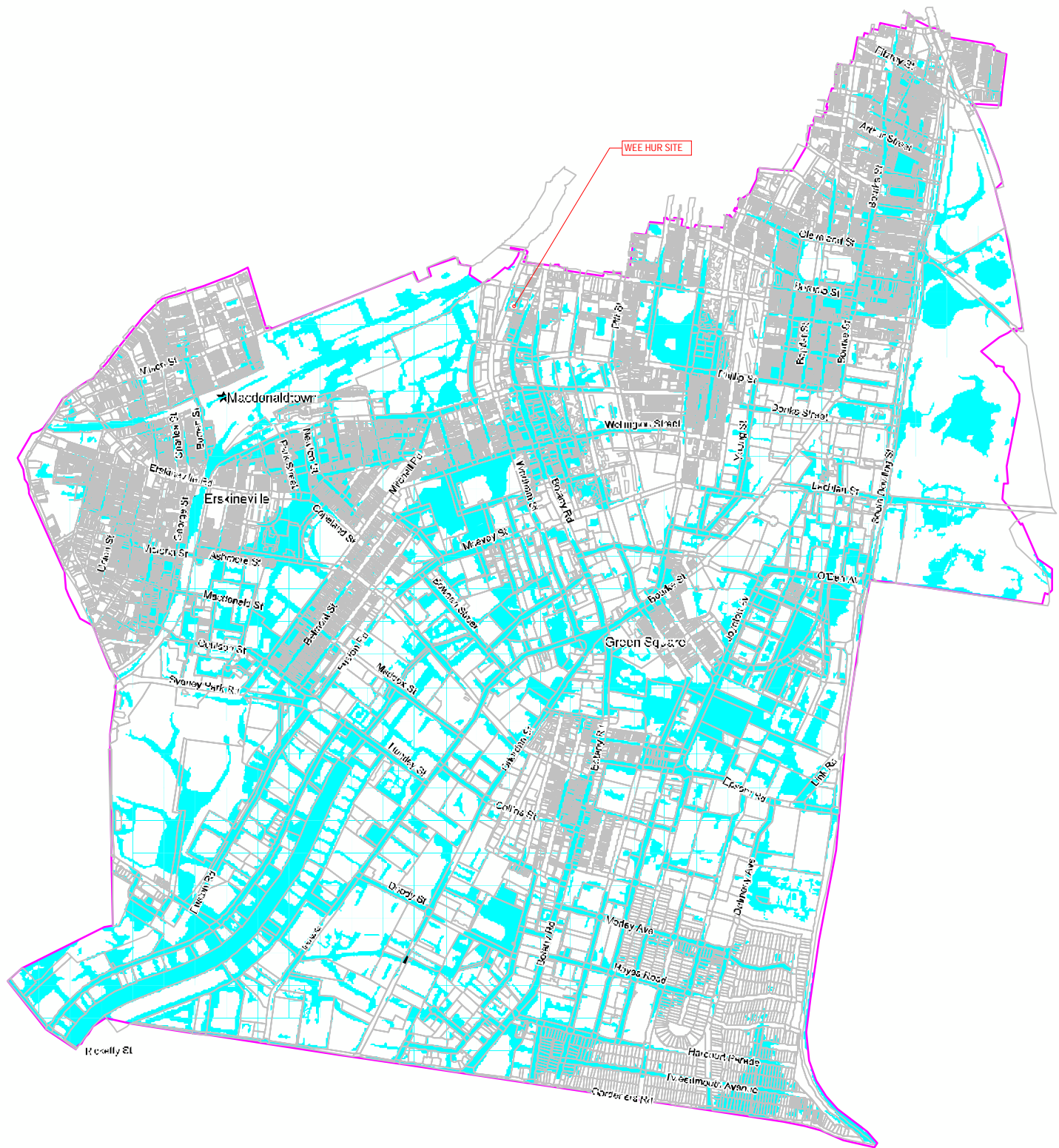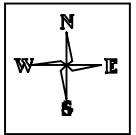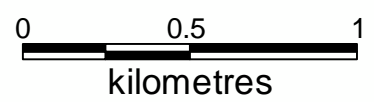
Figure 2-4   100 Year ARI Flood Hazard

ALEXANDRA CANAL CATCHMENT FLOOD STUDY

Figure 6.7

Flood Extents - PMF

Final
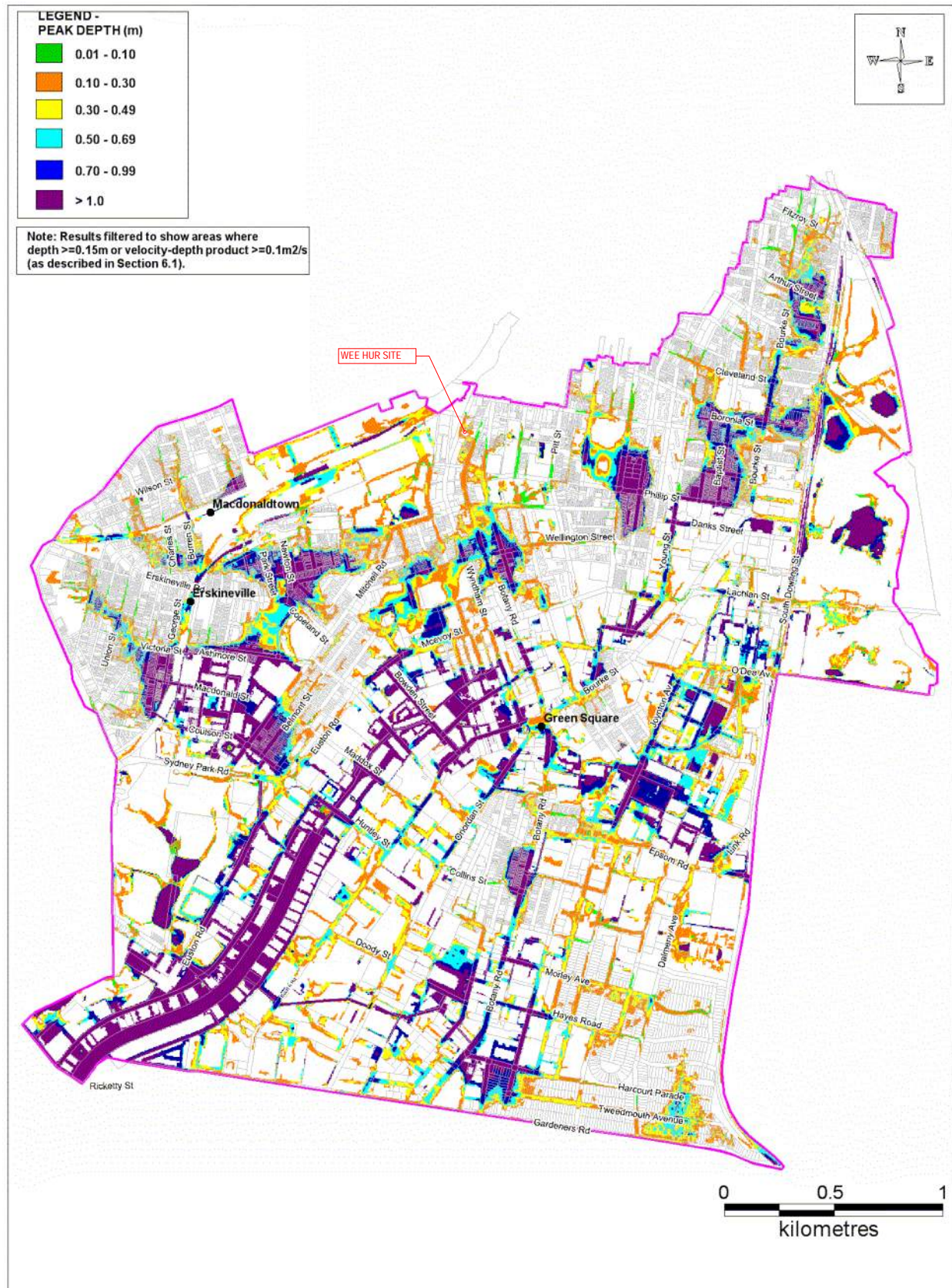
Figure 2-3   PMF Peak Flood Depths
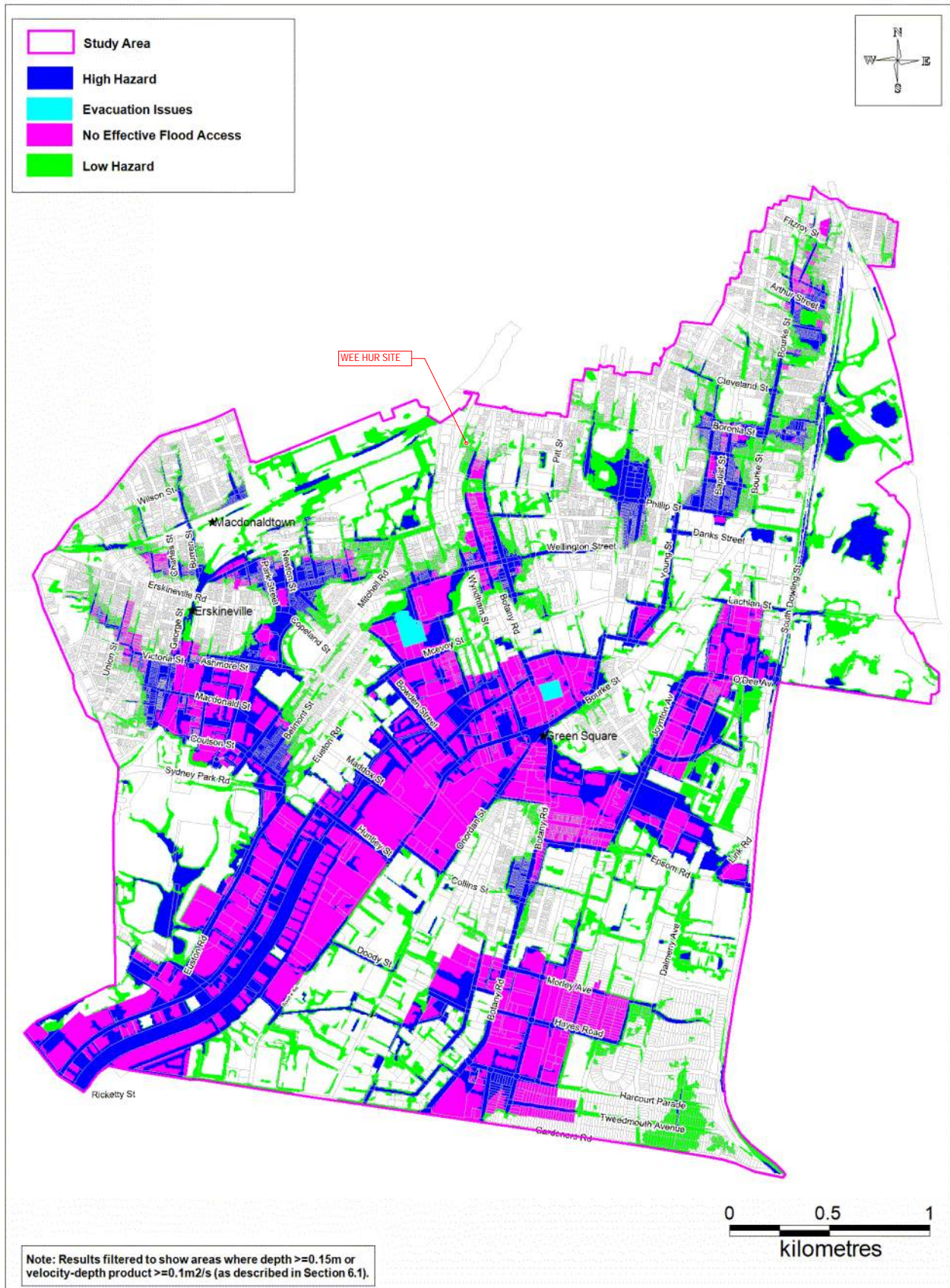
Figure 2-5   PMF Flood Hazard
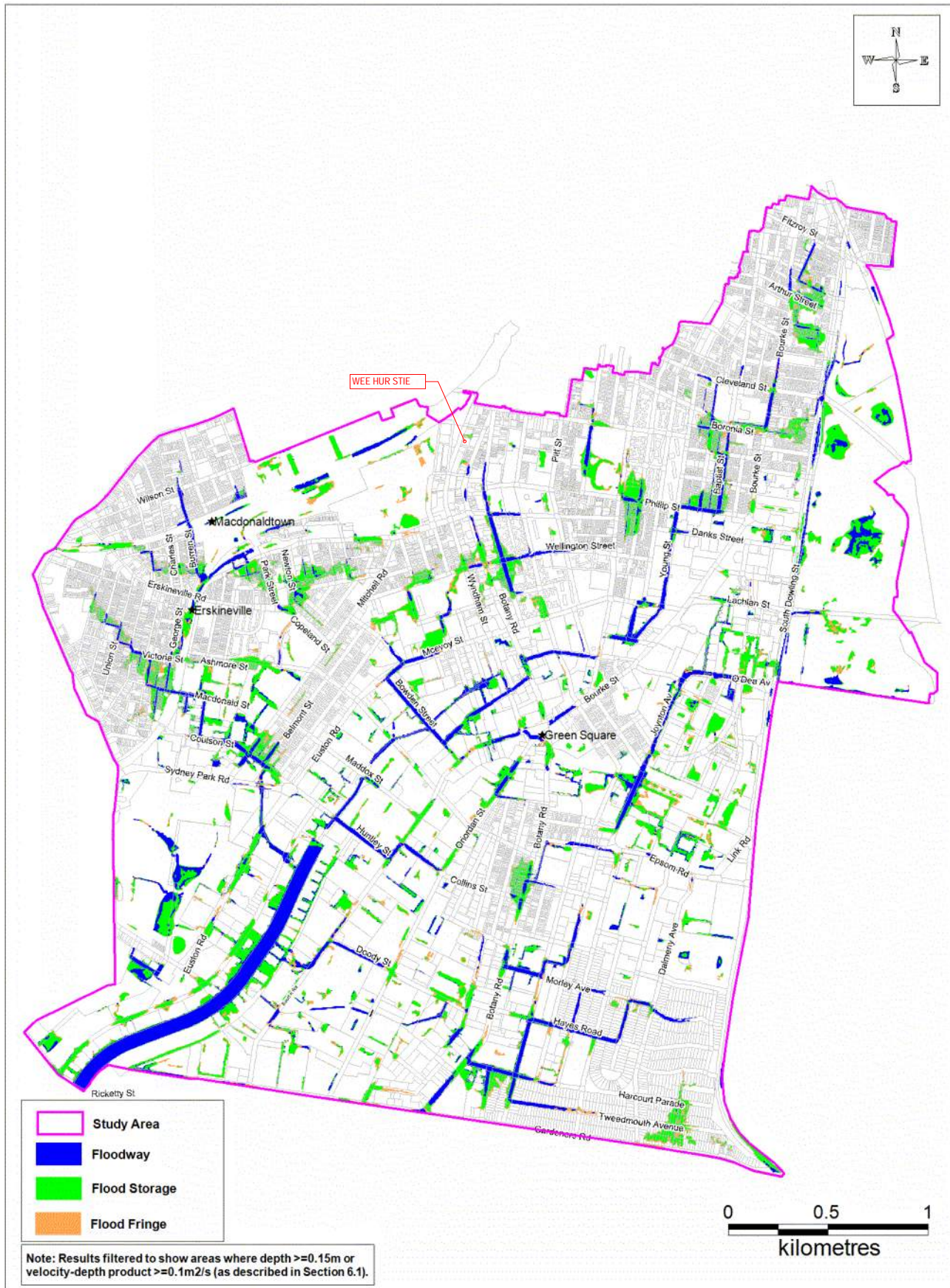
Figure 5-12 Hydraulic Categories – 100 Year ARI

WEE HUR SITE

Legend:
- Study Area
- Floodway
- Flood Storage
- Flood Fringe

Note: Results filtered to show areas where depth >=0.15m or
velocity-depth product >=0.1m2/s (as described in Section 6.1).

0   0.5   1
kilometres
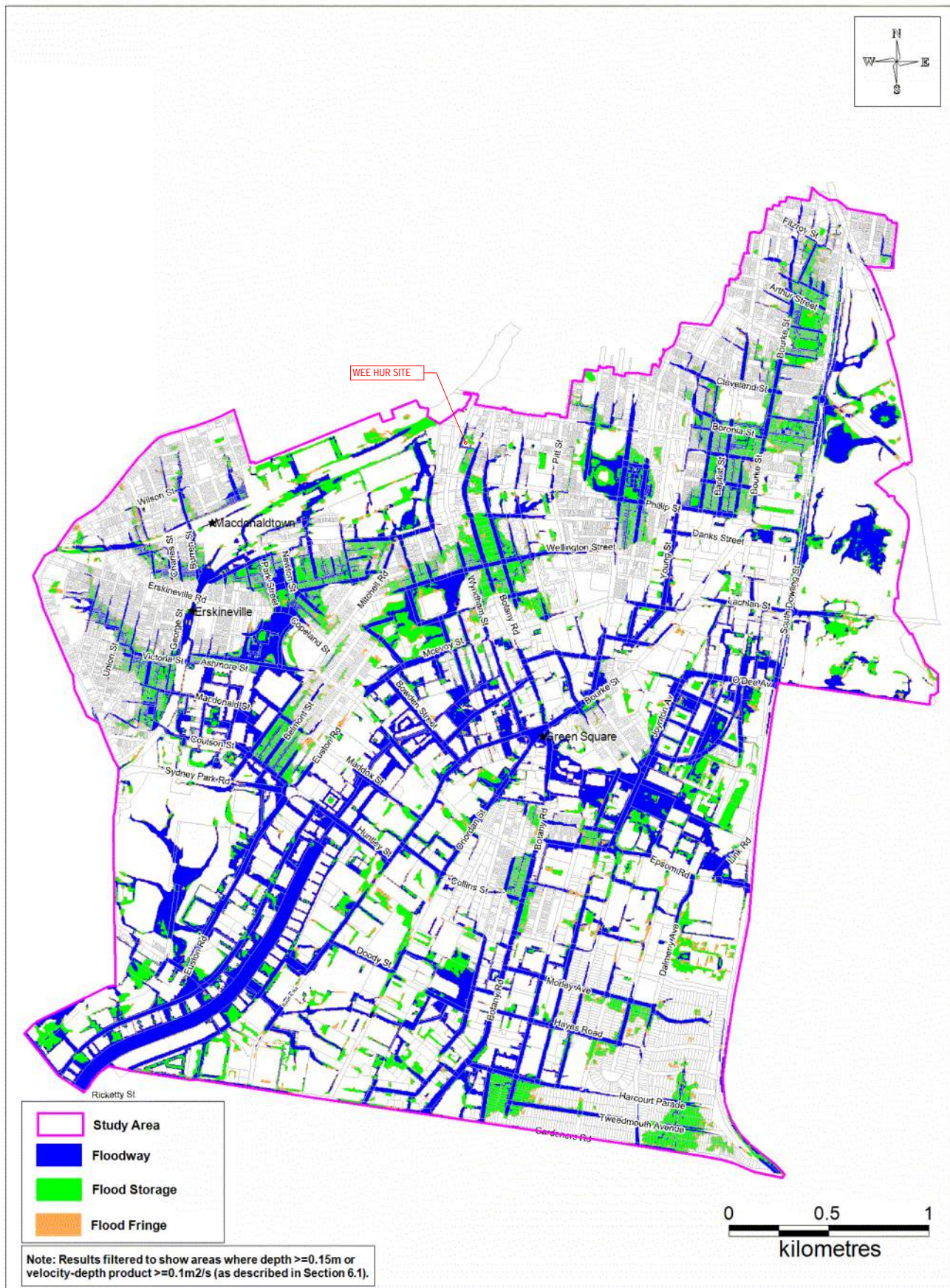
Figure 5-11 Hydraulic Categories – PMF

LEGEND - PEAK WATER LEVEL DIFFERENCE (m)

- -0.50m
- -0.10 to -0.49m
- -0.03 to -0.09m
- -0.01 to -0.02m
- 0.0m
- 0.01 to 0.02m
- 0.03 to 0.09m
- 0.10 to 0.49m
- 0.50m

kilometres
0   0.5   1

Cardno

W4785

ALEXANDRA CANAL CATCHMENT FLOOD STUDY

Final

Figure 8.1

Climate Change
100yr ARI Rainfall Plus 10%

LEGEND - PEAK WATER LEVEL DIFFERENCE (m)

- -0.50m
- -0.10 to -0.49m
- -0.03 to -0.09m
- -0.01 to -0.02m
- 0.0m
- 0.01 to 0.02m
- 0.03 to 0.09m
- 0.10 to 0.49m
- 0.50m

0   0.5   1
kilometres

Cardno

W4785

ALEXANDRA CANAL CATCHMENT FLOOD STUDY

Final

Figure 8.2

**Climate Change
100yr ARI Rainfall Plus 20%**

LEGEND - PEAK WATER LEVEL DIFFERENCE (m)

- -0.50m
- -0.10 to -0.49m
- -0.03 to -0.09m
- -0.01 to -0.02m
- 0.0m
- 0.01 to 0.02m
- 0.03 to 0.09m
- 0.10 to 0.49m
- 0.50m

0   0.5   1

kilometres

ALEXANDRA CANAL CATCHMENT FLOOD STUDY

Final

Figure 8.3

Climate Change
100yr ARI Rainfall Plus 30%

LEGEND

BENCH MARK	▲
TELSTRA PIT	▭ TEL
ELECTRIC LIGHT POLE	◑ ELP
POWER POLE	● PP
PIT WITH METAL LID	▫ MLID
STREET SIGN	⊠ SS
BOLLARD	○ BOL
GRATED INLET PIT	⊞ GIP
SEWER VENT	☻ SEV
SEWER MANHOLE	○ SMH
HYDRANT	◧ HYD
GAS VALVE	⊠ GAS
VEHICLE CROSSING	(VC)
PRAM CROSSING	(PC)
WINDOW	W
DOOR	D
HEAD/SILL	H/S
GAS (DBYD)	—— G ——
TELSTRA (DBYD)	—— T ——
OPTICAL FIBRE (DBYD)	—— OF ——
WATER (DBYD)	—— W ——
STORMWATER (DBYD)	—— SW ——
SEWER (DBYD)	—— S ——
ELECTRICITY (OVERHEAD)	—— P ——
ELECTRICITY (U'GROUND) (DBYD)	—— E ——
ELECTRICITY (HIGH VOLTAGE) (DBYD)	—— HV ——

NOTES

1. THE BOUNDARIES HAVE NOT BEEN MARKED
2. ALL AREAS AND DIMENSIONS HAVE BEEN COMPILED FROM PLANS MADE AVAILABLE BY NSW LAND REGISTRY SERVICES AND ARE SUBJECT TO FINAL SURVEY
3. ORIGIN OF LEVELS ON A.H.D. IS TAKEN FROM BM IN KERB FROM LINKER SURVEY R.L. 24.35 (A.H.D.) IN PLAN REFERENCE 170638
4. CONTOUR INTERVAL 0.2 m
5. CONTOURS ARE INDICATIVE ONLY. ONLY SPOT LEVELS SHOULD BE USED FOR CALCULATIONS OF QUANTITIES WITH CAUTION
6. KERB LEVELS ARE TO THE TOP OF KERB UNLESS SHOWN OTHERWISE
7. FLOOR LEVELS SHOWN ARE THRESHOLD LEVELS. NO INVESTIGATION OF INTERNAL FLOOR LEVELS HAS BEEN UNDERTAKEN
8. NO INVESTIGATION OF UNDERGROUND SERVICES HAS BEEN MADE. SERVICES HAVE BEEN PLOTTED FROM RELEVANT AUTHORITIES INFORMATION AND HAVE NOT BEEN SURVEYED. ALL RELEVANT AUTHORITIES SHOULD BE NOTIFIED PRIOR TO ANY EXCAVATION ON OR NEAR THE SITE
9. 8/.4/.7 DENOTES TREE SPREAD OF 8m, TRUNK DIAMETER OF 0.4m & APPROX HEIGHT OF 7m
10. BEARINGS SHOWN ARE MGA (MAP GRID OF AUSTRALIA) ADD APPROX. 1°00' FOR TRUE NORTH
11. BUILDING OUTLINE DATA USED FROM LINKER SURVEY PLAN REFERENCE 170638

EASEMENTS

(A) EASEMENT TO DRAIN WATER 1.73 WIDE (VIDE DP522349)

MGA

TN

'GIBBONS STREET RESERVE'

ROSEHILL

STREET

PARAPET RL51.48
T/O GUTTER RL49.55
RIDGE RL51.48
PARAPET RL47.84
T/O GUTTER RL49.55
PARAPET RL46.47
PARAPET RL39.03

WILLIAM LANE
GIBBONS STREET
MARGARET STREET
WILLIAM LANE

11 DP 4209

10 DP 1026349

SP 60485

SP 57425

'BP PETROL STATION'

No.104-116' 'BP PETROL STATION' CANOPY

SEE SHEET 2 FOR ENLARGED DETAIL

T/O GUTTER RL32.06
RIDGE RL34.82
T/O GUT. RL32.28
T/O GUTTER RL37.55
RIDGE RL38.0
RIDGE RL38.23
T/O GUTTER RL37.59
PARAPET RL31.14
PARAPET RL34.17

98°07'
30.685
98°40'
0.07
197°29'
5.175 (A)
36.185
192°59'
(A)
38.19
279°04'
2.775
319°38'

SCALE 1:200 @ A1
0 4 6 8 12 16 20

	D	00/00/00	-		00
	C	00/00/00	-		00
	B	00/00/00	-		00
	A	00/00/00	-		00
	Revision	Date	Description	Reference	

THIS IS THE PLAN REFERRED TO
IN MY LETTER DATED:
....
Registered Surveyor NSW

Client THE TRUST COMPANY AUSTRALIA (LIMITED) ATF WH GIBBONS TRUST
Drawing title
PLAN OF DETAIL AND LEVELS OVER SP60485 KNOWN AS
13-23 GIBBONS STREET, REDFERN

datum AHD	reference number 50422 001DT
site Area %*) a	scale 1:200 @A1 / date of survey 26/07/18
LGA SYDNEY	SHEET 1 OF 3

MGA

TN

SCALE 1:100

'GIBBONS STREET RESERVE'

GIBBONS STREET

MARGARET STREET

WILLIAM LANE

WILLIAM LANE

'BP PETROL STATION'

No.11 SINGLE STOREY BRICK BUILDING
11 DP 4209

PARAPET RL31.14

10 DP 1026349

No.104-116 'BP PETROL STATION' CANOPY

No.13-23 5 STOREY BRICK BUILDING (METAL PARAPET) BASEMENT UNDER

SP 60485

3 STOREY METAL ROOF

PAVED COURTYARD

PERGOLA

GARDEN

WALL

BRICK

4 STOREY BUILDING METAL ROOF

4 STOREY BUILDING METAL ROOF BASEMENT UNDER

PARAPET RL37.44
PARAPET RL37.43
PARAPET RL37.45

4 STOREY BUILDING METAL ROOF

PARAPET RL36.38
PARAPET RL36.37

GUTTER RL38.66
RIDGE RL39.94
GUTTER RL38.68
RIDGE RL39.93
GUTTER RL38.62
RIDGE RL39.95
PARAPET RL38.97

BALCONY

METAL ROOF
3 STOREY METAL ROOF
GARDEN

PERGOLA

GARDEN

COVERED ENTRY
GARDEN
METAL FENCE
CONCRETE DRIVEWAY
ELEC BOX

BENCHMARK ON KERB RL24.35 (AHD)

TOP OF KERB

CONCRETE FOOTPATH

POSSIBLE STORMWATER CHANNEL

No.1 5 STOREY BRICK BUILDING (BRICK PARAPET) BASEMENT UNDER
PARAPET RL38.52
SP 60485

No.118 'UNITING CHURCH' BRICK BUILDING TILE ROOF

98°07' 30.685
5.175
98°40'
279°04'
192°59'
329°38'

ROOF RIDGE ▽45.90

EAVE ▽40.50

40.45 TOP OF WALL

ROOF RIDGE ▽35.48

TOP OF PARAPET 38.52 38.49 38.56
38.11
▽37.84

37.13 TOP OF 36.78 FENCE 37.13

EAVE ▽34.97

TILE ROOF

ROOF RIDGE ▽34.45

33.11
▽31.95
▽32.67

31.66 GUTTER 31.66 31.30 GUTTER 31.30

29.73 ▽ ▽29.73 29.73 ▽29.73
29.73 ▽ 30.32 ▽30.32
29.94 ▽ ▽29.94

27.93 ▽ 29.21 ▽29.21 29.21 ▽29.21 28.41 ▽ ▽28.41

W W W W W W W W W

26.94
26.73 ▽26.73
▽26.05 26.27
25.89 ▽ 25.52 ▽ ▽25.52 25.51 ▽25.51 D TOP OF WALL ▽26.28

24.92

25.52 ▽ ▽25.52

TOP OF WALL 24.12 ▽ TOP OF WALL 23.77 ▽23.77
23.64

TOP OF PARAPET 34.02
33.84 35.11 35.12
35.12
▽33.84 ▽33.84 ▽33.93 BALC

32.36 32.36 32.36 32.35 32.36 32.36 35.36
▽31.16 BALC BALC ▽31.08 32.35 ▽31.18 BALC 32.88 35.36
BALC 32.67
W W W 31.08 W 30.12 BALC 35.08 35.74
W 35.36 ▽32.95 ▽32.32

29.68 29.68 29.68 29.68 29.68 29.68 30.21 29.69
▽28.51 28.41 28.41 28.41 28.39 28.49 BALC BALC ▽27.58 ▽27.00
W BALC BALC W W W 29.95 29.95

27.28 27.41 27.43 27.44 27.46 27.46 27.27 27.27 27.28 27.28
D ▽27.28 ▽27.27 ▽27.26 27.26 25.82 25.81 25.79
25.81 25.82 25.80 25.80 25.81 25.82 25.81

23.86 24.61 24.80 24.59 24.61 24.78 24.50 24.34 24.58
23.48 VENT WINDOW 24.77 TOP OF STEP VENT WINDOW 24.11 24.16 W ▽24.19
23.70 23.85 24.33 24.33 24.11 24.50 24.02
23.78
BOTTOM 23.82 OF STEP
TOP OF WALL ▽25.41

NORTH ELEVATION No 1 MARGARET STREET AND No 118 REGENT STREET – REDFERN

▽31.28 ROOF RIDGE ▽31.02
30.65 TOP OF WALL 30.65
ROOF RIDGE 29.87 ▽29.87
TOP OF PARAPET ▽29.06

24.80

SOUTH ELEVATION No 11 GIBBONS STREET–REDFERN

30.87 TOP OF WALL
TOP OF ▽30.29
CANOPY ROOF ▽29.59
▽28.99
28.55 TOP OF WALL

TP OF
SHED ▽27.06 TOP OF WALL ▽26.58

▽24.65 ▽24.39 ▽24.15

WEST ELEVATION No 104–116 REGENT STREET–REDFERN

0 2 4 6 8 10
SCALE 1:100 @ A1

Revision	Date	Description	Reference
D	00/00/00	-	00
C	00/00/00	-	00
B	00/00/00	-	00
A	00/00/00	-	00

THIS IS THE PLAN REFERRED TO
IN MY LETTER DATED:
....
Registered Surveyor NSW

Client THE TRUST COMPANY AUSTRALIA (LIMITED) ATF WH GIBBONS TRUST
Drawing title
PLAN OF DETAIL AND LEVELS OVER SP60485 KNOWN AS
13-23 GIBBONS STREET, REDFERN

datum AHD
site Area % *) a
LGA SYDNEY

reference number 50422 001DT
scale 1:100 @A1
date of survey 26/07/18
SHEET 3 OF 3

Street View from Gibbons Street – (from Google street view)

Street View from Margaret Street – (from Google street view)

View of footpath and boundary fence along Gibbons Street

View of footpath and boundary fence along Margaret Street

Photo taken from Margaret Street showing driveway to underground carpark and concrete staircase to courtyard.

Photo showing existing City of Sydney Council's kerb inlet pit in front of the driveway

Photo taken from William Lane with the blue painted wall of existing building as background.

Photo showing existing courtyard is about 3 steps (600mm) higher than the street level with the lowest point at the left kerb inlet pit. The retaining wall behind the black and white chequered board have collapsed.

Photo taken from William Lane showing damaged retaining wall.

Photo showing flood flow path at the BP Station compound overflow from William Lane (at the foreground not shown).
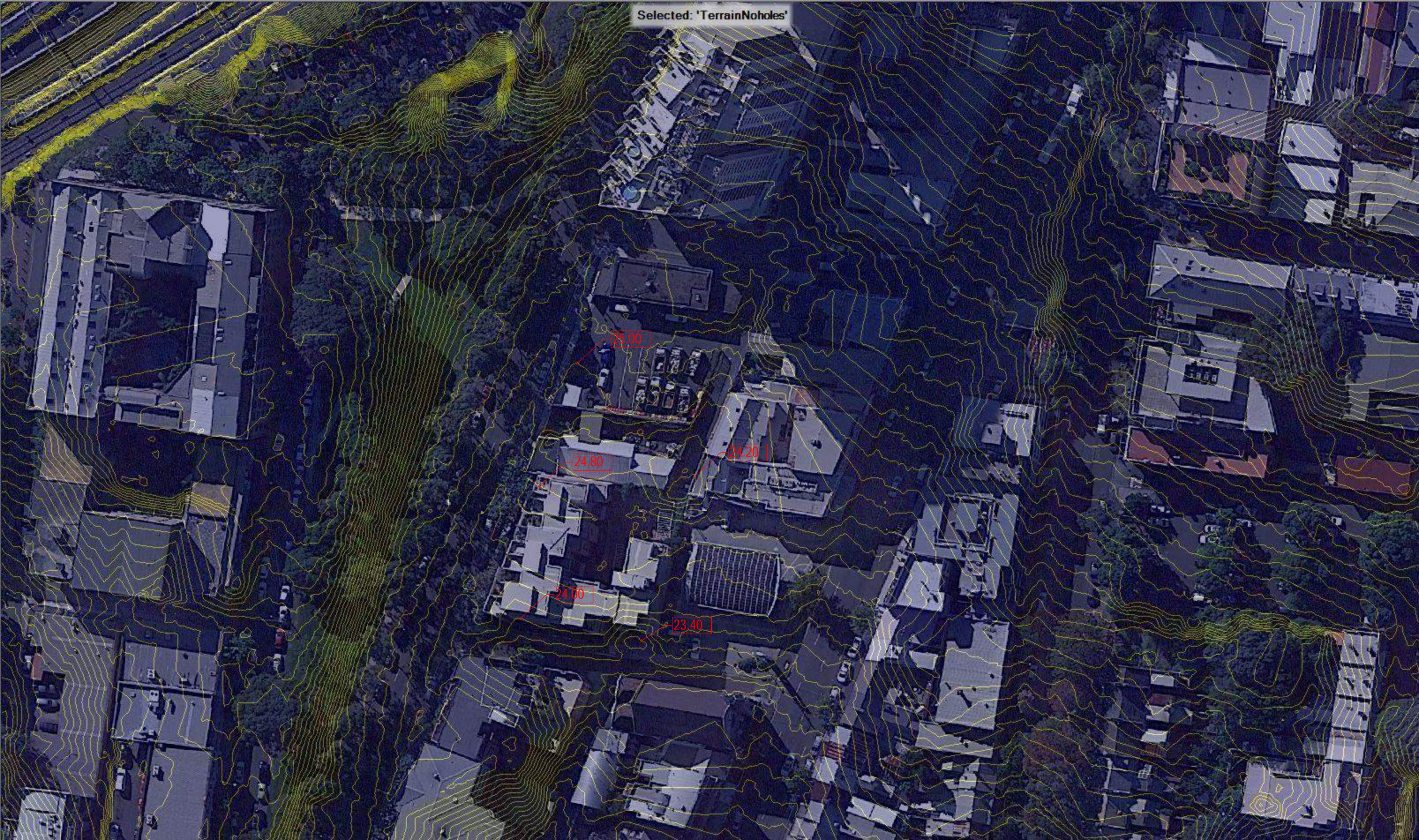
Selected: 'Perimeters'

LAWSON STREET

2D FLOW AREA OF 20,520 CELLS

WEE HUR SITE

MARGARET STREET

RASMapper Plot

Plot | Table

Combined Table
100Y60min

	Time (1/01/2020)	100Y60min (meters)
1	01Jan2020 00:00...	0.000
2	01Jan2020 00:05...	0.219
3	01Jan2020 00:10...	0.429
4	01Jan2020 00:15...	0.707
5	01Jan2020 00:20...	0.811
6	01Jan2020 00:25...	0.832
7	01Jan2020 00:30...	0.816
8	01Jan2020 00:35...	0.801
9	01Jan2020 00:40...	0.790
10	01Jan2020 00:45...	0.782
11	01Jan2020 00:50...	0.774
12	01Jan2020 00:55...	0.767
13	01Jan2020 01:00...	0.761
14	01Jan2020 01:05...	0.751

0.835

1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000

Max

RASMapper Plot

Plot | Table

Combined Table
100Y90min

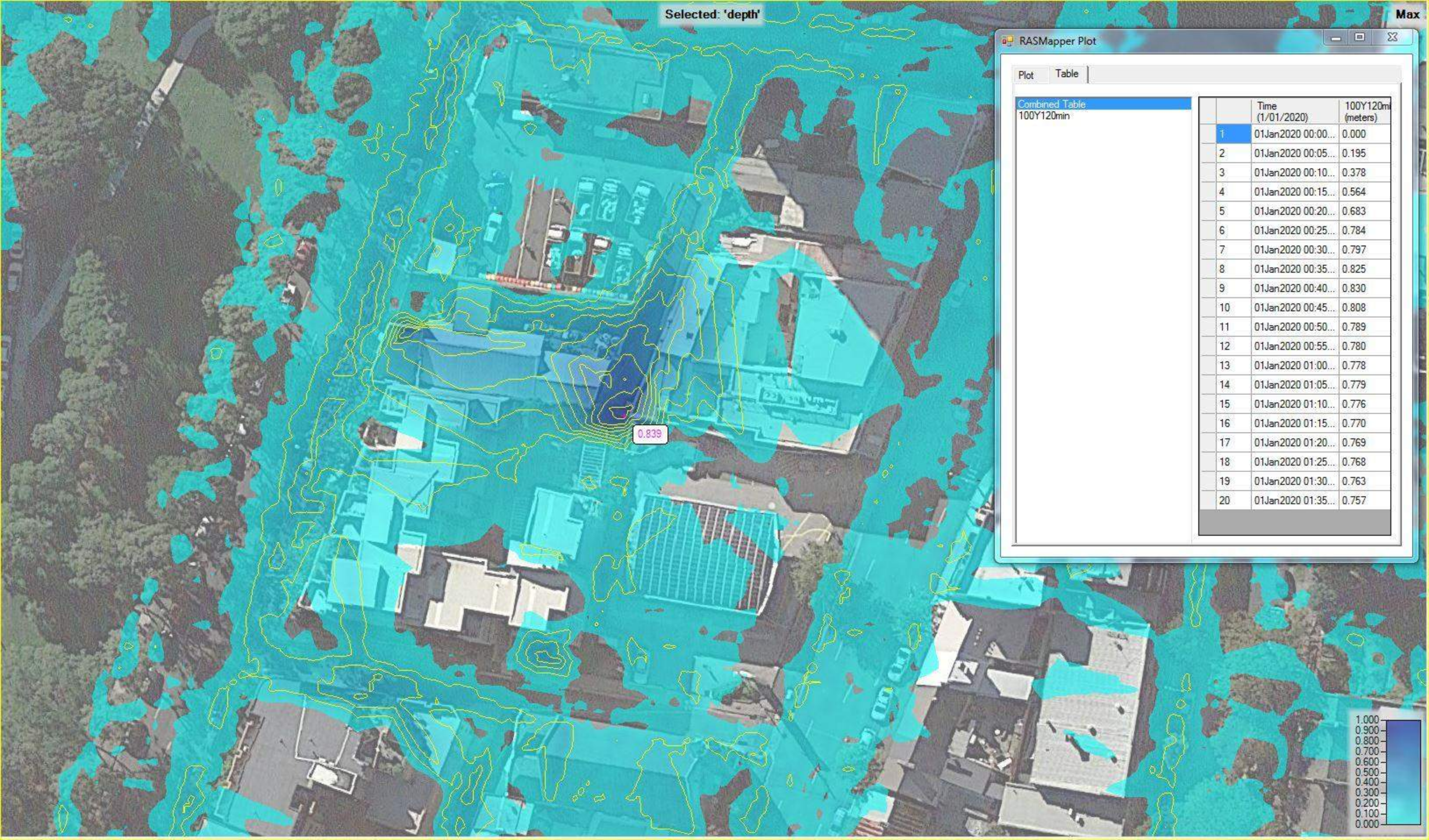|	Time (1/01/2020)	100Y90min (meters)
1	01Jan2020 00:00...	0.000
2	01Jan2020 00:05...	0.213
3	01Jan2020 00:10...	0.411
4	01Jan2020 00:15...	0.690
5	01Jan2020 00:20...	0.804
6	01Jan2020 00:25...	0.804
7	01Jan2020 00:30...	0.832
8	01Jan2020 00:35...	0.809
9	01Jan2020 00:40...	0.790
10	01Jan2020 00:45...	0.781
11	01Jan2020 00:50...	0.775
12	01Jan2020 00:55...	0.773
13	01Jan2020 01:00...	0.771
14	01Jan2020 01:05...	0.766
15	01Jan2020 01:10...	0.762
16	01Jan2020 01:15...	0.759
17	01Jan2020 01:20...	0.756
18	01Jan2020 01:25...	0.752
19	01Jan2020 01:30...	0.749
20	01Jan2020 01:35...	0.743

0.840

1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
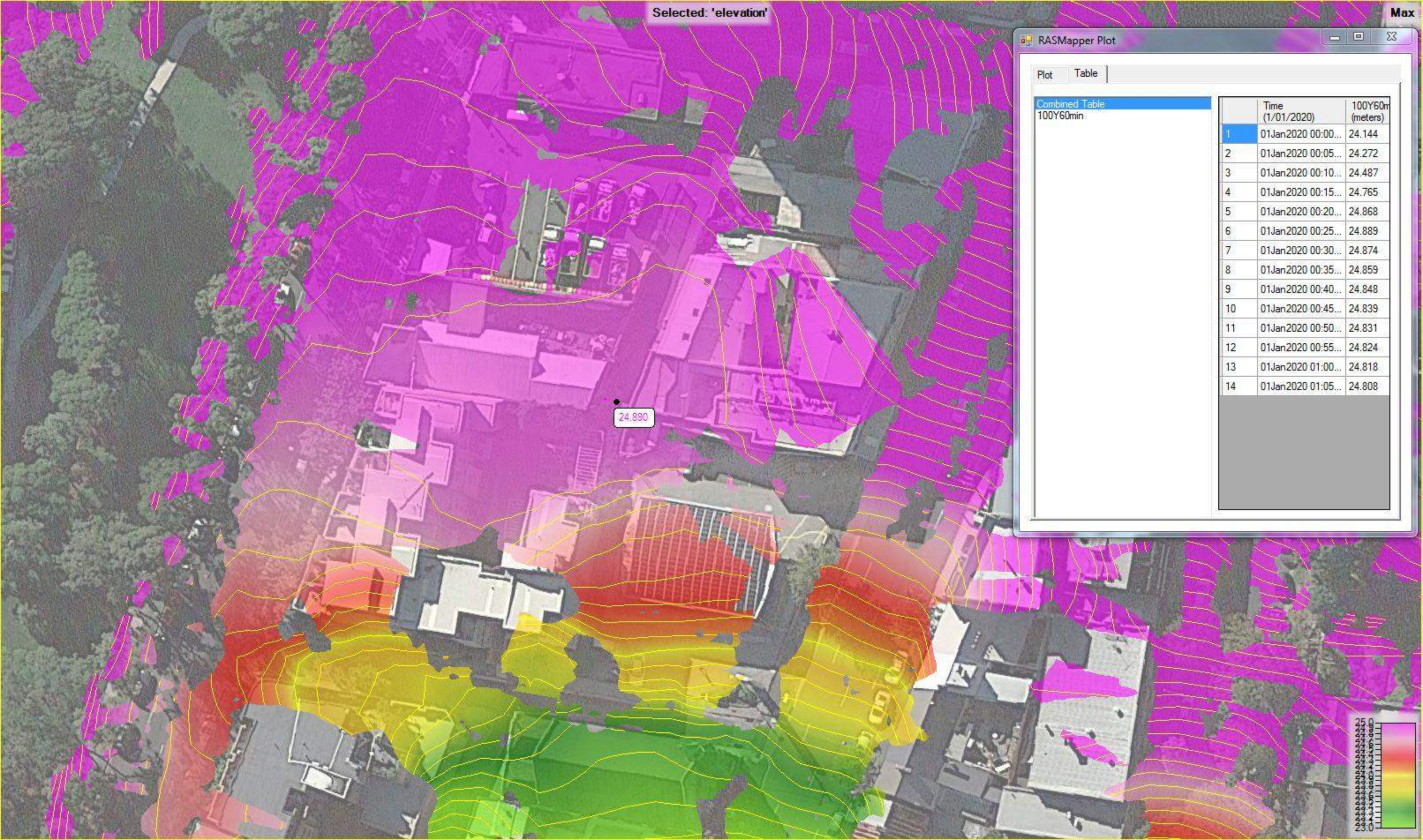
RASMapper Plot

Plot | Table

Combined Table
100Y60min

	Time (1/01/2020)	100Y60m (meters)
1	01Jan2020 00:00...	24.144
2	01Jan2020 00:05...	24.272
3	01Jan2020 00:10...	24.487
4	01Jan2020 00:15...	24.765
5	01Jan2020 00:20...	24.868
6	01Jan2020 00:25...	24.889
7	01Jan2020 00:30...	24.874
8	01Jan2020 00:35...	24.859
9	01Jan2020 00:40...	24.848
10	01Jan2020 00:45...	24.839
11	01Jan2020 00:50...	24.831
12	01Jan2020 00:55...	24.824
13	01Jan2020 01:00...	24.818
14	01Jan2020 01:05...	24.808

24.890

Max

RASMapper Plot

Plot | Table

Combined Table
100Y90min

	Time (1/01/2020)	100Y90min (meters)
1	01Jan2020 00:00...	24.149
2	01Jan2020 00:05...	24.263
3	01Jan2020 00:10...	24.469
4	01Jan2020 00:15...	24.748
5	01Jan2020 00:20...	24.861
6	01Jan2020 00:25...	24.861
7	01Jan2020 00:30...	24.890
8	01Jan2020 00:35...	24.866
9	01Jan2020 00:40...	24.847
10	01Jan2020 00:45...	24.839
11	01Jan2020 00:50...	24.832
12	01Jan2020 00:55...	24.830
13	01Jan2020 01:00...	24.829
14	01Jan2020 01:05...	24.824
15	01Jan2020 01:10...	24.820
16	01Jan2020 01:15...	24.817
17	01Jan2020 01:20...	24.813
18	01Jan2020 01:25...	24.809
19	01Jan2020 01:30...	24.806
20	01Jan2020 01:35...	24.800

24.890

RASMapper Plot

Plot | Table

Combined Table
100Y120min

	Time (1/01/2020)	100Y120m (meters)
1	01Jan2020 00:00...	24.179
2	01Jan2020 00:05...	24.232
3	01Jan2020 00:10...	24.431
4	01Jan2020 00:15...	24.617
5	01Jan2020 00:20...	24.736
6	01Jan2020 00:25...	24.837
7	01Jan2020 00:30...	24.850
8	01Jan2020 00:35...	24.878
9	01Jan2020 00:40...	24.883
10	01Jan2020 00:45...	24.860
11	01Jan2020 00:50...	24.842
12	01Jan2020 00:55...	24.832
13	01Jan2020 01:00...	24.831
14	01Jan2020 01:05...	24.832
15	01Jan2020 01:10...	24.828
16	01Jan2020 01:15...	24.823
17	01Jan2020 01:20...	24.821
18	01Jan2020 01:25...	24.820
19	01Jan2020 01:30...	24.816
20	01Jan2020 01:35...	24.809

24.886

OLS Height Limit
+90,000

65m HEIGHT LIMIT

RL 85.75m OLS (61m)

7 - 9 Gibbons Street
Residential Tower
Existing

PLANT   ROOF

+82,750
18 Roof Level   L18

TOW RL83,850   RL85,750   TOW RL83,850   TOW RL83,850

+79,500
17 Level 17   L17

+76,400
16 Level 16   L16

+73,300
15 Level 15   L15

+70,200
14 Level 14   L14

+67,100
13 Level 13   L13

+64,000
12 Level 12   L12

+60,900
11 Level 11   L11

+57,800
10 Level 10   L10

+54,700
9 Level 9   L09

+51,600
8 Level 8   L08

+48,500
7 Level 7   L07

+45,400
6 Level 6   L06

+42,300
5 Level 5   L05

COMMON   L04

Glazing Fence
+39,200
4 Level 4   L03

TOW RL37,400

+36,100
3 Level 3   L02

+32,800
2 Level 2   MEZZANINE

COMMON

+29,700
1 Level 1

COMMON   MARGARET ST.

+25,400
0 Ground   L01 (G)

Marian Street

EF-01 EF-02 EF-05 EF-01 EF-01 EF-02 EF-02 EF-02 EF-01

EF-02 EF-06 EF-05 EF-03 EF-06 EF-03 EF-04 EF-05

Site Boundary

MEZZANINE (Plan 3)

Void Below 81.8 m²
Condenser Location 31 m²
Cinema 1 45.1 m² FFL 27.900 160 160 160
Laundry
Gym 100.9 m² FFL 27.900
Common Not Enclosed
FFL 27.900
FFL 27.900
Lift 1 ~5.5 m² Lift 2 ~5.5 m²
Void Below Not Enclosed
UP
6800
11370

3 MEZZANINE   1 : 200

2 DA3104
1 DA3104

BASEMENT (Plan 1)

Waste Hold 3.9 m² Bin Wash Area
Substation Over
Cable Chamber
MSB 24.1 m² 5420 4460
Retail Waste
Bike Storage 235.6 m² 86 bike parking spaces
Comms 10.8 m² 4010 2700
Waste Room 17.3 m²
Batter
Clean Fill
Store 23.8 m² Lift 1 Lift 2
Bulk Waste
OSD Tank 31.7 m²
EXISTING RETAINING WALL TO BASEMENT CARPARK

1 BASEMENT   1 : 200

2 DA3104
1 DA3104

LEVEL 1 (Plan 2)

11 Gibbons Street Future Development
98 Regent Street
William Lane
116 Regent Street
Service Station
Margaret Street
St Luke Presbyterian Church 18 Regent Street
1 Margaret Street
William Lane
Gibbons Street

Existing Tree
Existing Tree
Existing Tree
Landscaped Entry Walkway
Landscaped Entry Walkway
Laneway
Rain Garden 31m²
Awning Over
Public Artwork Canopy Over Shown Dashed

RL 24.180 RL 24.122
RL 24.790
RL 24.750
RL 24.145
RL 24.032
RL 24.200
RL 24.360
RL 24.500
RL 25.050
28070

Fire Pumps 16 m²
Water Meter 7.1 m²
Chamber Substation 19.7 m² FFL 24.440
Waste 7.2 m² FFL 24.790
Retail Unit 86.8 m² FFL 25.110
Waste Hold 3.9 m²
FFL 25.110 FFL 25.050 FFL 25.050
Sliding Fire Door
Gate
COMPLYING ENVELOPE
Fire Control 9.9 m²
Cleaner 5.2 m² FFL 25.050
Bike Repair/Store
Cleaner WC 4.3 m² FFL 24.360
Gas Meter WORK BENCH
Meeting 15.8 m²
Office 41.7 m²
Kitchenette 7.6 m² FFL 24.700
Communal Kitchen 80.1 m² FFL 24.700
Manager 5.3 m²
Parcel Store 6.7 m²
Counsel 5.2 m²
Reception 11 m² FFL 22.5 m²
Lift 1 ~5.5 m² Lift 2 ~5.5 m²
FFL 25.050
Common 241.1 m² FFL 24.700
Games 86 m²
Level 2 Over
Awning Over
OSD Tank
UP

Location of Grease Arrestors Under
200 Kerb
Transformer handling area 4 x 4m
An all-weather heavy duty access roadway and plan for lifting and movement of equipment and associated transformer landing area must be provided and approved by Ausgrid prior to equipment delivery.
Landscaped Entry Walkway

1810 26910 7100 6800
2200 8090 11020 9790 11050 11370
28740
Proposed New Street Tree

2 LEVEL 1   1 : 200

2 DA3104
1 DA3104

Legend
| BACK OF HOUSE | COMMON AREAS | GYM | QUEEN STUDIO | SERVICES | SINGLE STUDIO | TWIN LOFT |
| BIKE STORAGE | DDA STUDIO | LIFT | RETAIL | SINGLE DORM | TWIN DORM | TWIN STUDIO |

Title Block

Client
The Trust Company Australia (Limited)
ATF WH Gibbons Trust

Architect
A J+C
ALLEN JACK+COTTIER
79 Myrtle Street Chippendale NSW 2008 AUSTRALIA
ph +61 2 9311 8222 fx +61 2 9311 8200
ABN 53 003 782 250

Project
WEE HUR STUDENT HOUSING
13-23 Gibbons Street, Redfern
Proj. No. 18029

Drawing Title
Basement, Mezzanine & Level 1 Plan

Sheet Status
NOT FOR CONSTRUCTION

Scale
1 : 200 @A1

Drawing No.
DA2001

Issue
03

0 2 4 8 16 m
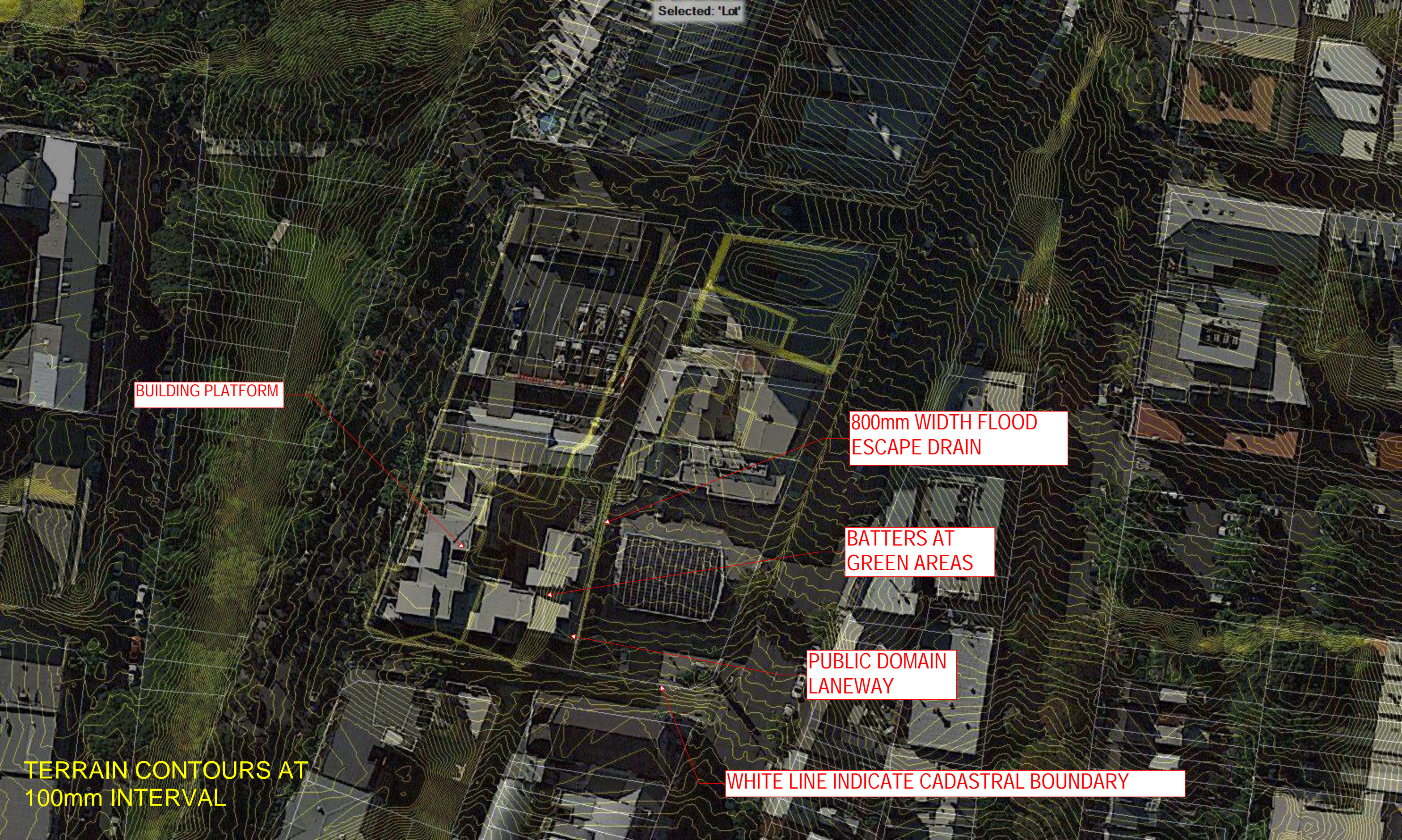
Selected: 'Lot'

BUILDING PLATFORM

800mm WIDTH FLOOD
ESCAPE DRAIN

BATTERS AT
GREEN AREAS

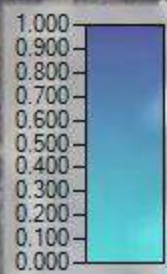PUBLIC DOMAIN
LANEWAY

WHITE LINE INDICATE CADASTRAL BOUNDARY

TERRAIN CONTOURS AT
100mm INTERVAL

Selected: 'depth'
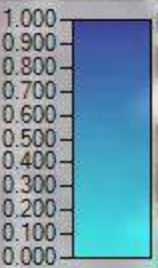
Max

0.411

MAX DEPTH FOR STORM 100Y 60 MIN

1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000

Selected: 'depth'

Max

0.417

MAX DEPTH FOR STORM 100Y 90 MIN

1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000

Selected: 'depth'

Max

0.411

MAX DEPTH FOR STORM 100Y 120 MIN

| 1.000 |
| 0.900 |
| 0.800 |
| 0.700 |
| 0.600 |
| 0.500 |
| 0.400 |
| 0.300 |
| 0.200 |
| 0.100 |
| 0.000 |
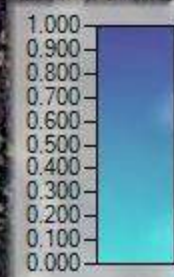
Selected: 'elevation'

Max

24.424

MAX SWE FOR STORM 100Y 60 MIN
WATER SURFACE CONTOURS AT 100mm INTERVAL

Selected: 'elevation'

Max

24.430

MAX SWE FOR STORM 100Y 90 MIN
WATER SURFACE CONTOURS AT 100mm INTERVAL

Selected: 'elevation'   Max

24.411
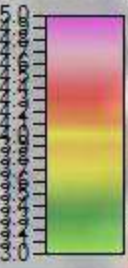
MAX SWE FOR STORM 100Y 120 MIN
WATER SURFACE CONTOURS AT 100mm INTERVAL

Selected: 'velocity'

Max
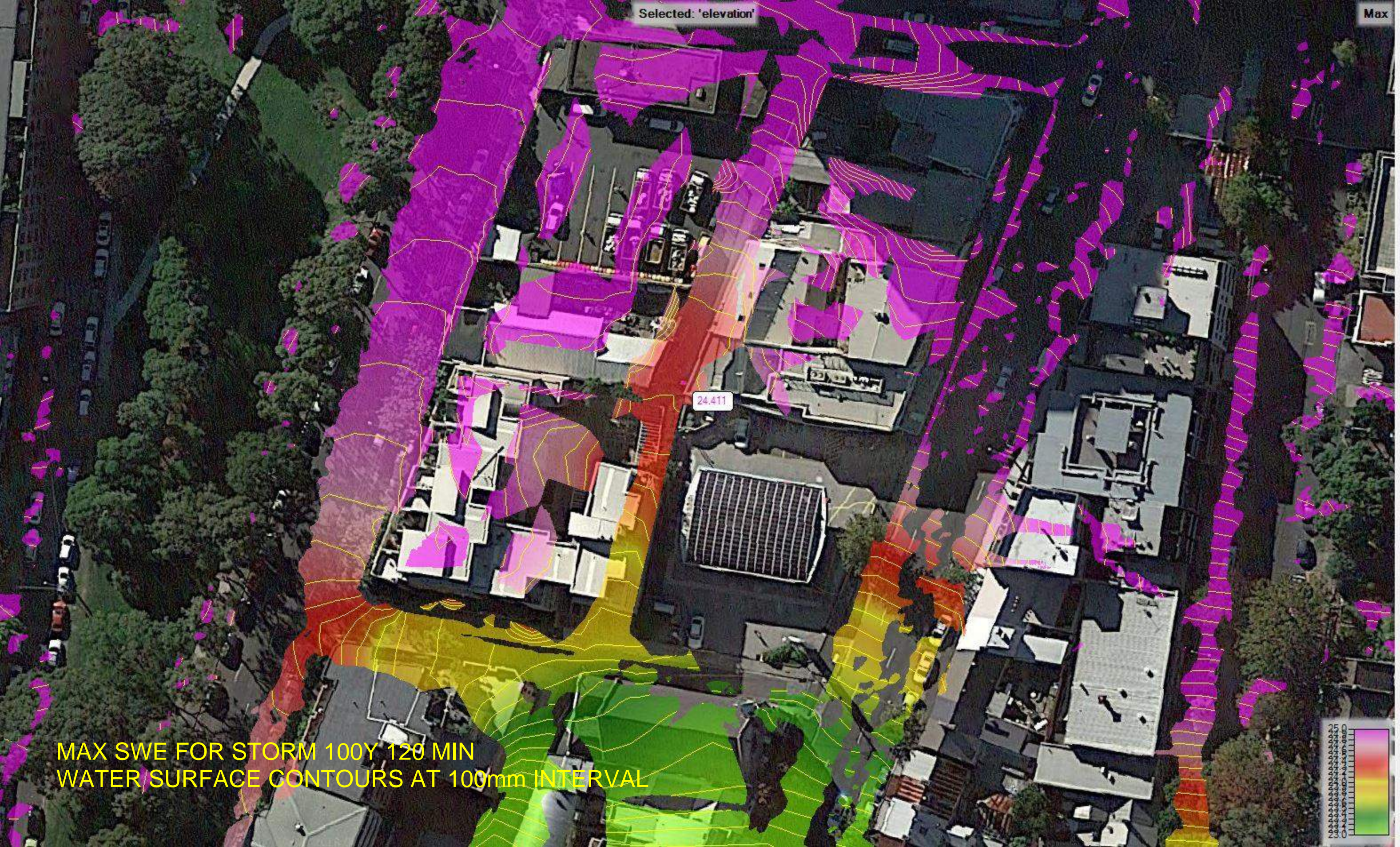
0.758

MAX VELOCITY FOR STORM 100Y 60 MIN

2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00

Selected: 'velocity'

Max

0.821

MAX DEPTH FOR STORM 100Y 90 MIN

2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00

Selected: 'velocity'

Max

0.768

MAX DEPTH FOR STORM 100Y 120 MIN

2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
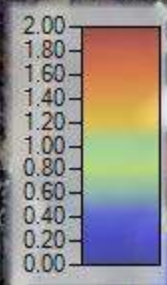
GIBBONS STREET PROFILE

WILLIAM LANE PROFILE

MARGARET STREET PROFILE
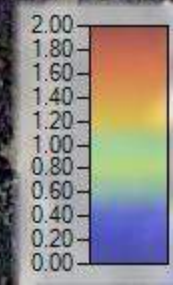
Selected: 'Profile Lines'

Water Surface Elevation on 'Line: Gibbons St'

Water Surface Elevation on 'Line: Margaret Street'
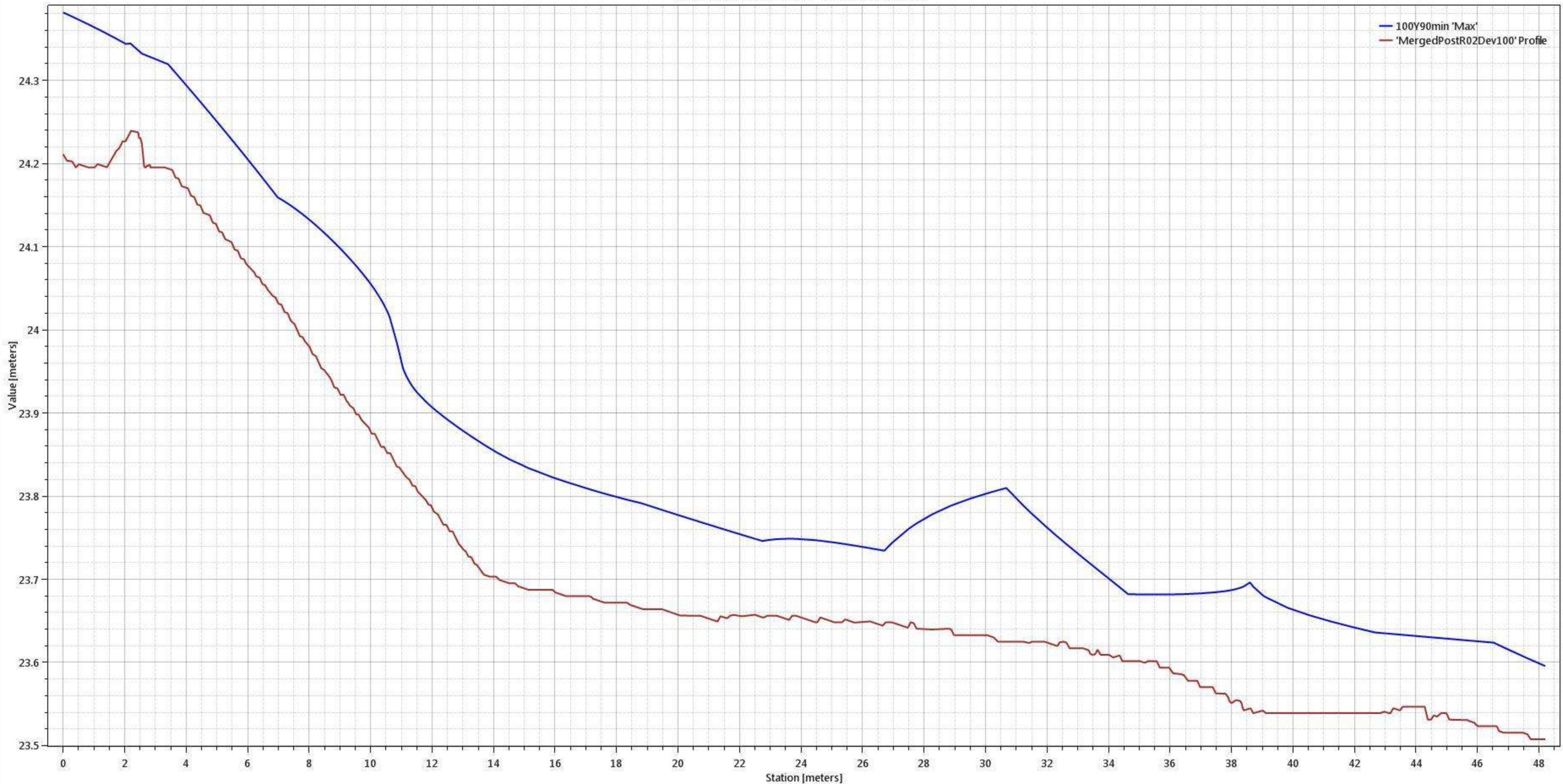
Water Surface Elevation on 'Line: William Ln'
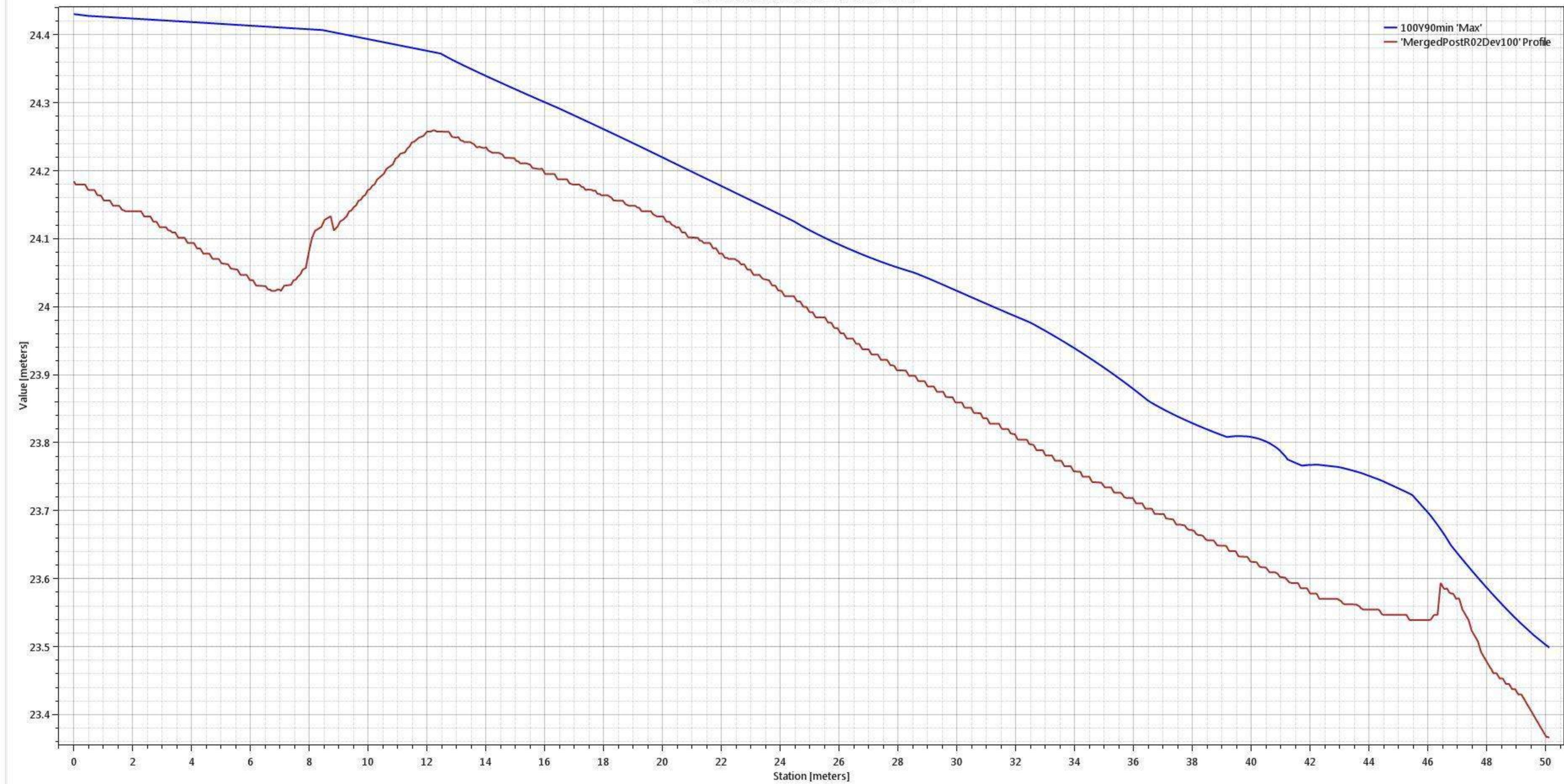
Selected: 'depth'

Max

0.858

MAX DEPTH FOR PMF STORM 15 MIN

2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
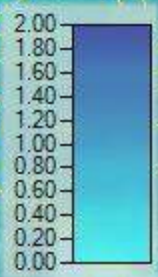
Selected: 'elevation'

Max

24.920

MAX WSE AT SAME SPOT FOR
PMF STORM 15 MIN
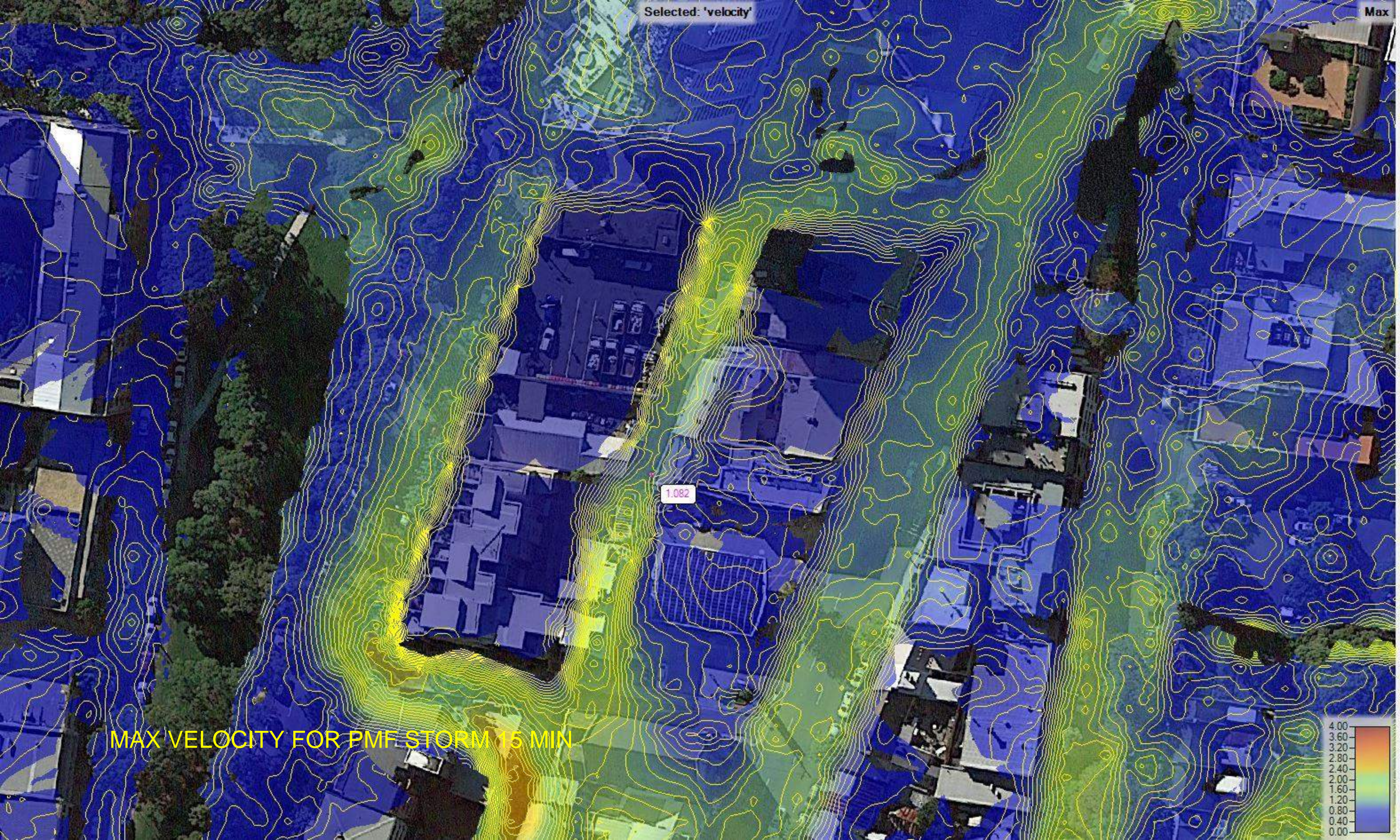
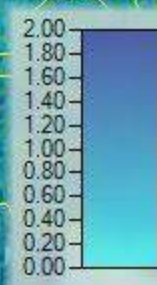Selected: 'velocity'

Max

1.082

MAX VELOCITY FOR PMF STORM 15 MIN

4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.80
0.40
0.00

Selected: 'depth'

Max

1.069

MAX DEPTH FOR PMF STORM 30 MIN

2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
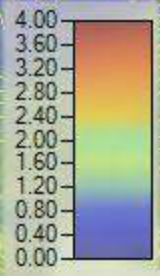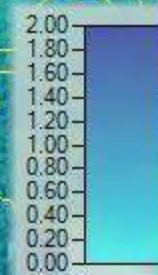
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Max

25.137

MAX WSE AT SAME SPOT FOR
PMF STORM 30 MIN
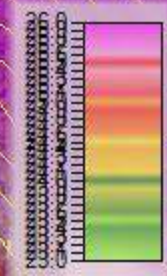
Selected: 'velocity'

Max

1.580

MAX VELOCITY FOR PMF STORM 30 MIN

4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.80
0.40
0.00

Selected: 'depth'

Max

1.075

MAX DEPTH FOR PMF STORM 45 MIN

2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
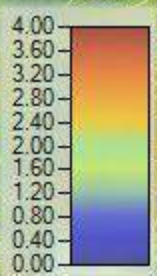
Selected: 'elevation'

Max

25.132

MAX WSE AT SAME SPOT FOR
PMF STORM 45 MIN

Selected: 'velocity'

Max

1.604

MAX VELOCITY FOR PMF STORM 45 MIN
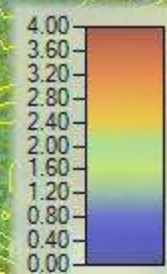
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.80
0.40
0.00

5 Flood Planning Levels

A Flood Planning Level refers to the permissible minimum building floor levels. For below-ground parking or other forms of below-ground development, the Flood Planning Level refers to the minimum level at each access point. Where more than one flood planning level is applicable the higher of the applicable Flood Planning Levels shall prevail.

Development		Type of flooding	Flood Planning Level
Residential	Habitable rooms	Mainstream flooding	1% AEP flood level + 0.5 m
		Local drainage flooding (Refer to Note 2)	1% AEP flood level + 0.5 m or Two times the depth of flow with a minimum of 0.3 m above the surrounding surface if the depth of flow in the 1% AEP flood is less than 0.25 m
		Outside floodplain	0.3 m above surrounding ground
	Non-habitable rooms such as a laundry or garage (excluding below-ground car parks)	Mainstream or local drainage flooding	1% AEP flood level
Industrial or Commercial	Business	Mainstream or local drainage flooding	Merits approach presented by the applicant with a minimum of the 1% AEP flood level
	Schools and child care facilities	Mainstream or local drainage flooding	Merits approach presented by the applicant with a minimum of the 1% AEP flood level + 0.5m
	Residential floors within tourist establishments	Mainstream or local drainage flooding	1% AEP flood level + 0.5 m
	Housing for older people or people with disabilities	Mainstream or local drainage flooding	1% AEP flood level + 0.5 m or a the PMF, whichever is the higher
	On-site sewer management (sewer mining)	Mainstream or local drainage flooding	1% AEP flood level
	Retail Floor Levels	Mainstream or local drainage flooding	Merits approach presented by the applicant with a minimum of the 1% AEP flood. The proposal must demonstrate a reasonable balance between flood protection and urban design outcomes for street level activation.
Below-ground garage/ car park	Single property owner with not more than 2 car spaces.	Mainstream or local drainage flooding	1% AEP flood level + 0.5 m

Development		Type of flooding	Flood Planning Level
	All other below-ground car parks	Mainstream or local drainage flooding	1% AEP flood level + 0.5 m or the PMF (whichever is the higher) See Note 1
	Below-ground car park outside floodplain	Outside floodplain	0.3 m above the surrounding surface
Above ground car park	Enclosed car parks	Mainstream or local drainage flooding	1% AEP flood level
	Open car parks	Mainstream or local drainage	5% AEP flood level
Critical Facilities	Floor level	Mainstream or local drainage flooding	1% AEP flood level + 0.5m or the PMF (whichever is higher)
	Access to and from critical facility within development site	Mainstream or local drainage flooding	1% AEP flood level

Note**s**
1) The below ground garage/car park level applies to all possible ingress points to the car park such as vehicle entrances and exits, ventilation ducts, windows, light wells, lift shaft openings, risers and stairwells.
2) Local drainage flooding occurs where:
- The maximum cross sectional depth of flooding in the local overland flow path through and upstream of the site is less than 0.25m for the 1% AEP flood; and
- The development is at least 0.5m above the 1% AEP flood level at the nearest downstream trapped low point; and
- The development does not adjoin the nearest upstream trapped low point; and
- Blockage of an upstream trapped low point is unlikely to increase the depth of flow past the property to greater than 0.25m in the 1% AEP flood.
3) Mainstream flooding occurs where the local drainage flooding criteria cannot be satisfied.
4) A property is considered to be outside the floodplain where it is above the mainstream and local drainage flood planning levels including freeboard.

Appendix H03

PROPOSED MINIMUM FLOOD PLANNING LEVELS TO COUNCIL REQUIREMENTS

Item	GroundFloor Rooms / Entry Point	1% AEP Flood Surface Levels (m)	Classification	Freeboard (mm)	Minimum	Proposed FPL	Comment
1	Chamber Substation	24.35	Local Drainage	50	24.40	24.44	Meet requirement above flood level
2	Bike Repair/Storage	24.25	Local Drainage	50	24.30	24.36	Meet requirement above flood level
3	Fire Pumps/Control,Water Meter	24.35	Local Drainage	50	24.40	25.05	Meet requirement above flood level
4	Communal Kitchen	24.10	Local Drainage	500	24.60	24.70	Meet requirement above flood level
5	Lounge	23.95	Local Drainage	500	24.45	24.70	Meet requirement above flood level
6	Retail Unit	24.90	Outside Floodplain	150	25.05	25.11	Commercial Requirement
7	Office, Meeting and Manager	24.55	Outside Floodplain	500	25.05	25.05	Residential Requirement
8	Reception and Counsel	24.54	Outside Floodplain	500	25.04	25.05	Residential Requirement
9	Common Area	24.52	Outside Floodplain	500	25.02	25.05	Residential Requirement
10	Games Area	24.50	Outside Floodplain	500	25.00	25.05	Residential Requirement

JHA CONSULTING ENGINEERS

Address : Wee Hur Student Village Redfern, NSW 2016

OSD TANK SIZING

Development Site Area		Ar =	1365	m^2
Sydney Water OSD volume requirement		=	24	m^3
1) **Provide OSD tank plan area**			31	m^2
Required OSD tank min depth			0.78	m

842 mm provided

Sydney Water PSD requirement	=	48	l/s

Orifice Calculation

Top water level	TWL	=	23.83	m
Outlet pipe invert level IL$_{outlet}$		=	22.95	m
2) Diameter of orifice	d	=	150	mm
Diameter of outlet Pipe	d	=	225	mm

Plate 350x350

Center of orifice		=	23.063	m
Invert of orifice or tank		=	22.988	m
Head for orifice	H	=	0.767	m
	C	=	0.6	(Orifice 0.6, Pipe 0.8)

$Q = C.A.\sqrt{(2.g.h)}$

Capacity of one orifice	Q	=	41.1	l/sec
No. of orifices used		=	1	Orifice
Total discharge	Q$_{tot}$	=	41.1	l/sec
PSD	Qpsd	=	48	l/sec	*OK !*

From: Stormwater [mailto:Stormwater@sydneywater.com.au]
Sent: Wednesday, 31 October 2018 9:59 AM
To: Jimmy Soo <Jimmy.Soo@jhaengineers.com.au>
Subject: RE: Wee Hur Student Village Redfern - OSD volume and PSD requirement

Jimmy,
The On Site Detention requirements for the
1,365 square meters site at 13 – 23 Gibbons Street, Redfern, are as follows:

On Site Detention	24 cubic meter
Permissible Site Discharge	48 L/s

CITY OF SYDNEY COUNCIL

WEE HUR REDFERN STUDENT VILLAGE

13-23 GIBBONS STREET, REDFERN, NSW 2016

DEVELOPMENT APPLICATION

STORMWATER CONCEPT PLAN

LAWSON STREET

GIBBONS STREET

REGENT STREET

REVISIONS / AMENDMENTS			
Rev	Date	Description	Verified
P1	02.11.18	PRELIMINARY ISSUE	J.S.
P2	22.11.18	PRELIMINARY ISSUE	J.S.
P3	11.12.18	PRELIMINARY ISSUE	J.S.
P4	19.12.18	PRELIMINARY ISSUE	J.S.
P5	11.01.19	PRELIMINARY ISSUE	J.S.
P6	14.08.19	PRELIMINARY ISSUE	J.S.
P7	09.10.19	PRELIMINARY ISSUE	J.S.

REVISIONS / AMENDMENTS			
Rev	Date	Description	Verified

CLIENT
WEE HUR

ARCHITECT
ALLEN JACK COTTIER

CONSULTANT
JHA
Level 23, 101 Miller Street,
North Sydney
NSW 2060
Australia
+61 (02) 9437 1000
general@jhaengineers.com.au
www.jhaservices.com

PROJECT
WEE HUR REDFERN STUDENT VILLAGE
13-23 GIBBONS STREET, REDFERN, NSW 2016

TITLE
STORMWATER SERVICES
GROUND LEVEL
COVER SHEET

PRELIMINARY
NOT FOR CONSTRUCTION

		SCALE @ A1
DRAWN	J.S.	
CHECKED	J.S.	
APPROVED	J.S.	**NTS**
CREATED	08/19	
JOB No.	DRAWING No.	REV
180391	**C000**	**P7**

LEGEND

	SEDIMENT FENCE
20m MAX	
27.0	EXISTING CONTOUR
	GEOTEXTILE INLET FILTER
	SANDBAG KERB SEDIMENT TRAP
	MATERIAL HANDLING AND/OR STORAGE
	ACCESS WASH BAY

SAND BAG KERB SEDIMENT TRAP

SAND BAG KERB SEDIMENT TRAP

SAND BAG KERB SEDIMENT TRAP

WILLIAM LANE

NORTH

ACCESS WASH BAY

POSSIBLE LOCATION OF BULK STORAGE

SEDIMENT FENCE ALL ROUND EXISTING SITE

ACCESS WASH BAY

SAND BAG KERB SEDIMENT TRAP

PROTECT EXISTING GULLY TRAP DURING CONSTRUCTION

SAND BAG KERB SEDIMENT TRAP

SAND BAG KERB SEDIMENT TRAPS

POSSIBLE STORMWATER CHANNEL

BALCONY (repeated throughout plan)

TREE

2 1 0 2 4 6 8 m

1 : 100-A1   1 : 200-A3

CLIENT
WEE HUR

ARCHITECT
ALLEN JACK COTTIER

CONSULTANT
JHA
Level 23, 101 Miller Street,
North Sydney
NSW 2060
Australia
+61 (02) 9437 1000
general@jhaengineers.com.au
www.jhaservices.com.au

PROJECT
WEE HUR REDFERN STUDENT VILLAGE
13-23 GIBBONS STREET,
REDFERN, NSW 2016

TITLE
STORMWATER SERVICES
GROUND LEVEL
SOIL AND EROSION
CONTROL PLAN

PRELIMINARY
NOT FOR CONSTRUCTION

|		SCALE @ A1
DRAWN	J.S.	
CHECKED	J.S.	
APPROVED	J.S.	**1:100**
CREATED	08/19	
JOB No.	DRAWING No.	REV
180391	**C101**	**P7**

SEDIMENT & EROSION CONTROL NOTES

1. THE CONTRACTOR SHALL IMPLEMENT ALL SOIL EROSION AND SEDIMENT CONTROL MEASURES PRIOR TO THE COMMENCEMENT OF ANY WORKS BEING CARRIED OUT. ALL SOIL AND EROSION MEASURES SHALL BE MAINTAINED AND KEPT IN PLACE FOR THE FULL DURATION OF THE WORKS AND SHALL ONLY BE REMOVED AT FINAL STABILISATION OF THE WORKS. WHERE IT IS NECESSARY TO UNDERTAKE STRIPPING IN ORDER TO CONSTRUCT A SEDIMENT CONTROL DEVICE ONLY SUFFICIENT GROUND SHALL BE STRIPPED TO ALLOW CONSTRUCTION.

2. ALL SOIL EROSION AND SEDIMENT CONTROL MEASURES SHALL BE CONSTRUCTED AND MAINTAINED AS INDICATED ON THESE DRAWINGS. LOCATION AND EXTENT OF SOIL AND WATER MANAGEMENT DEVICES IS DIAGRAMMATIC ONLY AND THE ACTUAL REQUIREMENTS SHALL BE CONFIRMED ON SITE PRIOR TO COMMENCEMENT.

3. CONFORMITY WITH THIS PLAN SHALL IN NO WAY REDUCE THE RESPONSIBILITY OF THE CONTRACTOR TO PROTECT AGAINST WATER DAMAGE DURING THE COURSE OF THE CONTRACT. IT SHALL BE THE CONTRACTORS RESPONSIBILITY TO ENSURE THAT ANY NECESSARY CONTROL IS IN PLACE EVEN THOUGH SUCH CONTROL MAY NOT BE SHOWN ON THE PLAN.

4. THE CONTRACTOR SHALL INFORM ALL SUBCONTRACTORS AND ALL EMPLOYEES OF THEIR RESPONSIBILITIES IN MINIMISING THE POTENTIAL FOR SOIL EROSION AND POLLUTION TO DOWNSTREAM AREAS

5. APART FROM SEDIMENT BASINS, THE CONTRACTOR SHALL REGULARLY MAINTAIN SEDIMENT AND EROSION CONTROL STRUCTURES AND DESILT STRUCTURES PRIOR TO THE REDUCTION IN CAPACITY OF 30% DUE TO ACCUMULATED SEDIMENT. THE SEDIMENT SHALL BE DISPOSED OF ON SITE IN A MANNER APPROVED BY THE ENGINEER.

6. THE CONTRACTOR SHALL TEMPORARILY REHABILITATE WITHIN TEN (10) DAYS ANY DISTURBED AREAS PROVIDING A MINIMUM 60% COVER. FINAL REHABILITATION IS TO BE PROVIDED WITHIN A FURTHER 60 DAYS WITH A MINIMUM 70% COVER.

8. THE CONTRACTOR SHALL PROVIDE WATERING OF THE VEGETATED BATTERS FOR MAINTENANCE PERIOD. PLANT, MACHINERY AND VEHICLES SHALL NOT BE DRIVEN OVER GRASSED AREAS UNLESS ON AN APPROVED HAULAGE ROUTE.

9. ALL DRAINAGE WORKS SHALL BE CONSTRUCTED AND STABILISED AS QUICKLY AS POSSIBLE TO MINIMISE RISK OF EROSION.

10. SITE ACCESS SHALL BE RESTRICTED TO THE NOMINATED POINTS. THE CONTRACTOR SHALL PROVIDE STABILISED SITE ACCESS.

11. DUST AND SITE DISTURBANCE MUST BE KEPT TO A MINIMUM. DURING WINDY WEATHER, LARGE, UNPROTECTED AREAS MUST BE KEPT MOIST (NOT WET) BY SPRINKLING WITH WATER TO REDUCE WIND EROSION. ERECT BARRIER FENCING TO MINIMISE LAND DISTURBANCE BY PREVENTING VEHICULAR AND PEDESTRIAN ACCESS TO AREAS BEING REHABILATATED AND LANDS THAT DO NOT NEED TO BE DISTURBED BY THIS PROJECT.

12. STOCKPILE TOPSOILS, SUBSOILS AND OTHER MATERIALS SEPARATELY.

13. TOPSOILS SHALL BE STORED IN LOW MOUNDS NO MORE THAN 2 METRES HIGH AND RE-USED WITHIN TWO MONTHS TO MAINTAIN ACTIVE POPULATIONS OF BENEFICIAL SOIL MICROBES AND SEED.

14. PLACE ALL STOCKPILES AT LEAST FIVE METRES FROM AREAS OF LIKELY CONCENTRATED OR HIGH VELOCITY FLOWS, ESPECIALLY EARTH BANKS AND ROADS. IF NECESSARY, EARTH BANKS OR DRAINS WILL BE CONSTRUCTED TO DIVERT LOCALISED RUN-ON.

15. TURN TOPSOIL STOCKPILES OVER TO AERATE THEM AT MONTHLY INTERVALS. ENSURE VEGETATION IS NOT INCORPORATED INTO THE SOIL.

16. AVOID REVERSING THE SOIL PROFILE MATERIALS DURING FILL OPERATIONS – REPLACE DISTURBED SOILS IN THEIR ORIGINAL ORDER.

17. ON COMPLETION OF MAJOR EARTHWORKS AND BEFORE ADDING TOPSOIL, LEAVE DISTURBED LANDS WITH A LOOSE SURFACE. ALTERNATELY, DISTURBED AREAS PREVIOUSLY COMPACTED BY CONSTRUCTION WORKS WILL BE RIPPED TO MORE THAN 200-MM ALONG THE CONTOUR BEFORE APPLYING TOPSOIL

18. PROVIDING MATERIALS ARE AVAILABLE, SPREAD TOPSOIL TO A MINIMUM DEPTH OF 75mm IN REVEGETATION AREAS ON SLOPES OF 4(H):1(V) OR LESS AND TO A DEPTH OF 40 TO 60mm IN REVEGETATION AREAS STEEPER THAN 4:1.

19. LEAVE TOPSOIL IN A SCARIFIED OR ROUGH CONDITION ONCE REPLACED TO HELP MOISTURE INFILTRATION AND REDUCE SOIL EROSION.

20. ENSURE SOIL IS THOROUGHLY SOAKED TO A DEPTH OF 75mm (RAIN OR IRRIGATION) IMMEDIATELY BEFORE PLANTING.

21. HANDLE TOPSOIL ONLY WHEN IT IS MOIST (NOT WET OR DRY) TO AVOID DECLINE OF SOIL STRUCTURE

22. SEDIMENT BASINS SHALL BE MAINTAINED FOR THE ENTIRE DURATION OF THE PROJECT OR UNTIL SUCH TIME AS ALL DISTURBED AREAS ARE HYDROMULCHED.

23. WHERE FLOCCULATION OF BASINS IS REQUIRED UNLESS OTHERWISE SPECIFIED THE RECOMMENDED INITIAL DOSING IS 30KG OF GYPSUM PER 100 CUBIC METRES OF BASIN VOLUME. THE CONTRACTOR MAY VARY THIS RATE SUBJECT TO TESTING OF PREVIOUS WATER SAMPLES AND THE ACHIEVEMENTS OF THE REQUIRED WATER QUALITY STANDARDS.

24. ANY DAMS TO BE DESILTED SHALL BE FLOCCULATED TO SETTLE ANY SUSPENDED SOLIDS CLEAR WATER SHALL THEN BE PUMPED OUT IN A MANNER THAT WILL NOT CAUSE DOWNSTREAM EROSION. THE DAM WALL SHALL THEN BE BREACHED AND ANY SILT REMOVED AND PLACED IN A SUITABLY CONSTRUCTED DRYING BASIN. WHEN DRY, THE SILT SHALL BE REMOVED FROM SITE OR MIXED WITH TOP SOIL FOR FUTURE SPREADING.

25. THE CONTRACTOR SHALL MAINTAIN A LOG BOOK DETAILING:
   – RECORDS OF ALL RAINFALL
   – CONDITION OF SOIL AND WATER MANAGEMENT STRUCTURES
   – ANY APPLICATION OF FLOCCULATING AGENTS TO SEDIMENT BASIN
   – VOLUMES OF ALL WATER DISCHARGED FROM SEDIMENT BASINS
   – ANY ADDITIONAL REMEDIAL WORKS REQUIRED.

26. THE LOG BOOK SHALL BE MAINTAINED ON A WEEKLY BASIS AND BE MADE AVAILABLE TO ANY AUTHORISED PERSON UPON REQUEST. THE ORIGINAL LOG BOOK SHALL BE ISSUED TO THE PROJECT MANAGER AT THE COMPLETION OF WORKS

27. ALL ROAD EMBANKMENTS TO BE STABILISED AS PER LANDSCAPE ARCHITECTS DETAILS.

28. A SELF AUDITING PROGRAM SHOULD BE ESTABLISHED BASED ON A CHECK SHEET DEVELOPED FOR THE SITE. A SITE INSPECTION USING THE CHECK SHEET SHOULD BE MADE BY THE SITE MANAGER AT LEAST WEEKLY, IMMEDIATELY BEFORE SITE CLOSURE AND IMMEDIATELY FOLLOWING RAINFALL EVENTS THAT CAUSE RUNOFF.

29. UNDERTAKE THE SELF AUDIT BY:
   – WALKING AROUND THE SITE SYSTEMATICALLY (E.G. CLOCKWISE)
   – RECORDING THE CONDITION OF EVERY BMP EMPLOYED
   – RECORDING MAINTENANCE REQUIREMENTS (IF ANY) FOR EACH BMP
   – RECORDING THE VOLUMES OF SEDIMENT REMOVED FROM THE SEDIMENT RETENTION SYSTEMS WHERE APPLICABLE
   – RECORDING THE SITE WHERE SEDIMENT IS DISPOSED
   – FORWARDING A SIGNED DUPLICATE OF THE COMPLETED CHECK SHEET TO THE PROJECT MANAGER/DEVELOPER/SITE OPERATOR FOR THEIR INFORMATION

30. IN PARTICULAR, INSPECT:
   – LOCATIONS WHERE VEHICLES ENTER AND LEAVE THE SITE
   – ALL INSTALLED EROSION AND SEDIMENT CONTROL MEASURES, ENSURING THEY ARE OPERATING CORRECTLY
   – AREAS THAT MIGHT SHOW WHETHER SEDIMENT OR OTHER POLLUTANTS ARE LEAVING THE SITE OR HAVE POTENTIAL TO DO SO
   – ALL DISCHARGE POINTS, TO ASSESS WHETHER THE EROSION AND SEDIMENT CONTROL MEASURES ARE EFFECTIVE IN PREVENTING IMPACTS TO THE RECEIVING WATERS

31. A SITE INSPECTION USING THE CHECK SHEET WILL BE MADE BY THE SITE MANAGER AT LEAST WEEKLY, IMMEDIATELY BEFORE SITE CLOSURE, AND IMMEDIATELY FOLLOWING RAINFALL EVENTS GREATER THAN 5mm IN 24 HOURS.


GEOTEXTILE INLET FILTER — SD 6–12
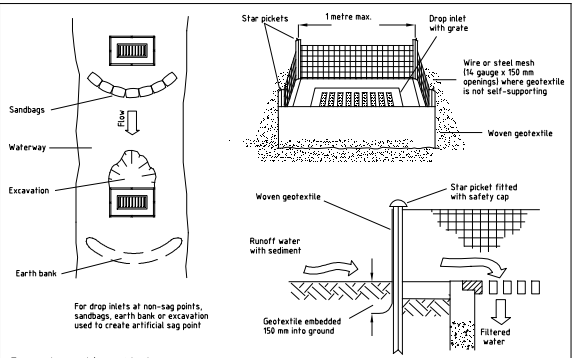
Construction Notes
1. Fabricate a sediment barrier made from geotextile or straw bales.
2. Follow Standard Drawing 6-7 and Standard Drawing 6-8 for installation procedures for the straw bales or geofabric. Reduce the picket spacing to 1 metre centres.
3. In waterways, artificial sag points can be created with sandbags or earth banks as shown in the drawing.
4. Do not cover the inlet with geotextile unless the design is adequate to allow for all waters to bypass it.

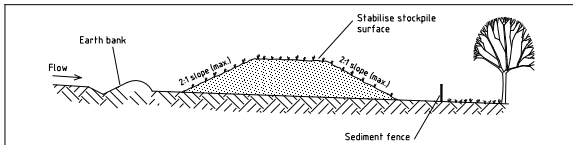## STABILISED SITE ACCESS — SD 6–14
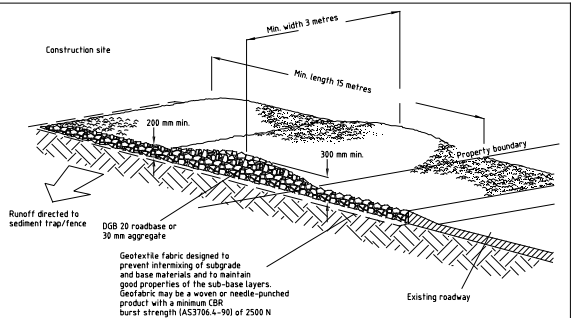
Construction Notes
1. Strip the topsoil, level the site and compact the subgrade.
2. Cover the area with needle-punched geotextile.
3. Construct a 200 mm thick pad over the geotextile using road base or 30 mm aggregate.
4. Ensure the structure is at least 15 metres long or to building alignment and at least 3 metres wide.
5. Where a sediment fence joins onto the stabilised access, construct a hump in the stabilised access to divert water to the sediment fence.


STOCKPILES — SD 4–1

Construction Notes
1. Place stockpiles more than 2 (preferably 5) metres from existing vegetation, concentrated water flow, roads and hazard areas.
2. Construct on the contour as low, flat, elongated mounds.
3. Where there is sufficient area, topsoil stockpiles shall be less than 2 metres in height.
4. Where they are to be in place for more than 10 days, stabilise following the approved ESCP or SWMP to reduce the C-factor to less than 0.10.
5. Construct earth banks (Standard Drawing 5–5) on the upslope side to divert water around stockpiles and sediment fences (Standard Drawing 6–8) 1 to 2 metres downslope.
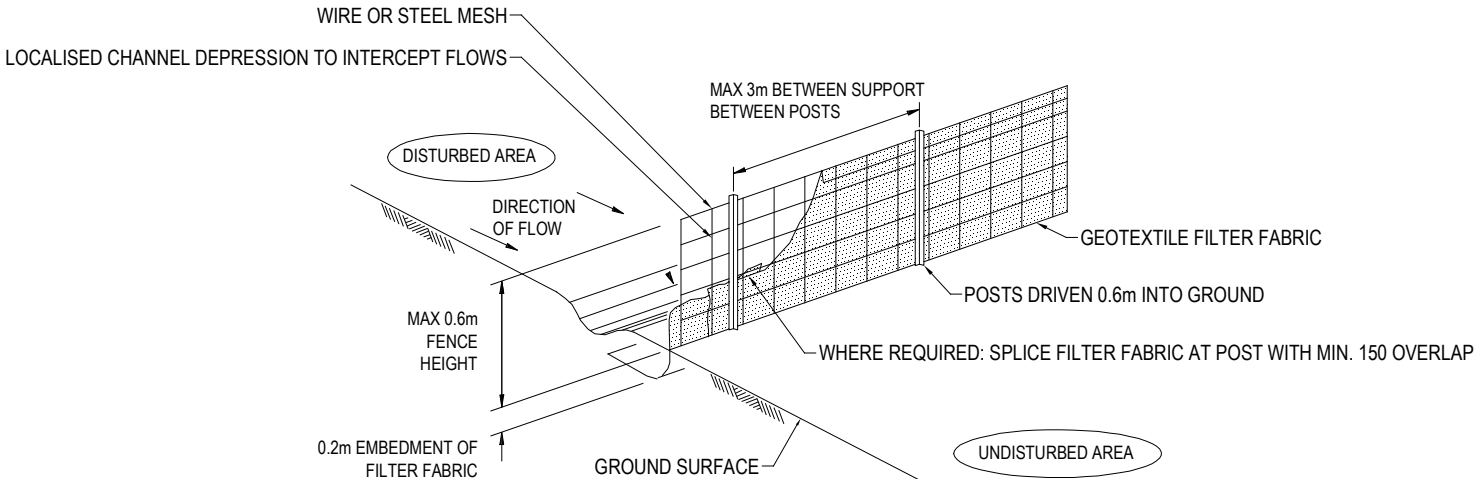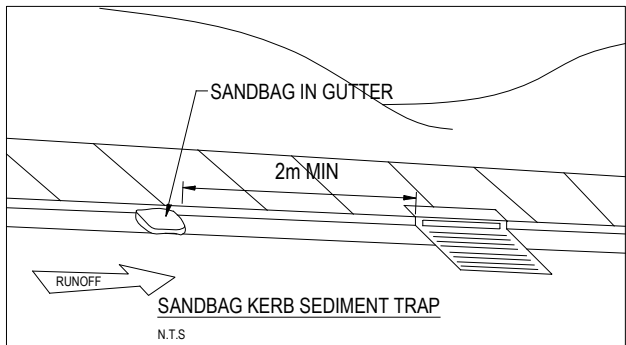
TEMPORARY SEDIMENT FENCE

NOT TO SCALE

BUILDER TO COORDINATE APPROPRIATE CONSTRUCTION SEQUENCE WITH CONSIDERATION FOR MATERIAL STORAGE AND ANTICIPATED SEDIMENT MOVEMENT DURING CONSTRUCTION

Labels: WIRE OR STEEL MESH; LOCALISED CHANNEL DEPRESSION TO INTERCEPT FLOWS; MAX 3m BETWEEN SUPPORT BETWEEN POSTS; DISTURBED AREA; DIRECTION OF FLOW; GEOTEXTILE FILTER FABRIC; POSTS DRIVEN 0.6m INTO GROUND; WHERE REQUIRED: SPLICE FILTER FABRIC AT POST WITH MIN. 150 OVERLAP; MAX 0.6m FENCE HEIGHT; 0.2m EMBEDMENT OF FILTER FABRIC; GROUND SURFACE; UNDISTURBED AREA

SANDBAG KERB SEDIMENT TRAP

N.T.S

Labels: SANDBAG IN GUTTER; 2m MIN; RUNOFF

SITE AREA TABULATION

OVERALL SITE AREA = 1365 m²

EXISTING SITE AREAS

IMPERMEABLE AREAS   = 1144 m²
PERMEABLE AREAS   = 221 m²

PERCENTAGE IMPERMEABLE = 84 %P

PROPOSED SITE AREAS

LANEWAY AREA DRAINING TO FILTERRA TREE PIT   = 330 m²
ROOF & HARDSTAND AREA DRAIN TO FILTERRA GARDEN   = 998 m²
BYPASS AREA   = 37 m²

TOTAL AREAS   = 1365 m²

PERCENTAGE IMPERMEABLE = 100 %

BOUNDARY WITH BP STATION, EXISTING WALL AT THIS LOCATION

LANEWAY, FLOOD DRAIN AND LANDSCAPING AREA, TOTAL CATCHMENT AREA 330 m² DRAINING INTO FILTERRA TREE/SHRUB PIT

ROOF, BALCONIES AND HARDSTAND CATCHMENT AREAS 998 m² DRAINING TO FILTERRA GARDEN

FLOOD DRAIN 800mm WIDTH DETAIL REFER TO C401

FILTERRA GARDEN

LANDSCAPING AREAS

KERB RETURN

POSSIBLE BYPASS CATCHMENT AREA. ASSUME 37 m² FOR A CONSERVATIVE CALCULATION

FILTERRA TREE/SHRUB PIT

BYPASS CATCHMENT AREA 37 m²

NORTH

1 : 100-A1   1 : 200-A3

2 1 0   2   4   6   8 m

JHA CONSULTING ENGINEERS

Address : Wee Hur Student Village Redfern, NSW 2016

OSD TANK SIZING

Development Site Area	Ar =	1365	m²
Sydney Water OSD volume requirement	=	24	m³
1) **Provide OSD tank plan area**		31	m²
Required OSD tank min depth		0.78	m

842 mm provided

Sydney Water PSD requirement	=	48	l/s

Orifice Calculation

Top water level	TWL	=	23.83	m
Outlet pipe invert level	IL$_{outlet}$	=	22.95	m
2) Diameter of orifice	d	=	150	mm	Plate 350x350
Diameter of outlet Pipe	d	=	225	mm

Center of orifice	=	23.063	m
Invert of orifice or tank	=	22.988	m
Head for orifice	H	0.767	m
	C	0.6	(Orifice 0.6, Pipe 0.8)

Q =   C.A.√(2.g.h)

Capacity of one orifice	Q	41.1	l/sec
No. of orifices used	=	1	Orifice
Total discharge	Q$_{tot}$	41.1	l/sec
PSD	Qpsd	48	l/sec	**_OK !_**

ORIFICE PLATE 150mm Ø
OUTLET PIPE 225mm Ø
DETAIL TO C301

300mm Ø INLET PIPE TO OSD TANK

FILTERRA GARDEN (AREA 6.5m2)
DETAIL REFER TO C301

FILTERRA INLET PIT FOR
DOWNPIPES FROM ROOF
(REFER TO HYDRAULIC DRAWINGS).
DUCTILE IRON GRATES TO COS
STANDARD

LEGEND

——	PROPERTY BOUNDARY
▪▪▪	PROPOSED PIPE NETWORK
	EXISTING PIPE NETWORK
➤	SURFACE FLOW PATH

PROPOSED 800mm WIDTH FLOOD DRAIN
WITH BESPOKE GRATE COVER, DUCTILE
IRON GRATE TO COS SPECIFICATION

OSD TANK TO SYDNEY WATER REQUIREMENT
SSR : 24m³
PSD : 48 l/s

225mm Ø INLET PIPE TO OSD TANK

FILTERRA OUTLET CHAMBER. DUCTILE IRON
GRATE TO COS STANDARD

FILTERRA SHRUB PIT (3.5m2),
DETAIL REFER TO C204.

FILTERRA INLET CHAMBER. DUCTILE IRON GRATE
TO COS STANDARD

900X600 INFILL
GRATES (4X)

TRENCH DRAIN (BESPOKE DUCTILE IRON GRATES TO C.O.S.
PUBLIC DOMAIN SPECIFICATION).

300 Ø OVERFLOW PIPE

900X900 PIT DUCTILE IRON GRATE TO COS STANDARD,
REFER TO C203 FOR FURTHER DETAIL

NEW 300mm Ø RC PIPES CLASS 4

EXISTING KERB INLET PITS TO BE MAINTAINED.
REFER TO C203 FOR FURTHER DETAIL

CONNECTION TO EXISTING KERB INLET PITS, CONTRACTOR
TO APPLY APPROVAL FROM THE RELEVANT AUTHORITIES,
MAKE GOOD AND COMPLY TO RELEVANT STANDARDS.

FILTERRA OUTLET CHAMBER. DUCTILE IRON
GRATES TO COS STANDARD

NEW KERB INLET LINTEL PIT 1.8m. DUCTILE
IRON GRATES TO COS STANDARD

900X600 OVERFLOW PIT.
DUCTILE IRON GRATE TO COS
STANDARD

NEW 300mm Ø RC PIPES CLASS 4

NORTH

1 : 100-A1   1 : 200-A3

PUMP SUMP WITH TWIN SUBMISSIBLE PUMPS TO PROVIDE IRRIGATION TO GARDENS.

4.700

0.900

0.600

6.750

1.200

1.000

DOWNPIPES AND OTHER INCOMING STORMWATER PIPES SHALL BE CONNECTED TO THIS INLET PIT

FILTERRA SHRUB PIT TO MANUFACTURER DETAIL

SMALL PLANT SPECIES SUCH AS CAREX APPRESSA, DETAIL TO BE COMFIRMED BY FILTERRA SPECIALIST

UP

CUT-OFF 300mm WIDTH TRENCH DRAIN WITH BYCICLE AND HEEL SAFE BESPOKE GRATE TO PUBLIC DOMAIN SPECIFICATION

225mm Ø UPVC PIPE

CONCRETE, BRICK OR HDPE LINING TO MANUFACTURER DETAIL

225 Ø OUTLET UPVC PIPE FROM OSD TANK

300mm Ø INLET UPVC PIPE TO OSD TANK

2.500

0.450

1.500

WEIR AT TOP RL 23.445 TO DIVERT LOW FLOW INTO FILTERRA PIT AND PROVIDE SUFFICIENT COVER TO OVERFLOW PIPE. REFER TO C204 AND C401 FOR DETAIL

0.800

0.450

0.450

A

0.450

WEIR

1.060

0.300

0.450

1.060

0.600

0.600

0.900

A

300mm Ø OVERFLOW UPVC PIPE REFER TO C204

6.320

0.600

0.900

300 mm Ø OVERFLOW RCP CLASS 4

CONCRETE, BRICK OR HDPE LINING TO MANUFACTURER DETAIL

0.900

B

ELEC BOX

EXISTING PIPE INVERT AT IL22.59 FROM SURVEY DATA

NEW KERB INLET PIT (LINTEL 1.8M) REFER TO COS STANDARD DETAIL

NEW 300 Ø DISCHARGE RC PIPE CLASS 4

PROPOSED EXISTING PITS TO BE MAINTAINED. CONDITION OF EXISTING PITS WILL BE ASSESS BY SURVEYOR BEFORE APPLICATION FOR CONSTRUCTION CERTIFICATE TO DETERMINE IF THEY ARE REUSEABLE.

REMOVE EXISTING STORMWATER PIPE DUE TO INSUFFICIENT DEPTH. INSTALL NEW RCP 300 Ø CLASS 4, MAKE GOOD HACKING AND BACKFILLED WITH COMPACTED SAND

CHANNEL 0.5h

STORMWATER CHANNEL

LEGEND

PROPERTY BOUNDARY

PROPOSED PIPE NETWORK

EXISTING PIPE NETWORK

SURFACE FLOW PATH

B — B   PROFILE SECTIONS

WILLIAM LANE

1   0.5   0   1   2   3   4 m

1 : 50-A1   1 : 100-A3

All dimensions to be verified on site/s prior to commencement of on-site work and/ or off-site prefabrication. Figured dimension to be taken in preference to scaled dimensions. This drawing is copyright and remains the property of JHA Consulting Engineers. Reproduction in whole or part of these drawings without written consent constitutes an infringement of copyright.

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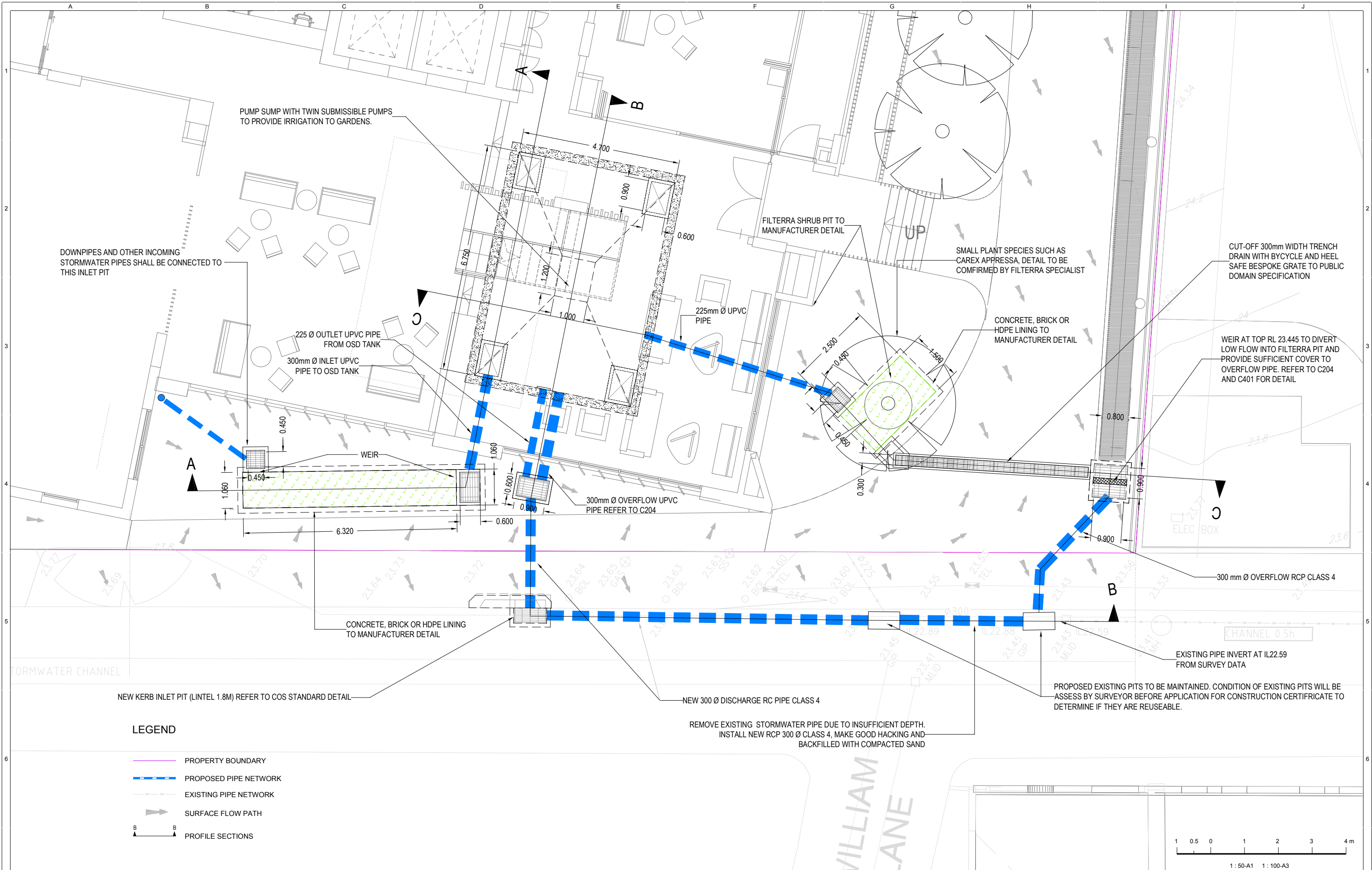general@jhaengineers.com.au
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PROJECT
WEE HUR REDFERN STUDENT VILLAGE
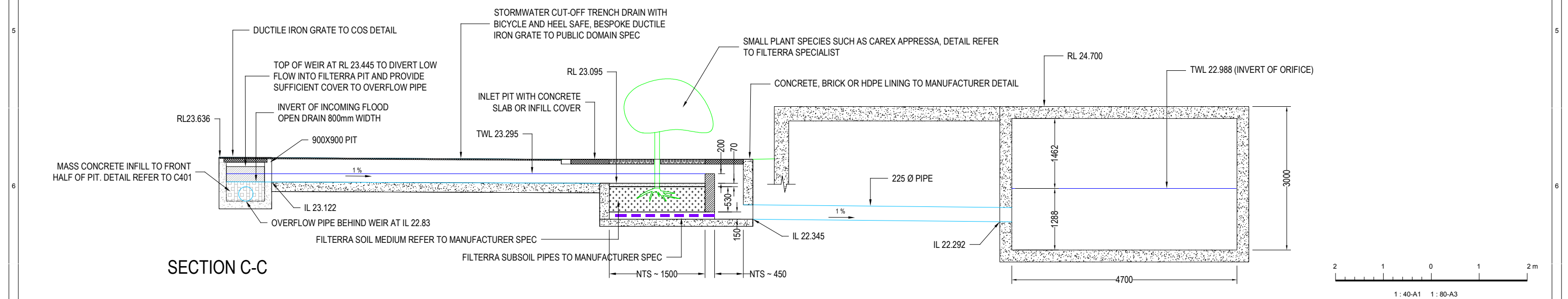13-23 GIBBONS STREET, REDFERN, NSW 2016

TITLE
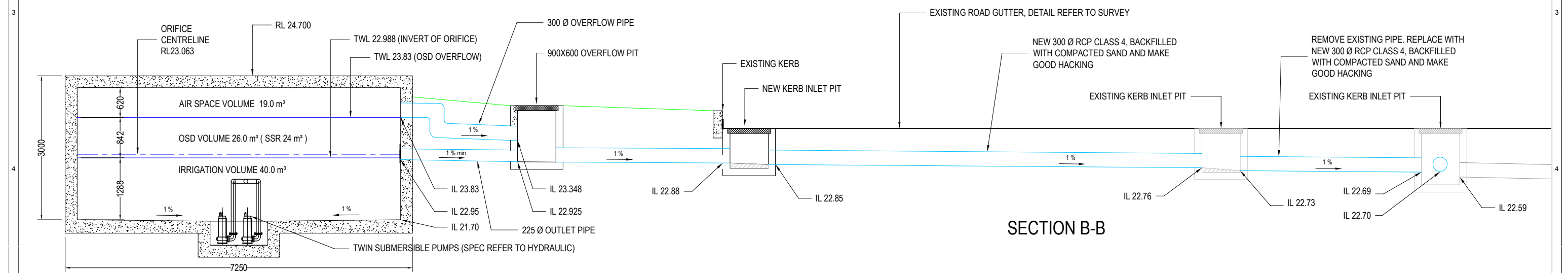STORMWATER SERVICES
GROUND LEVEL
OSD TANK DIMENSION
PIT AND PIPE DIMENSION

PRELIMINARY
NOT FOR CONSTRUCTION

		SCALE @ A1
DRAWN	J.S.	
CHECKED	J.S.	
APPROVED	J.S.	1:50
CREATED	08/19	
JOB No.		DRAWING No. REV
180391		C203 P7

SECTION A-A

INLET PIPE FROM ROOF (REFER TO HYDRAULIC FOR DETAIL)

FILTERRA SOIL MEDIUM REFER TO MANUFACTURER SPEC

FILTERRA PLANTS SPECIES REFER TO MANUFACTURER SPEC

CONCRETE, BRICK OR HDPE LINING TO MANUFACTURER DETAIL

TWL 23.938

WEIR AT RL23.938

IL 22.988

RL 24.700

TWL 22.988 (INVERT OF ORIFICE)

TWL 23.83 (OSD OVERFLOW)

AIR SPACE VOLUME 19.0 m³

OSD VOLUME 26.0 m³ (SSR 24 m³)

IRRIGATION VOLUME 40.0 m³

1 % min

UPVC 300 Ø

FILTERRA SUBSOIL PIPES TO MANUFACTURER SPEC

TWIN SUBMERSIBLE PUMPS (SPEC REFER TO HYDRAULIC)

1 %

70-200, 530, 150, 620, 842, 1288, 3000, 34, 250, 500, 1200, 7250

SECTION B-B

ORIFICE CENTRELINE RL23.063

RL 24.700

TWL 22.988 (INVERT OF ORIFICE)

TWL 23.83 (OSD OVERFLOW)

300 Ø OVERFLOW PIPE

900X600 OVERFLOW PIT

EXISTING ROAD GUTTER, DETAIL REFER TO SURVEY

NEW 300 Ø RCP CLASS 4, BACKFILLED WITH COMPACTED SAND AND MAKE GOOD HACKING

REMOVE EXISTING PIPE. REPLACE WITH NEW 300 Ø RCP CLASS 4, BACKFILLED WITH COMPACTED SAND AND MAKE GOOD HACKING

EXISTING KERB

NEW KERB INLET PIT

EXISTING KERB INLET PIT

EXISTING KERB INLET PIT

AIR SPACE VOLUME 19.0 m³

OSD VOLUME 26.0 m³ (SSR 24 m³)

IRRIGATION VOLUME 40.0 m³

1 % min

1 %

IL 23.83

IL 22.95

IL 21.70

IL 23.348

IL 22.925

225 Ø OUTLET PIPE

IL 22.88

IL 22.85

IL 22.76

IL 22.73

IL 22.69

IL 22.70

IL 22.59

TWIN SUBMERSIBLE PUMPS (SPEC REFER TO HYDRAULIC)

620, 842, 1288, 3000, 7250

SECTION C-C

DUCTILE IRON GRATE TO COS DETAIL

TOP OF WEIR AT RL 23.445 TO DIVERT LOW FLOW INTO FILTERRA PIT AND PROVIDE SUFFICIENT COVER TO OVERFLOW PIPE

INVERT OF INCOMING FLOOD OPEN DRAIN 800mm WIDTH

STORMWATER CUT-OFF TRENCH DRAIN WITH BICYCLE AND HEEL SAFE, BESPOKE DUCTILE IRON GRATE TO PUBLIC DOMAIN SPEC

INLET PIT WITH CONCRETE SLAB OR INFILL COVER

SMALL PLANT SPECIES SUCH AS CAREX APPRESSA, DETAIL REFER TO FILTERRA SPECIALIST

CONCRETE, BRICK OR HDPE LINING TO MANUFACTURER DETAIL

RL 23.095

RL 24.700

TWL 22.988 (INVERT OF ORIFICE)

RL23.636

TWL 23.295

900X900 PIT

MASS CONCRETE INFILL TO FRONT HALF OF PIT. DETAIL REFER TO C401

IL 23.122

OVERFLOW PIPE BEHIND WEIR AT IL 22.83

FILTERRA SOIL MEDIUM REFER TO MANUFACTURER SPEC

FILTERRA SUBSOIL PIPES TO MANUFACTURER SPEC

IL 22.345

225 Ø PIPE

IL 22.292

1 %

200, 70, 530, 150, 1462, 1288, 3000, NTS ~ 1500, NTS ~ 450, 4700

1 : 40-A1   1 : 80-A3

ORIFICE PLATE DETAIL
SCALE: NTS

- 225mmØ OUTLET PIPE BEHIND
- 6mm THICK STAINLESS STEEL ORIFICE PLATE
- FIX PLATE WITH 10mm Ø X 100mm LONG DYNABOLTS OR SIMILAR
- 225mm Ø OUTLET PIPE
- 150mm Ø ORIFICE
- 40
- 350
- 350
- 40
- SEAL BETWEEN ORIFICE PLATE AND PIT WALL WITH SILICONE TO PROVIDE WATERPROOF JOINT

DANGER
CONFINED SPACE
NO ENTRY WITHOUT
CONFINED SPACE
TRAINING

ORIFICE PLATE NOTES

1. HOLE IN ORIFICE PLATE TO BE PRECISION CUT WITH SHARP EDGES TO THE SPECIFIED DIAMETER.
2. ORIFICE PLATE TO BE PLACED CENTRALLY OVER THE OUTLET PIPE.
3. PLATE TO BE MADE FROM STAINLESS STEEL. HOT DIPPED GALVANISED OR OTHERS NOT ACCEPTABLE.
4. OUTLET PIPE TO BE CAST INTO THE WALL OF THE PIT.
5. HOLE IN PLATE TO BE CENTRALLY PLACED.

TRASH SCREEN NOTES

1. MAXIMESH SCREEN MUST BE PLACED SUCH THAT THE LONG AXIS OF THE OVAL SHAPED HOLES ARE ORIENTATED HORIZONTALLY WITH THE PROTRUDING LIP ANGLED UPWARDS AND FACING TOWARDS THE OUTLET
2. THE SCREEN IS TO BE FORMED BY WELDING TWO TRIANGULAR MAXIMESH (OR EQUIVALENT) PANELS TO A RECTANGULAR FRONT MAXIMESH PANEL (OR EQUIVALENT)

TRASH SCREEN DETAIL
SCALE: NTS

- STAINLESS STEEL BRACKET FIXED TO WALL WTIH DYNABOLTS
- 6mm THICK STAINLESS STEEL ORIFICE PLATE
- LYSAGHT' MAXIMESH RH3030 (HOT DIPPED GALVANISED) OR EQUIVALENT. FRONT, TOP, BOTTOM AND SIDES PANELS
- 600
- 500
- 200

TYPICAL FILTERRA LAYERS DETAIL
SCALE: NTS

- 70mm MULCH LAYER SPEC AND MAINTAINANCE TO MANUFACTURER DETAIL
- 530mm HIGH RATE FILTERRA BIO FILTRATION LAYER TO MANUFACTURER DETAIL
- PLANT SPECIES SUCH AS CAREX APPRESSA TO MANUFACTURER RECOMMENDATIONS
- 150mm DRAINAGE LAYER
- 65mm SUBSOIL PIPE TO MANUFACTURER RECOMMENDATION
- HEEL SAFE PIT COVER
- HEEL SAFE PIT COVER
- TWL AT MAJOR STORM EVENT OVERFLOW

Roof and hardstand - 998m² (100% Imp.) [Mixed]

Laneway and batters - 330m² (100% Imp.) [Mixed]

Ocean Protect Filterra garden - 6.5m²

Ocean Protect Filterra Tree pit- 3.5m²

MiscByPass-37m2 (100% imp) [Mixed]

Receiving Node

MUSIC-link

CITY OF SYDNEY

music link

Results

Parameter	Min	Max	Actual	Result
Other Nodes				
Receiving Nodes				
Receiving Node				
REPORT				
% Load Reduction	None	None	1.36	✓
GP % Load Reduction	90	None	97.3	✓
TN % Load Reduction	45	None	66.8	✓
TP % Load Reduction	65	None	85.3	✓
TSS % Load Reduction	85	None	88.8	✓
Source Nodes				
Urban Source Nodes				
Laneway and batters - 330m² (100% Imp.)				
AREA				
Area Impervious (ha)	None	None	0.033	✓
Area Pervious (ha)	None	None	0	✓
Total Area (ha)	None	None	0.033	✓

Next Steps

Create Report

TOP OF WEIR AT RL 23.445 TO ALLOW LOW FLOW DRAINING TO FILTERRA PIT AND PROVIDE SUFFICIENT COVER TO OVERFLOW PIPE 300Ø

REMOVE EXISTING RETAINING WALL AT BOUNDARY

900X900 PIT WITH DUCTILE IRON GRATE AT RL 23.636

CREST OF LANEWAY AT BOUNDARY

TWL 23.295

CONNECT 300Ø RCP TO EXISTING KERB INLET PIT AT IL 22.70 AND MAKE GOOD. CONTRACTOR TO APPLY PERMIT FROM LOCAL AUTHORITIES AND PAY THE RELEVANT FEES.

TRENCH DRAIN INVERT IL 23.122

BASE RL 22.83

HORIZONTAL CURVE DATA

VERTICAL GEOMETRY GRADE — -2.56% — -32.17% -3% -3%
VERTICAL GRADE LENGTH — 33.438m — 0.9m 2.497m 1.92m
VERTICAL CURVE LENGTH
VERTICAL CURVE RADIUS

DATUM 16.0

LANEWAY SURFACE LEVEL	24.033	24.082	24.131	24.181	24.161	24.121	24.081	24.041	24.001	23.961	23.921	23.881	23.841	23.801	23.756	23.712	23.668	23.636	23.641	23.645	23.653	23.579	23.573
DRAIN DEPTH ROAD VS DRAIN	-0.055	-0.155	-0.255	-0.356	-0.388	-0.399	-0.410	-0.421	-0.433	-0.444	-0.455	-0.466	-0.477	-0.488	-0.495	-0.502	-0.509	-0.514	-0.808	-0.862	-0.895	-0.857	-0.873
FLOOD DRAIN INVERT LEVEL	23.978	23.927	23.876	23.825	23.774	23.722	23.671	23.620	23.569	23.517	23.466	23.415	23.364	23.313	23.261	23.210	23.159	23.122	22.833	22.783	22.758	22.723	22.700
EXISTING LEVEL	24.178	24.570	24.829	24.782	24.703	24.709	24.662	24.569	24.485	24.432	24.391	24.369	24.334	24.245	23.986	23.838	23.771	23.250	23.370	23.533	23.549	23.533	23.554
CHAINAGE	0.000	2.000	4.000	6.000	8.000	10.000	12.000	14.000	16.000	18.000	20.000	22.000	24.000	26.000	28.000	30.000	32.000	33.438	34.338	36.000	36.835	38.000	38.755

LANEWAY INVERT

WILLIAM LANE

NORTH

192°59'0" L34.338

WILLIAM LANE

2 1 0 2 4 6 8 m

1 : 100-A1   1 : 200-A3

Filterra®

Stormwater Bio-retention Filtration System

Our waterways. Our future.

Stormwater360
AUSTRALIA

Filtration and biological treatment in one system

Filterra
Bioretention Systems

Stormwater management regulations such as Water Sensitive Urban Design (WSUD) and Green Infrastructure (GI) have proliferated throughout Europe, North America and Australia.

Implementing WSUD and GI in urban environments is challenging as they often require a large footprint. That doesn't mean WSUD is not possible, it just means the solution may take a more enqineered form. Stormwater360 has addressed this need by developing a unique solution - the Filterra Bioretention System.

What is Filterra?

Filterra is an engineered biofiltration device with components that make it similar to bioretention in pollutant removal and application, but has been optimised for high volume/flow treatment in a compact system. Its small footprint allows Filterra to be used on highly developed sites such as landscaped areas, parking lots, and streetscapes. Filterra is adaptable and can be used alone or in combination with other treatment technologies such as EnviroPod or StormFilter.

How Filterra Works?

Stormwater runoff enters the Filterra system through a kerb-inlet opening and flows through a specially designed filter media mixture contained in a landscaped modular container. The biofiltration media captures and immobilises pollutants; some of these pollutants are then decomposed, volatilised and incorporated into the biomass of the Filterra system's micro/macro fauna and flora. Stormwater runoff flows through the media and into an underdrain system at the bottom of the container, where the treated water is

discharged. In areas where runoff reduction and infiltration are mandated or desirable, Filterra can be paired with other Stormwater360 products such as ChamberMaxx to provide even greater alignment with WSUD/GI goals.

Features and Benefits

1 **Best Value**

Filterra offers the most cost effective stormwater treatment system, featuring low cost, easy installation and simple maintenance.

2 **Aesthetics**

Landscaping enhances the appearance of your site making it more attractive while removing pollutants.

3 **Maintenance**

Maintenance is simple and safe (no confined space access), and the first year is FREE with the purchase of every unit.

4 **Versatile**

Filterra is ideal for both new construction and urban retrofits in both private and public sites as well as:

- **Streetscapes**
- **Parking lots**
- **Highways**
- **Urban settings**
- **Subdivisions**
- **Industrial settings**

Filterra® Configurations
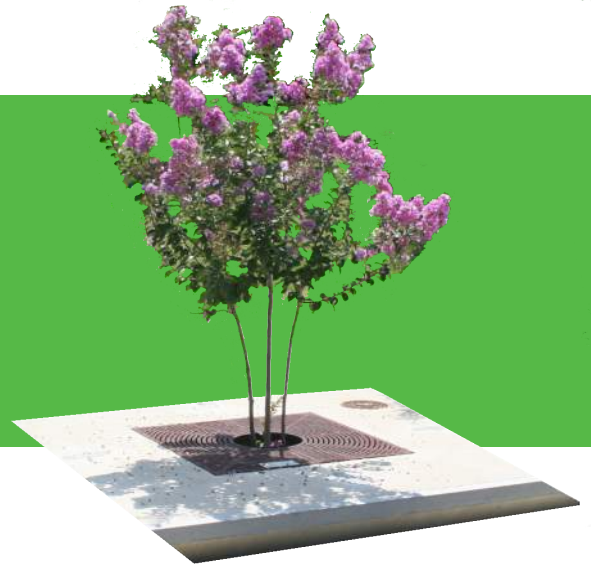
Filterra is offered in multiple configurations to meet site specific needs. These configurations make Filterra a versatile yet effective stormwater treatment option with a low life-cycle cost. For the first time, there is a proprietary WSUD treatment technology for publicly located and owned assets.

Filterra Internal Bypass - Kerb

The Filterra Internal Bypass – Kerb, incorporates a kerb inlet treatment chamber and internal high flow bypass in a single structure. This eliminates the need for a separate bypass structure and enables placement on grade or in a "sag" or "sump" condition.

Filterra Internal Bypass - Pipe

The Filterra Internal Bypass – Pipe, treats stormwater runoff from rooftops or other sub-grade sources such as area drains. Higher flows bypass the biofiltration treatment system via an overflow/bypass pipe design.

Filterra - Street Tree

The Filterra Street Tree accommodates trees larger than the standard small-medium-sized trees used in standard Filterra units. These larger trees can provide benefits to site landscape designs on canopy cover, tree count, or percentage of green area.

Filterra - Sediment Chamber

The Filterra Sediment Chamber includes a pre-treatment chamber that provides settling for debris and sediment, meeting water quality volume temporary hold requirements in some jurisdictions, and provides a treatment-train feature to a standard Filterra.

Filterra - Recessed Top

The Filterra Recessed Top allows for a seamless integration of Filterra into the landscape design with pavers, mulch, sod, or even architectural concrete.

Filterra - StormFilter Overflow

The Filterra StormFilter overflow combines the standard Filterra Internal Bypass System with a StormFilter cartridge configured to treat the internal overflow of stormwater during higher flows.

Filterra® - Regulatory Approvals

Based on more than 20 years of research and development, testing and field monitoring, Filterra's performance has been recognised by some of North America's most significant regulatory agencies, including the states of Washington, Virginia, Maryland and New Jersey, the District of Columbia, the Texas Commission on Environmental Quality and the Atlanta (GA) Regional Commission.

Highlights regarding these approvals include:

• Granted ESD (Environmental Site Design) status by the state of Maryland Department of the Environment (MDE).

• General Use Level Designation (GULD) - approved for ALL pollutants of concern with the state of Washington Department of Ecology (WA-Ecology) with (2) Technology Assessment Protocol-Ecology (TAPE) field tests.

• Third-party notationally recognised field/lab tests completed: (1) Technology Acceptance Reciprocity Partnership (TARP), (2) Technology Assessment Protocol-Ecology (TAPE), (1) New Jersey Corporation of Advanced Technology (NJCAT) and (1) North Carolina - Department of Environment and Natural Recourses (NC-DENR).
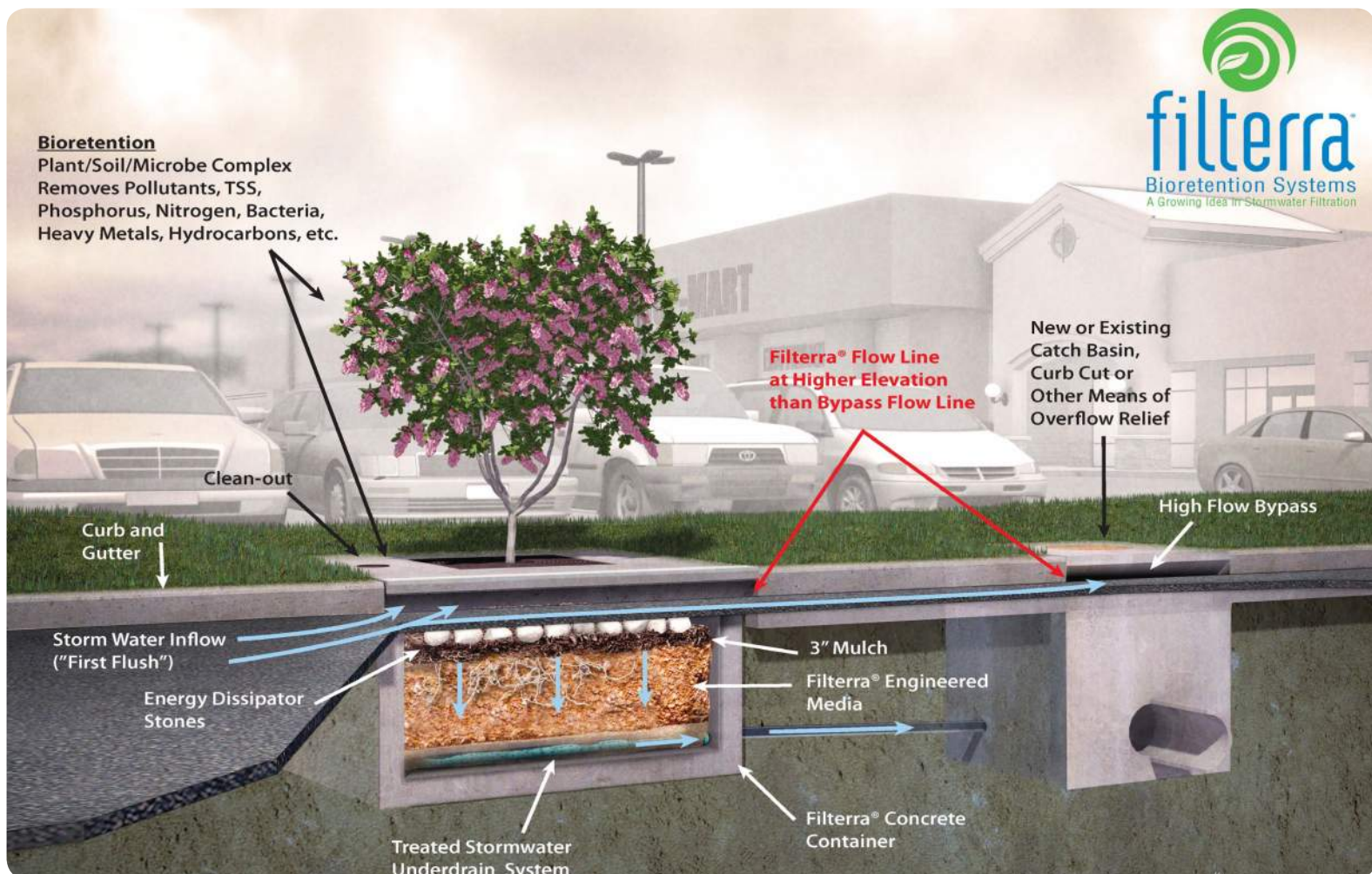
Filterra® - In the Field

We make it easy! The Filterra system is delivered to the job site with all components except plant and mulch.

Filterra – Installation

• Bioretention system sealed from construction sediment.

• Contractor off-loads top and vault separately.

• Set vault to grade on suitable subgrade, pipe up, backfill, set top.

Filterra – Activation

• Contractors: Do NOT remove throat plate nor tree grate covers.

• Vegetation selection guidance based on your climate zone.

• Stormwater360 certified providers conduct on-site activation with installation of mulch and plant.

Filterra – Maintenance

• The first year of maintenance is included with every system.

• Maintenance is low-cost, low-tech and simple:

　　» Remove trash, sediment, and mulch.

　　» Replace with a fresh layer of 3" of mulch.

　　» Can be done by landscape contractor.

　　» No confined space entry.

Sizing Procedure

1) Contact Stormwater360 Engineering Department.

2) Determine Filterra locations (with effective bypass) in accordance with placement guidelines.

3) Determine contributing drainage areas to each Filterra.

4) For best results, get us involved early in the design process. Please send your completed project information form along with plans to Stormwater360 for placement and application review.

Placement Review

Because we want your project with Filterra to be a great success, we respectfully require that each Filterra project be reviewed by our engineering staff. This review is mandatory, as proper placement ensures you of the most efficient and cost effective solution, as well as optimum performance and minimal maintenance.

Proper Placement

1) Do not place in a sump condition. The Standard Filterra cannot be used as a standalone inlet - it will need effective bypass during higher intensity rainfall events.

2) Do not direct surface flow to Filterra in a "head on" configuration. The ideal way to load Filterra to prevent system damage is a cross linear flow (left-to-right or right-to-left) in the gutter in front of the Filterra. This prevents the re-suspension and possible exit of the trapped pollutants, mulch, and engineered media from within Filterra during the high flow bypass stage.

3) Refer to example scenarios from Stormwater360.

Design Assistance

Please contact Stormwater360 Design Team on 1300 354 722 or design@stormwater360.com.au.

Stormwater360 supplies and maintains
a complete range of filtration,
hydrodynamic separation, screening and
oil/water separation technologies.

Call 1300 354 722

Filterra® Bioretention System Water Quality and Hydrologic Field-Scale Performance Evaluation

Fayetteville Amtrak Station

472 Hay Street

Fayetteville, NC

Prepared for:

Contech Engineered Solutions
9025 Centre Pointe Drive
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Prepared by:

Andrew Anderson, *Extension Associate*
Alessandra Smolek, *Graduate Research Assistant*

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Raleigh, NC 27695

August 23, 2015

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Executive Summary

Filterra® Bioretention Systems are biofilters offering a unique version of the typical flow-through filter by coupling high volume treatment with an engineered bioretention media (140 in/hr design infiltration rate) (Lenth et al. 2010). The systems are viable options for retrofitting stormwater infrastructure in ultra-urban areas where space is of concern. The purpose of this study was to quantify the hydrologic and water quality treatment capabilities of a standalone Filterra® device to obtain performance data that supports approval by the North Carolina Department of Environmental and Natural Resources (NCDENR). This monitoring was performed in accordance with Preliminary Evaluation Period (PEP) guidelines described in the 2007 NCDENR Stormwater BMP Manual and the Quality Assurance Project Plan (NC State 2013) previously submitted to NCDENR.

North Carolina State University conducted a third-party analysis of the sediment, nutrient, and metals removal performance and hydrologic mitigation of a Filterra® Bioretention System ("Filterra"). The NCDENR total suspended sediment (TSS) design criterion is 85% removal. Another widely-implemented protocol for approval of emergent stormwater technologies is the state of Washington's Technology Assessment Protocol – Ecology (WSDE, 2011). TAPE designates a basic treatment target of (a) TSS removal greater than 80% when influent TSS range: > 200 mg/L, (b) TSS removal greater than or equal to 80% when influent TSS range is 100-200 mg/L or (c) effluent TSS concentration of less than 20 mg/L when influent TSS range: 20 – 100 mg/L. Once this basic criterion is met, additional treatment for total phosphorus may be awarded if removal of TP is greater than or equal to 50% for influent concentrations between 0.1 and 0.5 mg/L. Comparisons to both these protocols were made.

Results show the monitored Filterra® system reduced median peak flow by 56% for storms monitored in the study (0.10 to nearly 5 inches in depth). During the study period (2013-2014), statistically-significant bypass did not occur before 0.69 inches (Figure 5 and Table 15). When plotting the observed rainfall intensity vs. site peak outflow against the theoretical peak flows from the Rational equation's pre- and post-development conditions, the Filterra® device nearly mimics the pre-development site peak (Figure 10 and Figure 7). Additionally 72% of inflow volume was treated by the Filterra®, while the remainder was either bypass flow (22%) or a combination of soil storage and/or instrument error (6%) (see Hydrology

section). Data from Smolek et al. (2015) show that the expected overflow from a traditional stormwater BMP following NCDENR design guidance during an average year, such as a wetland or wet pond, is consistent with the overflow percent seen by the Filterra® in our study, suggesting that the Filterra® behaved similarly to widely-used and approved BMPs in North Carolina (Figure 4).

Over a 22-month monitoring period, the Filterra® significantly reduced total suspended solids concentrations with an efficiency ratio of 96%, a cumulative load reduction of 76%, and a median storm-by-storm TSS load reduction of 80%. Another sediment metric, Suspended Sediment Concentration (SSC), was measured, resulting in a 97% significant efficiency ratio, a 77% cumulative load reduction, and a 77% median storm-by-storm load reduction. The 95% confidence interval of the mean TSS removal on a per storm event basis was determined to be 90% - 94%, satisfying both NCDENR and TAPE criteria.

Total phosphorus concentrations were significantly reduced with an efficiency ratio of 64%, a cumulative load reduction of 54% and a 63% median storm-by-storm load reduction. TAPE criteria for accreditation of TP removal require 50% TP removal when influent concentrations are between 0.1-0.5 mg/L in order to account for irreducible concentrations. The mean storm-by-storm event mean concentration reduction of the 16 TAPE-qualified events was 66% with the 95% confidence interval of the mean TP removal ranging from 57% - 75%, satisfying the TAPE criteria. Overall cumulative percent loading reduction was 54%, indicating excellent removal of phosphorus that is on par and/or above the 45% pollutant removal credit awarded by NCDENR for bioretention without internal water storage (NCDENR 2009). Concentrations of both total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) were very low both entering and leaving the system (below what is expected on an urban watershed).

While total nitrogen is not a pollutant targeted for TAPE approval, total nitrogen concentrations were significantly reduced with an efficiency ratio of 39%, a cumulative load reduction of 39% and a 45% median storm-by-storm load reduction. Although total nitrogen was reduced, likely due to filtration of particulate-bound N, nitrate export was witnessed. This finding was expected, and is typical in systems that do not have apparent mechanisms for denitrification. Total zinc concentrations were also significantly reduced with an

efficiency ratio of 69%. For the Filterra® system as a whole, cumulative percent load reductions for TSS, TP and TN were 76%, 54% and 39%, respectively. When only storms that did not produce bypass were considered, the cumulative percent load reduction increased to 96%, 75%, and 45% for TSS, TP and TN, respectively.

When looking at effluent concentrations as a benchmark, water quality of discharged and treated stormwater was generally lower than "good" and "excellent" water quality thresholds in the literature. The median effluent TP concentration of 0.038 mg/L met the 0.06 mg/L "excellent" threshold for over 80% of all measured events. The 0.53 mg/L TN median effluent concentration meant that the "excellent" benthic threshold of 0.69 mg/L determined for this specific eco-region was met or exceeded for 65% of measured events.

Future studies with higher nutrient concentrations entering the Filterra® (perhaps from watersheds with a high gross solids and leaf litter loading) will provide a better assessment of soluble phosphorus species, since nutrient influent concentrations for this site were below what is typically seen on urbanized watersheds.

Project Overview

North Carolina State University ("NC State") monitored a Filterra® Bioretention System in Fayetteville, North Carolina (Table 1, Figure 1). The existing parking lot of an Amtrak[TM] train station was retrofitted with a 6- by 4- foot Filterra® system, which treats 0.25 acres of impervious asphalt and concrete catchment (Figure 2). The system was installed in September of 2012 and activated October 2nd, 2012 by Contech Engineered Solutions, LLC (then Ameriscast/Filterra Bioretention Systems) staff.
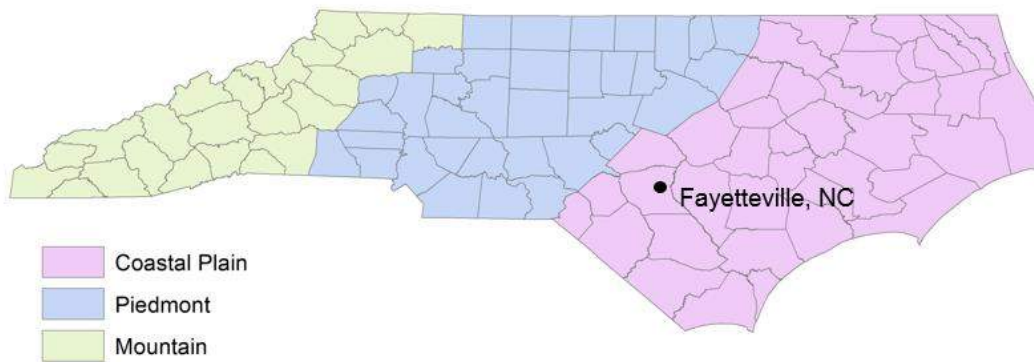
Figure 1. Location of project site in North Carolina.

Figure 2. Location of Filterra® at city-owned Amtrak^{TM} parking lot in Fayetteville.

Filterra® System Components

The Filterra® system is a high filtration rate, small unit storage volume stormwater control measure that uses proprietary bioretention filtration media topped with mulch in combination with a planted tree species. For this project, a crape myrtle *(Lagerstroemia)* was installed as the tree genus (Figure 21). The tree frame and grate cast in the top slab of the concrete structure sits at the top-of-curb elevation, below which is a headspace. Water conveyed via curb and gutter flow enters the system through a six foot wide open-throated curb inlet and is

conveyed at a design infiltration rate of 140 inches per hour through a media bed depth of 21 inches. Similar to conventional bioretention, an underdrain surrounded by washed aggregate drains treated stormwater to the existing drainage infrastructure.

Filterra® Maintenance Procedures

Routine, semi-annual maintenance is recommended for the Filterra® system. Maintenance procedures are described in the Filterra® Installation, Operation, and Maintenance Manual (see appendix). This manual and a one-year maintenance plan is provided by Contech Engineered Solutions. An extended maintenance service contract or maintenance training based on this manual for those who wish to perform their own maintenance is also offered by Contech Engineered Systems. Maintenance records indicate the Filterra® system at this study site was performed on May 16th, 2013 and December 17th, 2013, and October 20th, 2014.

Table 1. Site Details of the Filterra Monitoring Project

Site Address	472 Hay St, Fayetteville, NC 28301
Geographic coordinates	35.055968, -78.884026
River Basin (Hydrologic Unit Code)	Cape Fear (030300040704)
Sub-Basin	Upper Cape Fear
Sub-Watershed	Cross Creek
Predominant soil types	Sand / Sandy loam

Filterra® Sizing

Filterra® sizing utilizes a conservative design flow rate of 140 inches per hour (Geosyntec, 2008). To design the Filterra® to treat the necessary (1" or 1.5") water quality volume, Withers and Ravenel (2008) conducted an engineering analysis that developed sizing for Filterra in North Carolina. Through this analysis, the maximum size drainage area to each size of Filterra® unit was determined. Sizing charts were developed for both the 1" and 1.5" water quality treatment goals required for the state of North Carolina using a "worst case" 100% impervious drainage area.

Engineers for projects in North Carolina will be able to use these sizing charts to choose the correct size of Filterra® unit based on their location within the state and the size of drainage area going to the unit. Contech offers engineering support and review to specifying engineers to help with sizing and proper placement. As a condition of permit approval, Contech proposes to the State of North Carolina that a plan approval letter from Contech Engineered Solutions be required for all projects. This ensures that Contech provides a QA/QC check on the engineer's design and would prevent misuse of the product. Contech routinely provides this service to other parts of the country where the state or other approving authority has required it as part of the condition of permitted use.

Literature Review of Stormwater Filtration in North Carolina

Bioretention, also known as rain gardens, biofilters, and bio-infiltration devices, is an engineered stormwater control measure that provides soil and vegetation treatment of stormwater runoff. Traditional bioretention generally has 2-3 feet of engineered media replacing the *in-situ* native soil, with 6 to 12 inches of vegetated ponding area to allow temporary storage of stormwater before it infiltrates through the media, finally discharging through an underdrain system and/or exfiltrating into the sub-soil. In North Carolina, bioretention engineered media must meet composition specifications. The media must be 85-88% sand, 8-12% "fines" (clay and silt), and 3-5% organic matter (by volume). Drawdown or infiltration from the ponding zone into the media must be 1-2 inches per hour, resulting in a general 24 to 48 hour drawdown period.

Studies have been conducted on bioretention looking at its performance in removing nitrogen, phosphorus, sediment, heavy metals, and bacteria. These pollutants exist in both the solid and aqueous phases. Dissolved pollutants in stormwater typically exist as specific forms due to solubility, pH, and other chemical constraints present in the stormwater environment. Dissolved phosphorus is generally in the form of inorganic orthophosphate, while dissolved nitrogen is generally nitrate and nitrite ($NO_{3/2}$) and ammonia and ammonium ($NH_{3/4}$), the latter generally being dominated by NH_4 at typical stormwater pH values (Pitt et al, 1995). Dissolved pollutant removal in "traditional" bioretention occurs through transformation by

adsorption, precipitation, ion exchange, and biological processes, with many design variations of the media and/or drainage configuration to target specific pollutants (Davis et al., 2009). Many pollutants are associated with sediment, allowing for physical processes like sedimentation and filtration to remove them from the stormwater pollutant stream. Table 2 shows common pollutants targeted in bioretention, their typical removal efficiencies, and mechanisms that result in removal.

Table 2. Summary of mechanisms of pollutant removal supported by published field studies on bioretention performance.

Parameter of Interest	Load reduction (%)	Mechanism of removal	Factors affecting removal
Metals	54-99%*	Sorption Filtration Plant uptake Hydrolysis Precipitation	Media characteristics[bdfg] Flow rate[cf] Vegetation[l] Age/maturity of facility[c] Interaction with metal-emitting material[cd]
Phosphorus	52-99%†	Filtration Sorption Plant uptake	Media characteristics[adefghk] Saturation of soil[fh] Rooting depth[gl]
Nitrogen	30-99%¥	Microbial metabolism Plant uptake Denitrification	See Phosphorus
Total suspended solids	54-99%	Filtration Sedimentation	Flow rate[fik] Clogging of media[i] Media particle size[ik]

*: Zn only; †: total phosphorus (TP); ¥: total nitrogen (TN)

The data in Table 1 are based on the following studies: **a.** Davis et al. (2009), **b.** Davis (2007), **c.** Davis et al. (2003), **d.** Dietz & Clausen (2006), **e.** Dietz & Clausen (2005), **f.** Hatt et al. (2009), **g.** Hunt et al. (2012), **h.** Hunt et al. (2006), **i.** Li & Davis (2008), **j.** O'Reilly et al. (2012), **k.** O'Neill & Davis (2012), **l.** Passeport et al. (2009), **m.** Sun & Davis (2007)

Sediment removal is generally high in bioretention, since the surface of the systems can filter and settle out solids in stormwater (Table 2). The top mulch layer has been shown to filter most of the TSS in the runoff (Hsieh and Davis, 2005). Bioretention filter media are generally clogging-limited (rather than breakthrough limited), thus warranting suggestions

that the top 20-cm of media depth is the most crucial for maintenance purposes in insuring long-term removal of urban particles (Li and Davis, 2008).

Phosphorus in stormwater is generally considered to be about 55% bound to particles (Erickson et al., 2012). Phosphorus bound to sediment can be removed via filtration and sedimentation. Dissolved phosphorus is a more challenging constituent to remove in traditional bioretention due to complex chemical interactions in the media. Phosphorus has been known to leach due to the high background P in the media itself (often measured vis-à-vis the P-index). Organic matter is often correlated with phosphorus leaching (Bratieres et al. 2008). Media with low P indices and high cation exchange capacities are recommended (Hunt et al. 2006). Zhang et al. (2008) found 66-85% mass removal of dissolved phosphorus with fly ash amendment in bioretention. A conventional field cell in NC showed 14-91% dissolved phosphorus removal (Hunt and Line, 2009). Two internal water storage-modified bioretention cells showed 52 and 77% ortho-phosphate removal efficiencies (1.5 and 2.5 feet deep IWS zones, respectively). Vegetation has been suggested as an important way to remove orthophosphate as well, with 97-100% removal of Ortho-P seen in vegetated mesocosms vs 48-100% for non-vegetated (Henderson et al. 2007).

Nitrate is a challenging constituent to remove in stormwater because of its high solubility and low media sorbtive capability. In aerobic environments, nitrate will not be the primary electron recipient because of the availability of the much more electronegative constituent oxygen (O_2). To exacerbate the removal challenges, aerobic environments in soil media often promote nitrification, which is the conversion of ammonia/ammonium to nitrite (and eventually nitrate) by ammonia-oxidizing bacteria. Thus, aerobic bioretention conditions, which are common in flow-through media in bioretention, have been known to *add* nitrate-nitrogen rather than remove it. Only under anoxic conditions can nitrate be significantly converted to nitrogen gas (N_2), which is released from the system to the atmosphere. This occurs through the design variants seen in some bioretention cells commonly known as an upturned elbow, anoxic zone, or internal water storage zone. Table 3 (from LeFevre et al., 2015) shows the various studies of bioretention removal of nitrate under both conventional (no anoxic zone) and modified (internal water storage zones) specifications.

Table 3. Summary of nitrate removal studies for bioretention in the Atlantic region

Study	Study Location	Nitrate mass reduction (negative indicates export)	Drainage configuration
Davis et al. (2001)	Lab (MD, USA)	-204 to 24%	Conventional
Dietz and Clausen (2005)	Field (CT, USA)	35%	Conventional
Hsieh and Davis (2005a)	Lab (MD, USA)	1-43%	Conventional
Hsieh and Davis (2005b)	Lab (MD, USA)	-64 to 19%	Conventional
Davis et al. (2006)	Lab, field (MD)	<20%	Conventional
Davis (2007)	Field (MD, USA)	90%	Conventional
Hsieh et. al. (2007)	Lab (MD, USA)	-21% to 41%	Conventional
Line and Hunt (2009)	Field (NC, USA)	-766 to -26%	Conventional
Passeport et. al. (2009)	Field (NC, USA)	1-43%	Modified IWS
Diez and Clausen (2006)	Field (CT, USA)	36-87%	Modified IWS
Kim et al. (2003)	Lab (MD, USA)	80%	Modified IWS

Heavy metals in stormwater runoff generally come from anthropogenic sources. Major sources include metal roofing, tire wear, catalytic converters, brake linings (copper), and galvanized steel (Davis et al., 2001). In bioretention, most metal removal occurs in the top 2 to 9 inches of media and mulch (Davis et al, 2003). The following table adapted from Fears (2014) summarizes load reductions of heavy metals in traditional bioretention.

Table 4. Summary of Heavy Metal Performance of Various Field-scale Bioretention Studies (Fears, 2014).

Study	Location	Source of Runoff	Events Monitored (#)	Load Reduction (%)* Cu	Pb	Zn
Hatt et al., 2009	Melbourne, Aus.	Multi-level parking deck	7	67	80	84
Li & Davis, 2009	College Park, MD	Parking lot & roadway	15	60	65	83
	Silver Spring, MD	Parking lot	8	100	96[†]	100

Davis,	College Park, MD-Cell A	Parking lot (asphalt)	12	83	88	54[¥]
2007	College Park, MD-Cell B	Parking lot (asphalt)	12	77	84	69
Hunt et al., 2006	Greensboro, NC	Parking lot	11	99	81	98

*: Average load reduction reported except for Li & Davis, 2009 (median load reduction reported)
†: 15 events monitored
¥: One outlier removed

Based on research, feasibility, state water quality goals, and engineering judgement, North Carolina credits bioretention based on design variants outlined in Table 5 below. Lack of internal water storage results in lower nitrogen credit due to (a) inability to denitrify nitrate and (b) internal water storage results in larger volume reduction, and hence a larger pollutant mass reduction.

Table 5. Credit given to bioretention in North Carolina (Source: NCDENR BMP Manual)

Site and Design Specification	Analyte	Credit
No Internal Water Storage	Total Suspended Solids	85%
	Total Nitrogen	35%
	Total Phosphorus	45%
With IWS - Coastal Plain & Sand Hills	Total Suspended Solids	85%
	Total Nitrogen	60%
	Total Phosphorus	60%
With IWS – Piedmont & Mountains	Total Suspended Solids	85%
	Total Nitrogen	40%
	Total Phosphorus	45%

Site Description

The study site is an Amtrak[TM] train station located at 472 Hay Street in Fayetteville, North Carolina, 28301 (Figure 1). Fayetteville is a city located in the coastal plain of North Carolina, and receives 41.3 inches of rainfall per year (NOAA Station 316891). The site is located in 12-digit hydrologic unit code 030300040704 in the Cape Fear basin (9,700 mi^2), Upper Cape Fear sub-basin (1,630 mi^2), and the Cross Creek watershed. The region is comprised of predominately sandy or sandy loam soils.

The drainage area for the Filterra® system consists of overland and gutter channel flow from 0.25 acres of impervious asphalt parking lot through a modified curb cut (Figure 3). Due to

additional impervious area not thought to originally drain to the system (measured via a Total station survey and confirmed by observing runoff on-site), the Filterra® ended up being slightly undersized. The original survey did not consider a small area of impervious that was actually contributing to the system. The maximum impervious drainage area for the 6-foot by 4-foot system installed in Fayetteville is 0.21 acres according to the Filterra® sizing chart for the Piedmont/Sandhills region (1" design storm).

Figure 3. Filterra® at city-owned Amtrak^{TM} parking lot in Fayetteville.

Data Collection

Automated, flow-proportional water quality samplers were installed to collect influent and effluent aliquots (minimum 10) for the Filterra® device, and were completely powered by solar-charged by 12-volt marine batteries. All rainfall at the site was measured using a 0.01-inch resolution tipping-bucket rain gauge affixed approximately 6 feet above the ground (Davis Instruments, Hayward, California). To obtain flow-weighted composite samples for each storm event, runoff was routed to the influent sampling location into a sharp-crested compound weir flow-measuring device (Figure 22). The weir contained a stilling area for water to pond and spill over the weir, which allowed measuring flow proportional to water

head. A bubbler was affixed to the bottom of the stilling area before the weir to measure water head, and was connected to an ISCO 6712 automated sampler (Teledyne-Isco, Lincoln, Nebraska). A sample tube was also placed in this collection area to draw water quality aliquots for laboratory analysis at intervals that were proportional to the flow passing over the weir. Effluent flow was measured by two methods: (1) Prior to September 11, 2013, effluent flow was measured using an area-velocity flow meter installed in the 4-inch diameter pipe draining the Filterra, (2) After September 11, 2013, the 4-inch pipe was fitted with a Cipoletti-style weir and flow rate was continuously monitored by a bubbler placed just upstream of the weir. The area-velocity meter relied on ultrasonic pulses to determine flow velocity, which could then be converted to flow rate given water depth and pipe geometry. The primary measuring device was changed due to technical difficulties experienced during the fall of 2013. Despite this, flow-proportional sampling was maintained at all times during the study. Both flow measurement devices were relayed to the same ISCO 6712 automated sampler for flow-proportional aliquot sampling.

All flows not treated by the Filterra® were measured using an 8-inch diameter PVC bypass pipe installed in the curb island just downslope of the Filterra (Figure 20). The pipe upstream invert was flush with the existing pavement so as to immediately register bypass flow. A stand-alone bubbler was placed halfway down the pipe at its invert. All head measurements were converted to flow rate using the Manning's equation for open-channel flow using the pipe geometry, a roughness coefficient, and head as inputs.

Table 6. Equipment used for monitoring at various locations of the Filterra System

Measurement	Equipment	Qty.
Water velocity	ISCO® 750 Area Velocity Flow Module	1
Water head	ISCO® 730 Bubbler Module	3
Sample collection and storage	ISCO® 6712 Full-Size Portable Sampler	2
Head-to-flow Relationship (in)	Sharp-crested compound v-notch + rectangular weir	1
Head-to-flow Relationship (out)	Cipolleti-style weir	1
Rainfall	Davis Instruments 0.01-inch precision tipping bucket rain gauge ("Rain Collector" model)	1

Water quality samples were tested for event mean concentrations of total suspended solids (TSS), suspended sediment concentration (SSC), total ammoniacal nitrogen (TAN), nitrate/nitrite-nitrogen ($NO_{2,3}$-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), total copper (Cu), dissolved copper, total zinc (Zn), and dissolved zinc. A summary of laboratory methods and handling for all analytes is shown below.

Table 7. Summary of water quality parameters tested.

Analyte	Test method	Maximum Hold time	Method detection limit (mg/L)	Laboratory
TSS	EPA S.M. 2540D	7 d	1.0	ENCO Laboratories, Inc. (Cary, NC)
SSC	ASTM D-3977	7 d		NCSU Center for Applied Aq. Ecology (Raleigh, NC)
PSD	Laser diffraction	7 d		NCSU Dep. Of Marine, Earth, and Atm. Sciences
TKN	EPA 351.2	28 d	0.26	ENCO Laboratories, Inc. (Cary, NC)
$NO_{2,3}$-N	EPA 353.2	7 d	0.041	ENCO Laboratories, Inc. (Cary, NC)
TAN	EPA 350.1	28 d	0.045	ENCO Laboratories, Inc. (Cary, NC)
TN	TN = TKN+ $NO_{2,3}$-N	N/A	N/A	ENCO Laboratories, Inc. (Cary, NC)
TP	EPA 365.4	28 d	0.025	ENCO Laboratories, Inc. (Cary, NC)
TDP	EPA 365.4	28 d	0.025	ENCO Laboratories, Inc. (Cary, NC)
SRP	SM 4500 PF F-1999	48 h	0.16	ENCO Laboratories, Inc. (Cary, NC)
Cu	EPA 200.8	6 mo	0.002	NCDENR DWR Metals and Microbiology Unit
Zn	EPA 200.8	6 mo	0.010	NCDENR DWR Metals and Microbiology Unit

Table 8. Storm Sampling Criteria

Storm Criteria	Value	Criteria satisfied?
Minimum # of aliquots	10	YES
Minimum storm coverage	≥ 70%	YES
Total precipitation (in.)	> 0.10	YES
Antecedent dry period (h)[*]	6	YES
Minimum # of storm events	10	YES

Driscoll 1989

Data Analysis

Hydrology

Discrete hydrologic storm events were identified by a gap in precipitation exceeding six hours (Driscoll, 1989). The target storm size range for water quality sampling was generally 0.10 to 2.0 inches of depth, although a broader range was measured for non-water quality-related events. In general, storms were considered "completely captured" if flow-proportional sampling occurred for at least 70% of the hydrograph (by volume). To calculate influent and effluent runoff volumes from the raw weir level data, flow conversion was performed in FlowLink 5.1 (Teledyne-Isco, Lincoln, Nebraska). Occasionally, runoff volumes exceeded the capacity of the weir. When ponding levels exceeded the maximum height of the weir, the precise head-to-flow rate relationship no longer becomes valid. This was noted and addressed for each applicable storm. When this occurred, the modified NRCS Curve Number Method was used to estimate influent runoff volume instead (Eq. 1). Additionally, the Rational Method was used to estimate influent peak flow (NCDENR, 2009).

$$Q = \frac{(P - 0.05S_{0.05})^2}{P + 0.95S_{0.05}} * A * C \tag{1}$$

where Q = runoff volume (ft^3), P = storm event precipitation depth (in), $S_{0.20}$ = potential maximum retention (in) = $\frac{1000}{CN} - 10$, CN = Curve Number (98 for impervious surfaces), $S_{0.05}$ = modified maximum retention (in) = $1.33 * S_{0.20}^{1.15}$, A = watershed area (ft^2), C = conversion factor $\left(\frac{1\,ft}{12\,in}\right)$

Influent and effluent runoff volumes were compared to determine volume retention in the Filterra device. If the validity of flow data for any storm event was in question (i.e., noticeable drift in water level readings, water in weir froze during storm events, etc.), the most conservative approach of assuming negligible volume retention was used. Peak flow reduction and lag to peak were also assessed.

Additional peak flow metrics computed include the peak flow reduction factor (R_{peak}) and peak flow delay (R_{delay}) on a storm-by-storm basis (adapted after Davis *et al.*, 2008).

$$R_{peak} = \frac{q_{peak-out}}{q_{peak-in}} \tag{6}$$

$$R_{delay} = \frac{t_{q-peak-out}}{t_{q-peak-in}} \tag{7}$$

In the "Individual Storm Hydrograph" Appendix, the average underdrain flow rate was calculated for each water quality storm by dividing the event volume by the duration, yielding flow rate as cubic feet per second (cfs). Furthermore, next to each value in the Appendix is a hydraulic loading (or *volumetric flux*), which is simply the average flow rate divided by the filter media area (in this case 24 square feet). This volumetric flux is expressed as depth per time, but should not be confused with a measured saturated hydraulic conductivity reading or a surface infiltration test (ASTM D7764 and ASTM D3385, respectively).

Water Quality

Multiple analytes at various sites had a significant portion (>10%) of measured concentrations reported below the minimum detection limit (MDL). For such cases, robust regression on order statistics was performed after log-transforming the data (Bolks et al., 2014), in order to calculate summary statistics such as mean, median, standard deviation, and interquartile range (IQR). Both the efficiency ratio (ER, eq. 2) and the relative median efficiencies (RE$_{median}$, eq. 3, Drake *et. al.,* 2014) were calculated for ammoniacal nitrogen (TAN), nitrate/nitrite-nitrogen (NO$_{2,3}$-N), total Kjeldahl nitrogen (TKN), total nitrogen (TN), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), total suspended solids (TSS), suspended sediment concentration (SSC), total copper (Tot. Cu), dissolved copper (Diss. Cu), total zinc (Tot. Zn), and dissolved zinc (Diss. Zn). TN was determined by adding event mean concentrations (EMCs) of TKN and NO$_{2,3}$-N.

$$ER = \left(\frac{EMC_{inavg} - EMC_{out,avg}}{EMC_{in,avg}} \right) \tag{2}$$

$$RE_{median} = \left(\frac{EMC_{in,median} - EMC_{out,median}}{EMC_{in,median}} \right) \tag{3}$$

where $EMC_{in,avg}$ = average inlet event mean concentration (mg/L), $EMC_{out,avg}$ = average outlet event mean concentration (mg/L), $EMC_{in,median}$ = median inlet event mean concentration (mg/L) and $EMC_{out,median}$ = median outlet event mean concentration (mg/L) .

All water quality data sets were log-transformed and checked for normality using the Shapiro-Wilk test and visual confirmation of residual plots. When data were log-normal, paired t-tests were performed to determine significant differences in influent and effluent pollutant concentrations. Otherwise, the Peto & Peto modification of the Gerhan-Wilcoxon test (Bolks et al., 2014) was used to detect whether influent concentrations were significantly greater than effluent concentrations. Due to varying size of storm events and scope of the sampling regime, pollutant analysis for every sampling location was not possible for every storm event, therefore sample size varied for each pollutant. All analyses were performed in R 3.1.2 (R Core Team, 2014).

Individual and cumulative load reductions through the Filterra® unit were also assessed by pairing event mean concentrations for all pollutants with measured flow data (eqs. 4 and 5). Each EMC was paired with the stormwater volume pertinent to the sampling location for each storm. Event loading (mass per storm) was calculated by multiplication of the total volume and the event mean concentration. Percent load reduction on a storm-by-storm basis was assessed by calculating the percent mass of pollutant loading reduced. The cumulative percent load reduction was calculated by determining the percent reduction of the cumulative influent and effluent loads.

$$Individual\ Load\ Reduction = 100 \times \left(1 - \frac{L_o}{L_i} \right) = 100 \times \left(1 - \frac{EMC_{out,i} * V_{out,i} + V_{over,i}}{EMC_{in,i} * V_{in,i}} \right) \tag{4}$$

$$Cum.Perc.Load\ Reduction = 100 \times \left(1 - \frac{\sum_{i=1}^{n} L_o}{\sum_{i=1}^{n} L_i} \right)$$

$$= 100 \times \left(1 - \frac{\sum_{i=1}^{n} EMC_{out,i} * V_{out,i} + \sum_{i=1}^{n} EMC_{in,i} * V_{over,i}}{\sum_{i=1}^{n} EMC_{in,i} * V_{in,i}} \right) \tag{5}$$

where L_i = inlet load (mg), L_o = outlet load (mg) $EMC_{in,i}$ = inlet EMC for event i (mg/L) and $EMC_{out,i}$ = outlet EMC for event i (mg/L), $V_{in,i}$ = total runoff volume for event i, $V_{out,i}$ = effluent volume for event i, and $V_{over,i}$ = overflow volume for event i.

In equations 4 and 5, the sum of outlet loads includes both the underdrain outflow load and the overflow load when applicable, which is assumed to be untreated. Bootstrapping methods (Canty and Ripley, 2014; Davison and Hinkley, 1997) were used to determine the 95% confidence interval associated with the mean pollutant removal efficiency and mean individual load reduction per the TAPE protocol (WSDE, 2011). Mean pollutant removal efficiencies and mean load reductions for events that did not generate bypass were also included as additional analyses.

Results

Hydrology

A summary of the rainfall measured onsite is given in Table 9. Over the 22-month monitoring period, a variety of conditions were observed, including a maximum 5-minute intensity equivalent to the 2-year, 5-min storm, and a prolonged dry period of approximately 31 days. Analysis of the volume treated by the Filterra® system indicates 72% of runoff left as treated effluent through the Filterra® underdrain, while 22% was measured to have bypassed the system via the overflow pipe. The remaining 6% of unaccounted runoff volume losses was likely a composite of instrumentation error and potential soil storage and evapotranspiration.

Table 9. Analysis of all 125 hydrologic storm events from February 2013 to December 2014.

	Depth (in)	Average Intensity (in/hr)	5-min Peak Intensity (in/hr)	Catchment Peak Flow (cfs)	Antecedent Dry Period (days)
Min.	0.10	0.01	0.12	0.003	0.3
Median	0.40	0.07	1.02	0.214	3.1
Max.	4.94	2.10	6.36	1.516	31.3
Average	0.64	0.16	1.46	0.328	5.0

Table 10. Analysis of sediment-sampled hydrologic storm events (n=29).

	Depth (in)	Average Intensity (in/hr)	5-min Peak Intensity (in/hr)	Catchment Peak Flow (cfs)	Antecedent Dry Period (days)
Min.	0.10	0.02	0.30	0.043	0.26
Median	0.61	0.08	1.38	0.350	2.39
Max.	1.95	2.20	5.64	1.344	13.40
Average	0.73	0.19	1.57	0.369	4.02

Table 11. Analysis of nutrient-sampled hydrologic storm events (n=34).

	Depth (in)	Average Intensity (in/hr)	5-min Peak Intensity (in/hr)	Catchment Peak Flow (cfs)	Antecedent Dry Period (days)
Min.	0.10	0.02	0.30	0.038	0.26
Median	0.59	0.07	1.20	0.286	2.39
Max.	1.95	2.20	5.64	1.344	13.40
Average	0.69	0.17	1.42	0.327	3.87

Table 12. Fate of rainfall at Filterra® site for all 125 hydrologic storms.

	Inflow	Outflow	Bypass	Other
Total Volume (ft^3)	53,953	38,973	11,920	3061
Percent of Inflow (%)	NA	72	22	6

In 2013, the year encompassing a large portion of the sampling events, the total rainfall was 50.2 inches, which represents the 80th non-exceedance percentile historically. During this year, overflow was equivalent to 15% of the inflow volume (Table 13). In 2014, the total rainfall was 37.9 inches, which was a 14th-percentile year for the City of Fayetteville. During 2014, 29% of flow to the Filterra® was bypassed (Table 14). The increase in bypass percentage is hypothesized to be caused by surface clogging, potentially from decreased maintenance in 2014, which in turn caused the surface infiltration rate of the Filterra® to decrease. The 2013, 2014, and overall values for percent overflow from this study were compared to data from Smolek et al. (2015), which analyzed percent of total volume bypassed from traditional detention-based stormwater best management practices (BMPs) in North Carolina (e.g. wetland or wet retention pond) using the last 10 years of historical rainfall. The 22% average bypass volume calculated in the Filterra® monitoring study is consistent with percent overflows seen by traditional detention-based BMPs (Figure 4).

Table 13. Fate of rainfall at Filterra® site from February 2013 to December 2013.

	Inflow	Outflow	Bypass	Other
Total Volume (ft^3)	28,173	22,512	4,431	1,330
Percent of Inflow (%)	NA	80	15	5

Table 14. Fate of rainfall at Filterra® site from January 2014 to December 2014.

	Inflow	Outflow	Bypass	Other
Total Volume (ft^3)	25,781	16,461	7,589	1,731
Percent of Inflow (%)	NA	64	29	7
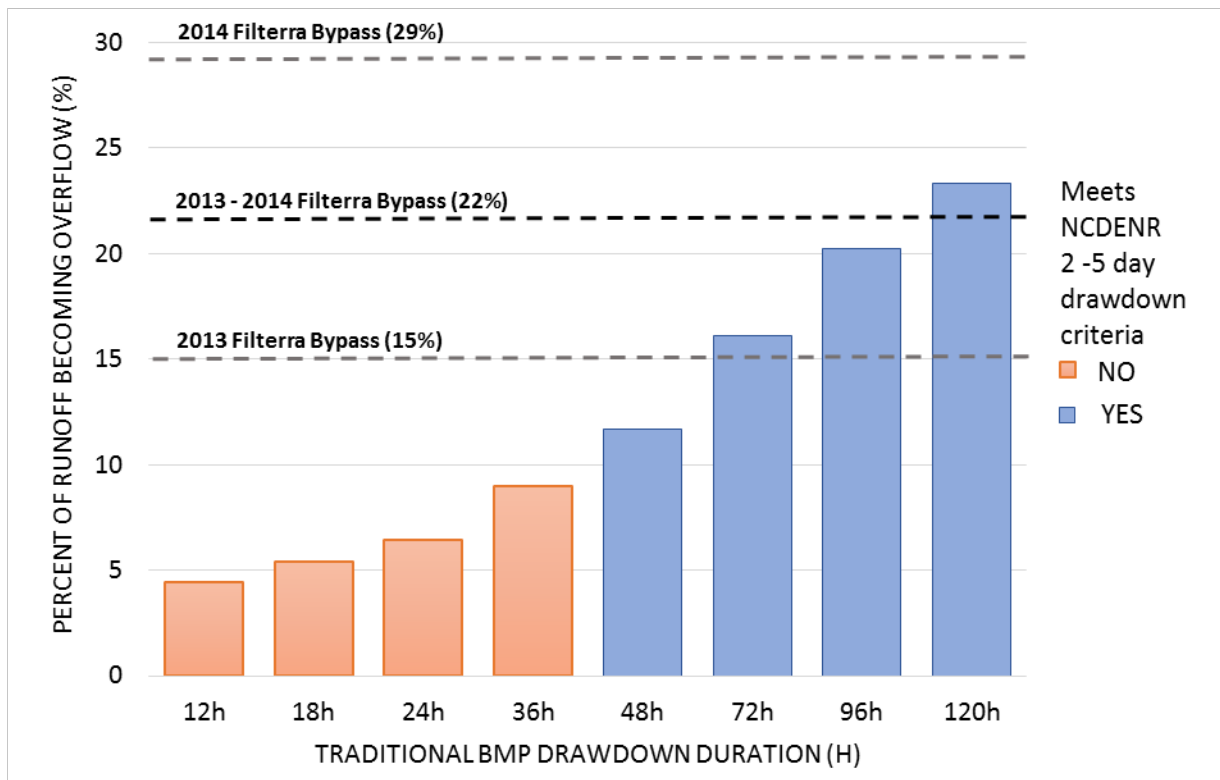
Figure 4. Calculated percent annual overflow from traditional BMPs during an average rainfall year (from Smolek et al. 2015). The monitored Filterra® showed 22% total bypass volume (dashed line).

Using a "hockey-stick" piece-wise linear regression (Chiu and Lockhart, 2010; Vito, 2008), where two piece-wise linear regressions are performed to find a "break point" value for a data set, the inflection point above which significant bypass is expected to occur was determined based on input rainfall depths and rainfall intensities. The data set included all rainfall events that occurred, including those below 0.10 inches. The plots and analyses were divided into three categories: storms occurring in 2013, storms occurring in 2014, and all storms (2013-2014). Below the plots, a table of the regression data for storm depth is included. This shows the calculated breakpoints (the "inflection point" separating two lines with statistically-different slopes) and the estimated slopes of each of the two lines per regression (labelled lines "A" and "B"). In brackets, the 95% confidence interval of each of the slopes is shown. The telling value of the confidence interval is that if it encompasses 0, then the line can be qualitatively judged to be "flat".
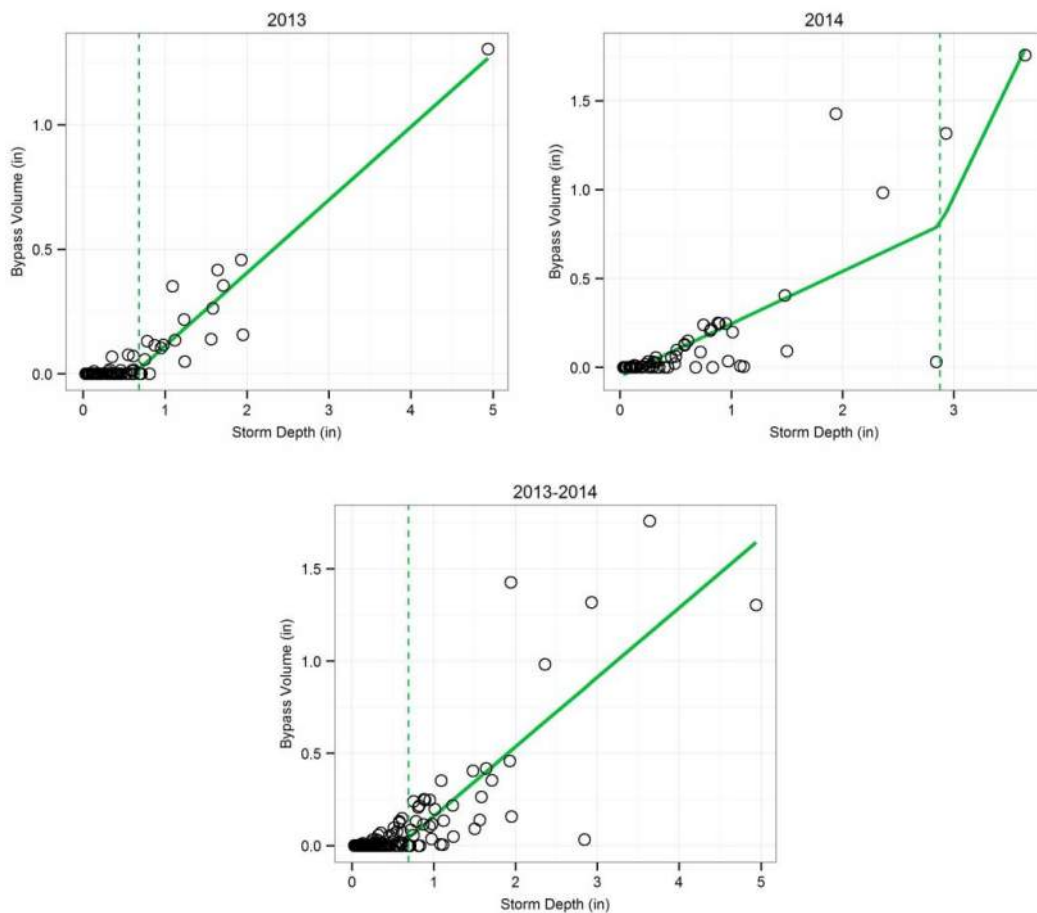
Figure 5. Piece-wise regression of storm depth and overflow volume (normalized to a depth value) for three time periods: (a) 2013, (b) 2014, and (c) 2013-2014.

Table 15. Regression estimates of rainfall depth breakpoints, and segment slopes by year.

Time Period	Est. Breakpoint	Std. Error	Slope A	Slope B
2013	0.68	0.08	0.032 [-0.03, 0.10]	0.293 [0.27, 0.32]
2014	2.86	0.20	0.292 [0.22, 0.36]	1.129 [0.64, 1.94]
2013-2014	0.69	0.14	0.065 [-0.06, 0.20]	0.376 [0.32, 0.42]

Bracketed values represent the 95% confidence interval around the estimated slopes.

In 2013, the estimated breakpoint is 0.68 inches of rainfall. As can be seen in the slope of that first "flat" section, the confidence interval spans zero, meaning that no outflow is expected below 0.68 inches in that year. Line "B" for 2013 shows a non-flat slope (0.293 slope value). This is visible in the plot of 2013's rainfall depth vs. outflow above. The 2014 regression shows an estimated breakpoint at 2.86 inches. This does not mean no runoff is expected below 2.86, but rather 2.86 was the optimal breakpoint of the data. The slope of the first segment was *not* zero (confidence interval of 0.22 – 0.36), meaning more outfall was seen at a lower rainfall threshold than in 2013. When aggregating 2013 and 2014, the behavior is similar to 2013, with an estimated breakpoint at 0.69 inches and a "flat" first piecewise line, indicating no runoff is expected overall below the breakpoint of 0.69 inches. Undersizing of the system (and a higher than average rainfall year) likely caused the runoff threshold in year 1 of the study to be less than 1 inch. A hypothesized explanation for the decreased runoff threshold in year 2 of the study is that there was little to no maintenance performed on the Filterra during this period, potentially resulting in faster outflow for a given storm. A recommendation stemming from this data suggests that the system needs to be maintained over time with a recommended twice per year frequency.

Performing the same analysis as above, but substituting 5-minute peak rainfall intensity for storm depth, yields less conclusive results compared to depth. For the combined 2013-2014 data set, a significant change in outflow occurs at the breakpoint of about 4 inches per hour. Splitting into 2013 and 2014 sub-groups (Figure 6 (a) and (b)), a non-zero slope is seen for the first segment of each pairwise regression. The lack of a clear flat line, despite the prevalence of many non-outflow events between 0 and 1.5 inches per hour, is likely due to isolated outflow events during relatively low peak 5-minute intensity events (see the three data points in Figure 6 (b) with outflow near 1.5 inches that occur before the breakpoint is reached). These data values may be skewing what otherwise appears to be a 1-2 inch per hour

threshold before runoff is *consistently* occurring. Figure 6(c) clearly shows a cluster of zero-outflow events for intensities up to about 2 inches per hour before runoff consistently occurs, which represents the combined 2013 and 2014 time frames of the study.
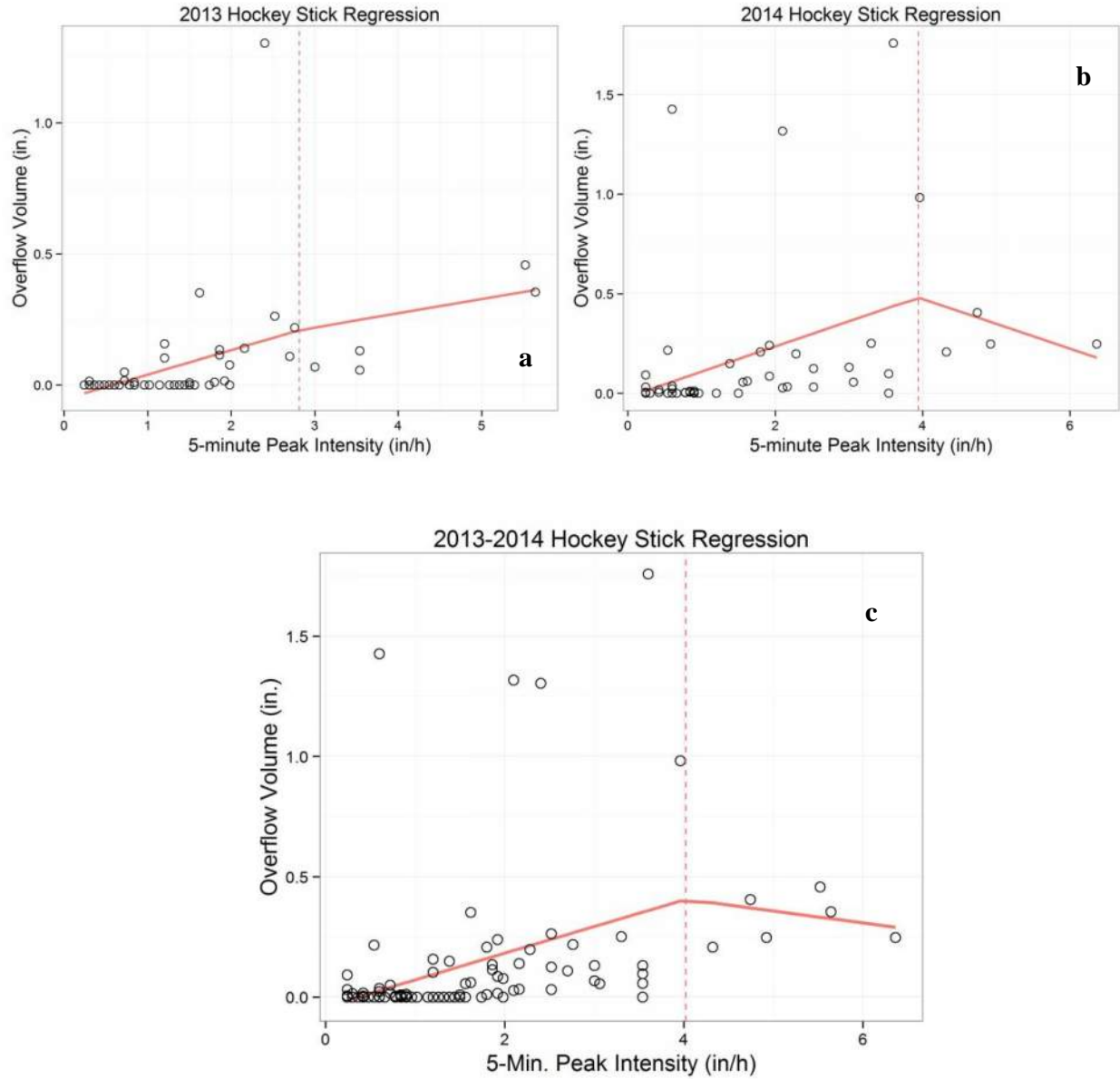
Figure 6. Piece-wise regression of recorded 5-minute peak rainfall intensities and overflow volume (normalized to a depth value) for three time periods: (a) 2013, (b) 2014, and (c) 2013-2014.

Table 16. Regression estimates of rainfall intensity breakpoints, and segment slopes by year.

Time Period	Est. Breakpoint	Std. Error	Slope A	Slope B
2013	2.82	3.52	0.09 [0.03, 0.16]	0.05 [-0.08, 0.19]
2014	3.94	1.04	0.13 [0.04, 0.22]	-0.12 [-0.49, 0.24]
2013-2014	4.02	1.48	0.11 [0.06, 0.16]	-0.05 [-0.37, 0.27]

Bracketed values represent the 95% confidence interval around the estimated slopes.

Peak Flow

In addition to facilitating volume reduction, the Filterra® also reduced peak flows by a median of 56%. Table 17 summarizes peak flow reduction by the system. Comparing the peak outflow to the estimated pre-development conditions (using the Rational Method with a Rational Coefficient of 0.35 for a forested condition), peak flows only exceeded the expected pre-development conditions approximately 21% of the time (Figure 7).
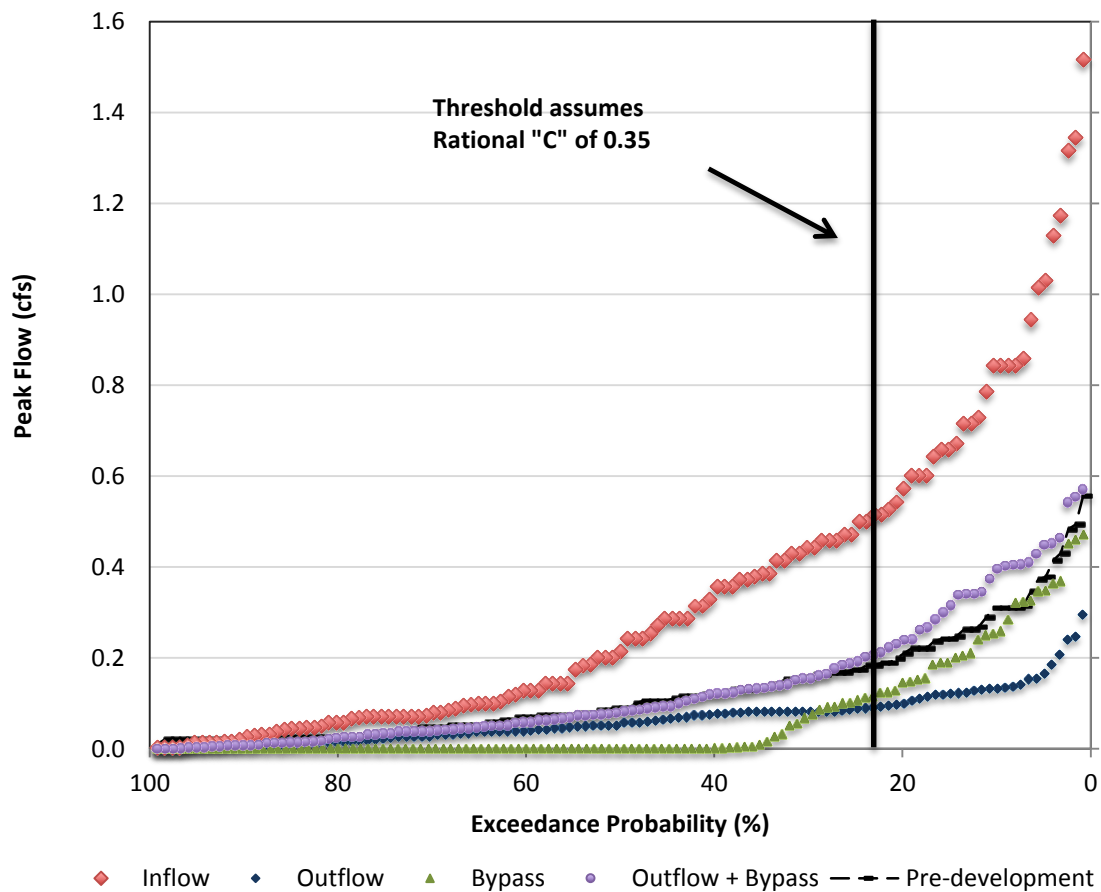
Figure 7. Exceedance probability of peak flows for the Filterra® unit.

Peak flow reduction ratio is a metric used to quantify how much reduction of peak flow is occurring because of a stormwater control measure (SCM). The median peak flow reduction ratio for the Filterra® system for all storm events was 0.44. By comparison, results from the literature for optimal bioretention peak flow ratios suggests 0.33 as a target hydrologic value for traditional bioretention systems (Davis *et al.*, 2008), with lower numbers indicating better peak flow reduction. The peak delay ratio is a measure of lag to peak; in general, time of peak outflow from the Filterra® did not vary substantially from the time of peak inflow. Overall, it can be reasonably concluded that the outflow peak for the studied Filterra® is generally near 50% of the value of the inflow peak for a large range of storms (0.10 to 4.94"; see Table 17).

Table 17. Summary of peak flow results for all hydrologic events (*n =125* storms)

Metric	Influent Peak Flow (cfs)	Effluent Peak Flow (cfs)	Peak Flow Reduction Ratio (unitless)	Peak Flow Reduction (%)	Peak Delay Ratio (unitless)
Median	0.21	0.08	0.44	57%	1.02
Mean	0.33	0.13	0.50	50%	5.06
St. Dev.	0.33	0.14	0.35	35%	29.5

Table 18. Summary of peak flow results for sediment-sampled events (*n =29* storms)

Metric	Influent Peak Flow (cfs)	Effluent Peak Flow (cfs)	Average Effluent Flow (in/hr)	Peak Flow Reduction Ratio (unitless)	Peak Flow Reduction (%)	Peak Delay Ratio (unitless)
Median	0.35	0.11	22.9	0.39	58.61	1.01
Mean	0.37	0.13	35.8	0.43	53.22	1.39
St. Dev.	0.29	0.10	39.6	0.24	24.38	2.45

Table 19. Summary of peak flow results for nitrogen-sampled events (*n =34* storms)

Metric	Influent Peak Flow (cfs)	Effluent Peak Flow (cfs)	Average Effluent Flow (in/hr)	Peak Flow Reduction Ratio (unitless)	Peak Flow Reduction (%)	Peak Delay Ratio (unitless)
Median	0.29	0.09	20.1	0.39	58.61	1.01
Mean	0.33	0.12	31.2	0.45	52.36	1.35
St. Dev.	0.29	0.10	37.0	0.24	24.30	2.29
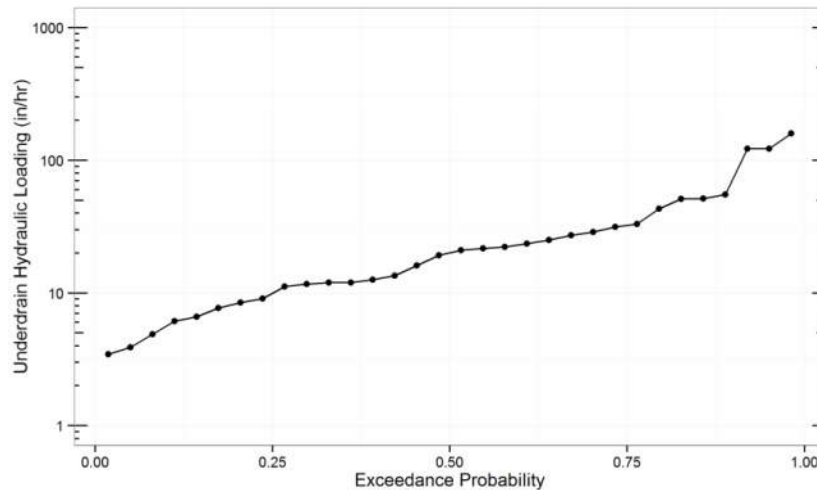
Figure 8. Exceedance probability plot of average underdrain volumetric flux (in/h)

Figure 8 shows a plot of all of the underdrain average volumetric fluxes (in inches per hour), where each data point is associated with each storm event sampled for water quality (see Appendix on "individual hydrographs" for specific information per storm). The underdrain flux values ranged from 3 in/h to 160 in/h, with a median (50th percentile) value of 20.1 in/hour. Little linear correlation was found between the volumetric underdrain flux and rainfall depth or inflow volume. With what little dataset exists, however, it appears there may be a slight seasonal variation with higher rates occurring during the more intense summer rainfall months (Figure 9). The maximum flow through the system will necessarily be governed by the surface infiltration rate of the system--if any impediment to flow was occurring in the surface layer due to temporary clogging or otherwise, this would limit the average underdrain volume flux observed for any given storm. The highest average value (160 in/h) translates to 0.088 cfs of flow. Compared to the theoretical maximum open channel flow a 4-inch underdrain can carry (using the Manning's equation) of 0.15 cfs, these lower values indicate that the underdrain is likely not flowing full a majority of the time.
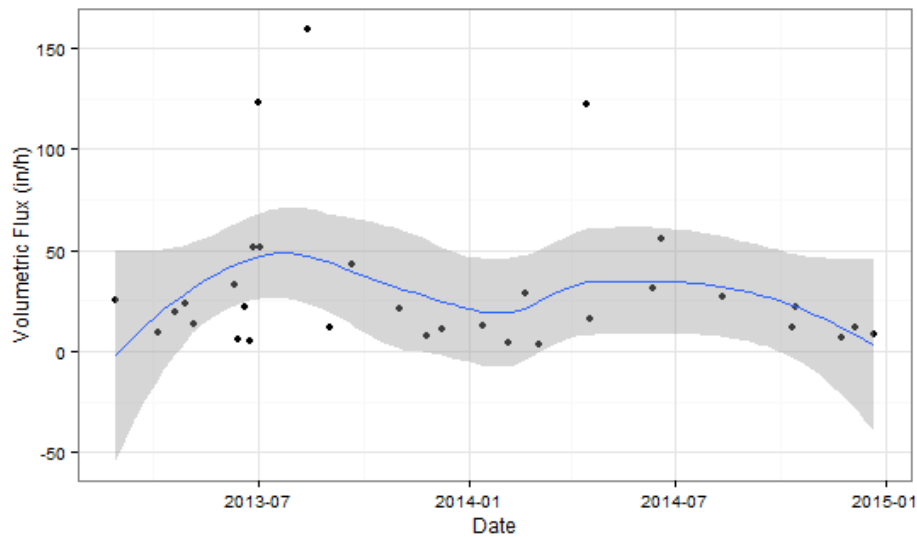
Figure 9. Volumetric flux time series (for water quality-sampled storms only, covering a range from 0.11 to 1.95 inches of precipitation).

Often, the flows of concern for peak flow reduction are much larger than the most common storms, which are usually an inch or less. For many regulatory purposes, peak flows of significant recurrence interval storms (1-year recurrence and above) are targeted for reduction. The North Carolina Administrative Code 15A NCAC 2H. 1008(h)(2) states that the 1-year peak flow of a watershed with an alternative stormwater control measure must be about equal to the peak flow of the pre-developed condition of the watershed. Assuming a forested condition, and a time of concentration of 5 minutes, the combined underdrain + bypass (i.e. total outflow) data were compared to this theoretical benchmark. Figure 10 shows the outflow peak flow data (with linear fit) from the study site plotted against theoretical Rational Method peak flow curves for pre- and post-development conditions. As can be seen, the site roughly follows, and is slightly less, than the calculated pre-development peak flow conditions. At the 1-year intensity (5.17 in/hr) for the site, peak outflow from the site roughly matches the calculated values.
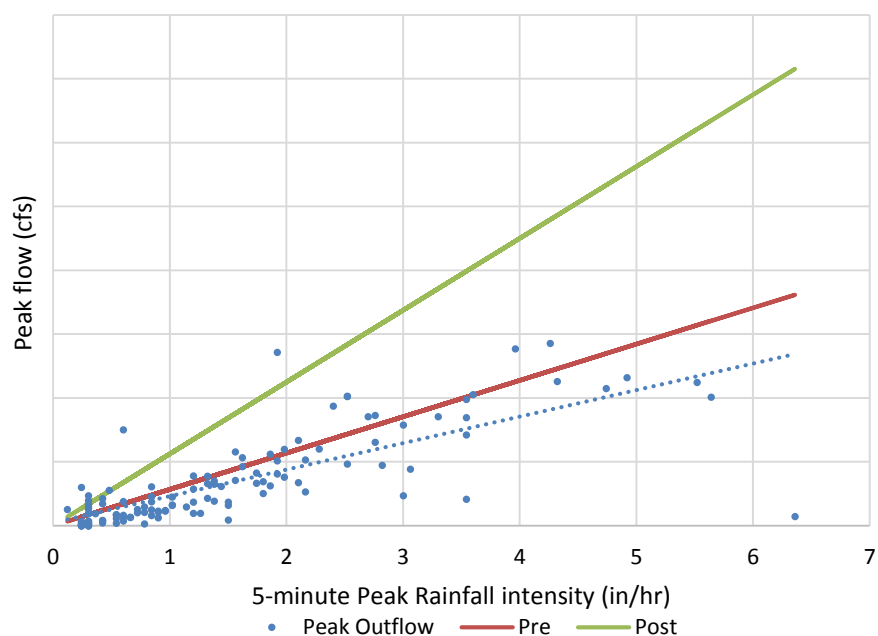
Figure 10. Plot of Filterra® combined peak outflow (underdrain + bypass) plotted and linearly-fit in comparison to pre-development and post-development theoretical peak flows. C = 0.35 and 0.90 for pre- and post-dev. watersheds, respectively, and a time of concentration of 5 minutes.

Water Quality

The NCDENR Preliminary Evaluation Protocol (PEP) requires data be collected from 10 qualified events over the course of at least 1 full year with samples collected in each of the four seasons (NCDENR 2007). This requirement was met for all analytes except SRP, where concentrations were never detected above the minimum detection limit (MDL). For other analytes, when data were censored, the concentration was estimated at half the minimum detection limit for storm-by-storm paired comparisons and loading calculations. All other summary statistics including mean ($\bar{x}$), median ($\tilde{x}$), interquartile range, etc., were estimated using the following criteria: A) if the number of data points below the MDL was less than 10%, half the minimum detection limit was used, B) if the number of data points below the MDL was between 10% and 80%, a robust order on regression was used, or C) if the number of data points below the MDL was greater than 80% summary statistics were not calculated. Per the state of Washington's Technology Assessment Protocol – Ecology (TAPE), the two primary criteria assessed were the pollutant removal efficiency and pollutant load reduction

for individual storms (eqs. 2 and 4) (WSDE, 2011). TAPE designates a basic treatment target of greater than 80% TSS removal using either method (influent concentration: > 200 mg/ L), greater than or equal to 80% TSS removal (influent range: 100 – 200 mg/L), or an effluent TSS concentration less than or equal to 20 mg/L (influent TSS range: 20 – 100 mg/L). Once this basic criterion is met, additional treatment for total phosphorus may be awarded if removal of TP exceeds 50% when the influent range of TP is between 0.10 and 0.50 mg/L. . The TAPE program has these data analysis and screening criteria in order to account for irreducible concentrations. Irreducible concentrations in stormwater monitoring has been a publicly discussed issue for many years (Schueler, 1996) and is noted in several regulatory programs throughout the United States. Comparisons to the 85% sediment removal targeted under the NCDENR PEP were also made.

Summary statistics for each analyte at each site are displayed in Table 20. Table 21 summarizes the ER and RE_{median} for each pollutant based on the unpaired, overall distributions. Significant differences between the overall distributions were determined based on the appropriate test for the distribution.

Table 20. Summary Statistics of Event Mean Concentrations of Sampled Parameters

Pollutant	Location	<MDL (%)	n	$\bar{x}$	$\tilde{x}$	SD	IQR
				Statistical Parameters (in mg/L)			
TSS	IN	0	29	122	68	137	117
	OUT	0		5	4	4	4
SSC	IN	0	22	118	82.4	95.46	128.3
	OUT	0		4	3.1	2.78	3.3
TP	IN	0	33	0.130	0.10	0.115	0.148
	OUT[a]	24		0.047	0.038	0.031	0.03
TP (TAPE)	IN	0	16	0.208	0.185	0.121	0.113
	OUT[b]	6		0.063	0.052	0.037	0.054
TDP	IN[a]	58	31	0.068	0.014	0.147	0.057
	OUT[a]	61		0.024	0.016	0.021	0.020
OrthoP	IN[c]	94	32	---	---	---	---
	OUT[c]	100		---	---	---	---
NH_3/NH_4^+-N	IN[a]	32	34	0.15	0.09	0.16	0.15
	OUT[a]	47		0.07	0.05	0.09	0.06
TKN	IN	0	34	1.08	0.99	0.57	0.58
	OUT[a]	12		0.56	0.46	0.32	0.35
NO_3^-/NO_2^--N	IN[a]	15	34	0.13	0.11	0.10	0.14
	OUT[a]	12		0.18	0.15	0.16	0.13
Cu (Total)	IN[b]	8	13	0.0080	0.0073	0.0069	0.0057
	OUT	0		0.0062	0.0049	0.0034	0.0063
Cu (Diss.)	IN[a]	40	5	0.0043	0.0044	0.0017	0.0075
	OUT	0		0.0055	0.0048	0.0028	0.0030
Zn (Total)	IN[b]	8	13	0.059	0.049	0.047	0.060
	OUT[a]	46		0.018	0.013	0.010	0.015
Zn (Diss.)	IN	0	5	0.060	0.049	0.008	0.013
	OUT[a]	60		0.026	0.026	2.5E-17	3.5E-12

[a] Robust regression on order statistics were used (Bolks et al. 2014)
[b] For data reported below detection limit, simple substitution of ½ the min. detection limit was performed
[c] All data were below detection limit. No population statistics computed.

Table 21. Efficiency Ratios (Eqs. 2 and 3) for Measured Water Quality Analytes. Significant values are bolded.

Pollutant	Efficiency Ratio	Removal Efficiency (Median)	In vs. Out Significance p-value	Test Performed
TSS	0.95641	0.94118	**5.23e-16**	paired t-test with log-trans EMCs
SSC	0.96689	0.9624	**3.43e-13**	paired t-test with log-trans EMCs
TP	0.63846	0.62	**3.76e-6**	Peto & Peto mod. of Gehan-Wilcoxon test
TP (TAPE)	0.82692	0.71892	**7.71e-7**	paired t-test with log-trans EMCs
TDP	0.64705	-0.14286	0.352	Peto & Peto mod. of Gehan-Wilcoxon test
OrthoP	--	--	--	
TN[a]	0.3932	0.2534	**0.0002**	unpaired t-test with log-trans EMCs
TAN	0.5294	0.44444	**0.0299**	Peto & Peto mod. of Gehan-Wilcoxon test
TKN	0.4944	0.53535	**7.05e-6**	Peto & Peto mod. of Gehan-Wilcoxon test
$NO_{2,3}{}^-N$	-0.4603	-0.3636	0.0974	Peto & Peto mod. of Gehan-Wilcoxon test
Cu (Total)	0.225	0.32877	0.5954	paired t-test with log-trans EMCs
Cu (Diss.)	-0.2941	-0.0909	0.251	Peto & Peto mod. of Gehan-Wilcoxon test
Zn (Total)	0.69492	0.73469	**0.0019**	Peto & Peto mod. of Gehan-Wilcoxon test
Zn (Diss.)	0.56667	0.46939	0.0663	Peto & Peto mod. of Gehan-Wilcoxon test

[a] Calculation of total nitrogen assumed ½ the detection limit when TKN or $NO_{2,3}$-N data were censored

Censored data includes all data that was measured below the minimum detection limit. When the data sets were comprised of 10% or greater censored data, a maximum likelihood estimation fit the data to a known distribution so the samples could be compared to each other. For other paired storm-by-storm analyses and calculation of loading, if data were censored, half the detection limit was used. Results from Table 20 and Table 21 show significant reduction (p-value < 0.05) of all analytes except nitrate/nitrite-nitrogen, total dissolved phosphorus, total and dissolved copper, and dissolved zinc. More thorough discussion of pollutant removal performance can be found in the following sections.

Table 22 summarizes cumulative percent load reductions for all sampled storms both with and without censored data included. For all sampled storms, the cumulative percent load reduction exceeded 75% for sediment removal and 50% for TP. When only storms that did not produce bypass were considered, percent load reduction increased to over 95% and 70% for sediment and TP, respectively. TN loading removal was lower at 39%, but exceeds NCDENR's regulatory credit of 35% TN removal for bioretention without internal water storage (NCDENR 2009).

Table 22. Summary of cumulative loading reductions (%) for all analyzed parameters

Pollutant	Cumulative Load Reduction (all storms)	Cumulative LoadReduction (storms without censored[a] data)	Cumulative Load Reduction (all storms without bypass)	Cumulative Load Reduction (all storms without bypass or censored data)	Sample size (n)
TSS	76	76	96	96	29
SSC	77	77	98	98	22
TP	54	50	70	73	33
TP (TAPE)	58	57	84	83	16
TDP	66	40	65	86	31
OrthoP	--	--	--	--	32
TN[b]	39	37	45	52	34
NH_3/NH_4^+-N	49	42	40	48	34
TKN	46	44	54	54	34
NO_3^-/NO_2^-N	-22	-10	34	-27	34
Cu (Total)	14	18	-11	-11	13
Zn (Total)	63	61	74	73	13

[a]Censored data are values reported below the minimum detection limit
[b]Load reduction for TN based on substituting half the detection limit if TKN or $NO_{2,3}$-N were censored

To demonstrate the diversity of storm events sampled in the study, a summary of the rainfall depths and seasonal distribution of sampled events for each analyte are given in Table 23 and Table 24, respectively.

Table 23. Rainfall depths of sampled storm events.

	TSS	SSC	Phosphorus Species	Nitrogen Species	Total Metals	Dissolved Metals
Min (in.)	0.10	0.25	0.10	0.10	0.25	0.46
Med (in.)	0.61	0.72	0.60	0.60	0.81	0.81
Max (in.)	1.95	1.95	1.95	1.95	1.95	1.71
n	29	22	33	34	13	5

Table 24. Seasonal distribution of sampled storm events.

	TSS	SSC	Phosphorus Species	Nitrogen Species	Total Metals	Dissolved Metals
Winter	5	2	6	6	2	2
Spring	9	8	11	11	4	1
Summer	7	7	7	8	5	1
Fall	8	5	9	9	2	1
n	29	22	33	34	13	5

Sediment

Sediment data collected from the influent and effluent runoff are displayed in Figure 11. It is observed that despite a large variation in influent TSS concentration, the measured concentrations after treatment by the Filterra® never exceeded 20 mg/L (maximum concentration: 16 mg/L).
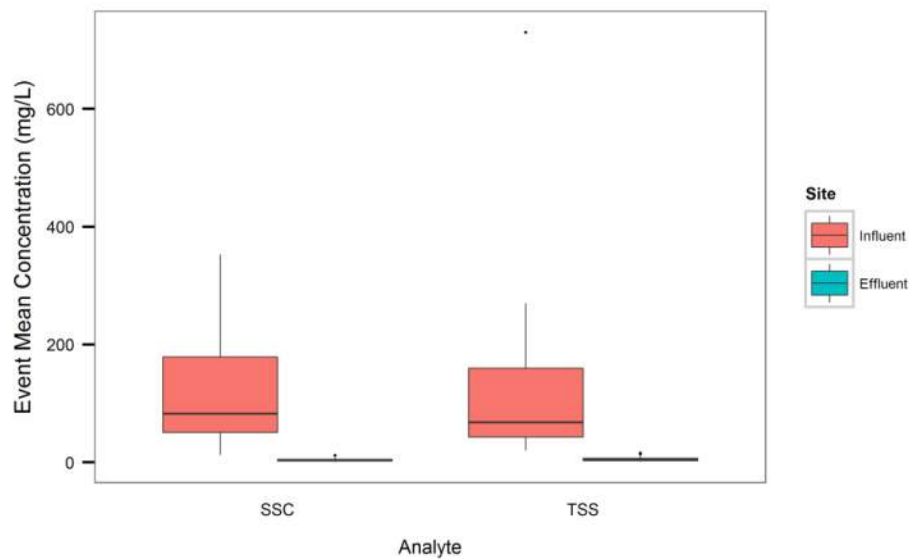
Figure 11. Boxplot of measured sediment event mean concentrations (as both Total Suspended Solids, TSS and Suspended Sediment Concentration, SSC)

Table 25 summarizes all performance metrics for TSS and SSC. Individual storm EMC removal was quite high, with a 94% and 97% median reduction in EMCs for TSS and SSC, respectively. This meets the 85% sediment removal criterion targeted by NCDENR. Due to the occurrence of bypass, load reduction was somewhat less than the EMC reduction. When only storms that did not produce bypass were considered in the calculations, the overall load efficiency of the system increased to over 95% for both TSS and SSC, indicating excellent sediment removal for small storms. The lower-bound of the 95% confidence interval for the TSS EMC percent removal by the Filterra® was 90%, meeting the 80% target set by TAPE. Additionally, the upper bound of the 95% confidence interval on the outlet mean was 6.6 mg/L. The TAPE basic treatment criteria was met in that the Filterra® consistently exceeded the effluent goal of less than or equal to 20 mg/L when the TSS influent was in the range of

20-100 mg/L, greater than or equal to 80% TSS removal was observed for TSS influent in the range of 100 – 200 mg/L, and greater than 80% TSS removal occurred for influent samples greater than 200 mg/L. The highest effluent value recorded for all 29 TSS samples was 16 mg/L.

Table 25. Summary statistics of sediment performance metrics evaluated in the study.

Evaluation Metric	Statistical Parameter	TSS	SSC
Event Mean Concentration (EMC)	N	29	22
	inlet mean [std. dev.] (mg/L)	122 [137]	118 [96]
	inlet median (mg/L)	68	82.4
	outlet mean [std. dev.] (mg/L)	5 [4]	4.0 [3]
	outlet median (mg/L)	4	3.1
	outlet Boot. 95% CI (mg/L)	3.9 – 6.6	2.8 – 5.0
	log-trans. paired t-test p-values	<0.001	<0.001
EMC Percent Removal (all storms)	N	28[a]	21[a]
	Mean	92%	94%
	Median	94%	97%
	std. dev.	7%	6%
	Bootstrapped 95% Conf. Int. (+/-)	90% - 94%	92% - 97%
EMC Percent Removal (storms with no bypass only)	N	9	4
	Mean	92%	97%
	Median	95%	97%
	std. dev.	7%	1%
Individual Load Reductions (all storms)	N	28[a]	21[a]
	Mean	81%	79%
	Median	80%	77%
	std. dev.	13%	12%
	Bootstrapped 95% Conf. Int. (+/-)	77% - 86%	74% - 84%
Individual Load Reductions (storms with no bypass only)	N	9	4
	Mean	94%	97%
	Median	96%	97%
	std. dev.	6%	1%
Load Efficiency (all storms)		76%	77%
Load Efficiency (only storms with no bypass)		96%	98%

[a]Pair-wise comparison for 11/24/2014 – 11/26/2014 storm excluded because < 75% of the storm was captured.
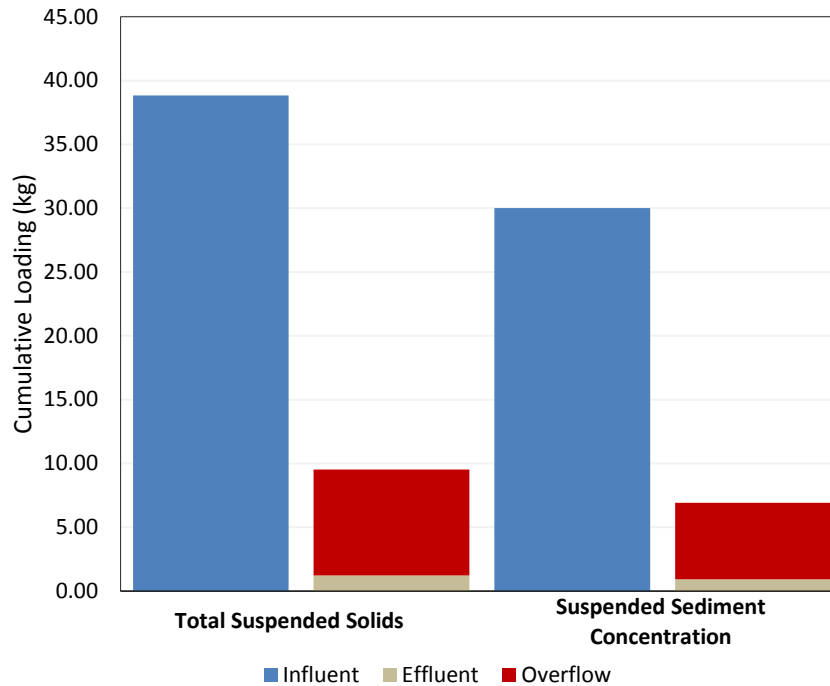
Figure 12. Cumulative sediment loading for total suspended solids (n = 29) and suspended sediment concentration (n = 22).

Particle Size Distribution

Particle size distributions were determined for storm events when enough material was present in the sampling bottles for analysis. A total of fifteen (15) samples were taken over the course of the study, and sent to the Department of Marine, Earth, and Atmospheric Sciences for laser diffraction analysis. The result of each sample analysis is a particle size (in µm) vs. percent-finer-than data set for that particular storm event and sampling site (influent or effluent of the Filterra® system).

Due to lack of material for proper laser diffraction analysis, only four outlet particle size distributions were obtained. The sediment concentrations were deemed too low in the other effluent samples to run the analysis. The four events for which effluent data were calculable, the rainfall intensities of the respective storms were relatively high, ranging from the median to the 99.9[th] percentile 5-minute peak intensities. A summary of when each inlet and outlet PSD were collected is outlined in Table 25.

Table 25. Summary of Sample Collection Dates for Particle Size Distribution

Storm Event Date	PSD Collected at Inlet?	PSD Collected at Outlet?
Feb. 26, 2013	X	
Mar. 04, 2013	X	
Mar. 19, 2013	X	
Mar. 29, 2013	X	
Jun. 10, 2013	X	
Jun. 26, 2013	X	X
July 02, 2013	X	X
Aug. 13, 2013	X	
Sep. 2, 2013	X	X
Sep. 21, 2013	X	
Nov. 1, 2013	X	
Feb. 19, 2014	X	
Apr 15, 2014	X	X
Apr. 19, 2014	X	
June 12, 2014	X	

For each individual particle size distribution, a set of common descriptive metrics were calculated. "Percent-finer-than" particle diameters were determined for the 10th, 30th, 50th (or median), 60th, and 90th percentile (percent finer than), the diameters of which are hereafter referred to as d_{10}, d_{30}, d_{50}, d_{60}, and d_{90}, respectively. Two additional common metrics were also calculated for each particle size distribution to quantify the variability or spread of the data. Span is the width of the particle size distribution based on the 10%, 50%, and 90% quantile:

$$Span = \frac{D_{90} - D_{10}}{D_{50}}$$

where:

D_{90} = Diameter of the 90th percentile particle size

D_{10} = Diameter of the 10th percentile particle size

D_{50} = Diameter of the 50th percentile particle size

The coefficient of uniformity is the measure of how tightly the PSD curve is maintained from 0 to 100 percent-finer-than. In soil science, the larger the value of C_u, the more well-graded the soil is considered, with smaller values indicating a highly-uniform particle size mix.

$$Coefficient\ of\ Uniformity\ (C_u) = \frac{D_{60}}{D_{10}}$$

Finally, to compare inlet and outlet average particle sizes for each of the chosen percentiles above, a percent difference was calculated. A summary of PSD parameters and their relative difference is shown in both Table 26 and 27. Table 26 summarizes all inlet and outlet samples taken, even if they were not able to be paired. Table 27 limits the analysis to only the four dates on which inlet and outlet were successfully paired (see Table 25 for the particular dates).

Table 26. Summary of average particle diameters for critical particle size bins for Filterra® inlet and outlet (inlet n = 15, outlet n = 4) (all D values in micrometers, *μm*)

	D_{10}	D_{30}	D_{50}	D_{60}	D_{90}	Span	C_u
Inlet (n = 15)	24.6	67.1	146.6	225.1	793.1	5.8	8.5
Outlet (n = 4)	17.0	44.6	69.1	83.0	226.7	3.5	5.2
Percent Diff.	31%	33%	53%	63%	71%	40%	39%

Table 27. Summary of average particle diameters for critical particle size bins for Filterra® inlet and outlet for only paired events (n = 4) (all D values in micrometers, *μm*)

	D_{10}	D_{30}	D_{50}	D_{60}	D_{90}	Span	C_u
Inlet (n = 4)	27.4	73.8	175.3	241.9	872.0	6.0	7.9
Outlet (n = 4)	17.0	44.6	69.1	83.0	226.7	3.5	5.2
Percent Diff.	38%	40%	61%	66%	74%	41%	34%

Looking at the paired data only (Table 27), the percent difference between the larger particle diameters (D_{60} and D_{90}) are greater than the percent differences for finer particles. This makes sense, as any media will more easily be able to filter larger particles than smaller ones. Looking at the span and C_u values, it is also evident that the effluent PSDs are not as highly-varied with respect to particle sizes than the influent, meaning the effluent PSDs are not influenced as much by extremely large or small PSDs. From a graphical perspective, Figure

13 shows the entirety of the four paired inlet / outlet PSDs as well as a comparison to USGS soil-classification categories for sand/silt/clay.
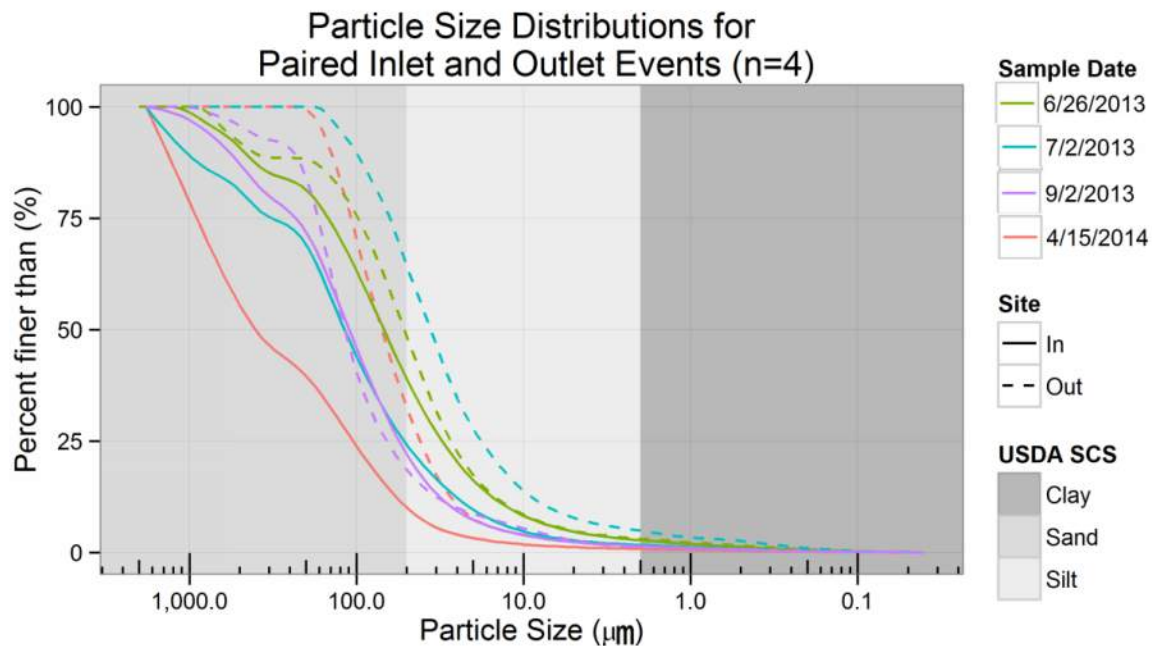
Figure 13. Entire continuous particle size distribution for each paired sample at the respective sampling location (inlet vs. outlet) on a given sampling date. PSDs generally shifted from sand-dominant to a very fine sand / large silt range.

Each event shows the effluent PSD is shifted right of the inlet PSD, indicating filtration of larger particles is being performed. For percentiles above about the 25th percentile, the effluent PSD is "right-shifted" nearly an order of magnitude. For large sand-sized particle fractions, nearly two orders of magnitude decrease is evident in some cases (7/2/2013). As one gets toward the clay particle size, the curves deviate less and less, demonstrating the potential difficulty all bioretention and filtration systems face in capturing the smallest of particles. Due to the lack of numerous paired data, statistical significance was not able to be determined.

The relationship between 5-minute peak rainfall intensity and PSD metrics was hypothesized, which led to a further investigation of the potential relationship. A simple linear regression of

inlet particle size for each percentile group as a function of 5-minute peak rainfall intensity did not detect any significant slope or linear fit, as can be seen in Figure 14.

Finally, for the paired storm event PSDs, a comparison was made with the TSS concentration of each respective storm at a given sampling site. There was a lack of strong linear trend for the influent and effluent PSD percentiles vs. TSS (Figure 15 and 16).

In summary, the particle size distribution data helps compliment the sediment analysis insofar as it demonstrates that not only is sediment being reduced, but the PSD is shifting away from the larger particle fractions and toward a dominance of small, hard-to-capture particles. Because the effluent sediment concentrations were so low across the board, however (average of 5 mg/L, median of 4 mg/L), PSDs were indeterminate for a vast majority of events. The events for which effluent data were produced (n = 4), may exist only because they resulted from extremely high intensity rainfall intensities, which may dislodge materials in the media or force through enough sediment to allow for enough material to analyze. Of the four storms with detectable effluent PSD, the rainfall intensities were high, representing the 56th, 81st, 96th and 99.9th percentile intensities for the 9/2/2013, 7/2/2013, 4/15/2014, and 6/26/2013 storms, respectively. For these four events, TSS effluent values were an average of 6.6 mg/L and median of 7.4 mg/L, which all are considered excellent water quality values. The effluent PSDs from these high-intensity events do not represent the entire spectrum of storm events, but rather represent the only storms with detectable PSD. No statistical conclusions could be made with the data.
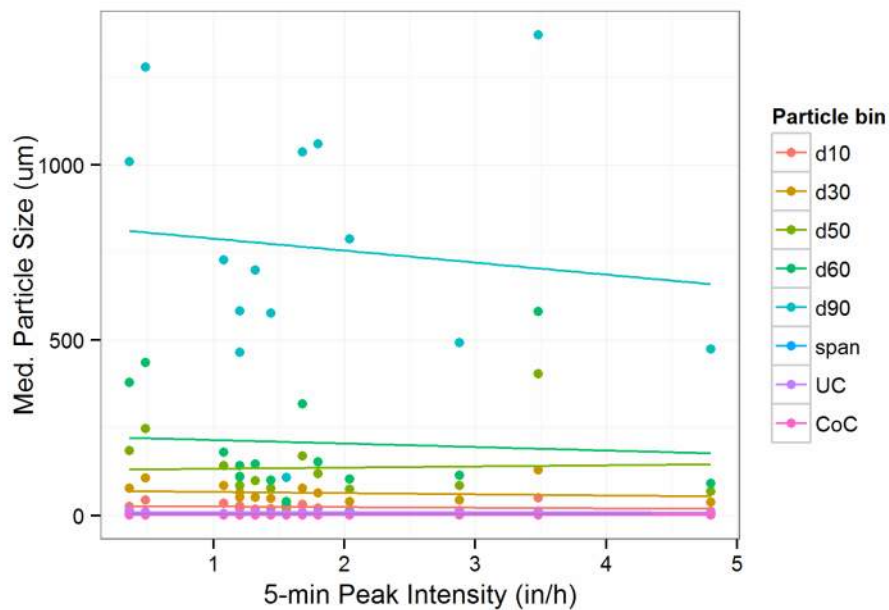
Figure 13. Linear regression of peak intensity vs median particle size for various bins which does not suggest significant correlations with the data collected (10-90th percentile bins).
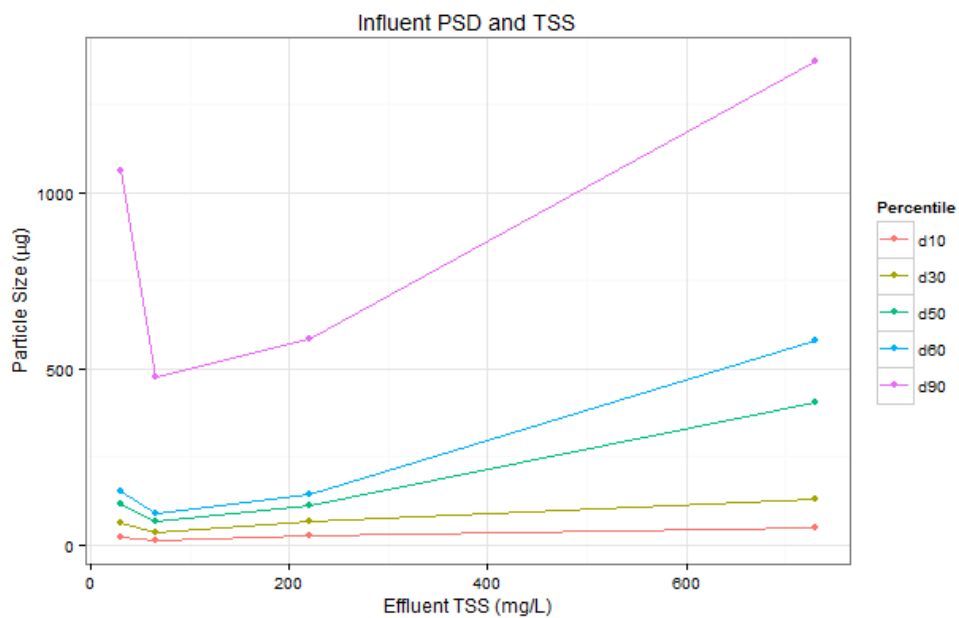
Figure 15. Influent TSS vs. various particle sizes, grouped by percent-finer-than designations
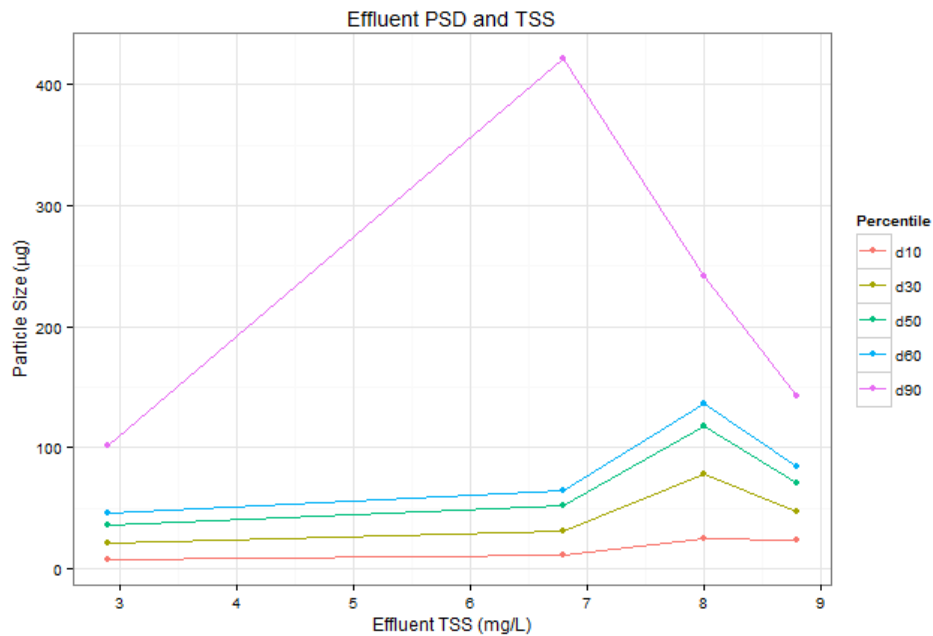
Figure 16. Effluent TSS vs. effluent particle sizes.

Phosphorus

Table 28 summarizes performance metrics for total phosphorus (TP), total dissolved phosphorus (TDP), and TAPE-qualified TP events (influent TP concentration between 0.1 and 0.5 mg/L). While soluble reactive phosphorus (SRP) was also analyzed, concentration levels failed to exceed the minimum detection limit and therefore analysis of this analyte was not possible. Figure 14 displays TP data collected at the inlet and the outlet. The data are ranked in ascending order to determine the cumulative probability of occurrence for the overall distribution. McNett et al. (2010) established that an effluent TP concentration of 0.06 mg/L corresponded to excellent ambient water quality and benthic macroinvertebrate health in North Carolina. Effluent concentrations of TP met this target approximately 80% of the time.
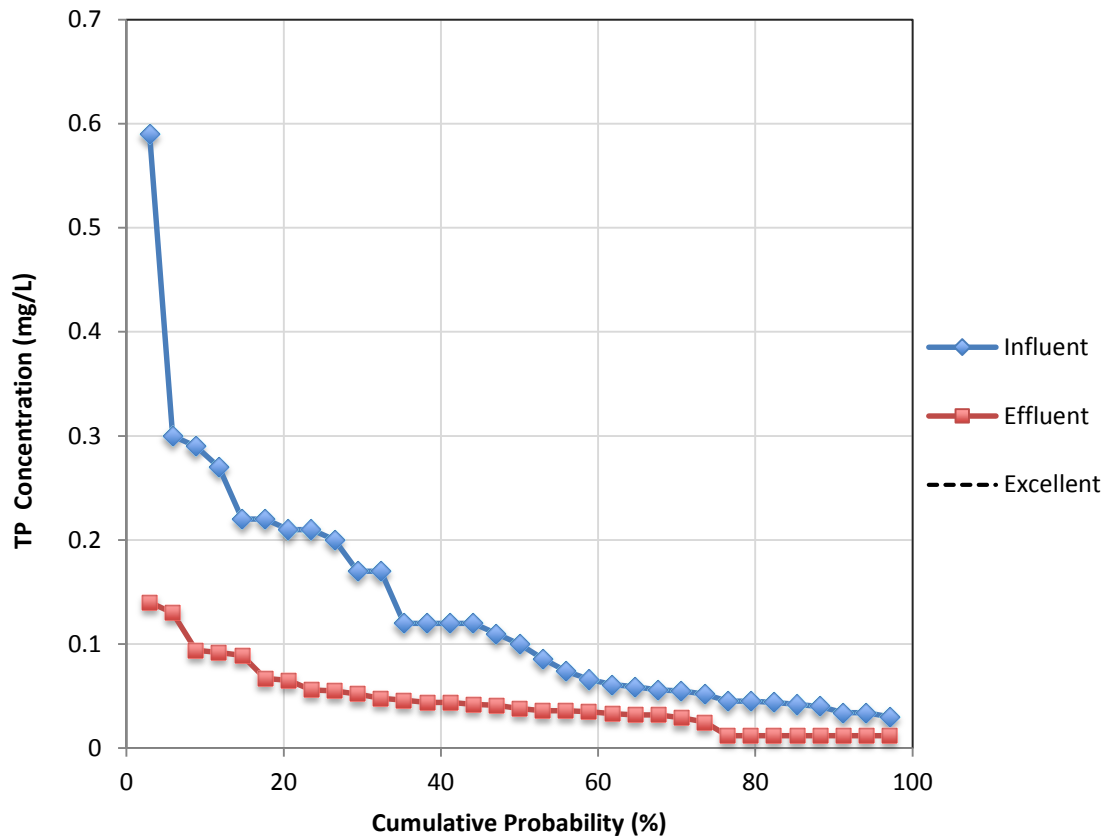
Figure 14. Exceedance probability of measured influent and effluent total phosphorus (TP).

For all total phosphorus data, storm-by-storm median removal efficiencies for EMC and load were 60% and 63%, respectively. The TAPE criterion for TP requires a minimum of 50% TP removal when influent concentrations range from 0.1 – 0.5 mg/L. 16 of the 33 events met this criterion; for these events, median removal efficiencies for EMC and load increased to 70% and 72%. The lower limit of the bootstrapped 95% confidence interval on the mean EMC for TAPE qualified events was above the 50% target set by TAPE (95% CI: 57% - 75%). The lower limit for the mean individual load reduction was also above the target with a 95% confidence interval of 56% - 76%, although the overall percent load reduction was lower at 54%. Cumulative loading reduction increased to 75% when storms with bypass were excluded from the analysis, indicating excellent TP removal. Total dissolved phosphorus (TDP) testing showed an average influent concentration of 0.068 mg/L, and an average effluent concentration of 0.024 mg/L. The detection limit was 0.025 mg/L, so robust order on

regression was performed to compute population statistics. Despite a 65% lower average EMC in the effluent than the influent, and a 66% overall percent load reduction, the percent reduction (or efficiency ratio) is not statistically significant. Despite a lower-than-expected and wide range of influent TDP values, the effluent concentrations were at or below detection limits 61% of the time. The traditional TAPE protocol for dissolved phosphorus removal cannot be applied due to the lack of qualifying influent TDP concentrations, limiting conclusions that can be made within that protocol. Overall, the system performed well and met TAPE criteria for total phosphorus removal, as well as exceeding the regulatory credit of 45% phosphorus removal awarded to bioretention without internal water storage by NCDENR (2009).

Table 28. Summary statistics of phosphorus performance metrics evaluated in the study

Evaluation Metric	Statistical Parameter	TP	TP (TAPE Qualified)	TDP
Event Mean Concentration (EMC)	N	33	16	31
	inlet mean [std. dev.] (mg/L)	0.130 [0.115]	0.208 [0.121]	0.068 [0.147]
	inlet median (mg/L)	0.10	0.185	0.014
	outlet mean [std. dev.] (mg/L)	0.047 [0.031]	0.063 [0.037]	0.024 [0.021]
	outlet median (mg/L)	0.038	0.052	0.016
	p-value for test of differences	<0.001[a]	<0.001[b]	0.352[a]
EMC Percent Removal (all storms)	N	32[c]	16	30
	Mean	54%	66%	2%
	Median	62%	70%	0%
	std. dev.	33%	19%	71%
	Bootstrapped 95% Conf. Int.	43% - 65%	57% - 75%	-27% - 23%
EMC Percent Removal (storms with no bypass only)	N	11	6	9
	Mean	59%	76%	0%
	Median	60%	79%	10%
	std. dev	28%	15%	72%
Individual Load Reductions (all storms)	N	32	16	30
	Mean	55%	66%	15%
	Median	63%	72%	19%
	std. dev.	32%	22%	61%
	Bootstrapped 95% Conf. Int.	44% - 66%	56% - 76%	-6% - 37%
Individual Load Reductions (storms with no bypass only)	N	11	6	9
	Mean	70%	84%	31%
	Median	79%	85%	64%
	std. dev.	28%	7%	80%
Cumulative Load Reduction (all storms)		54%	58%	66%
Cumulative Load Reduction (all storms without censored data)		50%	57%	40%
Cumulative Load Reduction (only storms with no bypass)		75%	84%	65%

[a] Peto & Peto modification of Gehsan-Wilcoxon test

[b] log-transformed paired t-test

[c] Pair-wise comparison for 11/24/2014 – 11/26/2014 storm excluded because < 75% of the storm was captured.
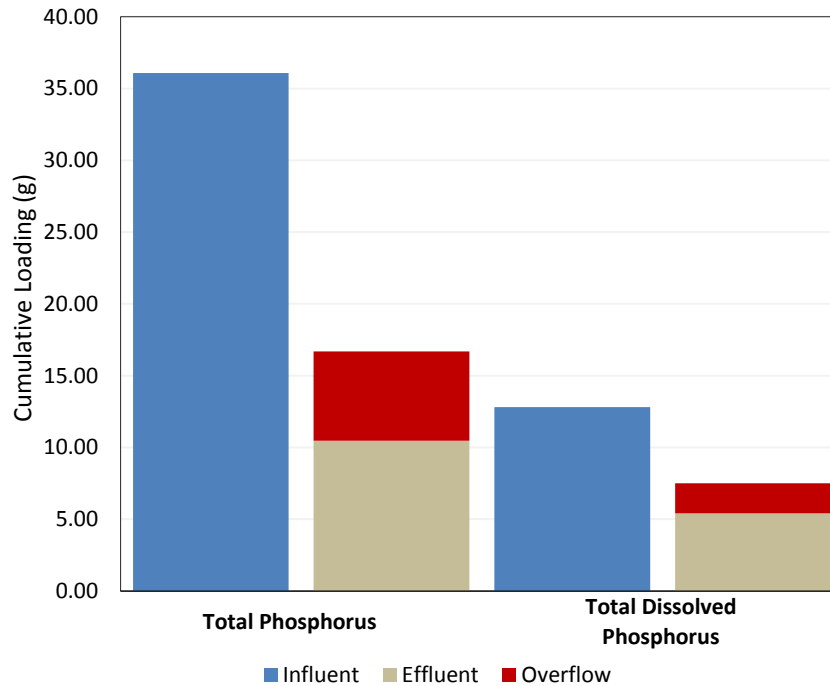
Figure 15. Cumulative loading for total phosphorus (n = 33) and total dissolved phosphorus (n = 31).

Nitrogen

Figure 16 displays the exceedance probability of nitrogen data collected from the inlet and the outlet. For the calculation of total nitrogen, if either TKN or $NO_{2,3}$-N was below the minimum detection limit, half the detection limit was used. McNett et al. (2010) determined the ambient water quality concentration for total nitrogen correlating to excellent stream health in North Carolina was 0.69 mg/L; treatment by the Filterra® reduced total nitrogen below this limit approximately 65% of the time.
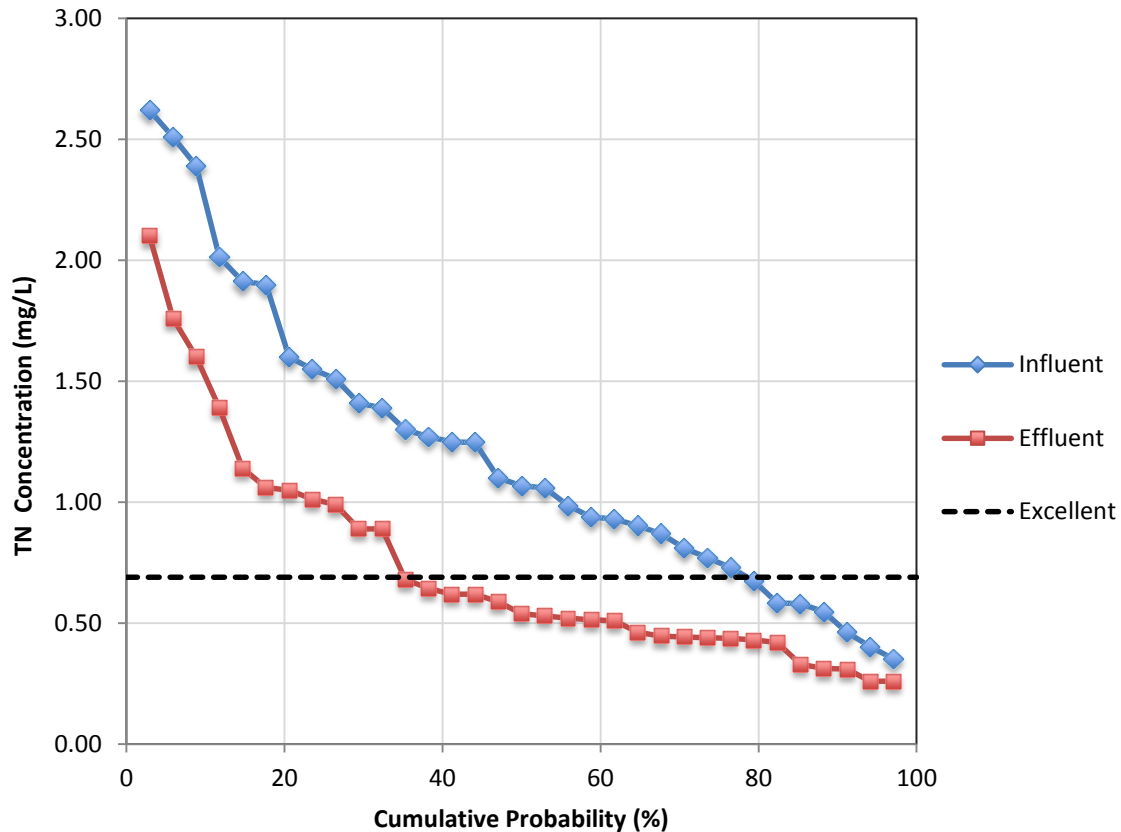
Figure 16. Exceedance probability of measured influent and effluent total nitrogen (TN).

Table 29 displays summary statistics for total nitrogen and all other nitrogen species. Treatment by the Filterra® significantly reduced all nitrogen species except $NO_{2,3}$-N. The storm-by-storm median EMC and loading removal for TN was 35% (95% CI: 21% - 44%) and 45% (95% CI: 29% - 50%), respectively, with an overall load reduction of 39%. This is on par with the 35% nitrogen removal credited to bioretention without internal water storage in North Carolina (NCDENR). When loading attributed to untreated bypass was not included into the analysis, cumulative load reduction increased to 45%, indicating excellent removal of TN.

Nitrate concentrations increased after treatment by the Filterra®, although not significantly. This is explained by the introduction of NO_3^- via the nitrification of NH_4^+, which has been documented in several other bioretention studies that do not have internal water storage, and thus have commonly shown export of nitrate-nitrogen (Davis et al., 2001; Dietz and Clausen,

2006; Hunt et al. 2006). Under aerobic conditions, NH_4^+ is readily oxidized to NO_3^-, a much more stable and mobile form of nitrogen, which is highly soluble and does not readily sorb to bioretention media (Davis et al., 2006; Clark and Pitt, 2012). Denitrifying NO_3^- to N_2 gas requires anaerobic conditions (typically created through a saturated zone) and the presence of organic carbon. Without internal water storage, the Filterra® system does not have a mechanism to create anaerobic conditions, thus concentrations of NO_3^- tended to persist in the effluent. Still, all other nitrogen forms were significantly reduced and contributed to an overall reduction of total nitrogen. Since the primary removal mechanism of Filterra® is filtration and sedimentation, it makes sense that the greatest reduction observed was for TKN, a primarily sediment-bound form of nitrogen.

Table 29. Summary statistics of all nitrogen performance metrics evaluated in the study.

Evaluation Metric	Statistical Parameter	TN[a]	TKN	NO$_{2,3}$-N	TAN
Event Mean Concentration (EMC)	n	34	34	34	34
	inlet mean [std. dev.] (mg/L)	1.17 [0.63]	1.08 [0.57]	0.13 [0.10]	0.15 [0.16]
	inlet median (mg/L)	1.06	0.99	0.11	0.09
	outlet mean [std. dev.] (mg/L)	0.71 [0.46]	0.56 [0.32]	0.18 [0.16]	0.07 [0.09]
	outlet median (mg/L)	0.53	0.46	0.15	0.05
	Peto & Peto mod. of Gehsan-Wilcoxon test p-values	0.0002[b]	<0.001	0.0974	0.0299
EMC Percent Removal (all storms)	n	33	33	33	33
	mean	33%	43%	-97%	13%
	median	35%	44%	-53%	39%
	std. dev.	34%	29%	213%	92%
	Bootstrapped 95% Conf. Int.	21% - 44%	34% - 53%	-168% to -26%	-17% - 44%
EMC Percent Removal (storms with no bypass only)	n	12	12	12	12
	mean	28%	38%	-88%	-1%
	median	30%	40%	-50%	18%
	std. dev.	39%	36%	159%	128%
Individual Load Reductions (all storms)	n	33	33	33	33
	mean	40%	47%	-51%	22%
	median	45%	50%	-1%	39%
	std. dev.	32%	29%	151%	88%
	Bootstrapped 95% Conf. Int.	29% - 50%	38% - 57%	-100% to -1%	-6% - 50%
Individual Load Reductions (storms with no bypass only)	n	12	12	12	12
	mean	45%	53%	-49%	18%
	median	55%	65%	-35%	53%
	std. dev.	40%	38%	147%	133%
Cumulative Load Reduction (all storms)		39%	46%	-1%	39%
Cumulative Load Reduction (all storms without censored data)		37%	44%	-10%	42%
Cumulative Load Reduction (only storms with no bypass)		45%	54%	-40%	40%

[a] Calculation of total nitrogen assumed ½ the detection limit when TKN or NO$_{2,3}$-N data were censored
[b] Unpaired t-test of log-transformed values performed

Figure 17 shows the distribution of various nitrogen species and the proportion of data which were below the minimum detection limit.
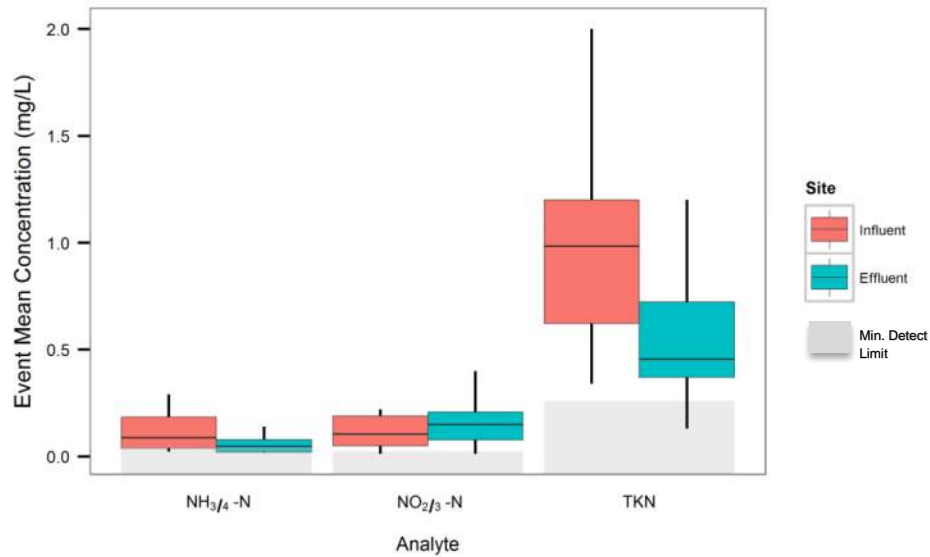
Figure 17. Boxplot of measured nitrogen species event mean concentrations with each respective minimum detection limit (MDL) shown in gray bar.
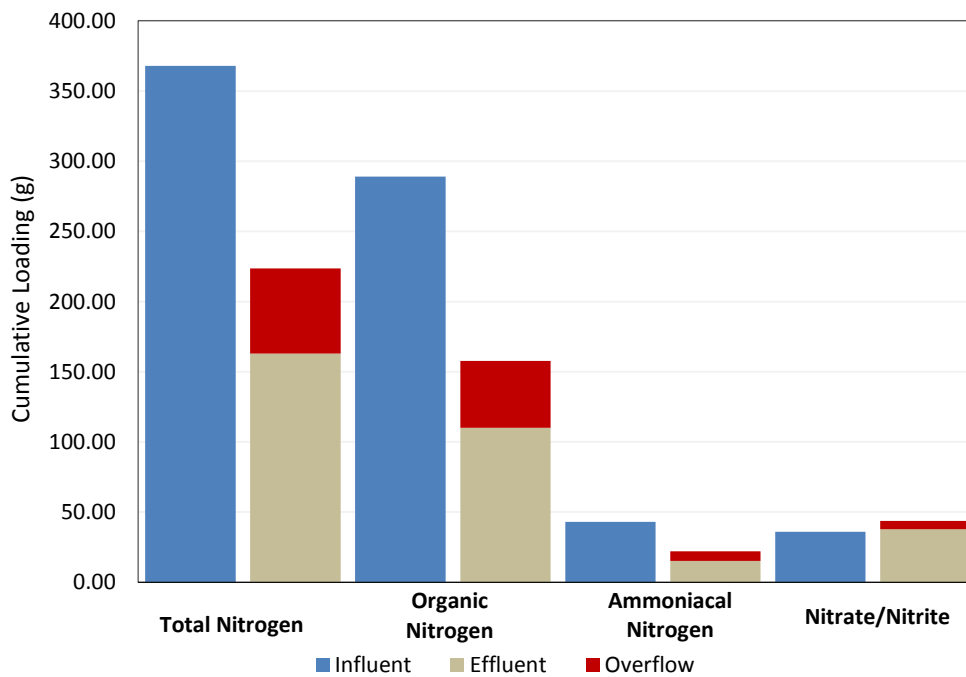
Figure 18. Cumulative loading for total nitrogen and nitrogen species (n = 34).

Metals

A summary of metal removal performance is given in Table 30. It is cautioned that the sample size for metals analysis was much smaller than other analytes due to most data falling below detection limits, especially for dissolved metals, and thus further testing is needed to confirm results. Generally speaking, the majority of the influent metals data collected were below TAPE screening criteria for enhanced metals treatment, which are designed to address pollutant irreducible concentrations. TAPE requires an influent range of 0.005 to 0.02 mg/L for dissolved copper and 0.02 to 0.30 mg/L for dissolved zinc; median dissolved concentrations of copper and zinc were 0.003 mg/L and 0.02 mg/L, respectively. After it became clear the study site was unable to produce influent concentrations of metals within the acceptable range, the research team chose not to analyze water quality samples for metals for the remainder of the study. The last water quality samples analyzed for metals were collected on June 12, 2014, approximately seven months prior to the study conclusion.

Of the data collected, total zinc was significantly reduced, with a median storm-by-storm removal efficiency of 74%. While dissolved zinc was also reduced, it was not significant at the $\alpha = 0.05$-level (p=0.0663). Inconclusive performance of dissolved zinc removal indicates the total zinc removal is most likely from sediment-bound metals, since that metric is similar to TSS and SSC. The mean influent total copper concentration of 0.008 mg/L (median of 0.0073 mg/L) was reduced to a mean effluent EMC of 0.0062 mg/L (median of 0.0049 mg/L), but results were not statistically significant. Dissolved copper measurements only resulted in a sample size of 5, disallowing statistical comparison. Dissolved copper concentrations were also close to the minimum detection limit (0.002 mg/L) at both the inlet (0.0043 mg/L) and outlet (mean: 0.0055 mg/L); the negative efficiency ratio observed is thus confounded by these very low influent concentrations. Due to the irreducible concentration levels, as illustrated by the majority of the metals influent data being below the TAPE screening criteria, the metals data presented have limited value and applicability. For these reasons, more robust analytics were not performed and metals monitoring concluded prior to the end of the study.

Table 30. Summary statistics of all metal performance metrics evaluated in the study.

Evaluation Metric	Statistical Parameter	Cu (Tot.)	Cu (Diss.)	Zn (Tot.)	Zn (Diss.)
Event Mean Concentration (EMC)	n	13	5	13	5
	inlet mean [std. dev.] (mg/L)	0.0080 [0.0069]	0.0043 [0.0055]	0.059 [0.047]	0.060 [0.008]
	inlet median (mg/L)	0.0073	0.0044	0.049	0.049
	outlet mean [std. dev.] (mg/L)	0.0062 [0.0034]	0.0055 [0.0028]	0.018 [0.010]	0.020 [2.5E-17]
	outlet median (mg/L)	0.0049	0.0048	0.013	0.026
	Peto & Peto mod. of Gehsan-Wilcoxon test p-values	0.5954	0.251	0.0019	0.0663
EMC Percent Removal (all storms)	n	13	5	13	5
	mean	-10%	-204%	66%	32%
	median	28%	-51%	74%	62%
	std. dev.	81%	366%	25%	67%
	Bootstrapped 95% Conf. Int.	-54% - 31%	-528% to 139%	53% - 79%	-28% to 95%
EMC Percent Removal (storms with no bypass only)	n	3	2	3	2
	mean	-51%	-421%	67%	4%
	median	29%	-421%	82%	4%
	std. dev.	141%	606%	30%	110%
Individual Load Reductions (all storms)	n	13	5	13	5
	mean	-6%	0%	58%	31%
	median	25%	-12%	62%	47%
	std. dev.	76%	374%	19%	63%
	Bootstrapped 95% Conf. Int.	-46% - 35%	-517% - 139%	48% to 68%	-21% to 85%
Individual Load Reductions (storms with no bypass only)	n	3	2	3	2
	mean	-48%	-415%	67%	6%
	median	29%	-415%	82%	6%
	std. dev.	144%	615%	30%	112%
Cumulative Load Reduction (all storms)		14%	-50%	63%	48%
Cumulative Load Reduction (all storms without censored data)		18%	7%	61%	-14%
Cumulative Load Reduction (only storms with no bypass)		-11%	-193%	10%	74%
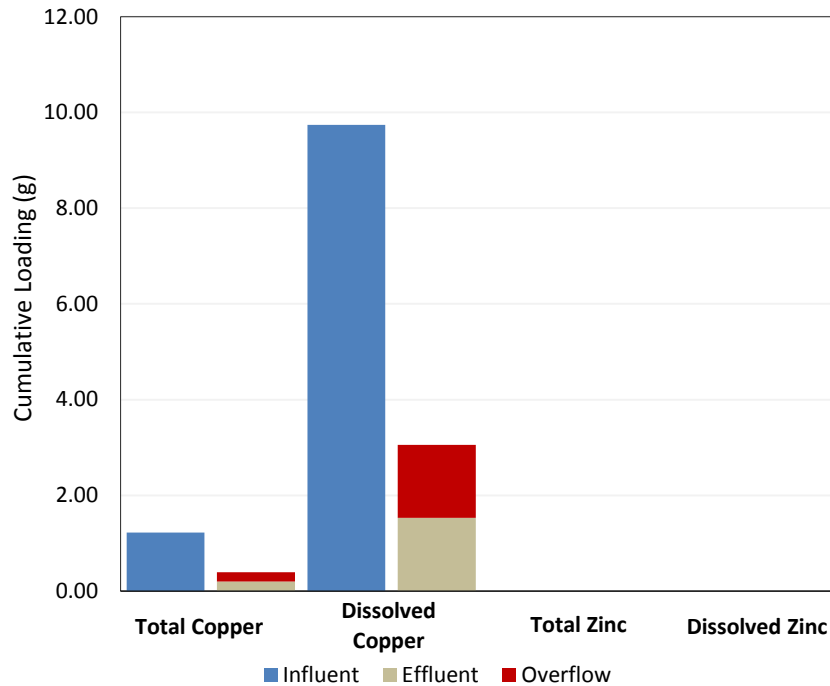
Figure 19. Cumulative loading for total metals species (n = 13) and dissolved metals species (n = 5).

Conclusions and Recommendations

The purpose of this study was to quantify the hydrologic and water quality treatment capabilities of a Filterra® Bioretention System to obtain performance data that supports approval by the North Carolina Department of Environmental and Natural Resources (NCDENR). This monitoring was performed in accordance with the Preliminary Evaluation Period (PEP) guidelines described in the 2007 NCDENR Stormwater BMP Manual and the Quality Assurance Project Plan (NC State 2013) previously submitted to NCDENR. Assessments were also conducted using the state of Washington's Technology Assessment Protocol – Ecology (TAPE).

North Carolina State University conducted a third-party analysis of the pollutant removal performance and hydrologic mitigation of a Filterra® Bioretention System. For removal of total suspended solids (TSS), guidelines set forth by TAPE target either (a) TSS removal greater than 80% (influent TSS range: > 200 mg/L), (b) TSS removal greater than or equal to 80% (influent TSS range: 100 – 200 mg/L), or (c) effluent TSS concentration less than or equal to 20 mg/L (influent TSS range: 20 – 100 mg/L). As a whole, the Filterra® system met

these criteria. The bootstrapped 95% confidence interval of the mean TSS removal efficiency and mean effluent concentration were 90% - 94% and 3.9 – 6.6 mg/L, respectively. This also meets NCDENR's criterion of 85% TSS removal. While the cumulative loading reduction (76%) was lower due to bypass, when storms that generated bypass were excluded from the analysis, cumulative load reduction increased to 96%, indicating adequate treatment of smaller storms.

The Filterra® system also met TAPE's target of 50% removal of total phosphorus. The mean EMC removal efficiency for TAPE-qualified events was 66% with a 95% confidence interval of 57% - 75%. The mean load reduction was 65%, with a 95% confidence interval of 56% - 76%. Overall load reduction was 54%, indicating excellent removal of phosphorus that is on par and/or above the 45% pollutant removal credit awarded by NCDENR for bioretention without internal water storage (NCDENR 2009). When storms generating bypass were excluded, TP load reduction increased to 75%. The studied Filterra® system was slightly undersized and not maintained on the recommended biannual schedule; were the Filterra® system properly sized and maintained, it is expected less bypass would have occurred, and perhaps greater load reduction achieved as a result. Concentrations of both total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) were very low. Despite a cumulative load reduction of 66% for TDP, reduction of TDP concentrations was not significant. This is partially due to very low influent concentrations, and indicates the removal mechanisms for aqueous phosphorus species were more variable than the filtration and sedimentation removal mechanisms responsible for sediment-bound phosphorus removal.

While total nitrogen is not a pollutant targeted for TAPE approval, total nitrogen was also reduced, with the 95% confidence interval of the mean loading reduction ranging from 29% - 50%. Although total nitrogen was reduced, likely due to filtration of particulate-bound N, nitrate export was witnessed. This finding was expected, and is typical in systems that do not have apparent mechanisms for denitrification.

When looking at effluent concentrations as a benchmark, water quality of discharged and treated stormwater was generally better than "good" and "excellent" water quality thresholds found in the published literature. Over 80% of all measured TP effluent event mean concentrations met the 0.06 mg/L "excellent" threshold, with a median effluent concentration

of 0.038 mg/L. 65% of the measured TN effluent samples (median: 0.53 mg/L) met or exceeded the "excellent" benthic threshold of 0.69 mg/L for the Piedmont of North Carolina. The 0.53 mg/L TN median effluent concentration meant that the "excellent" benthic threshold of 0.69 mg/L determined for this specific eco-region was met or exceeded for 65% of measured events.

Hydrologic mitigation was primarily provided via peak flow reduction. Despite bypass occurring for larger and high-intensity events, peak flow was reduced by a median value of 56%, with effluent peak flows mimicking pre-development conditions. While 22% of runoff bypassed the system, data from Smolek et al. (2015) show that this is within the expected overflow from traditional stormwater BMPs following NCDENR design guidance, such as a wetland or wet pond, suggesting that the Filterra® behaved similarly to widely-used and approved BMPs in North Carolina. In 2013 and 2014, significant bypass did not occur before 0.69 inches (Figure 5 and Table 15).

Future studies with higher nutrient concentrations entering the Filterra® (perhaps from watersheds with a high gross solids and leaf litter loading) will provide a better assessment of soluble phosphorus species.

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Appendices

Site and Monitoring Photos

Figure 20. Filterra Site with overflow bypass pipe

Figure 21. Planted tree species in the spring of 2013.

Figure 22. Inflow compound weir for flow measurement

Figure 23. Primary measuring device on the outlet pipe (Cipolleti-style weir)
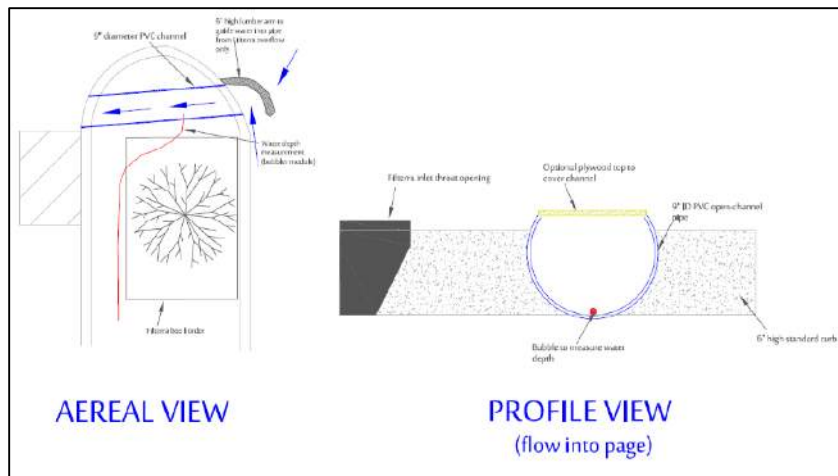
Figure 24. Plan and cross section of the overflow pipe for bypass monitoring

Additional Tables

Table 31. Summary of all hydrologic storms (n = 125). Sampled storms are marked by an asterisk.

Storm	Date	Rainfall	Duration	Intensity	Antecedent Dry Period	Inflow	Outflow	Overflow	Instrumentation Error/Other Abstraction
#		in	hr	in/hr	days	ft^3	ft^3	ft^3	ft^3
1	2/22/2013	0.58	26.1	0.02	-	376.8	354.0	0.0	22.8
2	2/26/2013*	1.12	14.5	0.08	2.1	846.9	741.4	122.1	-16.6
3	3/5/2013	0.10	14.7	0.01	6.7	24.0	24.0	0.0	0.0
4	3/12/2013	0.42	8.0	0.05	5.9	244.8	244.8	0.0	0.0
5	3/18/2013	0.14	1.3	0.11	6.5	44.4	44.4	0.0	0.0
6	3/24/2013	0.70	12.1	0.06	5.2	479.0	423.8	0.0	55.3
7	3/31/2013	0.10	2.7	0.04	6.5	24.0	24.0	0.0	0.0
8	4/1/2013	0.69	4.6	0.15	0.8	470.5	354.6	0.0	115.9
9	4/4/2013*	0.81	12.7	0.06	3.2	198.6	172.0	0.0	26.7
10	4/12/2013	0.32	2.8	0.11	7.2	126.0	139.8	15.0	-28.8
11	4/19/2013*	0.60	8.1	0.07	7.5	393.7	383.8	9.9	0.0
12	4/28/2013*	1.95	29.7	0.07	8.5	1590.5	1034.2	143.0	413.3
13	5/6/2013*	0.38	5.4	0.07	6.3	213.0	161.9	0.0	51.0
14	5/19/2013	0.62	11.2	0.06	0.5	410.7	427.7	0.0	-17.0
15	5/20/2013	0.45	14.9	0.03	0.3	269.0	269.0	0.0	0.0
16	5/23/2013	0.28	1.4	0.20	2.9	136.7	144.1	0.0	-7.4
17	6/3/2013	0.12	4.4	0.03	0.3	33.7	33.7	0.0	0.0
18	6/6/2013	4.94	27.1	0.18	2.8	4301.9	3118.9	1183.0	0.0
19	6/7/2013	0.30	2.8	0.11	0.4	151.5	138.6	8.5	4.4
20	6/9/2013	0.35	0.2	2.10	1.7	189.5	125.4	62.0	2.2
21	6/10/2013*	0.55	3.9	0.14	0.8	351.6	281.7	70.0	0.0
22	6/13/2013*	0.17	2.8	0.06	3.0	61.9	43.0	0.0	18.9
23	6/17/2013	0.20	1.4	0.14	4.0	80.9	74.7	0.0	6.3
24	6/19/2013*	0.19	1.0	0.19	1.0	74.5	64.9	0.0	9.6
25	6/22/2013	0.29	9.4	0.03	3.3	144.0	121.0	0.0	23.1
26	6/23/2013	0.11	1.9	0.06	0.3	28.7	28.7	0.0	0.0
27	6/23/2013*	0.35	11.0	0.03	0.7	189.5	189.5	0.0	0.0
28	6/25/2013	0.41	3.6	0.11	1.0	236.8	194.9	0.0	41.9
29	6/26/2013*	1.71	9.3	0.18	0.9	1374.4	1052.6	321.8	0.0
30	6/28/2013	0.47	4.2	0.11	1.9	173.9	172.3	0.0	1.6
31	6/30/2013	0.62	1.5	0.41	1.8	410.7	396.9	13.8	0.0
32	7/1/2013*	0.60	1.3	0.47	0.4	393.7	368.0	98.9	-73.2
33	7/1/2013	0.46	5.8	0.08	0.4	203.2	176.6	13.3	13.3
34	7/2/2013*	0.87	5.5	0.16	0.5	626.5	478.1	103.9	44.5
35	7/3/2013	0.98	4.2	0.24	1.0	723.1	617.6	105.5	0.0
36	7/8/2013	1.64	6.1	0.27	4.8	1311.5	932.8	378.7	0.0

37	7/9/2013	0.17	4.9	0.03	0.6	61.9	35.4	0.0	26.5
38	7/11/2013	0.37	9.7	0.04	1.9	205.1	156.5	0.0	48.6
39	7/12/2013	0.60	2.8	0.22	0.4	393.7	329.0	64.7	0.0
40	7/13/2013	0.40	9.3	0.04	0.7	228.8	205.9	0.0	22.9
41	7/14/2013	0.23	4.2	0.06	0.7	101.1	80.1	0.0	21.0
42	7/18/2013	0.13	0.2	0.56	1.4	63.4	77.1	0.0	-13.7
43	7/24/2013	0.13	1.2	0.11	5.9	39.6	43.4	9.0	-12.8
44	7/25/2013	0.43	1.4	0.31	0.4	284.8	223.7	0.0	61.1
45	7/27/2013	0.17	5.3	0.03	2.7	61.9	61.9	0.0	0.0
46	7/29/2013	0.75	2.1	0.35	1.8	522.2	408.0	51.8	62.3
47	8/2/2013	0.34	6.3	0.05	3.7	181.8	141.6	0.0	40.2
48	8/12/2013	0.16	3.7	0.04	10.1	55.9	49.7	0.0	6.2
49	8/13/2013*	0.78	5.5	0.14	0.6	548.1	371.0	118.7	58.4
50	8/16/2013	0.20	14.9	0.01	2.6	80.9	80.9	0.0	0.0
51	8/17/2013	1.23	4.2	0.30	0.3	944.6	746.4	198.2	0.0
52	8/19/2013	1.56	14.5	0.11	1.5	1239.7	1020.9	126.8	92.0
53	8/21/2013	1.93	6.3	0.31	1.9	1572.5	1156.8	415.7	0.0
54	9/1/2013*	0.37	6.1	0.06	11.0	205.1	179.6	0.0	25.5
55	9/16/2013	0.12	3.3	0.04	14.3	18.4	20.9	0.0	-2.5
56	9/21/2013*	0.95	8.0	0.12	1.5	696.7	603.0	93.7	0.0
57	10/7/2013	0.34	11.0	0.03	15.3	132.4	65.5	0.0	66.9
58	10/8/2013	0.18	3.1	0.06	0.6	82.2	20.1	0.0	62.2
59	10/13/2013*	0.10	3.2	0.03	2.4	36.5	0.0	0.0	36.5
60	11/1/2013*	0.71	7.2	0.10	13.4	368.2	368.2	0.0	0.0
61	11/7/2013	0.20	15.7	0.01	5.0	80.9	70.0	0.0	10.9
62	11/26/2013*	1.24	27.7	0.04	8.0	369.3	324.3	45.0	0.0
63	12/4/2013	0.13	4.7	0.03	6.4	9.9	0.0	0.0	9.9
64	12/8/2013	0.19	12.9	0.01	0.9	74.5	74.5	0.0	0.0
65	12/9/2013*	0.53	16.8	0.03	1.1	334.9	334.9	0.0	0.0
66	12/14/2013	1.09	10.5	0.10	3.9	820.3	501.1	319.2	0.0
67	12/23/2013	0.35	15.8	0.02	8.5	189.5	189.5	0.0	0.0
68	12/29/2013	1.58	12.8	0.12	4.9	1257.6	1018.9	238.7	0.0
69	1/2/2013	0.30	17.1	0.02	3.6	151.5	68.8	29.1	53.6
70	1/10/2014	2.84	18.6	0.15	7.3	2395.3	2366.2	29.1	0.0
71	1/11/2014	1.00	8.1	0.12	0.5	740.7	560.8	179.9	0.0
72	1/14/2014*	0.20	11.2	0.02	2.32	84.5	50.4	4.0	30.1
73	1/21/2014	0.13	2.7	0.05	7.22	15.2	14.5	0.0	0.7
74	1/30/2014	0.14	5.2	0.03	8.58	39.0	0.4	0.0	38.7
75	1/31/2014	0.10	4.8	0.02	0.73	30.0	0.5	0.0	29.5
76	2/1/2014	0.26	8.5	0.03	0.93	115.4	34.4	0.0	81.0
77	2/4/2014	0.20	2.8	0.07	2.65	33.1	24.1	0.0	9.0
78	2/5/2014*	0.28	12.3	0.02	0.26	78.2	64.4	0.0	13.8
79	2/13/2014	0.40	12.2	0.03	1.90	264.6	120.5	0.0	144.1
80	2/15/2014	0.35	5.2	0.07	1.29	97.2	50.5	0.0	46.7

81	2/19/2014*	0.46	2.4	0.19	3.72	277.2	173.0	50.2	53.9
82	2/21/2014	0.19	1.5	0.13	2.23	91.1	52.7	0.0	38.4
83	3/3/2014*	0.35	7.6	0.05	9.90	71.9	58.6	0.0	13.3
84	3/5/2015	0.10	5.2	0.02	1.40	5.1	5.1	0.0	0.0
85	3/6/2014	1.50	26.2	0.06	1.32	1004.5	920.9	83.6	0.0
86	3/16/2014	0.22	15.0	0.01	8.65	28.1	28.1	0.0	0.0
87	3/17/2014	0.68	10.0	0.07	0.56	650.8	650.8	0.0	0.0
88	3/28/2014	1.11	22.3	0.05	9.03	482.4	478.4	4.0	0.0
89	3/29/2014	0.32	9.9	0.03	0.31	166.5	94.4	24.9	47.2
90	4/7/2014	0.22	10.3	0.02	8.24	94.3	25.1	15.5	53.7
91	4/15/2014*	0.81	0.8	1.01	7.35	574.2	386.2	188.0	0.0
92	4/15/2014	0.82	1.9	0.42	0.46	556.8	361.0	195.8	0.0
93	4/18/2014*	1.08	23.6	0.05	3.03	811.4	804.5	6.9	0.0
94	4/28/2014	1.48	2.2	0.66	8.80	1167.9	800.3	367.6	0.0
95	4/29/2014	2.36	4.6	0.52	0.89	1960.8	1069.0	891.7	0.0
96	4/30/2014	0.27	2.3	0.12	0.67	129.4	120.8	8.6	0.1
97	5/15/2014	3.64	16.0	0.23	14.87	3120.9	1418.9	1595.1	106.9
98	5/29/2014	0.32	0.2	1.92	13.02	166.5	115.5	51.1	0.0
99	6/10/2014	0.11	0.2	0.66	11.89	28.7	23.7	4.8	0.2
100	6/12/2014*	0.22	0.1	2.20	2.39	94.3	62.8	30.0	1.5
101	6/17/2014	0.19	3.3	0.06	5.26	17.0	16.2	0.7	0.1
102	6/19/2014*	0.61	1.2	0.51	1.94	402.2	239.9	135.2	27.1
103	6/21/2014	0.57	2.8	0.20	1.91	368.4	246.4	118.7	3.3
104	6/22/2014	0.14	0.2	0.84	0.95	44.4	28.0	10.6	5.8
105	7/3/2014	0.29	3.3	0.09	5.97	144.0	143.6	0.4	0.0
106	7/10/2014	0.50	4.7	0.11	6.73	310.0	289.6	20.5	0.0
107	7/21/2014	0.88	9.2	0.10	10.59	635.3	407.1	228.2	0.0
108	8/9/2014	2.93	6.6	0.45	18.61	2476.8	1281.5	1195.3	0.0
109	8/10/2014	0.83	11.1	0.07	0.35	591.6	591.6	0.0	0.0
110	8/11/2014*	0.59	10.3	0.06	0.97	385.3	272.1	113.2	0.0
111	8/18/2014	0.51	5.0	0.10	6.80	318.3	229.7	88.6	0.0
112	8/19/2014	0.11	1.4	0.08	0.86	7.0	13.0	2.3	-8.3
113	8/23/2014	0.89	4.4	0.20	3.91	644.0	419.8	224.2	0.0
114	9/24/2014	0.33	10.1	0.03	31.32	84.5	40.7	0.0	43.9
115	9/25/2014	0.15	9.5	0.02	0.45	50.1	27.3	0.0	22.8
116	9/29/2014	0.12	10.0	0.01	4.12	33.7	33.7	0.0	0.0
117	10/11/2014*	0.43	4.0	0.11	11.65	252.9	89.6	0.0	163.3
118	10/14/2014*	0.72	3.4	0.21	2.49	496.3	163.0	77.8	255.4
119	10/15/2014	0.50	7.9	0.06	0.67	310.0	96.7	55.2	158.2
120	11/1/2014	0.21	14.6	0.01	16.62	55.2	7.1	5.1	43.0
121	11/23/2014	0.75	13.8	0.05	21.73	570.2	168.2	217.5	184.5
122	11/24/2014*	1.94	48.1	0.04	0.65	1581.5	488.5	1295.0	-202.0
123	12/6/2014*	0.21	13.4	0.02	9.93	43.4	24.0	3.2	16.2
124	12/16/2014	0.10	13.4	0.01	9.39	33.1	3.6	4.4	25.0

125	12/22/2014*	0.97	13.4	0.07	5.09	398.4	135.1	32.6	230.6
	SUM	**80.18**				**53953**	**38973**	**11920**	**3061**
	% of Inflow						**72%**	**22%**	**6%**

Table 32. Peak flow summary of all hydrologic storms (n = 125). Sampled storms are marked by an asterisk.

Storm Event	Date	Peak Rainfall Intensity	Peak Inflow	Peak Outflow (NOUT + Bypass)	NOUT Flow		Bypass Flow
		in/hr	cfs	cfs	cfs	in/hr	cfs
1	2/22/2013	1.02	0.243	0.065	0.065	117.0	0
2	2/26/2013*	1.86	0.443	0.125	0.124	223.2	0.001
3	3/5/2013	0.12	0.029	0.051	0.051	91.8	0.000
4	3/12/2013	0.30	0.071	0.094	0.094	169.2	0.000
5	3/18/2013	0.30	0.071	0.079	0.079	142.2	0.000
6	3/24/2013	0.42	0.100	0.085	0.085	153.0	0.000
7	3/31/2013	0.30	0.071	0.038	0.038	68.4	0.000
8	4/1/2013	1.14	0.272	0.059	0.059	106.2	0.000
9	4/4/2013*	0.36	0.086	0.038	0.038	68.4	0.000
10	4/12/2013	0.72	0.066	0.041	0.040	72.0	0.001
11	4/19/2013*	1.80	0.429	0.101	0.097	174.6	0.004
12	4/28/2013*	1.20	0.286	0.115	0.088	158.4	0.027
13	5/6/2013*	1.32	0.315	0.086	0.086	154.8	0.000
14	5/19/2013	1.98	0.472	0.240	0.240	432.0	0.000
15	5/20/2013	0.84	0.200	0.091	0.091	163.8	0.000
16	5/23/2013	1.74	0.415	0.165	0.165	297.0	0.000
17	6/3/2013	0.30	0.071	0.038	0.038	68.4	0.000
18	6/6/2013	2.40	0.572	0.375	0.247	444.6	0.128
19	6/7/2013	1.50	0.357	0.064	0.061	109.8	0.003
20	6/9/2013	3.00	0.715	0.316	0.115	207.0	0.201
21	6/10/2013*	1.98	0.472	0.152	0.027	48.6	0.125
22	6/13/2013*	0.54	0.038	0.034	0.034	61.2	0.000
23	6/17/2013	0.30	0.071	0.067	0.067	120.6	0.000
24	6/19/2013*	0.78	0.186	0.059	0.059	106.2	0.000
25	6/22/2013	1.32	0.315	0.132	0.132	237.6	0.000
26	6/23/2013	0.66	0.031	0.027	0.027	48.6	0.000
27	6/23/2013*	0.42	0.100	0.069	0.069	124.2	0.000
28	6/25/2013	1.44	0.129	0.123	0.123	221.4	0.000
29	6/26/2013*	5.64	1.344	0.403	0.296	532.8	0.107
30	6/28/2013	1.38	0.143	0.130	0.130	234.0	0.000
31	6/30/2013	1.92	0.458	0.162	0.129	232.2	0.033
32	7/1/2013*	2.70	0.643	0.342	0.137	246.6	0.205
33	7/1/2013	0.30	0.071	0.052	0.052	93.6	0.000

34	7/2/2013*	1.86	0.443	0.224	0.077	138.6	0.147
35	7/3/2013	2.82	0.672	0.189	0.096	172.8	0.092
36	7/8/2013	4.26	1.015	0.571	0.207	372.6	0.364
37	7/9/2013	1.20	0.286	0.074	0.074	133.2	0.000
38	7/11/2013	1.02	0.243	0.090	0.090	162.0	0.000
39	7/12/2013	2.76	0.658	0.262	0.106	190.8	0.156
40	7/13/2013	0.30	0.071	0.058	0.058	104.4	0.000
41	7/14/2013	1.02	0.243	0.064	0.063	113.4	0.001
42	7/18/2013	0.84	0.080	0.122	0.122	219.6	0.000
43	7/24/2013	0.84	0.080	0.075	0.075	135.0	0.000
44	7/25/2013	1.32	0.254	0.155	0.155	279.0	0.000
45	7/27/2013	0.24	0.057	0.120	0.120	216.0	0.000
46	7/29/2013	3.54	0.844	0.339	0.186	334.8	0.153
47	8/2/2013	1.74	0.415	0.133	0.133	239.4	0.000
48	8/12/2013	0.48	0.114	0.111	0.111	199.8	0.000
49	8/13/2013*	3.54	0.844	0.396	0.154	277.2	0.241
50	8/16/2013	1.50	0.357	0.074	0.074	133.2	0.000
51	8/17/2013	2.76	0.658	0.346	0.135	243.0	0.211
52	8/19/2013	2.16	0.515	0.206	0.120	216.0	0.086
53	8/21/2013	5.52	1.315	0.449	0.100	180.0	0.349
54	9/1/2013*	1.56	0.372	0.142	0.142	255.6	0.000
55	9/16/2013	1.26	0.073	0.039	0.039	70.2	0.000
56	9/21/2013*	1.20	0.286	0.156	0.032	57.6	0.124
57	10/7/2013	0.96	0.183	0.048	0.048	86.4	0.000
58	10/8/2013	0.30	0.033	0.008	0.008	14.4	0.000
59	10/13/2013*	0.30	0.174	0.000	0.000	0.0	0.000
60	11/1/2013*	1.38	0.526	0.077	0.077	138.6	0.000
61	11/7/2013	0.24	0.057	0.004	0.004	7.2	0.000
62	11/26/2013*	0.72	0.089	0.051	0.049	88.2	0.002
63	12/4/2013	0.30	0.004	0.000	0.000	0.0	0.000
64	12/8/2013	0.42	0.013	0.016	0.016	28.8	0.000
65	12/9/2013*	0.54	0.043	0.035	0.035	63.0	0.000
66	12/14/2013	1.62	0.386	0.213	0.027	48.6	0.186
67	12/23/2013	0.60	0.050	0.026	0.026	46.8	0.000
68	12/29/2013	2.52	0.601	0.406	0.083	149.4	0.322
69	1/2/2013	0.24	0.015	0.014	0.009	16.2	0.005
70	1/10/2014	2.52	0.601	0.405	0.080	144.0	0.325
71	1/11/2014	2.28	0.543	0.241	0.051	91.8	0.190
72	1/14/2014*	0.42	0.047	0.017	0.015	27.0	0.002
73	1/21/2014	0.30	0.008	0.006	0.006	10.8	0.000
74	1/30/2014	0.24	0.003	0.000	0.000	0.0	0.000
75	1/31/2014	0.24	0.003	0.001	0.001	1.8	0.000
76	2/1/2014	0.30	0.047	0.014	0.014	25.2	0.000
77	2/4/2014	0.24	0.017	0.008	0.008	14.4	0.000

78	2/5/2014*	0.90	0.120	0.046	0.046	82.8	0.000
79	2/13/2014	0.30	0.026	0.014	0.014	25.2	0.000
80	2/15/2014	0.30	0.017	0.008	0.008	14.4	0.000
81	2/19/2014*	1.56	0.372	0.231	0.083	149.4	0.148
82	2/21/2014	0.96	0.105	0.046	0.046	82.8	0.000
83	3/3/2014*	0.66	0.045	0.026	0.026	46.8	0.000
84	3/5/2015	0.24	0.003	n/a	n/a	n/a	0.000
85	3/6/2014	0.24	0.096	n/a	n/a	n/a	0.010
86	3/16/2014	0.24	0.044	n/a	n/a	n/a	0.000
87	3/17/2014	0.30	0.380	n/a	n/a	n/a	0.000
88	3/28/2014	0.78	0.097	0.042	0.042	75.6	0.000
89	3/29/2014	2.10	0.500	0.135	0.083	149.4	0.051
90	4/7/2014	0.42	0.100	0.009	0.003	5.4	0.005
91	4/15/2014*	4.32	1.029	0.452	0.083	149.4	0.369
92	4/15/2014	1.80	0.429	0.138	0.025	45.0	0.113
93	4/18/2014*	0.54	0.129	0.023	0.023	41.4	0.000
94	4/28/2014	4.74	1.130	0.430	0.083	149.4	0.347
95	4/29/2014	3.96	0.944	0.554	0.083	149.4	0.471
96	4/30/2014	0.84	0.200	0.032	0.032	57.6	0.000
97	5/15/2014	3.60	0.858	0.411	0.083	149.4	0.327
98	5/29/2014	3.06	0.729	0.177	0.083	149.4	0.094
99	6/10/2014	0.84	0.200	0.050	0.050	90.0	0.000
100	6/12/2014*	2.16	0.515	0.106	0.038	68.4	0.068
101	6/17/2014	0.60	0.020	0.015	0.015	27.0	0.000
102	6/19/2014*	1.38	0.329	0.140	0.039	70.2	0.101
103	6/21/2014	3.00	0.715	0.094	0.018	32.4	0.076
104	6/22/2014	0.90	0.214	0.025	0.009	16.2	0.016
105	7/3/2014	1.20	0.286	0.039	0.039	70.2	0.000
106	7/10/2014	0.60	0.143	0.033	0.033	59.4	0.000
107	7/21/2014*	3.30	0.786	0.342	0.083	149.4	0.259
108	8/9/2014	2.10	0.500	0.268	0.014	25.2	0.254
109	8/10/2014	1.50	0.357	0.018	0.018	32.4	0.000
110	8/11/2014*	2.52	0.601	0.193	0.003	5.4	0.190
111	8/18/2014	3.54	0.844	0.285	0.000	0.0	0.285
112	8/19/2014	0.78	0.014	0.006	0.006	10.8	0.000
113	8/23/2014	4.92	1.172	0.464	0.012	21.6	0.452
114	9/24/2014	6.36	1.516	0.015	0.015	27.0	0.000
115	9/25/2014	0.54	0.129	0.008	0.008	14.4	0.000
116	9/29/2014	0.30	0.071	n/a	n/a	n/a	n/a
117	10/11/2014*	3.54	0.844	0.083	0.083	149.4	0.000
118	10/14/2014*	1.92	0.458	0.203	0.083	149.4	0.102
119	10/15/2014	1.62	0.386	0.185	0.070	126.0	0.115
120	11/1/2014	0.24	0.014	0.003	0.003	5.4	0.000
121	11/23/2014	1.92	0.458	0.543	0.083	149.4	0.460

122	11/24/2014*	0.60	0.143	0.301	0.051	91.8	0.250
123	12/6/2014*	0.90	0.069	0.043	0.043	77.4	0.000
124	12/16/2014	0.24	0.057	0.003	0.003	5.4	0.000
125	12/22/2014*	0.60	0.143	0.076	0.020	36.0	0.056

Table 33. Water quality results for total suspended solids, suspended sediment concentration, total phosphorus, total dissolved phosphorus, and soluble reactive phosphorus.

Date	Rainfall (in)	Total Suspended Solids (mg/L)		Suspended Sediment Concentration (mg/L)		Total Phosphorus (mg/L) MDL: 0.024 mg/L		Total Dissolved Phosphorus (mg/L) MDL: 0.024 mg/L		Soluble Reactive Phosphorus (mg/L) MDL: 0.055 mg/L	
		IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
2/26/2013	1.12	50.00	4.40	62.25	2.90	0.07	*<MDL*	0.74	*<MDL*	0.12	*<MDL*
4/4/2013	0.81	37.00	2.80	57.34	1.51	0.03	*<MDL*	0.03	*<MDL*	*<MDL*	*<MDL*
4/19/2013	0.60	51.00	6.80	48.94	6.44	0.11	0.09	0.05	0.05	*<MDL*	*<MDL*
4/29/2013	1.95	20.00	4.00	12.30	3.54	0.04	0.04	*<MDL*	*<MDL*	*<MDL*	*<MDL*
5/6/2013	0.38	68.00	5.20	*0.00*	*0.00*	0.06	0.04	0.03	*<MDL*	*<MDL*	*<MDL*
6/10/2013	0.55	32.00	4.00	43.38	3.40	0.03	0.06	0.14	*<MDL*	*<MDL*	*<MDL*
6/13/2013	0.17	*0.00*	*0.00*	*0.00*	*0.00*	0.21	0.07	*0.00*	*0.00*	*0.00*	*0.00*
6/19/2013	0.30	*0.00*	*0.00*	*0.00*	*0.00*	0.22	0.04	*0.00*	*0.00*	*<MDL*	*<MDL*
6/24/2013	0.35	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
6/26/2013	1.71	66.00	6.80	95.77	7.03	0.03	*<MDL*	*<MDL*	*<MDL*	*<MDL*	*<MDL*
7/1/2013	0.60	30.00	6.80	39.10	4.27	0.05	0.03	*<MDL*	*<MDL*	*<MDL*	*<MDL*
7/2/2013	0.87	30.00	2.90	19.51	2.30	0.05	0.04	*<MDL*	*<MDL*	*<MDL*	*<MDL*
8/13/2013	0.78	190.00	2.80	226.41	3.33	0.21	0.07	0.09	*<MDL*	*<MDL*	*<MDL*
9/2/2013	0.37	220.00	8.00	353.17	12.09	0.10	*<MDL*	*<MDL*	*<MDL*	*<MDL*	*<MDL*
9/21/2013	0.95	40.00	3.60	79.09	3.09	0.04	*<MDL*	*<MDL*	0.03	*<MDL*	*<MDL*
10/13/2013	0.10	55.00	1.60	*0.00*	*0.00*	0.07	0.03	*<MDL*	*<MDL*	*<MDL*	*<MDL*
11/1/2013	0.71	94.00	4.00	71.84	3.05	0.05	0.05	*<MDL*	*<MDL*	0.08	*<MDL*
11/26/2013	1.24	*0.00*	*0.00*	*0.00*	*0.00*	0.20	0.04	0.03	0.04	*0.00*	*0.00*
12/10/2013	0.53	270.00	9.20	*0.00*	*0.00*	0.12	0.03	*<MDL*	0.03	*<MDL*	*<MDL*
12/14/2013	0.30	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*<MDL*	*<MDL*
1/14/2014	0.20	*0.00*	*0.00*	*0.00*	*0.00*	0.12	0.05	*<MDL*	*<MDL*	*<MDL*	*<MDL*
2/5/2014	0.29	170.00	16.00	*0.00*	*0.00*	0.06	0.03	*<MDL*	*<MDL*	*<MDL*	*<MDL*
2/19/2014	0.46	120.00	3.20	86.67	2.07	0.06	*<MDL*	*<MDL*	*<MDL*	*<MDL*	*<MDL*
3/3/2014	0.35	54.00	14.00	*0.00*	*0.00*	0.59	0.05	0.39	0.02	*<MDL*	*<MDL*
4/15/2014	0.81	730.00	8.80	194.72	8.39	0.29	0.14	0.06	0.04	*<MDL*	*<MDL*
4/19/2014	1.08	43.00	1.60	39.37	0.74	0.04	*<MDL*	*<MDL*	*<MDL*	*<MDL*	*<MDL*
6/12/2014	0.25	220.00	3.60	309.03	1.57	0.30	0.09	0.14	0.06	*<MDL*	*<MDL*
6/19/2014	0.61	100.00	1.20	111.87	1.01	0.09	0.04	*<MDL*	*<MDL*	*<MDL*	*<MDL*
8/11/2014	0.51	200.00	2.40	230.13	2.39	0.17	0.04	*<MDL*	0.02	*<MDL*	*<MDL*

10/11/2014	0.43	150.00	7.60	219.75	6.49	0.27	0.13	0.14	0.08	*<MDL*	*<MDL*
10/14/2014	0.72	62.00	2.80	85.66	1.78	0.06	*<MDL*	*<MDL*	*<MDL*	*<MDL*	*<MDL*
11/24/2014	0.75	160.00	2.00	133.10	3.03	0.17	0.09	0.07	0.08	*<MDL*	*<MDL*
12/6/2014	0.20	82.00	11.00	*0.00*	*0.00*	0.12	0.06	*<MDL*	0.04	*<MDL*	*<MDL*
12/22/2014	0.97	33.00	3.60	*0.00*	*0.00*	0.12	0.03	*<MDL*	*<MDL*	*<MDL*	*<MDL*

Table 34. Water quality results for total nitrogen and nitrogen species.

Date	Rainfall (in)	Total Nitrogen		Total Ammoniacal Nitrogen (mg/L) MDL: 0.045 mg/L		Nitrate/Nitrite (mg/L) MDL: 0.025 mg/L		Total Kjedhal Nitrogen (mg/L) MDL: 0.26 mg/L	
		IN	OUT	IN	OUT	IN	OUT	IN	OUT
2/26/2013	1.12	1.25	0.54	0.14	0.06	0.05	0.08	1.20	0.46
4/4/2013	0.81	0.87	0.44	0.29	0.11	0.16	0.17	0.71	0.27
4/19/2013	0.60	1.41	1.14	0.07	0.06	0.11	0.18	1.30	0.96
4/29/2013	1.95	*0.35*	0.51	*<MDL*	*<MDL*	*<MDL*	0.15	0.34	0.36
5/6/2013	0.38	0.94	0.68	0.27	0.24	0.07	0.13	0.87	0.55
6/10/2013	0.55	0.73	0.89	0.05	*<MDL*	0.11	0.39	0.62	0.50
6/13/2013	0.17	2.39	1.60	0.28	*<MDL*	0.19	0.40	2.20	1.20
6/19/2013	0.30	2.51	0.89	0.02	*<MDL*	0.11	0.22	2.40	0.67
6/24/2013	0.35	1.55	*0.26*	0.46	*<MDL*	0.45	0.13	1.10	*<MDL*
6/26/2013	1.71	0.77	*0.31*	0.14	*<MDL*	0.21	0.18	0.56	*<MDL*
7/1/2013	0.60	0.67	0.51	0.17	0.08	0.04	0.05	0.63	0.46
7/2/2013	0.87	0.58	0.43	*<MDL*	*<MDL*	0.07	0.06	0.51	0.37
8/13/2013	0.78	1.39	0.62	0.10	0.07	0.19	0.20	1.20	0.42
9/2/2013	0.37	1.25	1.05	0.13	0.14	0.15	0.22	1.10	0.83
9/21/2013	0.95	1.10	0.52	0.13	0.06	0.20	0.11	0.90	0.41
10/13/2013	0.10	0.93	*0.46*	*<MDL*	*<MDL*	0.13	*<MDL*	0.80	0.45
11/1/2013	0.71	*0.40*	0.64	*<MDL*	0.11	*<MDL*	0.07	0.39	0.57
11/26/2013	1.24	*2.01*	*0.31*	*<MDL*	*<MDL*	*<MDL*	*<MDL*	2.00	0.30
12/10/2013	0.53	1.07	0.42	0.07	*<MDL*	0.10	0.15	0.97	0.27
12/14/2013	0.30	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
1/14/2014	0.20	1.27	0.44	0.05	*<MDL*	0.07	0.07	1.20	0.37
2/5/2014	0.29	0.58	0.53	0.08	0.08	0.14	0.15	0.44	0.38
2/19/2014	0.46	0.81	*0.33*	0.11	0.07	0.20	0.20	0.61	*<MDL*
3/3/2014	0.35	1.51	1.39	0.56	0.42	0.41	0.51	1.10	0.88
4/15/2014	0.81	*1.91*	*1.01*	*<MDL*	0.05	*<MDL*	*<MDL*	1.90	1.00
4/19/2014	1.08	*0.46*	*0.44*	*<MDL*	0.06	*<MDL*	*<MDL*	0.45	0.43
6/12/2014	0.25	2.62	1.76	0.57	0.31	0.22	0.36	2.40	1.40
6/19/2014	0.61	1.30	1.06	0.17	0.08	0.20	0.32	1.10	0.74
8/11/2014	0.51	1.60	0.62	0.25	*<MDL*	0.10	0.17	1.50	0.45

10/11/2014	0.43	1.90	2.10	0.19	0.11	0.20	0.80	1.70	1.30
10/14/2014	0.72	0.99	0.45	0.56	*<MDL*	0.05	0.08	0.94	0.37
11/24/2014	0.75	0.90	0.59	*<MDL*	*<MDL*	0.05	0.09	0.85	0.50
12/6/2014	0.20	1.06	0.99	*<MDL*	0.05	0.06	0.21	1.00	0.78
12/22/2014	0.97	0.55	*0.26*	0.07	*<MDL*	0.06	0.13	0.49	*<MDL*

Table 35. Water quality results for metals species.

Date	Rainfall (in)	Total Copper (microg/L) MDL: 2 µg/L		Dissolved Copper (µg/L) MDL: 2 µg/L		Total Zinc (microg/L) MDL: 10 µg/L		Dissolved Zinc (µg/L) MDL: 10 µg/L	
		IN	OUT	IN	OUT	IN	OUT	IN	OUT
2/26/2013	1.12	7.80	3.20	4.40	3.80	66.00	<MDL	30.00	<MDL
4/4/2013	0.81	7.30	4.90	5.20	4.80	35.00	<MDL	28.00	<MDL
4/19/2013	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4/29/2013	1.95	3.30	4.10	0.00	0.00	5.00	<MDL	0.00	0.00
5/6/2013	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/10/2013	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/13/2013	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/19/2013	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/24/2013	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/26/2013	1.71	<MDL	2.50	<MDL	2.40	19.00	<MDL	13.00	<MDL
7/1/2013	0.60	3.00	3.20	0.00	0.00	22.00	<MDL	0.00	0.00
7/2/2013	0.87	2.10	2.10	0.00	0.00	18.00	<MDL	0.00	0.00
8/13/2013	0.78	7.60	5.40	0.00	0.00	82.00	19.00	0.00	0.00
9/2/2013	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9/21/2013	0.95	6.70	4.80	0.00	0.00	49.00	12.00	0.00	0.00
10/13/2013	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11/1/2013	0.71	3.50	11.00	0.00	0.00	37.00	25.00	0.00	0.00
11/26/2013	1.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12/10/2013	0.53	14.00	10.00	<MDL	9.50	180.00	32.00	15.00	26.00
12/14/2013	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1/14/2014	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2/5/2014	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2/19/2014	0.46	12.00	7.60	4.50	6.80	87.00	24.00	28.00	26.00
3/3/2014	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4/15/2014	0.81	9.00	9.50	0.00	0.00	71.00	35.00	0.00	0.00
4/19/2014	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/12/2014	0.25	27.00	12.00	0.00	0.00	99.00	31.00	0.00	0.00
6/19/2014	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8/11/2014	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10/11/2014	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10/14/2014	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11/24/2014	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12/6/2014	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12/22/2014	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 36. Individual storm loading for total suspended solids and suspended sediment concentration.

Date	Rainfall (in)	Total Suspended Solids (mg)			Suspended Sediment Concentration (mg)		
		IN	OUT	OVER	IN	OUT	OVER
2/26/2013	1.12	1199011.40	92371.32	172817.43	1492769.19	60881.09	215157.70
4/4/2013	0.81	208116.28	13635.39	0.00	322523.98	7353.37	0.00
4/19/2013	0.60	568607.23	73908.01	14297.15	545639.96	69995.23	13719.66
4/29/2013	1.95	900761.14	117140.94	80986.05	553968.10	103669.73	49806.42
5/6/2013	0.38	410068.40	23842.29	0.00			
6/10/2013	0.55	318636.66	31904.96	63397.01	431951.82	27119.21	85942.57
6/13/2013	0.17						
6/19/2013	0.30						
6/24/2013	0.35						
6/26/2013	1.71	2568615.05	202681.23	601414.85	3727216.11	209536.63	872689.40
7/1/2013	0.60	334474.84	70859.96	84052.47	435932.21	44495.89	109548.39
7/2/2013	0.87	532249.48	39260.39	88271.96	346139.58	31137.55	57406.20
8/13/2013	0.78	2949105.76	29413.91	638806.34	3514247.55	34981.54	761221.80
9/2/2013	0.37	1277727.21	40682.86	0.00	2051158.72	61481.97	0.00
9/21/2013	0.95	789128.00	61473.77	106086.06	1560303.34	52764.99	209758.66
10/13/2013	0.10	56791.47	0.00	0.00			
11/1/2013	0.71	980152.28	41708.61	0.00	749086.59	31802.81	0.00
11/26/2013	1.24						
12/10/2013	0.53	2560791.18	87256.59	0.00			
12/14/2013	0.30						
1/14/2014	0.20						
2/5/2014	0.29	376520.56	29182.16	0.00			
2/19/2014	0.46	941910.82	15679.81	170685.74	680295.09	10142.87	123277.78
3/3/2014	0.35	109889.29	23230.31	0.00			
4/15/2014	0.82	11869534.94	96237.49	3886197.63	3166076.50	91753.70	1036603.29
4/19/2014	1.08	987994.60	36449.97	8401.59	904589.48	16858.11	7692.34
6/12/2014	0.25	587278.70	6398.40	186623.00	824939.72	2790.41	262145.94
6/19/2014	0.61	1138895.30	8151.43	382894.11	1274082.17	6860.79	428343.64
8/11/2014	0.51	2181965.01	18489.25	641194.29	2510678.04	18412.21	737790.21
10/11/2014	0.43	1073995.23	19272.28	0.00	1573403.01	16457.51	0.00
10/14/2014	0.72	871253.70	12926.56	136664.41	1203735.35	8217.60	188817.31
11/24/2014	0.75	2583262.38	9525.04	985510.72	2148951.39	14430.43	819821.73
12/6/2014	0.20	100739.00	7469.72	7411.75			
12/22/2014	0.97	372282.90	13775.52	30486.57			

Table 37. Individual storm loading for total phosphorus, total dissolved phosphorus, and soluble reactive phosphorus. Italicized values were estimated using half the minimum detection limit.

Date	Rainfall (in)	Total Phosphorus (mg)			Total Dissolved Phosphorus (mg)			Soluble Reactive Phosphorus (mg)		
		IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER
2/26/2013	1.12	1774.54	*251.92*	255.77	17745.37	*251.92*	2557.70	2877.63	*577.32*	414.76
4/4/2013	0.81	168.74	*58.44*	*0.00*	168.74	*58.44*	*0.00*	*154.68*	*133.92*	*0.00*
4/19/2013	0.60	1226.41	999.93	30.84	524.01	532.57	13.18	*306.60*	*298.89*	*7.71*
4/29/2013	1.95	1891.60	1200.69	170.07	*540.46*	*351.42*	*48.59*	*1238.55*	*805.34*	*111.36*
5/6/2013	0.38	367.86	201.74	*0.00*	150.76	55.02	*0.00*	*165.84*	*126.09*	*0.00*
6/10/2013	0.55	338.55	438.69	67.36	1394.04	*95.71*	277.36	273.83	219.35	*54.48*
6/13/2013	0.17	368.26	79.13	*0.00*						
6/19/2013	0.30	463.88	64.31	*0.00*				57.99	*50.53*	*0.00*
6/24/2013	0.35									
6/26/2013	1.71	1323.23	*357.67*	309.82	*467.02*	*357.67*	*109.35*	1070.26	819.67	250.59
7/1/2013	0.60	501.71	343.88	126.08	*133.79*	*125.05*	*33.62*	*306.60*	*286.57*	*77.05*
7/2/2013	0.87	798.37	514.45	132.41	212.90	*162.46*	*35.31*	487.90	372.30	80.92
8/13/2013	0.78	3259.54	703.83	706.05	1443.51	*126.06*	312.68	426.84	288.89	92.46
9/2/2013	0.37	580.79	*61.02*	*0.00*	69.69	*61.02*	*0.00*	159.72	139.85	*0.00*
9/21/2013	0.95	789.13	*204.91*	106.09	236.74	478.13	*31.83*	542.53	469.59	72.93
10/13/2013	0.10	68.15	*0.00*	0.00	12.39	*0.00*	0.00	28.40	*0.00*	0.00
11/1/2013	0.71	542.21	542.21	*0.00*	*125.13*	*125.13*	*0.00*	865.45	286.75	*0.00*
11/26/2013	1.24	2091.65	330.62	254.85	292.83	394.91	35.68			
12/10/2013	0.53	1138.13	303.50	*0.00*	*113.81*	294.02	*0.00*	260.82	260.82	*0.00*
12/14/2013	0.30							*638.75*	*390.20*	*248.55*
1/14/2014	0.20	287.11	68.48	13.59	*28.71*	*17.12*	*1.36*	65.80	39.23	*3.11*
2/5/2014	0.29	121.82	52.89	*0.00*	26.58	21.89	*0.00*	60.91	50.16	*0.00*
2/19/2014	0.46	463.11	*58.80*	83.92	*94.19*	*58.80*	*17.07*	215.85	134.75	*39.12*
3/3/2014	0.35	1200.64	76.33	*0.00*	793.64	39.82	*0.00*	*55.96*	*45.63*	*0.00*
4/15/2014	0.82	4715.29	1531.05	1543.83	910.54	470.25	298.12	*447.14*	*300.74*	*146.40*
4/19/2014	1.08	1010.97	*273.37*	8.60	275.72	*273.37*	2.34	631.86	626.48	5.37
6/12/2014	0.25	800.83	158.18	254.49	373.72	108.42	118.76	*73.41*	*48.88*	*23.33*
6/19/2014	0.61	979.45	285.30	329.29	*136.67*	*81.51*	*45.95*	313.20	186.80	105.30
8/11/2014	0.51	1854.67	338.97	545.02	*130.92*	184.89	*38.47*	300.02	211.86	88.16
10/11/2014	0.43	1933.19	329.66	*0.00*	1002.40	205.40	*0.00*	196.90	69.74	*0.00*
10/14/2014	0.72	786.94	*55.40*	123.44	*168.63*	*55.40*	*26.45*	386.44	126.96	60.62
11/24/2014	0.75	2744.72	447.68	1047.11	1049.45	361.95	400.36	*444.00*	*130.97*	*169.38*
12/6/2014	0.20	147.42	38.03	10.85	*14.74*	25.13	*1.08*	*33.78*	*18.67*	*2.49*
12/22/2014	0.97	1353.76	95.66	110.86	*135.38*	*45.92*	*11.09*	310.24	105.23	*25.41*

Table 38. Individual storm loading for total nitrogen and nitrogen species. Italicized values were estimated using half the minimum detection limit.

Date	Rainfall (in)	Total Nitrogen (mg)			Total Ammoniacal Nitrogen (mg)			Nitrate/Nitrite (mg)			Total Kjedhal Nitrogen (mg)		
		IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER
2/26/2013	1.12	29903.34	11315.49	4310.07	3357.23	1280.60	483.89	1127.07	1658.48	162.45	28776.27	9657.00	4147.62
4/4/2013	0.81	4893.54	2142.70	*0.00*	1631.18	535.68	*0.00*	899.96	827.86	*0.00*	3993.58	1314.84	*0.00*
4/19/2013	0.60	15720.32	12390.46	395.27	735.84	630.39	18.50	1226.41	1956.39	30.84	14493.91	10434.07	364.44
4/29/2013	1.95	*15875.92*	14935.47	*1427.38*	*1013.36*	658.92	*91.11*	*562.98*	4392.79	*50.62*	15312.94	10542.68	1376.76
5/6/2013	0.38	5656.53	3117.84	*0.00*	1628.21	1100.41	*0.00*	410.07	596.06	*0.00*	5246.46	2521.78	*0.00*
6/10/2013	0.55	7268.90	7098.85	1446.24	517.78	*179.47*	103.02	1095.31	3110.73	217.93	6173.59	3988.12	1228.32
6/13/2013	0.17	4191.12	1947.83	*0.00*	491.01	*27.39*	*0.00*	333.19	486.96	*0.00*	3857.94	1460.88	*0.00*
6/19/2013	0.30	5292.46	1635.23	*0.00*	47.44	*41.34*	*0.00*	231.94	404.21	*0.00*	5060.51	1231.01	*0.00*
6/24/2013	0.35	145.50	*24.41*	*0.00*	43.18	*2.11*	*0.00*	42.24	12.20	*0.00*	103.26	*12.20*	*0.00*
6/26/2013	1.71	29967.18	*9239.88*	7016.51	5448.58	*670.64*	1275.73	8172.87	5365.09	1913.59	21794.31	*3874.79*	5102.91
7/1/2013	0.60	7514.53	5356.18	1888.38	1895.36	844.07	476.30	490.56	562.71	123.28	7023.97	4793.47	1765.10
7/2/2013	0.87	10361.12	5821.37	1718.36	*399.19*	*304.61*	*66.20*	1312.88	812.28	217.74	9048.24	5009.08	1500.62
8/13/2013	0.78	21575.04	6513.08	4673.37	1552.16	745.85	336.21	2949.11	2100.99	638.81	18625.93	4412.09	4034.57
9/2/2013	0.37	7259.81	5339.63	*0.00*	755.02	711.95	*0.00*	871.18	1118.78	*0.00*	6388.64	4220.85	*0.00*
9/21/2013	0.95	21701.02	8879.55	2917.37	2564.67	990.41	344.78	3945.64	1878.37	530.43	17755.38	7001.18	2386.94
10/13/2013	0.10	960.29	*0.00*	*0.00*	23.23	*0.00*	*0.00*	134.23	*0.00*	*0.00*	826.06	*0.00*	*0.00*
11/1/2013	0.71	*4196.93*	6704.66	*0.00*	*234.61*	1146.99	*0.00*	*130.34*	761.18	*0.00*	4066.59	5943.48	*0.00*
11/26/2013	1.24	*21047.22*	2870.00	2564.44	235.31	206.64	28.67	*130.73*	*114.80*	*15.93*	20916.49	2755.20	2548.51
12/10/2013	0.53	10129.35	3983.45	*0.00*	663.91	*213.40*	*0.00*	929.47	1422.66	*0.00*	9199.88	2560.79	*0.00*
12/14/2013	0.30												
1/14/2014	0.20	3038.57	623.42	143.85	117.24	*32.10*	5.55	167.48	95.58	7.93	2871.09	527.84	135.92
2/5/2014	0.29	1284.60	966.66	*0.00*	168.33	145.91	*0.00*	310.08	273.58	*0.00*	974.52	693.08	*0.00*
2/19/2014	0.46	6357.90	*1616.98*	1152.13	863.42	328.30	156.46	1569.85	979.99	284.48	4788.05	*636.99*	867.65
3/3/2014	0.35	3072.83	2306.44	*0.00*	1139.59	696.91	*0.00*	834.34	846.25	*0.00*	2238.49	1460.19	*0.00*
4/15/2014	0.82	*31096.56*	*11072.78*	*10181.31*	365.84	535.87	*119.78*	*203.25*	*136.70*	*66.54*	30893.31	10936.08	10114.76
4/19/2014	1.08	*10626.69*	*10080.70*	*90.37*	*516.97*	1252.97	*4.40*	*287.21*	284.77	*2.44*	10339.48	9795.93	87.92
6/12/2014	0.25	6993.96	3128.10	2222.51	1521.59	550.97	483.52	587.28	639.84	186.62	6406.68	2488.27	2035.89
6/19/2014	0.61	14805.64	7200.43	4977.62	1936.12	529.84	650.92	2277.79	2173.72	765.79	12527.85	5026.72	4211.84
8/11/2014	0.51	17455.72	4776.39	5129.55	2727.46	*173.34*	801.49	1090.98	1309.66	320.60	16364.74	3466.73	4808.96
10/11/2014	0.43	13603.94	5325.23	*0.00*	1360.39	278.94	*0.00*	1431.99	2028.66	*0.00*	12171.95	3296.57	*0.00*
10/14/2014	0.72	13855.74	2063.63	2173.40	7869.39	*103.87*	1234.39	646.41	355.48	101.40	13209.33	1708.15	2072.01
11/24/2014	0.75	14579.29	2800.36	5561.98	*363.27*	*107.16*	*138.59*	855.71	419.10	326.45	13723.58	2381.26	5235.53
12/6/2014	0.20	1301.01	672.27	95.72	27.64	30.56	*2.03*	72.48	142.60	5.33	1228.52	529.67	90.39
12/22/2014	0.97	6182.15	*994.90*	506.26	733.28	*86.10*	60.05	654.32	497.45	53.58	5527.84	*497.45*	452.68

Table 39. Individual storm loading for metal species. Italicized values were estimated using half the minimum detection limit.

Date	Rainfall (in)	Total Copper (mg)			Dissolved Copper (mg)			Total Zinc (mg)			Dissolved Zinc (mg)		
		IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER
2/26/2013	1.12	187.05	67.18	26.96	105.51	79.78	15.21	1582.70	*104.97*	228.12	719.41	*104.97*	103.69
4/4/2013	0.81	41.06	23.86	*0.00*	29.25	23.37	*0.00*	196.87	*24.35*	*0.00*	157.49	*24.35*	*0.00*
4/19/2013	0.60												
4/29/2013	1.95	148.63	120.07	13.36				225.19	*146.43*	20.25			
5/6/2013	0.38												
6/10/2013	0.55												
6/13/2013	0.17												
6/19/2013	0.30												
6/24/2013	0.35												
6/26/2013	1.71	*38.92*	74.52	*9.11*	*38.92*	71.53	*9.11*	739.45	*149.03*	173.13	505.94	*149.03*	118.46
7/1/2013	0.60	33.45	33.35	8.41				245.28	*52.10*	61.64			
7/2/2013	0.87	37.26	28.43	6.18				319.35	*67.69*	52.96			
8/13/2013	0.78	117.96	56.73	25.55				1272.77	199.59	275.70			
9/2/2013	0.37												
9/21/2013	0.95	132.18	81.97	17.77				966.68	204.91	129.96			
10/13/2013	0.10												
11/1/2013	0.71	36.50	114.70	*0.00*				385.80	260.68	*0.00*			
11/26/2013	1.24												
12/10/2013	0.53	132.78	94.84	*0.00*	9.48	90.10	*0.00*	1707.19	303.50	*0.00*	142.27	246.59	*0.00*
12/14/2013	0.30												
1/14/2014	0.20												
2/5/2014	0.29												
2/19/2014	0.46	94.19	37.24	17.07	35.32	33.32	6.40	682.89	117.60	123.75	219.78	127.40	39.83
3/3/2014	0.35												
4/15/2014	0.82	146.34	103.89	47.91				1154.43	382.76	377.97			
4/19/2014	1.08												
6/12/2014	0.25	72.08	21.33	22.90				264.28	55.10	83.98			
6/19/2014	0.61												
8/11/2014	0.51												
10/11/2014	0.43												
10/14/2014	0.72												
11/24/2014	0.75												
12/6/2014	0.20												
12/22/2014	0.97												

Statistical Analyses

Bootstrapping Methodology

```
> boot.TSS1 <- boot(data=stand$TSS1,statistic=mymean.func,R=1000)
> boot.ci(boot.TSS1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TSS1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.8974,  0.9445 )   ( 0.8989,  0.9471 )

Level      Percentile          BCa
95%   ( 0.8962,  0.9445 )   ( 0.8880,  0.9396 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.TSS1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TSS2 <- boot(data=stand$TSS2,statistic=mymean.func,R=1000)
> boot.ci(boot.TSS2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TSS2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.7653,  0.8575 )   ( 0.7659,  0.8563 )

Level      Percentile          BCa
95%   ( 0.7676,  0.8580 )   ( 0.7628,  0.8550 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TSS2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.SSC1 <- boot(data=stand$SSC1,statistic=mymean.func,R=1000)
> boot.ci(boot.SSC1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.SSC1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.9156,  0.9712 )   ( 0.9203,  0.9741 )

Level      Percentile          BCa
95%   ( 0.9130,  0.9668 )   ( 0.8933,  0.9631 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.SSC1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.SSC2 <- boot(data=stand$SSC2,statistic=mymean.func,R=1000)
```

```
> boot.ci(boot.SSC2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.SSC2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.7397,  0.8454 )    ( 0.7427,  0.8456 )

Level      Percentile            BCa
95%   ( 0.7379,  0.8408 )    ( 0.7390,  0.8421 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.SSC2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TP1 <- boot(data=stand$TP1,statistic=mymean.func,R=1000)
> boot.ci(boot.TP1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TP1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.4285,  0.6515 )    ( 0.4396,  0.6592 )

Level      Percentile            BCa
95%   ( 0.4211,  0.6407 )    ( 0.4050,  0.6297 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TP1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TP2 <- boot(data=stand$TP2,statistic=mymean.func,R=1000)
> boot.ci(boot.TP2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TP2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.4400,  0.6598 )    ( 0.4523,  0.6681 )

Level      Percentile            BCa
95%   ( 0.4323,  0.6482 )    ( 0.4210,  0.6414 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TP2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TDP1 <- boot(data=stand$TDP1,statistic=mymean.func,R=1000)
 > boot.ci(boot.TDP1,conf=0.95)
 BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
 Based on 1000 bootstrap replicates

 CALL :
 boot.ci(boot.out = boot.TDP1, conf = 0.95)

 Intervals :
 Level      Normal                Basic
```

```
95%   (-0.2553,  0.2117 )    (-0.2478,  0.2299 )

Level      Percentile              BCa
95%   (-0.2865,  0.1912 )    (-0.2856,  0.1918 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TDP1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TDP2 <- boot(data=stand$TDP2,statistic=mymean.func,R=1000)
> boot.ci(boot.TDP2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TDP2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-0.0692,  0.3627 )    (-0.0465,  0.3912 )

Level      Percentile              BCa
95%   (-0.0963,  0.3413 )    (-0.1339,  0.3133 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TDP2, conf = 0.95) :
  bootstrap variances needed for studentized intervals


> boot.TN1 <- boot(data=stand$TN1,statistic=mymean.func,R=1000)
> boot.ci(boot.TN1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TN1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.2113,  0.4426 )    ( 0.2145,  0.4509 )

Level      Percentile              BCa
95%   ( 0.2038,  0.4402 )    ( 0.1977,  0.4307 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TN1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TN2 <- boot(data=stand$TN2,statistic=mymean.func,R=1000)
> boot.ci(boot.TN2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TN2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.2886,  0.5061 )    ( 0.2926,  0.5056 )

Level      Percentile              BCa
95%   ( 0.2917,  0.5048 )    ( 0.2815,  0.4976 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TN2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
```

```
> boot.TKN1 <- boot(data=stand$TKN1,statistic=mymean.func,R=1000)
> boot.ci(boot.TKN1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TKN1, conf = 0.95)

Intervals :
Level       Normal              Basic
95%   ( 0.3357,  0.5307 )   ( 0.3369,  0.5366 )

Level      Percentile           BCa
95%   ( 0.3327,  0.5323 )   ( 0.3229,  0.5280 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TKN1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TKN2 <- boot(data=stand$TKN2,statistic=mymean.func,R=1000)
> boot.ci(boot.TKN2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TKN2, conf = 0.95)

Intervals :
Level       Normal              Basic
95%   ( 0.3799,  0.5712 )   ( 0.3807,  0.5776 )

Level      Percentile           BCa
95%   ( 0.3688,  0.5658 )   ( 0.3659,  0.5623 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TKN2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.ci(boot.NH31,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.NH31, conf = 0.95)

Intervals :
Level       Normal              Basic
95%   (-0.1763,  0.4418 )   (-0.1347,  0.4828 )

Level      Percentile           BCa
95%   (-0.2268,  0.3907 )   (-0.3321,  0.3452 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.NH31, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.NH32 <- boot(data=stand$NH32,statistic=mymean.func,R=1000)
> boot.ci(boot.NH32,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.NH32, conf = 0.95)

Intervals :
Level       Normal              Basic
```

```
95%   (-0.0638,  0.5032 )   (-0.0206,  0.5387 )

Level      Percentile           BCa
95%   (-0.0957,  0.4637 )   (-0.2284,  0.4191 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.NH32, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.NO31<- boot(data=stand$NO31,statistic=mymean.func,R=1000)
> boot.ci(boot.NO31,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.NO31, conf = 0.95)

Intervals :
Level      Normal             Basic
95%   (-1.6872, -0.2675 )   (-1.5447, -0.1889 )

Level      Percentile           BCa
95%   (-1.7509, -0.3951 )   (-2.1262, -0.4928 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.NO31, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.NO32 <- boot(data=stand$NO32,statistic=mymean.func,R=1000)
> boot.ci(boot.NO32,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.NO32, conf = 0.95)

Intervals :
Level      Normal             Basic
95%   (-1.0024, -0.0102 )   (-0.9357,  0.0462 )

Level      Percentile           BCa
95%   (-1.0578, -0.0760 )   (-1.3071, -0.1388 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.NO32, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.DissCu1<- boot(data=stand$DissCu1,statistic=mymean.func,R=1000)
> boot.ci(boot.DissCu1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 999 bootstrap replicates

CALL :
boot.ci(boot.out = boot.DissCu1, conf = 0.95)

Intervals :
Level      Normal             Basic
95%   (-5.288,  1.391 )   (-4.176,  2.262 )

Level      Percentile           BCa
95%   (-6.341,  0.097 )   (-8.500, -0.079 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
```

```
> boot.DissCu2 <- boot(data=stand$DissCu2,statistic=mymean.func,R=1000)
> boot.ci(boot.DissCu2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 993 bootstrap replicates

CALL :
boot.ci(boot.out = boot.DissCu2, conf = 0.95)

Intervals :
Level       Normal              Basic
95%   (-5.170,  1.392 )   (-3.909,  1.950 )

Level      Percentile            BCa
95%   (-5.708,  0.150 )   (-8.500,  0.059 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
```
```
> boot.DissZn1<- boot(data=stand$DissZn1,statistic=mymean.func,R=1000)
> boot.ci(boot.DissZn1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 995 bootstrap replicates

CALL :
boot.ci(boot.out = boot.DissZn1, conf = 0.95)

Intervals :
Level       Normal              Basic
95%   (-0.2878,  0.9538 )   (-0.1841,  1.0699 )

Level      Percentile            BCa
95%   (-0.4266,  0.8274 )   (-0.7333,  0.8214 )
Calculations and Intervals on Original Scale
```
```
> boot.DissZn2 <- boot(data=stand$DissZn2,statistic=mymean.func,R=1000)
> boot.ci(boot.DissZn2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 997 bootstrap replicates

CALL :
boot.ci(boot.out = boot.DissZn2, conf = 0.95)

Intervals :
Level       Normal              Basic
95%   (-0.2115,  0.8536 )   (-0.1516,  0.8645 )

Level      Percentile            BCa
95%   (-0.2515,  0.7646 )   (-0.4615,  0.6868 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
```
```
> boot.TotCu1<- boot(data=stand$TotCu1,statistic=mymean.func,R=1000)
> boot.ci(boot.TotCu1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
```

```
boot.ci(boot.out = boot.TotCu1, conf = 0.95)

Intervals :
Level      Normal               Basic
95%   (-0.5378,  0.3114 )    (-0.4811,  0.3591 )

Level      Percentile           BCa
95%   (-0.5603,  0.2798 )    (-0.7453,  0.2121 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.TotCu1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TotCu2 <- boot(data=stand$TotCu2,statistic=mymean.func,R=1000)
> boot.ci(boot.TotCu2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TotCu2, conf = 0.95)

Intervals :
Level      Normal               Basic
95%   (-0.4602,  0.3473 )    (-0.4024,  0.3971 )

Level      Percentile           BCa
95%   (-0.5271,  0.2724 )    (-0.6670,  0.2307 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.TotCu2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TotZn2 <- boot(data=stand$TotZn2,statistic=mymean.func,R=1000)
> boot.ci(boot.TotZn2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TotZn2, conf = 0.95)

Intervals :
Level      Normal               Basic
95%   ( 0.4776,  0.6829 )    ( 0.4856,  0.6916 )

Level      Percentile           BCa
95%   ( 0.4679,  0.6738 )    ( 0.4670,  0.6734 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TotZn2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TotZn1<- boot(data=stand$TotZn1,statistic=mymean.func,R=1000)
> boot.ci(boot.TotZn1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TotZn1, conf = 0.95)

Intervals :
Level      Normal               Basic
95%   ( 0.5319,  0.7881 )    ( 0.5420,  0.7997 )

Level      Percentile           BCa
95%   ( 0.5236,  0.7813 )    ( 0.4742,  0.7593 )
```

```
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.TotZn1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> stand <- read.csv("C:/Users/Alessandra/Dropbox/R/stand.csv")
>   View(stand)
> boot.TSSOut <- boot(data=stand$TSSOut,statistic=mymean.func,R=1000)
> boot.ci(boot.TSSOut,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TSSOut, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 3.904,  6.579 )   ( 3.802,  6.486 )

Level     Percentile            BCa
95%   ( 4.045,  6.729 )   ( 4.093,  6.891 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TSSOut, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> stand <- read.csv("C:/Users/Alessandra/Dropbox/R/stand.csv")
>   View(stand)
> boot.SSCOut <- boot(data=stand$SSCOut,statistic=mymean.func,R=1000)
> boot.ci(boot.SSCOut,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.SSCOut, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 2.758,  5.024 )   ( 2.717,  4.894 )

Level     Percentile            BCa
95%   ( 2.942,  5.119 )   ( 3.024,  5.325 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.SSCOut, conf = 0.95) :
  bootstrap variances needed for studentized intervals


> boot.tapeEMC <- boot(data=tpstand$emc.tp.tape,statistic=mymean.func,R
=1000)
> boot.ci(boot.tapeEMC,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.tapeEMC, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.5691,  0.7522 )   ( 0.5754,  0.7516 )

Level     Percentile            BCa
95%   ( 0.5713,  0.7475 )   ( 0.5507,  0.7409 )
Calculations and Intervals on Original Scale
```

```
Warning message:
In boot.ci(boot.tapeEMC, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.tapeLOAD <- boot(data=tpstand$load.tp.tape,statistic=mymean.func
,R=1000)
> boot.ci(boot.tapeLOAD,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.tapeLOAD, conf = 0.95)

Intervals :
Level       Normal               Basic
95%   ( 0.5566,  0.7578 )   ( 0.5618,  0.7644 )

Level      Percentile             BCa
95%   ( 0.5514,  0.7540 )   ( 0.5447,  0.7506 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.tapeLOAD, conf = 0.95) :
  bootstrap variances needed for studentized intervals
```

Robust Order on Regression of Event Mean Concentrations
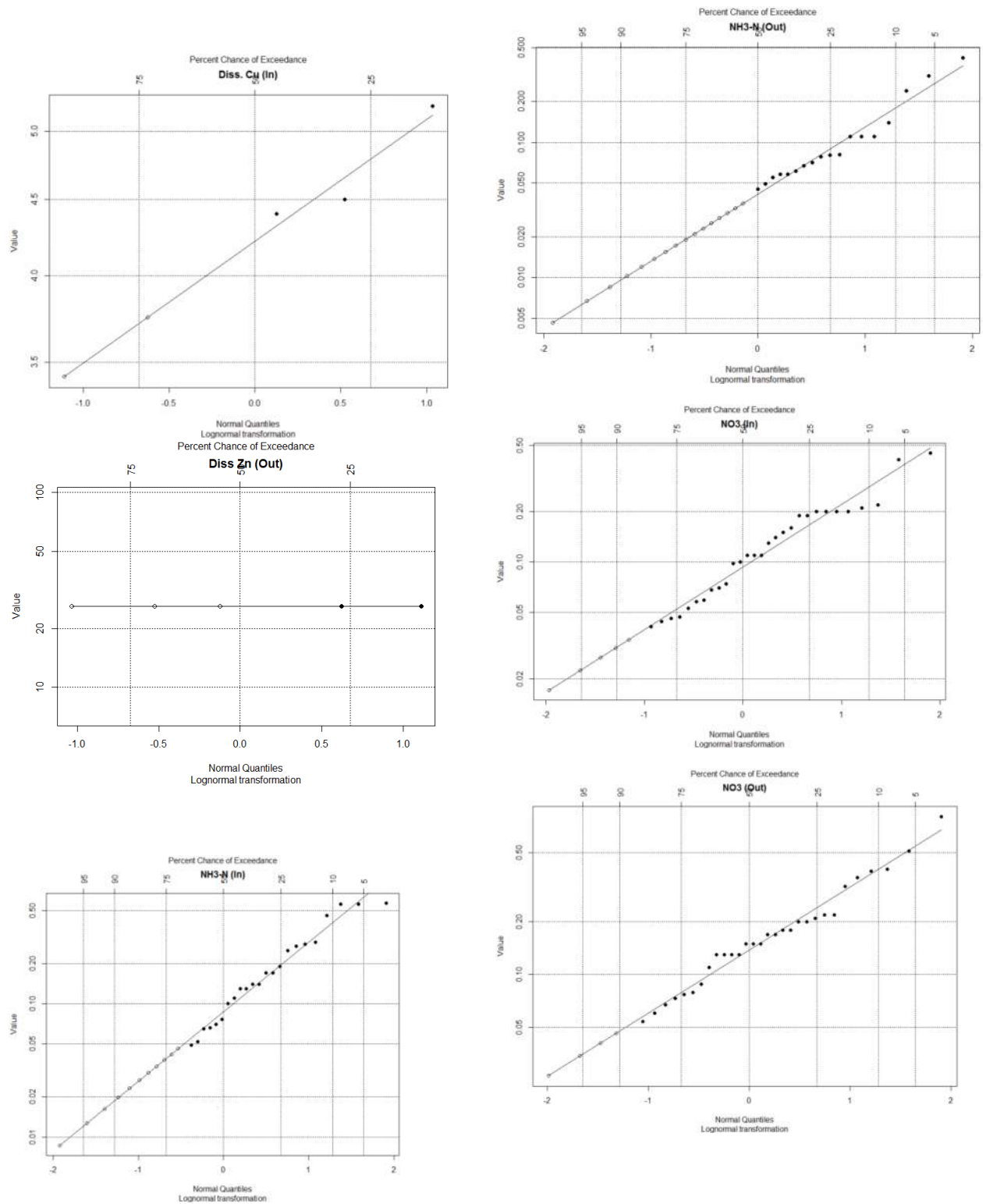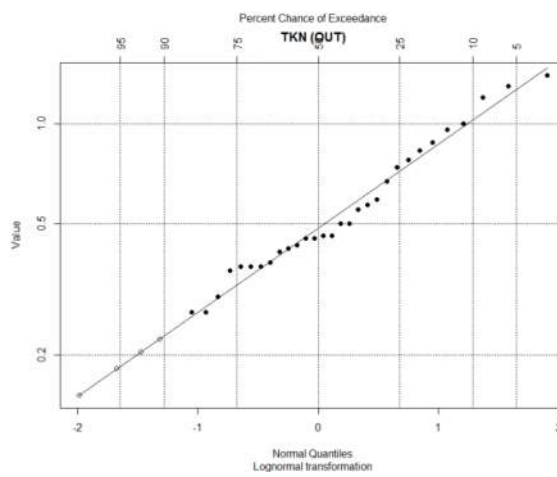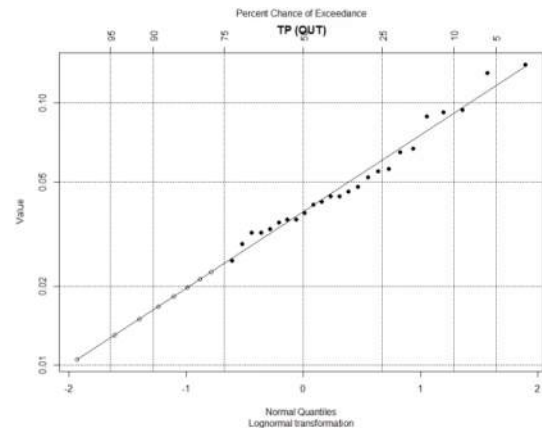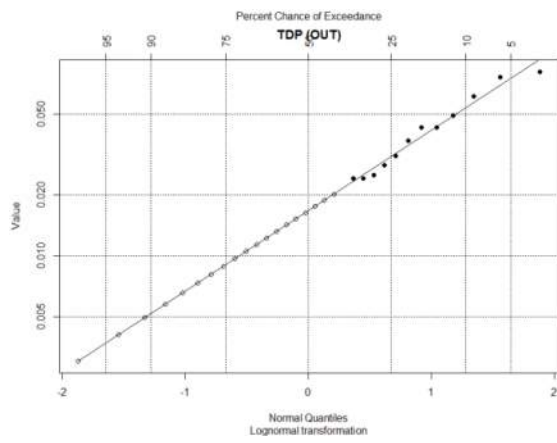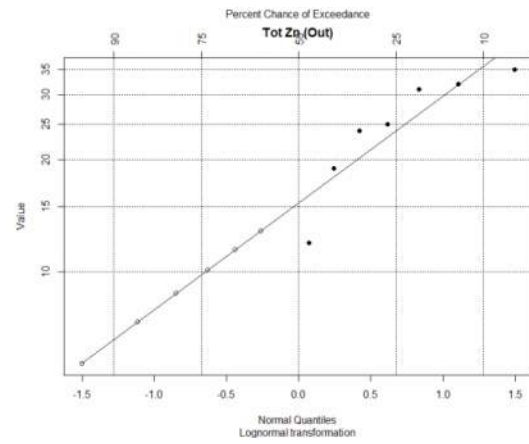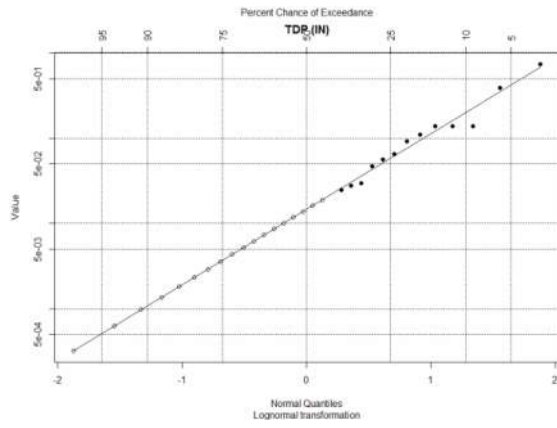
Individual Storm Hydrographs Sampled for Water Quality Parameters

Notes on hydrograph data set:

- Plots are of underdrain and bypass flow time series only. Inflow often had inundation that rendered the visualization unusable, at which point peak flows and volumes were estimated using engineering methods (see report). Inflow aliquot sampling frequency is shown in the "Sample Frequency" time series plot for comparison to underdrain.

- Time-stamped aliquot data (circle points in graphs below) are available for storms sampled after August 2013.

- EMC values in bold font were below the minimum detection limit reported by the laboratory. The numbers reported in the EMC chart are ½ of the minimum detection limit.

- Because total nitrogen (TN) is the sum of Total Kjehldahl Nitrogen and nitrate/nitrate-nitrogen, in some cases one of these analytes were below detection limits. In no case were both TKN and $NO_{2/3}$-N below detection limit for the same storm. When one was below detection limit, half of the minimum detection limit (MDL) was taken as the value, and it was added to the complimentary analyte. In such cases, the TN value will be shown in italics in the appendices that follow.

- The average underdrain flow rate was determined by dividing the total underdrain volume by the duration of drainage. Volumetric flux (or flow rate divided by area of media) was then calculated in inches per hour.
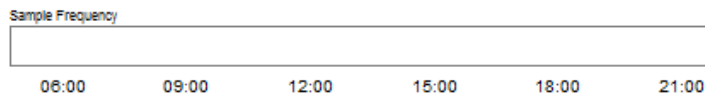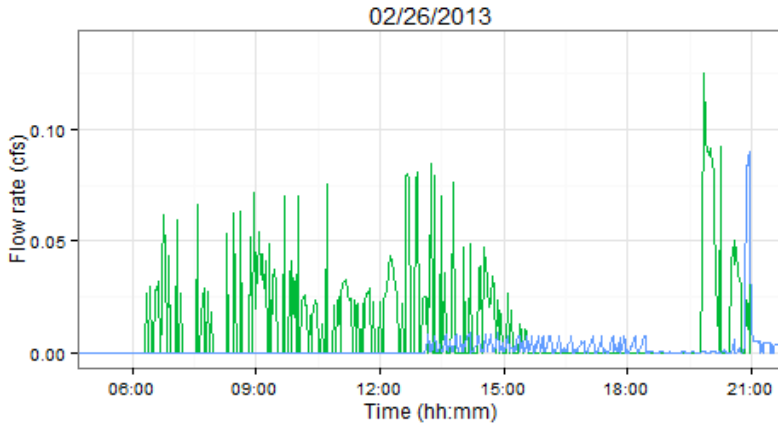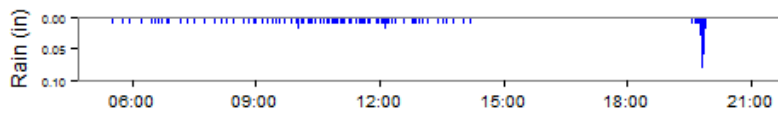
02/26/2013

Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.12		
Rainfall duration (h)	14.4		
Max 5-min intensity (in/h)	0.22		
Mean intensity (in/h)	0.08		
Antecedent dry period (h)	62		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	50.0		4.40		0.91
SSC	mg L^{-1}	62.25		2.90		0.95
TP	mg L^{-1}	0.074		**0.012**	0.024	0.84
Ortho-P	mg L^{-1}	0.120		**0.0275**	0.055	0.77
TDP	mg L^{-1}	0.74		**0.012**	0.460	0.98
TKN	mg L^{-1}	1.20		0.460		0.62
NH$_{3/4}$-N	mg L^{-1}	0.140		0.061		0.56
TN	mg L^{-1}	1.247		0.539		0.57
NO$_{2/3}$-N	mg L^{-1}	0.047		0.079		-0.68
Cu	µg L^{-1}	7.80		3.20		0.59
Zn	µg L^{-1}	66.0		**5.0**	10.0	0.92

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1095.5	Y[a]	846.9	0.443	-	-	Y
UNDERDRAIN	751.4	N	741.4	0.124	0.014	25.1	Y
BYPASS	122.1	N	122.1	0.001	-	-	-

[a]Backwater in weir observed.
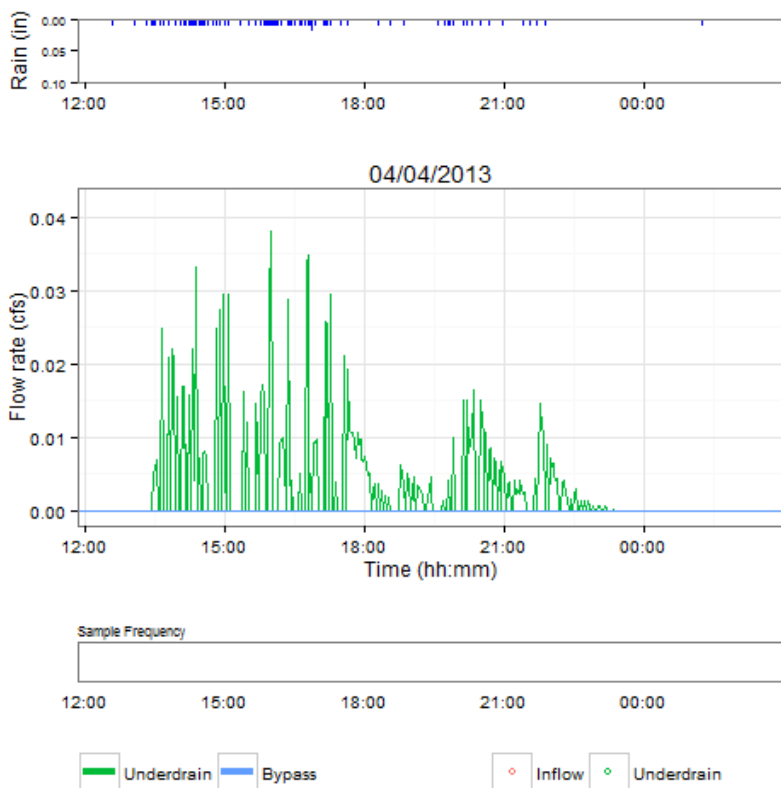
04/04/2013

Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.81		
Rainfall duration (h)	12.7		
Max 5-min intensity (in/h)	0.19		
Mean intensity (in/h)	0.06		
Antecedent dry period (h)	76		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	37.0		2.80		0.92
SSC	mg L^{-1}	57.34		1.510		0.97
TP	mg L^{-1}	0.03		**0.012**	0.024	0.60
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.030		**0.012**	0.024	0.60
TKN	mg L^{-1}	0.710		0.270		0.62
NH$_{3/4}$-N	mg L^{-1}	0.290		0.11		0.62
TN	mg L^{-1}	0.87		0.44		0.49
NO$_{2/3}$-N	mg L^{-1}	0.160		0.17		-0.06
Cu	µg L^{-1}	7.3		4.9		0.33
Zn	µg L^{-1}	35.0		**5.0**	10.0	0.86

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	198.6	N	198.6	0.086	-	-	Y
UNDERDRAIN	172.0	N	172.0	0.038	0.005	9.05	Y
BYPASS	0.0	-	0.0	0.000	-	-	-

95

04/19/2013
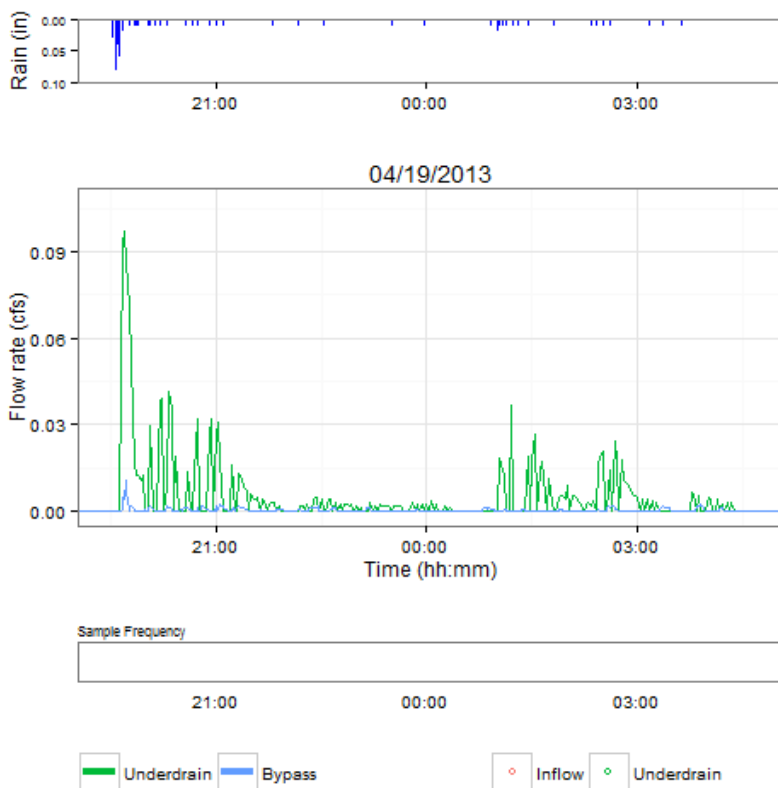
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.60		
Rainfall duration (h)	8.1		
Max 5-min intensity (in/h)	0.32		
Mean intensity (in/h)	0.07		
Antecedent dry period (h)	180		

| Analyte | Units | Inflow | | Underdrain | | Efficiency |
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	51.0		6.8		0.87
SSC	mg L^{-1}	48.94		6.44		0.87
TP	mg L^{-1}	0.11		0.092		0.16
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.0470		0.049		-0.04
TKN	mg L^{-1}	1.30		0.960		0.26
NH$_{3/4}$-N	mg L^{-1}	0.066		0.058		0.12
TN	mg L^{-1}	1.41		1.14		0.19
NO$_{2/3}$-N	mg L^{-1}	0.11		0.18		-0.64
Cu	μg L^{-1}					
Zn	μg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	590.8	Y[a]	393.7	0.101	-	-	Y
UNDERDRAIN	81.0	Y[b]	383.8	0.097	0.011	19.2	Y
BYPASS	9.9	N	9.9	0.004	-	-	-

[a]Backwater in weir observed.
[b]Weir readings low.

04/28/2013
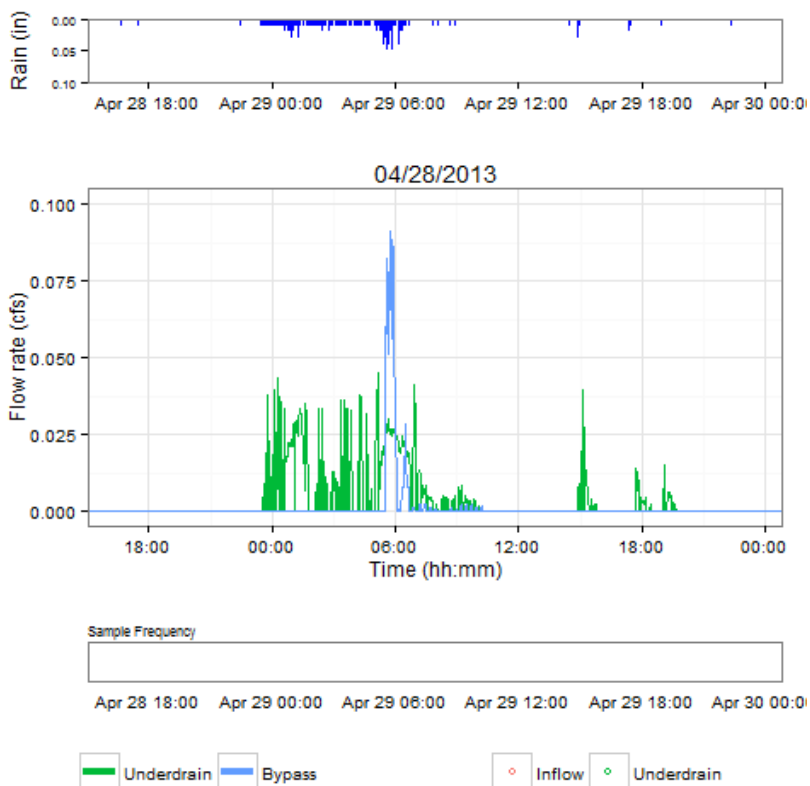
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.95		
Rainfall duration (h)	29.7		
Max 5-min intensity (in/h)	0.58		
Mean intensity (in/h)	0.07		
Antecedent dry period (h)	205		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	20.0		4.0		0.80
SSC	mg L^{-1}	12.3		3.54		0.71
TP	mg L^{-1}	0.042		0.041		0.02
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.0120**	0.024	NA
TKN	mg L^{-1}	0.34		0.360		-0.06
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	*0.3525*		0.51		-0.45
NO$_{2/3}$-N	mg L^{-1}	**0.0125**	0.025	0.15		-11.00
Cu	µg L^{-1}	3.3		4.1		-0.24
Zn	µg L^{-1}	5.0		5.0		0.00

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	5627.1	Y[a]	1590.5	0.286	-	-	Y
UNDERDRAIN	1034.2	N	1034.2	0.088	0.013	23.5	Y
BYPASS	143.0	N	143.0	0.027	-	-	-

[a]Backwater in weir observed.

05/06/2013
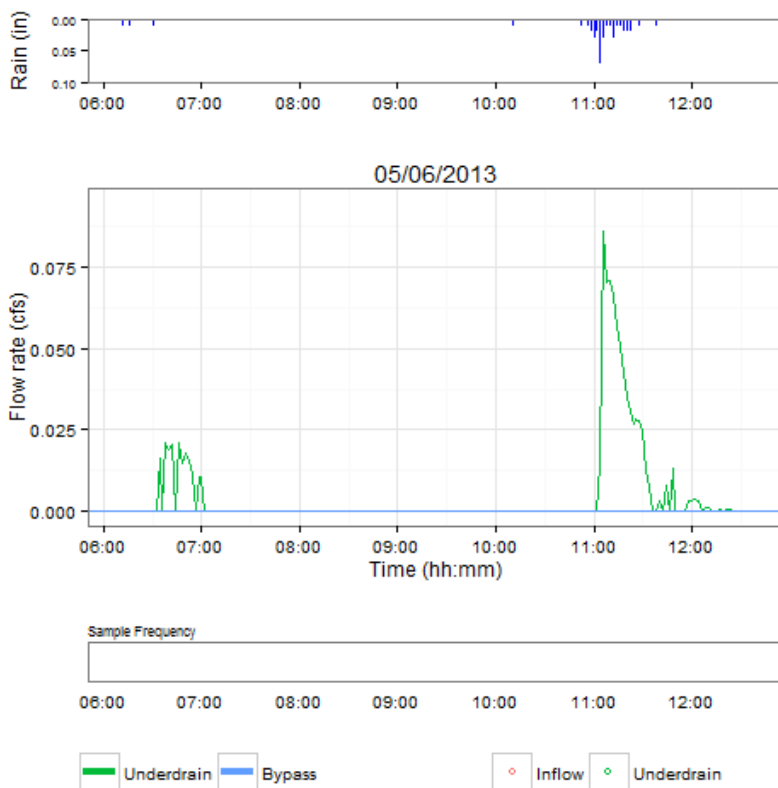
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.38		
Rainfall duration (h)	5.4		
Max 5-min intensity (in/h)	0.33		
Mean intensity (in/h)	0.07		
Antecedent dry period (h)	152		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	68.0		5.20		0.92
SSC	mg L^{-1}					
TP	mg L^{-1}	0.0610		0.044		0.28
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.025		**0.012**	0.024	0.52
TKN	mg L^{-1}	0.87		0.55		0.37
NH$_{3/4}$-N	mg L^{-1}	0.27		0.24		0.11
TN	mg L^{-1}	0.938		0.68		0.28
NO$_{2/3}$-N	mg L^{-1}	0.068		0.13		-0.91
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	519.1	Y^a	213.0	0.315	-	-	Y
UNDERDRAIN	161.9	N	161.9	0.086	0.007	13.5	Y
BYPASS	0.0	N	0.0	0.000	-	-	-

^{a}Backwater in weir observed.

06/10/2013
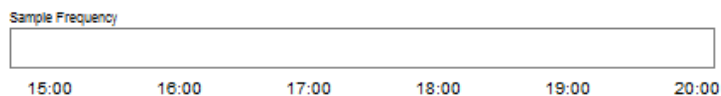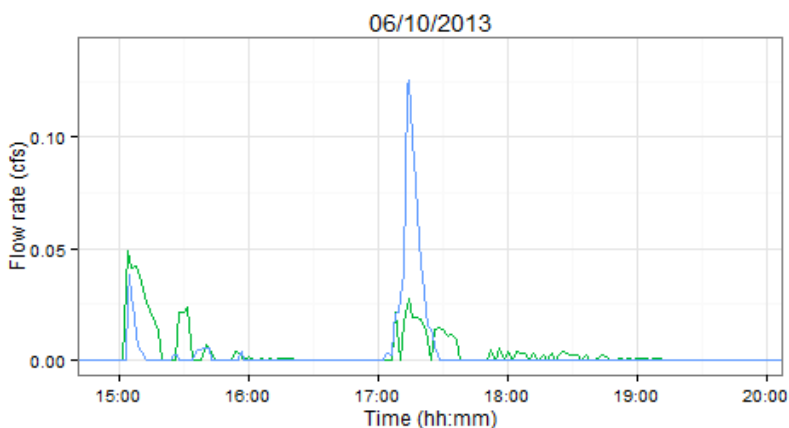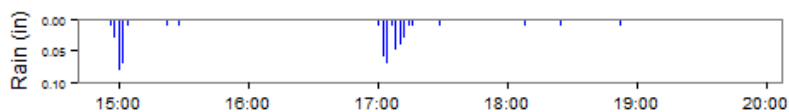
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.55		
Rainfall duration (h)	3.9		
Max 5-min intensity (in/h)	0.30		
Mean intensity (in/h)	0.14		
Antecedent dry period (h)	19.9		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	32.0		4.0		0.88
SSC	mg L^{-1}	43.38		3.4		0.92
TP	mg L^{-1}	0.034		0.055		-0.62
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.14		**0.012**	0.024	0.91
TKN	mg L^{-1}	0.62		0.50		0.19
NH$_{3/4}$-N	mg L^{-1}	0.052		**0.0225**	0.045	0.57
TN	mg L^{-1}	0.73		0.890		-0.22
NO$_{2/3}$-N	mg L^{-1}	0.11		0.390		-2.55
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	2677.2	Y[a]	351.6	0.472	-	-	Y
UNDERDRAIN	73.28	Y[b]	281.7	0.027	0.018	33.1	Y
BYPASS	70.0	N	70.0	0.125	-	-	-

[a]Backwater in weir observed.
[b]Weir readings low

06/13/2013
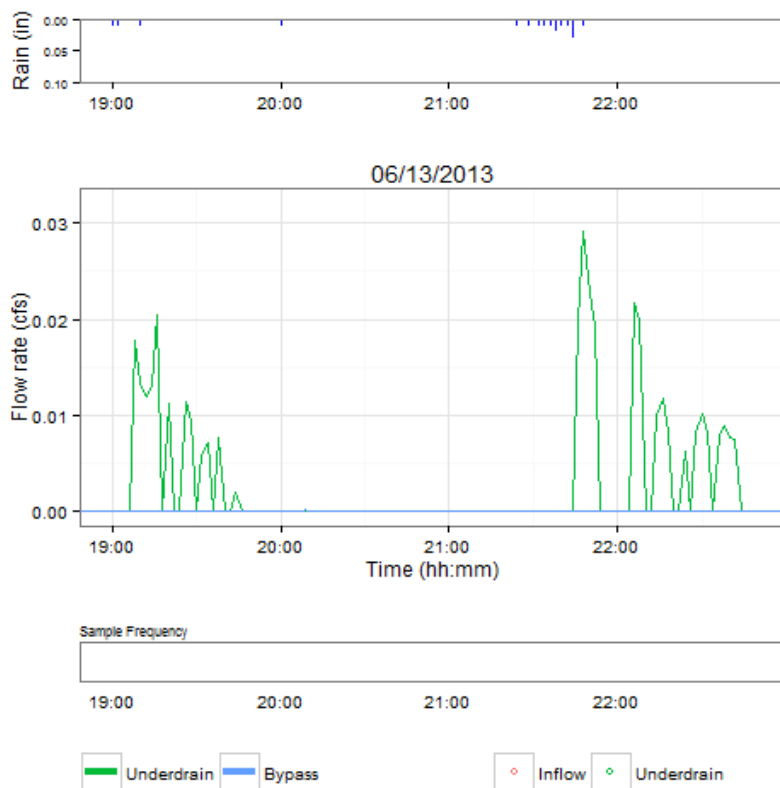
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.17		
Rainfall duration (h)	2.8		
Max 5-min intensity (in/h)	0.12		
Mean intensity (in/h)	0.06		
Antecedent dry period (h)	72.1		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}	0.21		0.0650		0.69
Ortho-P	mg L^{-1}					
TDP	mg L^{-1}					
TKN	mg L^{-1}	2.20		1.20		0.45
NH$_{3/4}$-N	mg L^{-1}	0.28		**0.0225**	0.045	0.92
TN	mg L^{-1}	2.39		1.60		0.33
NO$_{2/3}$-N	mg L^{-1}	0.19		0.40		-1.11
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	25.2	Y[a]	61.9	0.038	-	-	Y
UNDERDRAIN	43.0	N	43.0	0.034	0.003	6.14	Y
BYPASS	0.0	N	0.0	0.000	-	-	-

[a]Weir readings low

06/19/2013
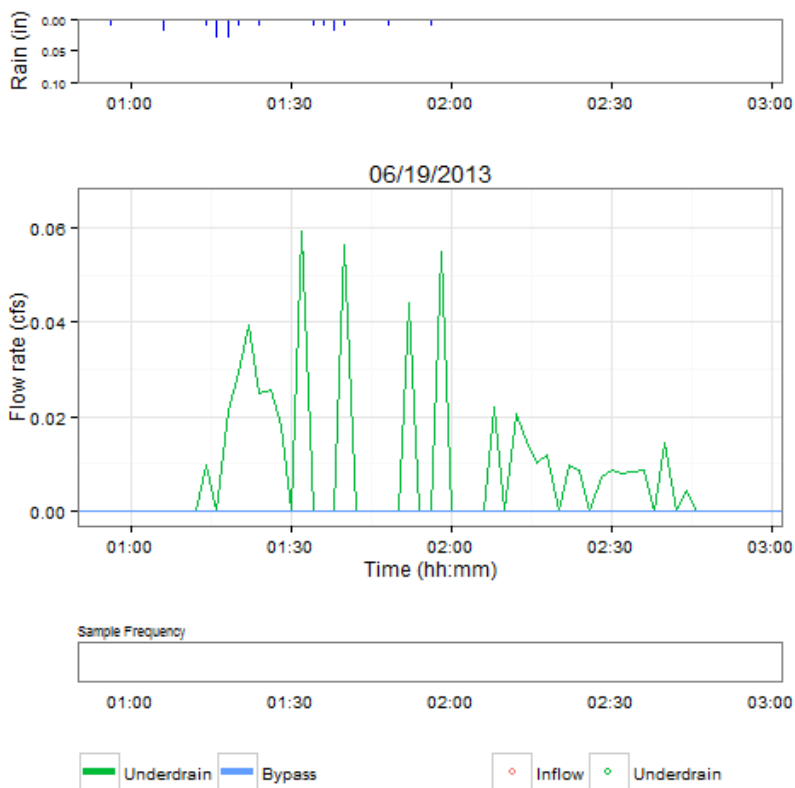
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.19		
Rainfall duration (h)	1.0		
Max 5-min intensity (in/h)	0.18		
Mean intensity (in/h)	0.19		
Antecedent dry period (h)	25.0		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}	0.220		0.035		0.84
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}					
TKN	mg L^{-1}	2.40		0.67		0.72
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	2.51		0.89		0.58
NO$_{2/3}$-N	mg L^{-1}	0.11		0.22		-1.0
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	37.5	Y[a]	74.5	0.186	-	-	Y
UNDERDRAIN	64.9	N	64.9	0.059	0.012	21.6	Y
BYPASS	0.0	N	0.0	0.000	-	-	-
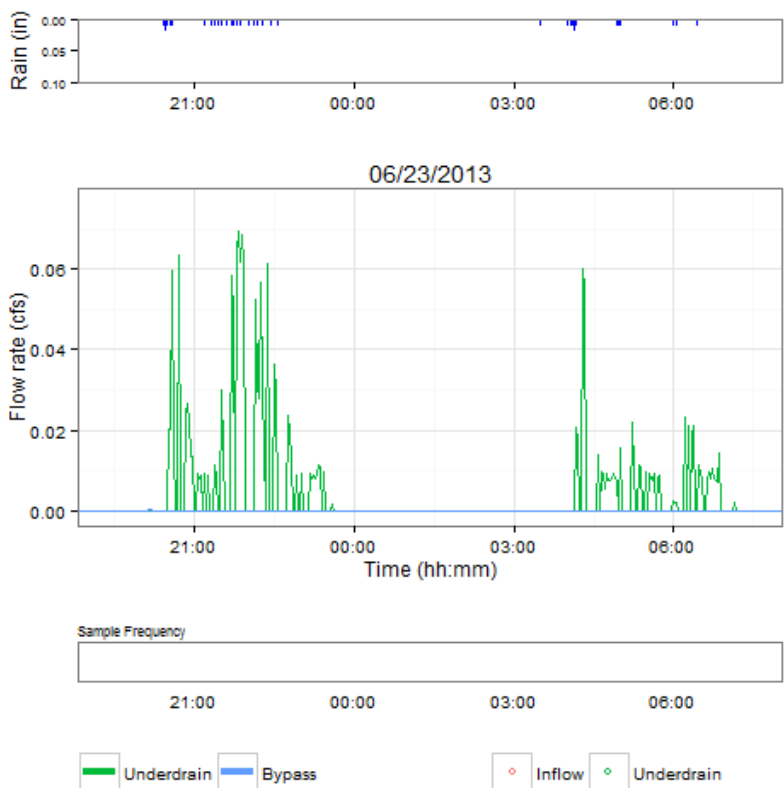
[a]Weir readings low

06/23/2013

Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.35		
Rainfall duration (h)	10		
Max 5-min intensity (in/h)	0.12		
Mean intensity (in/h)	0.035		
Antecedent dry period (h)	16.9		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}					
Ortho-P	mg L^{-1}					
TDP	mg L^{-1}					
TKN	mg L^{-1}	1.10		**0.13**	0.26	0.88
NH$_{3/4}$-N	mg L^{-1}	0.46		**0.0225**	0.045	0.95
TN	mg L^{-1}	1.55		0.26		0.83
NO$_{2/3}$-N	mg L^{-1}	0.45		0.13		0.71
Cu	μg L^{-1}					
Zn	μg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	50.6	Y^a	189.5	0.100	-	-	Y
UNDERDRAIN	221.5	Y^b	189.5	0.069	0.003	4.9	Y
BYPASS	0.0	N	0.0	0.000	-	-	-

^{a}Weir readings low
^{a}Weir readings high

06/26/2013
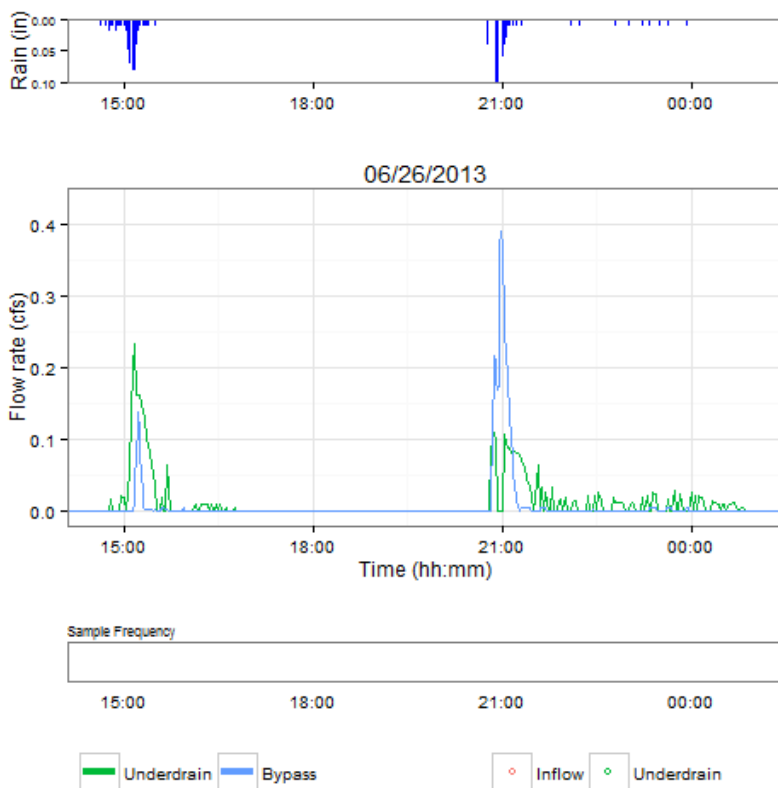
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.71		
Rainfall duration (h)	9.3		
Max 5-min intensity (in/h)	1.08		
Mean intensity (in/h)	0.18		
Antecedent dry period (h)	20.9		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	66.0		6.8		0.90
SSC	mg L^{-1}	95.77		7.03		0.93
TP	mg L^{-1}	0.034		0.012		0.65
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.56		**0.13**	0.26	0.77
NH$_{3/4}$-N	mg L^{-1}	0.14		**0.0225**	0.045	0.84
TN	mg L^{-1}	0.77		0.31		0.60
NO$_{2/3}$-N	mg L^{-1}	0.21		*0.18*		0.14
Cu	µg L^{-1}	**1.0**	2.0	2.5		-1.50
Zn	µg L^{-1}	19.0		**5.0**	10	0.74

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	3006.2	Y[a]	1374.4	1.344	-	-	Y
UNDERDRAIN	477.3	Y[b]	1052.6	0.296	0.029	51.4	Y
BYPASS	321.8	N	321.8	0.107	-	-	-

[a]Backwater in weir observed

[a]Weir readings low

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07/01/2013
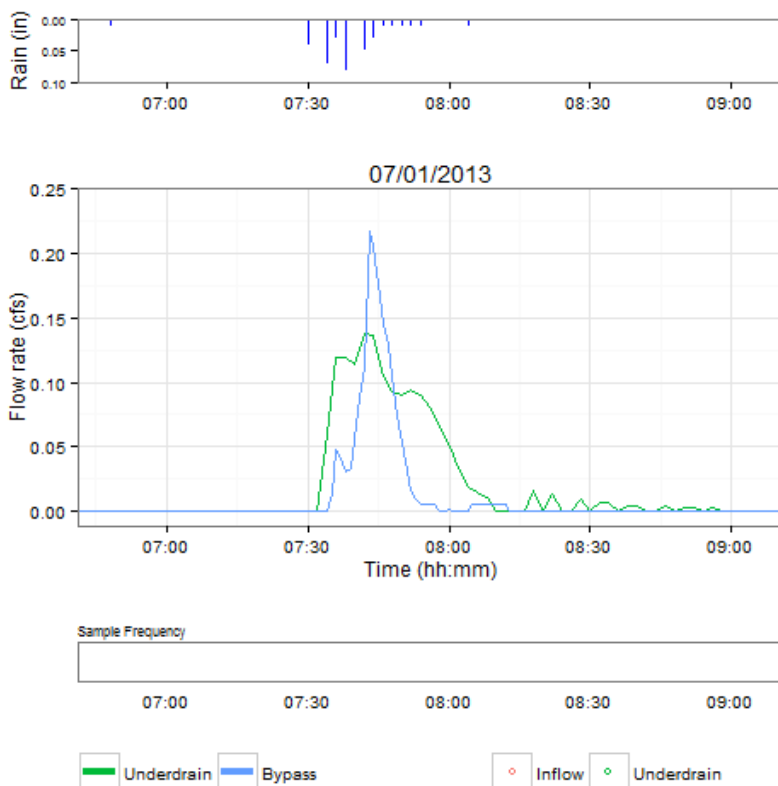
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.6		
Rainfall duration (h)	1.27		
Max 5-min intensity (in/h)	0.58		
Mean intensity (in/h)	0.47		
Antecedent dry period (h)	9.3		

Analyte	Units	Inflow		Underdrain		Efficiency Ratio
		EMC	MDL	EMC	MDL	
TSS	mg L^{-1}	30.0		6.8		0.77
SSC	mg L^{-1}	39.1		4.27		0.89
TP	mg L^{-1}	0.045		0.033		0.27
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.63		0.46		0.27
NH$_{3/4}$-N	mg L^{-1}	0.17		0.081		0.52
TN	mg L^{-1}	0.674		1.0		-0.48
NO$_{2/3}$-N	mg L^{-1}	0.044		0.54		-0.23
Cu	µg L^{-1}	3.0		3.2		-0.07
Zn	µg L^{-1}	22.0		**5.0**	10.0	0.77

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	1639.8	Y[a]	393.7	0.643	-	-	Y
UNDERDRAIN	368.0	N	368.0	0.137	0.068	122.7	Y
BYPASS	98.9	N	98.9	0.205	-	-	-

[a]Backwater in weir observed

07/02/2013
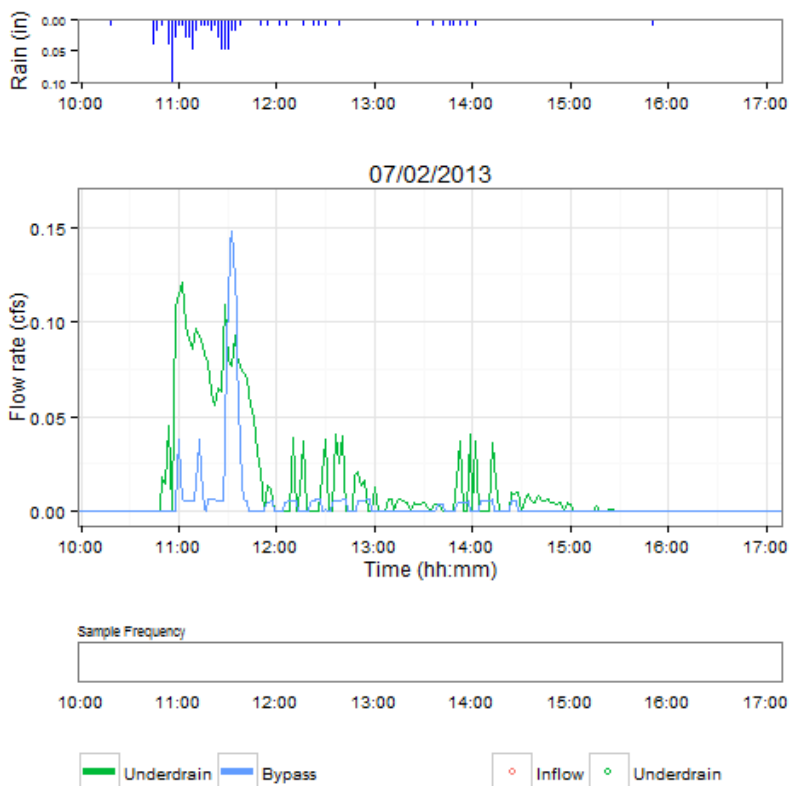
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.87		
Rainfall duration (h)	5.53		
Max 5-min intensity (in/h)	0.68		
Mean intensity (in/h)	0.16		
Antecedent dry period (h)	11.4		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	30.0		2.9		0.90
SSC	mg L^{-1}	19.51		2.3		0.88
TP	mg L^{-1}	0.045		0.038		0.16
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.51		0.37		0.27
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	0.584		0.43		0.26
NO$_{2/3}$-N	mg L^{-1}	0.0740		0.06		0.19
Cu	µg L^{-1}	2.1		2.1		0
Zn	µg L^{-1}	18.0		**5.0**	10.	0.72

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	2094.7	Y[a]	626.5	0.443	-	-	Y
UNDERDRAIN	478.1	N	478.1	0.077	0.028	51.2	Y
BYPASS	103.9	N	103.9	0.147	-	-	-

[a]Backwater in weir observed

08/13/2013
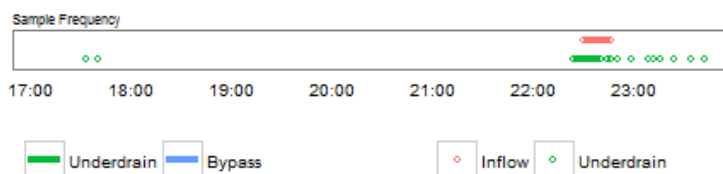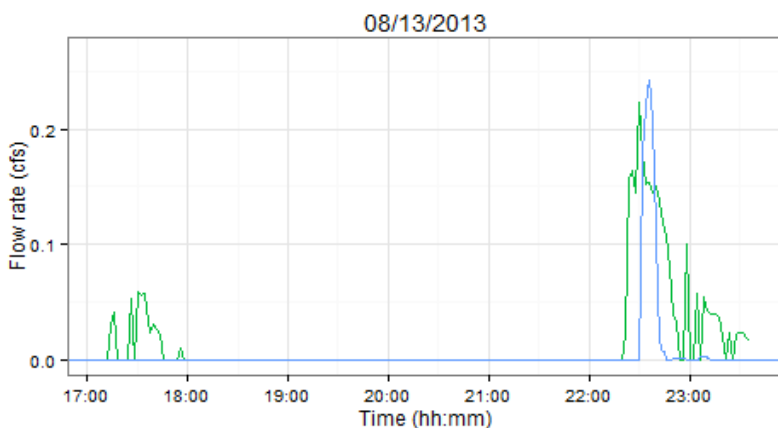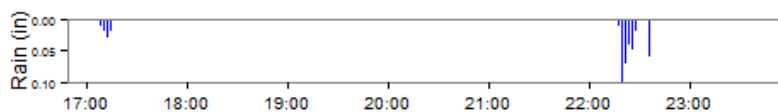
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.78		
Rainfall duration (h)	5.5		
Max 5-min intensity (in/h)	0.64		
Mean intensity (in/h)	0.14		
Antecedent dry period (h)	13.6		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	190.0		2.80		0.99
SSC	mg L^{-1}	226.4		3.33		0.99
TP	mg L^{-1}	0.21		0.067		0.68
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.093		**0.012**	0.024	0.87
TKN	mg L^{-1}	1.2		0.42		0.65
NH$_{3/4}$-N	mg L^{-1}	0.10		0.071		0.29
TN	mg L^{-1}	1.39		0.62		0.55
NO$_{2/3}$-N	mg L^{-1}	0.19		0.2		-0.05
Cu	µg L^{-1}	7.6		5.4		0.29
Zn	µg L^{-1}	82.0		19.0		0.77

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	1365.9	Y[a]	548.1	0.844	-	-	Y
UNDERDRAIN	371.0	N	371.0	0.154	0.088	159.0	Y
BYPASS	118.7	N	118.7	0.241	-	-	-

[a]Backwater in weir observed

09/01/2013
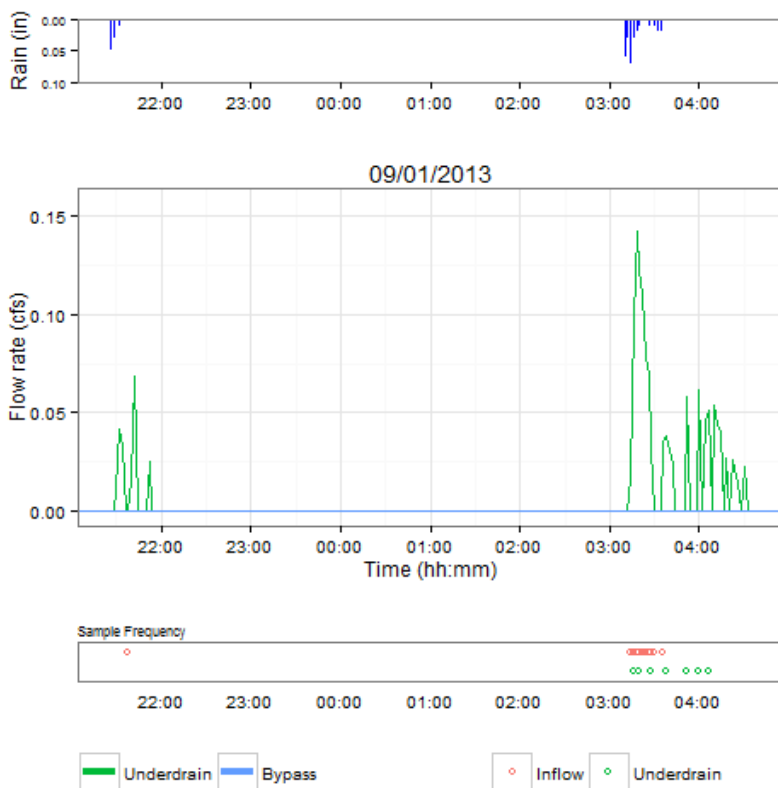
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.37		
Rainfall duration (h)	6.1		
Max 5-min intensity (in/h)	0.24		
Mean intensity (in/h)	0.06		
Antecedent dry period (h)	264		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	220		8.0		0.96
SSC	mg L^{-1}	353.17		12.09		0.97
TP	mg L^{-1}	0.10		0.012		0.88
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	1.10		0.83		0.25
NH$_{3/4}$-N	mg L^{-1}	0.13		0.14		-0.08
TN	mg L^{-1}	1.25		1.05		0.16
NO$_{2/3}$-N	mg L^{-1}	0.15		0.22		-0.47
Cu	μg L^{-1}					
Zn	μg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	515.3	Y[a]	205.1	0.372	-	-	Y
UNDERDRAIN	179.6	N	179.6	0.142	0.007	11.7	Y
BYPASS	0.0	N	0.0	0.000	-	-	-

[a]Backwater in weir observed

09/21/2013
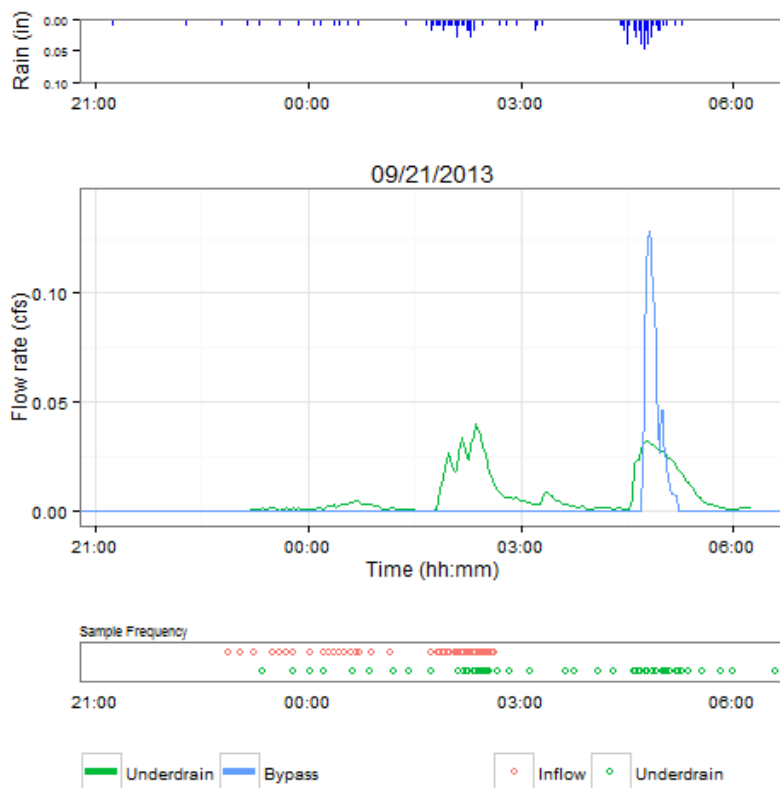
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.95		
Rainfall duration (h)	8.0		
Max 5-min intensity (in/h)	0.43		
Mean intensity (in/h)	0.12		
Antecedent dry period (h)	128		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	40.0		3.6		0.91
SSC	mg L^{-1}	79.09		3.09		0.96
TP	mg L^{-1}	0.04		**0.012**	0.024	0.70
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.0120**	0.024	0.028		-1.33
TKN	mg L^{-1}	0.90		0.041		0.54
NH$_{3/4}$-N	mg L^{-1}	0.13		0.058		0.55
TN	mg L^{-1}	1.1		0.151		0.86
NO$_{2/3}$-N	mg L^{-1}	0.20		0.11		0.45
Cu	µg L^{-1}	6.7		4.8		0.28
Zn	µg L^{-1}	49.0		12.0		0.76

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	3220.8	Y[a]	696.7	0.286	-	-	Y
UNDERDRAIN	197.0	Y[b]	603.0	0.032	0.024	43.1	Y
BYPASS	93.7	N	93.7	0.124	-	-	-

[a]Backwater in weir observed
[b]Weir readings low

10/13/2013
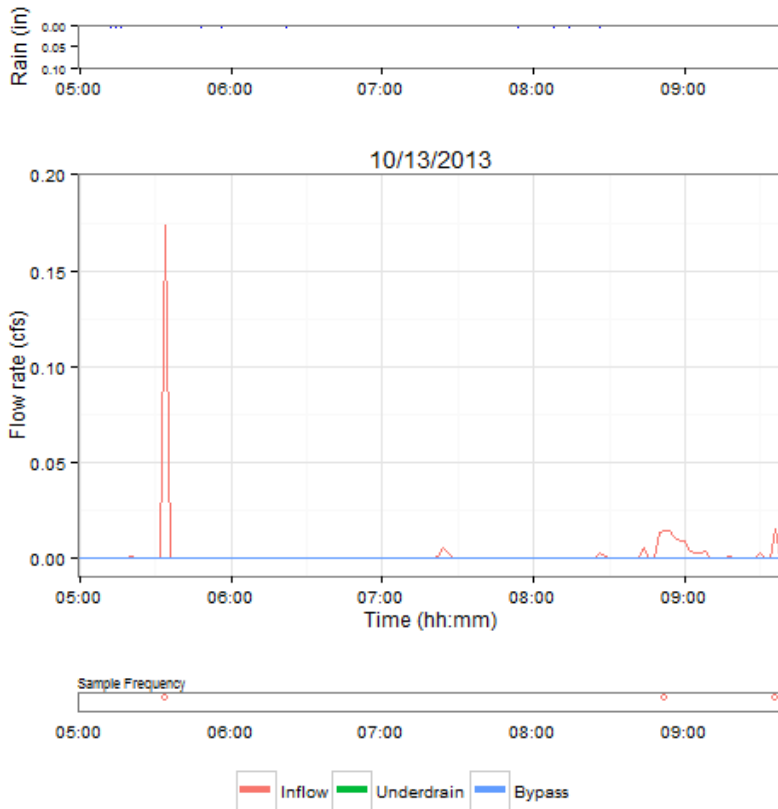
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.1		Underdrain hydrograph not available, sample filled 12 bottles
Rainfall duration (h)	3.2		
Max 5-min intensity (in/h)	0.05		
Mean intensity (in/h)	0.04		
Antecedent dry period (h)	108		

Analyte	Units	Inflow		Underdrain		Efficiency Ratio
		EMC	MDL	EMC	MDL	
TSS	mg L^{-1}	55.0		1.6		0.97
SSC	mg L^{-1}					
TP	mg L^{-1}	0.066		0.032		0.52
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.80		0.45		0.44
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	0.93		0.4625		0.50
NO$_{2/3}$-N	mg L^{-1}	0.13		**0.0125**	0.025	0.90
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	36.5	N	36.5	0.174	-	-	Y
UNDERDRAIN	-	-	-	-	-	-	Y
BYPASS	0.0	N	0.0	0.0	-	-	-

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11/01/2013
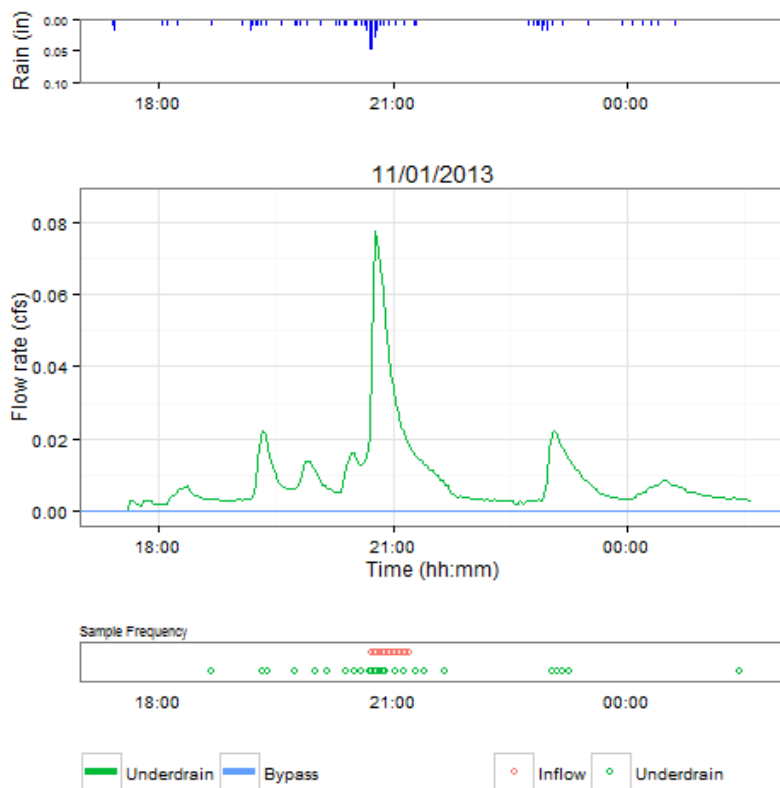
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.71		
Rainfall duration (h)	7.2		
Max 5-min intensity (in/h)	0.30		
Mean intensity (in/h)	0.10		
Antecedent dry period (h)	465		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	94.0		4.0		0.96
SSC	mg L^{-1}	71.84		3.05		0.96
TP	mg L^{-1}	0.052		0.052		0.0
Ortho-P	mg L^{-1}	0.083		**0.0275**	0.055	0.67
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.39		0.57		-0.46
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	0.11		-3.89
TN	mg L^{-1}	0.4025		0.643		-0.60
NO$_{2/3}$-N	mg L^{-1}	**0.0125**	0.025	0.0730		-4.84
Cu	µg L^{-1}	3.5		11.0		-2.14
Zn	µg L^{-1}	37.0		25.0		0.32

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	368.2	N	368.2	0.526	-	-	Y
UNDERDRAIN	335.1	N	335.1	0.077	0.012	21.0	Y
BYPASS	0.0	N	0.0	0.0	-	-	-

11/26/2013

Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.24		
Rainfall duration (h)	27.7		
Max 5-min intensity (in/h)	0.29		
Mean intensity (in/h)	0.04		
Antecedent dry period (h)	462		

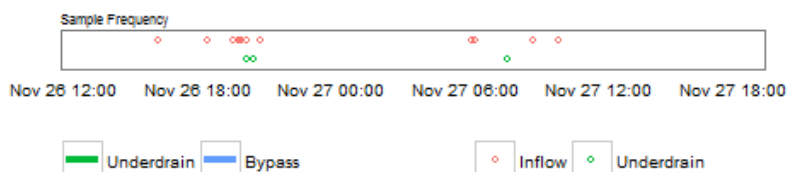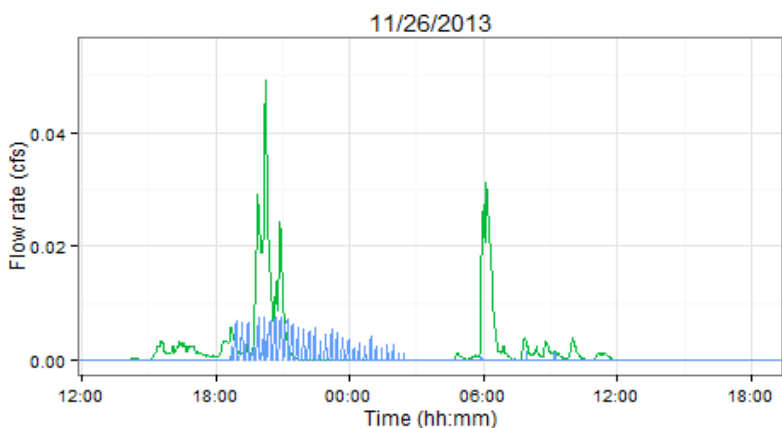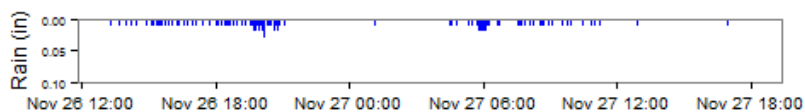| Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}	0.20		0.036		0.82
Ortho-P	mg L^{-1}					
TDP	mg L^{-1}	0.028		0.0430		-0.54
TKN	mg L^{-1}	2.0		0.30		0.85
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	*2.0125*		*0.3125*		0.84
NO$_{2/3}$-N	mg L^{-1}	**0.0125**	0.025	**0.0125**	0.025	NA
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	369.3	N	369.3	0.089	-	-	Y
UNDERDRAIN	197.2	Y[a]	324.3	0.049	0.004	7.72	Y
BYPASS	45.0	N	45.0	0.002	-	-	-

[a] Weir readings low

12/09/2013
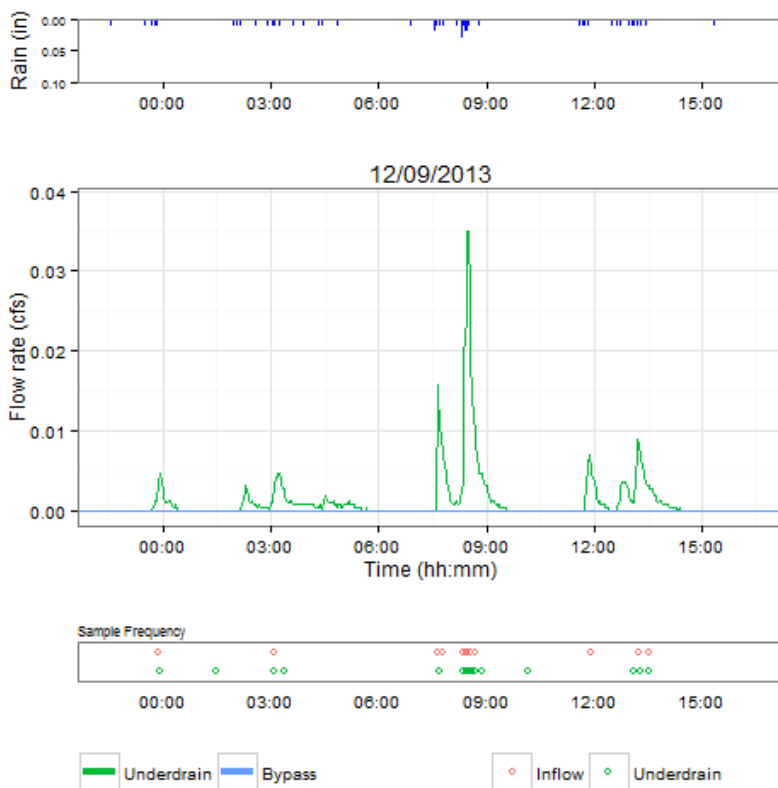
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.53		
Rainfall duration (h)	16.8		
Max 5-min intensity (in/h)	0.18		
Mean intensity (in/h)	0.03		
Antecedent dry period (h)	25.6		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	270		9.2		0.97
SSC	mg L^{-1}					
TP	mg L^{-1}	0.12		0.032		0.73
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	
TDP	mg L^{-1}	**0.0120**	0.024	0.031		-1.58
TKN	mg L^{-1}	0.97		0.27		0.72
NH$_{3/4}$-N	mg L^{-1}	0.07		**0.0225**	0.045	0.68
TN	mg L^{-1}					
NO$_{2/3}$-N	mg L^{-1}	0.098		0.15		-0.53
Cu	µg L^{-1}	14		10		0.29
Zn	µg L^{-1}	180		32		0.82

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	50.9	Y[a]	334.9	0.043	-	-	Y
UNDERDRAIN	85.0	Y[a]	334.9	0.035	0.006	11.2	Y
BYPASS	0.0	N	0.0	0.0	-	-	-

[a]Weir readings low

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01/14/2014
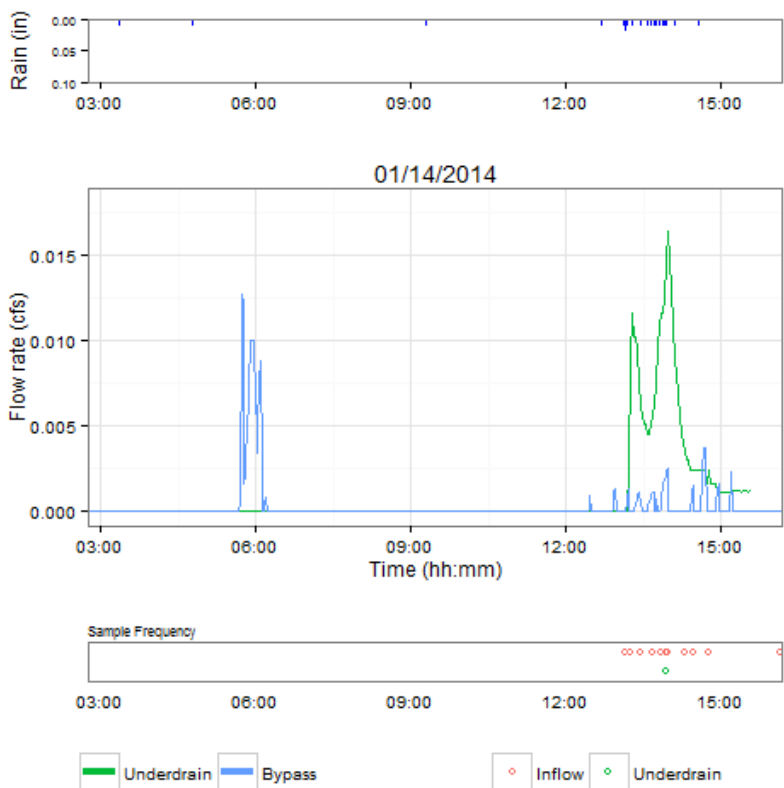
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.2		
Rainfall duration (h)	11.2		
Max 5-min intensity (in/h)	0.14		
Mean intensity (in/h)	0.02		
Antecedent dry period (h)	50.5		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}	0.12		0.048		0.60
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	1.20		0.37		0.69
NH$_{3/4}$-N	mg L^{-1}	0.049		**0.0225**	0.045	0.54
TN	mg L^{-1}	1.27		0.437		0.66
NO$_{2/3}$-N	mg L^{-1}	0.07		0.0670		0.04
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	84.5	N	84.5	0.047	-	-	Y
UNDERDRAIN	50.4	N	50.4	0.015	0.007	12.6	Y
BYPASS	4.0	N	4.0	0.002	-	-	-

02/04/2014

Rainfall Parameter table:
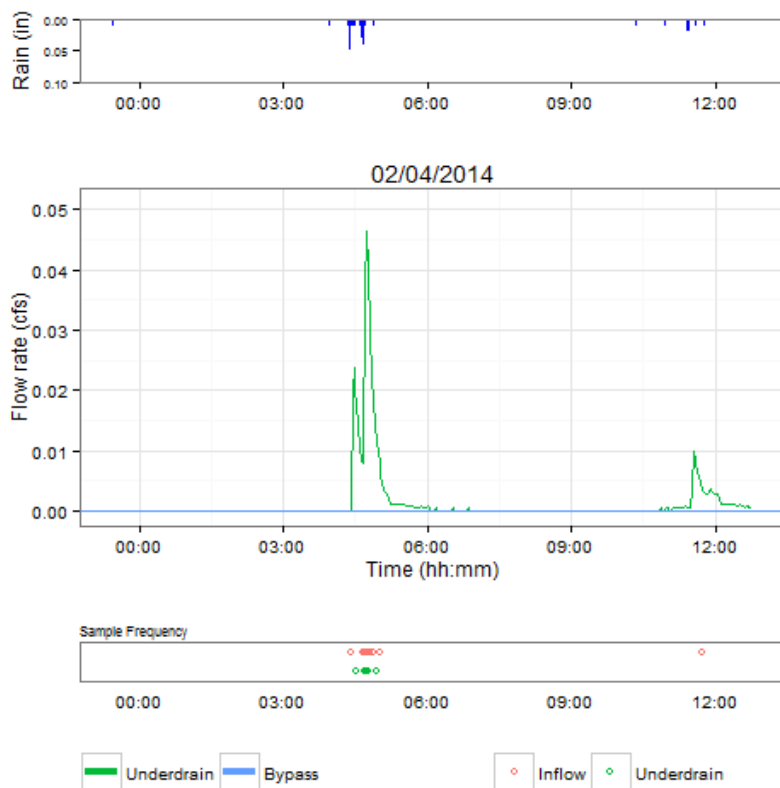
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.29		
Rainfall duration (h)	12.3		
Max 5-min intensity (in/h)	0.2		
Mean intensity (in/h)	0.02		
Antecedent dry period (h)	6.3		

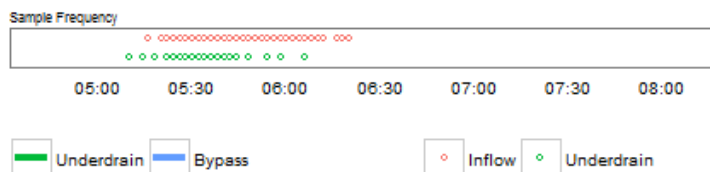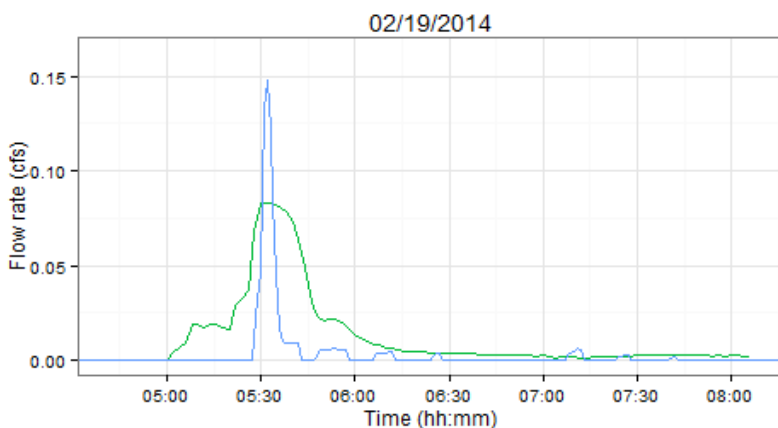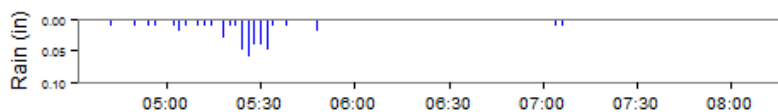| Analyte	Units	Inflow EMC	MDL	Underdrain EMC	MDL	Efficiency Ratio
TSS	mg L^{-1}	170.0		16.0		0.91
SSC	mg L^{-1}					
TP	mg L^{-1}	0.055		0.029		0.47
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.44		0.38		0.14
NH$_{3/4}$-N	mg L^{-1}	0.076		0.08		-0.05
TN	mg L^{-1}	0.58		0.53		0.09
NO$_{2/3}$-N	mg L^{-1}	0.14		0.15		-0.07
Cu	μg L^{-1}					
Zn	μg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	78.2	N	78.2	0.120	-	-	Y
UNDERDRAIN	64.4	N	64.4	0.046	0.002	3.9	Y
BYPASS	0.0	N	0.0	0.046	-	-	-

02/19/2014

Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.46		
Rainfall duration (h)	2.4		
Max 5-min intensity (in/h)	0.42		
Mean intensity (in/h)	0.19		
Antecedent dry period (h)	89.2		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	120.0		3.20		0.97
SSC	mg L^{-1}	86.67		2.07		0.98
TP	mg L^{-1}	0.059		**0.012**	0.024	0.80
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.61		**0.13**	0.26	0.79
NH$_{3/4}$-N	mg L^{-1}	0.11		0.067		0.39
TN	mg L^{-1}	0.81		0.33		0.59
NO$_{2/3}$-N	mg L^{-1}	0.20		0.20		0
Cu	µg L^{-1}	12.0		7.60		0.37
Zn	µg L^{-1}	87.0		24.0		0.72

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	953.7	Y[a]	277.2	0.372	-	-	Y
UNDERDRAIN	173.0	N	173.0	0.083	0.016	28.9	Y
BYPASS	50.2	N	50.2	0.148	-	-	-

[a]Backwater in weir observed
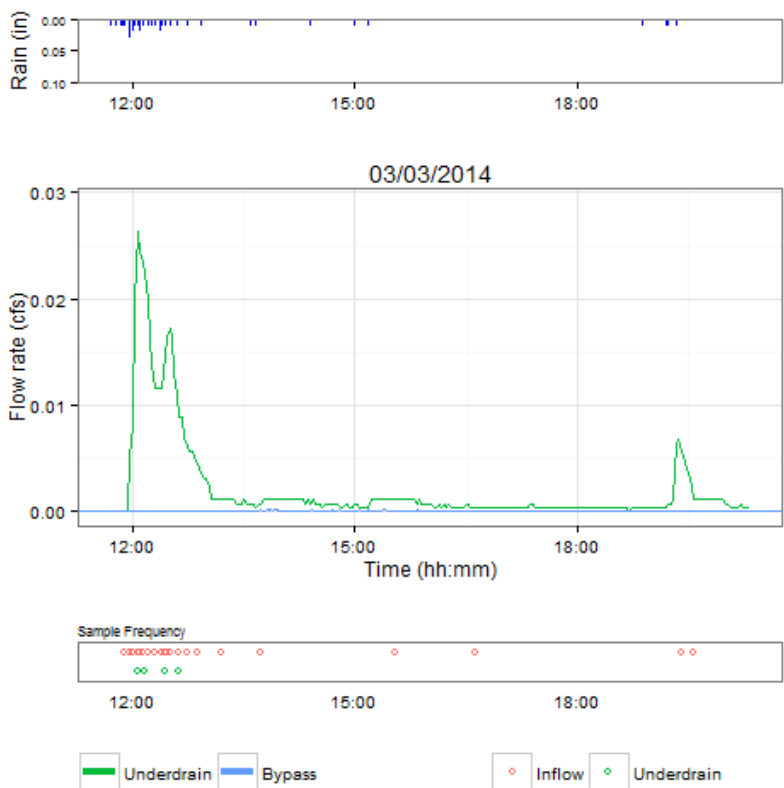
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03/03/2014

Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.35		
Rainfall duration (h)	7.6		
Max 5-min intensity (in/h)	0.24		
Mean intensity (in/h)	0.05		
Antecedent dry period (h)	238		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	54.0		14.0		0.74
SSC	mg L^{-1}					
TP	mg L^{-1}	0.59		0.046		0.92
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.39		0.024		0.94
TKN	mg L^{-1}	1.10		0.88		0.20
NH$_{3/4}$-N	mg L^{-1}	0.56		0.42		0.25
TN	mg L^{-1}	1.51		1.39		0.08
NO$_{2/3}$-N	mg L^{-1}	0.41		0.51		-0.24
Cu	μg L^{-1}					
Zn	μg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	71.9	N	71.9	0.045	-	-	Y
UNDERDRAIN	58.6	N	58.6	0.026	0.002	3.5	Y
BYPASS	0.0	N	0.0	0.0	-	-	-

04/15/2014
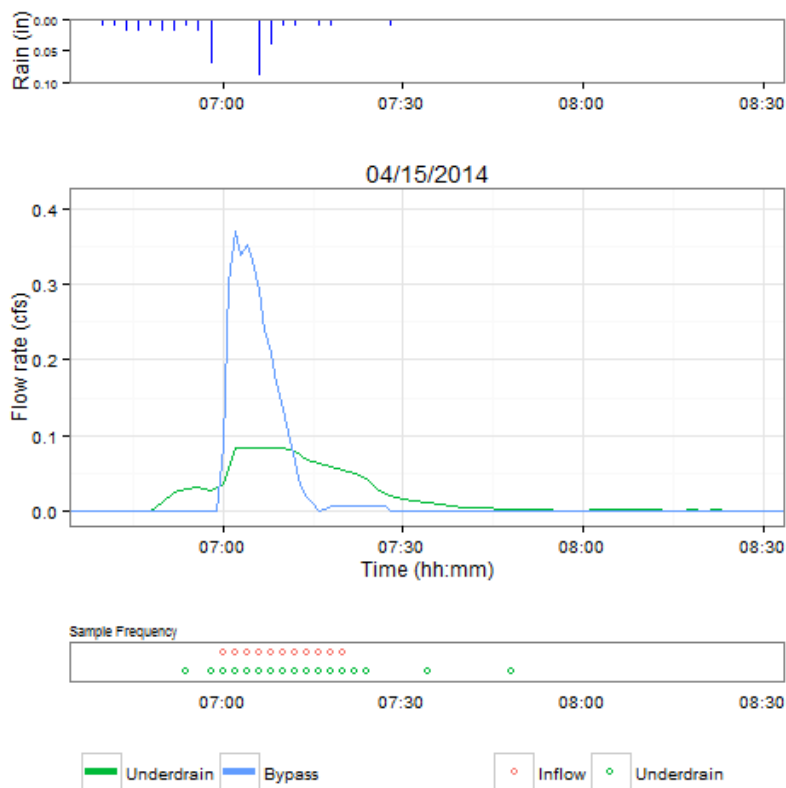
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.81		
Rainfall duration (h)	0.8		
Max 5-min intensity (in/h)	0.8		
Mean intensity (in/h)	1.0		
Antecedent dry period (h)	172		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	730		8.80		0.99
SSC	mg L^{-1}	194.7		8.39		0.96
TP	mg L^{-1}	0.29		0.14		0.52
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.0560		0.043		0.23
TKN	mg L^{-1}	1.90		1.0		0.47
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	0.049		-1.18
TN	mg L^{-1}	*1.913*		*1.013*		0.47
NO$_{2/3}$-N	mg L^{-1}	**0.0125**	0.025	**0.0125**	0.025	NA
Cu	µg L^{-1}	9.0		9.5		-0.06
Zn	µg L^{-1}	71.0		35.0		0.51

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	1191.8	Y[a]	574.2	1.029	-	-	Y
UNDERDRAIN	139.7	Y[b]	386.2	0.083	0.068	122.0	Y
BYPASS	188.0	N	188.0	0.369	-	-	-

[a]Backwater in weir observed
[b]Weir readings low

04/18/2014
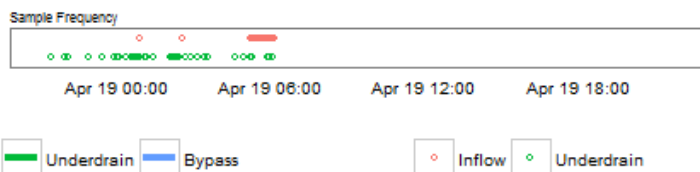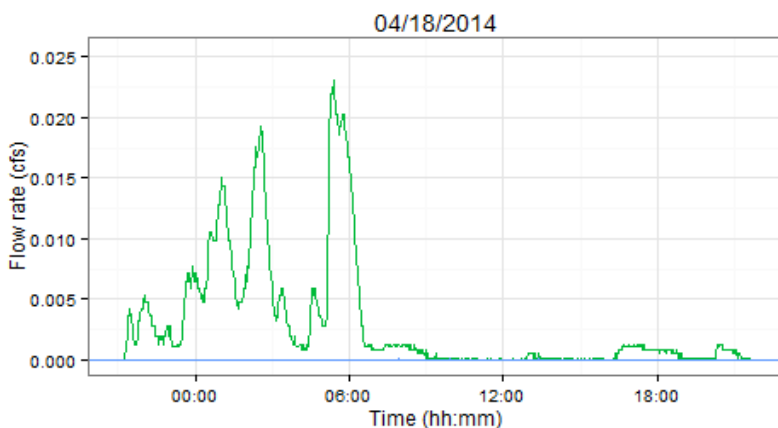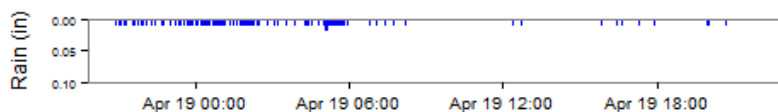
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.08		
Rainfall duration (h)	23.7		
Max 5-min intensity (in/h)	0.21		
Mean intensity (in/h)	0.05		
Antecedent dry period (h)	72.4		

Analyte	Units	Inflow		Underdrain		Efficiency
		EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	43.0		1.6		0.96
SSC	mg L^{-1}	39.37		0.74		0.98
TP	mg L^{-1}	0.044		**0.012**	0.0224	0.73
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.0120**	0.024	NA
TKN	mg L^{-1}	0.450		0.43		0.04
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	0.055		-1.44
TN	mg L^{-1}	*0.463*		*0.443*		0.04
NO$_{2/3}$-N	mg L^{-1}	**0.0125**	0.025	**0.0125**	0.025	NA
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	(in/hr)	>70% of Hydrograph Captured?
IN	1938.8	Y[a]	811.4	1.029	-	-	Y
UNDERDRAIN	263.2	Y[b]	804.5	0.083	0.009	16.1	Y
BYPASS	6.90	N	6.90	0.369	-	-	-

[a]Backwater in weir observed
[b]Weir readings low

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06/12/2014
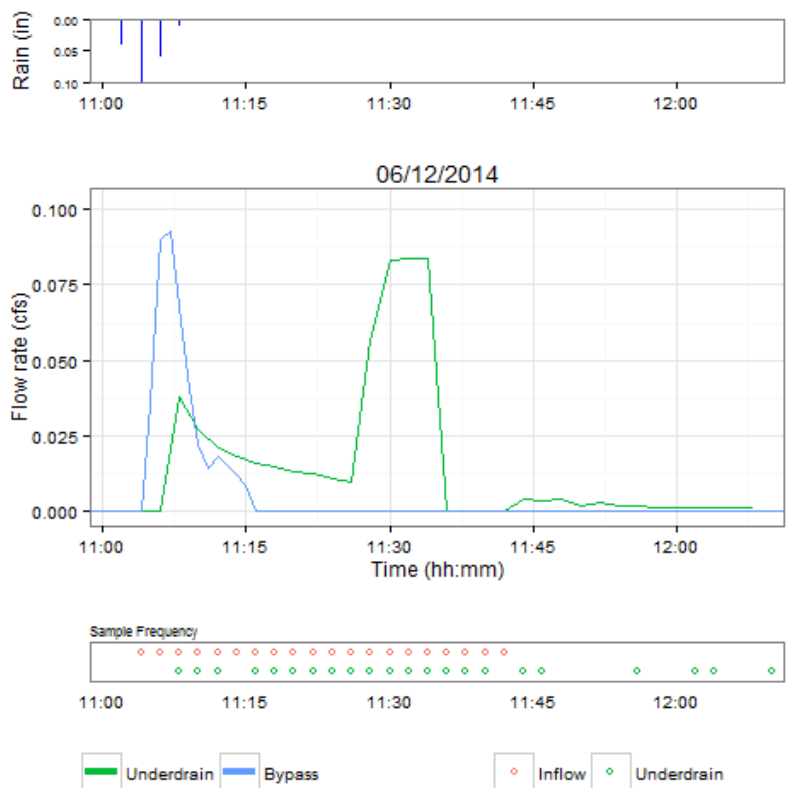
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.25		
Rainfall duration (h)	7.6		
Max 5-min intensity (in/h)	0.21		
Mean intensity (in/h)	0.03		
Antecedent dry period (h)	57.4		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	220		3.60		0.98
SSC	mg L^{-1}	309		1.57		0.99
TP	mg L^{-1}	0.30		0.0890		0.70
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.14		0.0610		0.56
TKN	mg L^{-1}	2.40		1.40		0.42
NH$_{3/4}$-N	mg L^{-1}	0.57		0.31		0.46
TN	mg L^{-1}	2.62		1.76		0.33
NO$_{2/3}$-N	mg L^{-1}	0.22		0.36		-0.64
Cu	µg L^{-1}	27		12		0.56
Zn	µg L^{-1}	99		31		0.69

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1459.1	Y[a]	94.3	0.515	-	-	Y
UNDERDRAIN	62.8	N	62.8	0.038	0.017	31.4	Y
BYPASS	30.0	N	30.0	0.068	-	-	-

[a]Backwater in weir observed

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06/19/2014
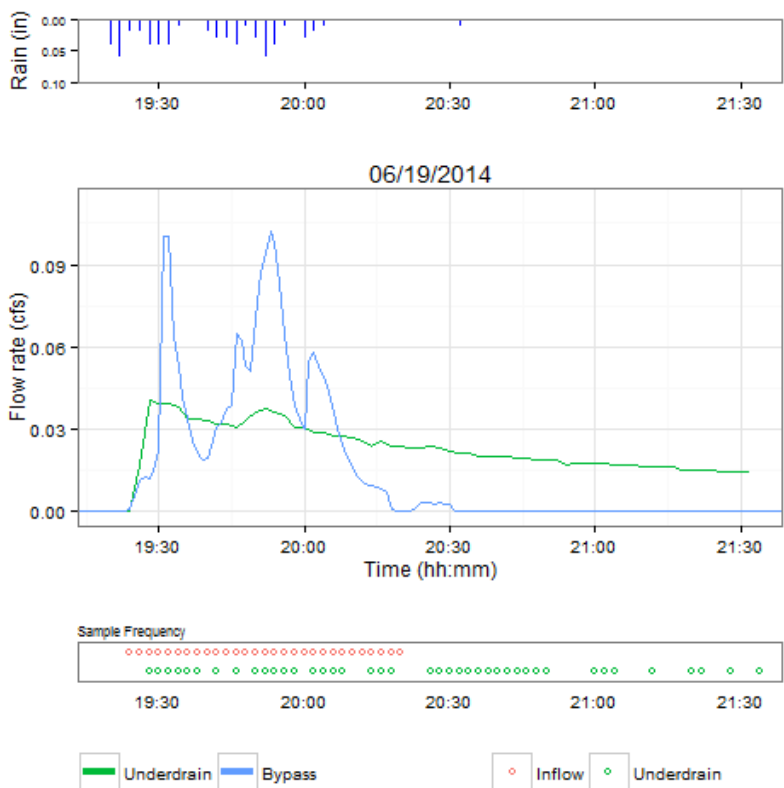
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.61		
Rainfall duration (h)	1.2		
Max 5-min intensity (in/h)	0.6		
Mean intensity (in/h)	0.51		
Antecedent dry period (h)	46.6		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	100		1.2		0.99
SSC	mg L^{-1}	111.87		1.01		0.99
TP	mg L^{-1}	0.086		0.042		0.51
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.0120**	0.024	NA
TKN	mg L^{-1}	1.1		0.740		0.33
NH$_{3/4}$-N	mg L^{-1}	0.17		0.078		0.54
TN	mg L^{-1}	1.30		1.06		0.18
NO$_{2/3}$-N	mg L^{-1}	0.20		0.32		-0.60
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	4928.6	Y[a]	402.2	0.329	-	-	Y
UNDERDRAIN	239.9	N	239.9	0.039	0.031	55.4	Y
BYPASS	135.2	N	135.2	0.101	-	-	-

[a]Backwater in weir observed

08/11/2014
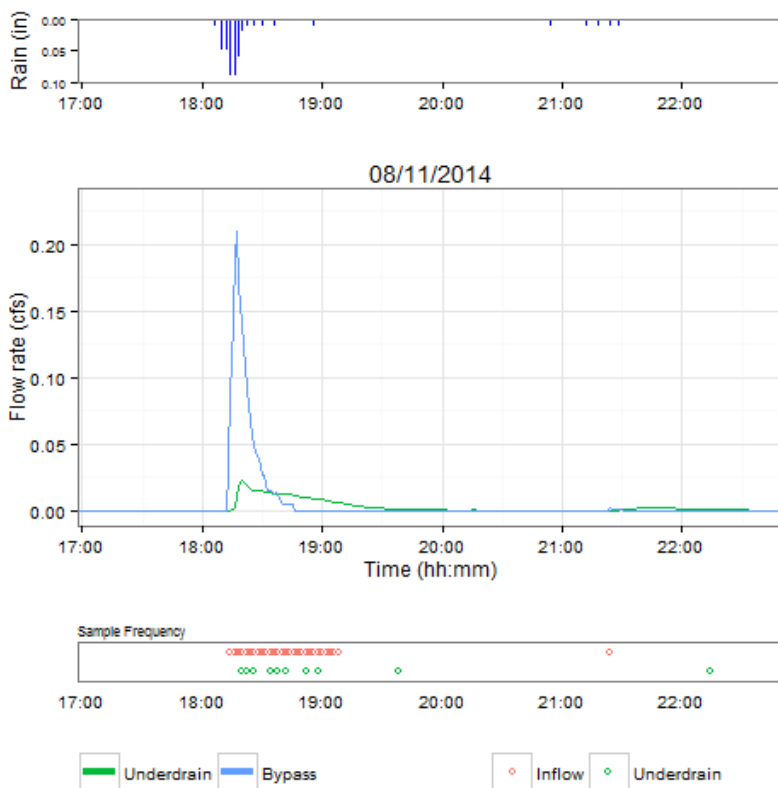
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.51		
Rainfall duration (h)	10.2		
Max 5-min intensity (in/h)	0.42		
Mean intensity (in/h)	0.05		
Antecedent dry period (h)	23.4		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	200		2.40		0.99
SSC	mg L^{-1}	230.13		2.39		0.99
TP	mg L^{-1}	0.17		0.044		0.51
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	1.5		0.45		0.33
NH$_{3/4}$-N	mg L^{-1}	0.25		**0.0225**		0.54
TN	mg L^{-1}	1.6		0.62		0.61
NO$_{2/3}$-N	mg L^{-1}	0.1		0.17		-0.60
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	2738.6	Y[a]	385.3	0.601	-	-	Y
UNDERDRAIN	46.1	Y[b]	272.1	0.003	0.015	27.2	Y
BYPASS	113.2	N	113.2	0.190	-	-	-

[a]Backwater in weir observed
[b]Weir readings low

10/11/2014
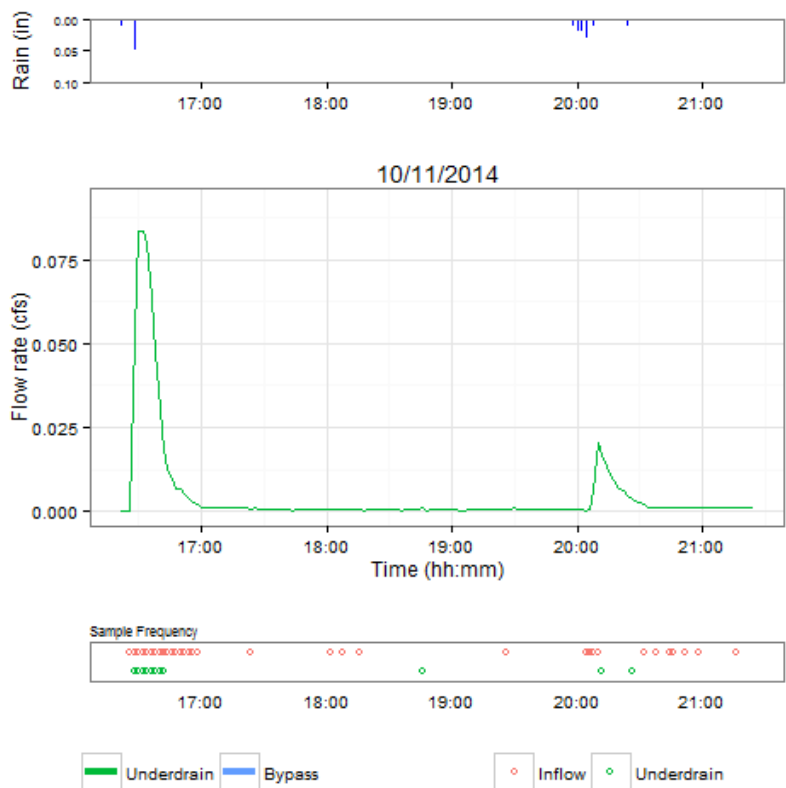
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.43		Bypass hydrograph unavailable
Rainfall duration (h)	4.0		
Max 5-min intensity (in/h)	0.33		
Mean intensity (in/h)	0.11		
Antecedent dry period (h)	286.3		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	150.0		7.60		0.95
SSC	mg L^{-1}	219.75		6.49		0.97
TP	mg L^{-1}	0.27		0.13		0.52
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.014		0.0810		0.42
TKN	mg L^{-1}	1.7		1.30		0.24
NH$_{3/4}$-N	mg L^{-1}	0.19		0.11		0.42
TN	mg L^{-1}	1.90		2.10		-0.11
NO$_{2/3}$-N	mg L^{-1}	0.20		0.80		-3.0
Cu	μg L^{-1}					
Zn	μg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1489.8	Y^a	252.8	0.844	-	-	Y
UNDERDRAIN	89.5	N	89.5	0.083	0.007	11.9	Y
BYPASS	-	-	-	-	-	-	-

^{a}Backwater in weir observed

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10/14/2014
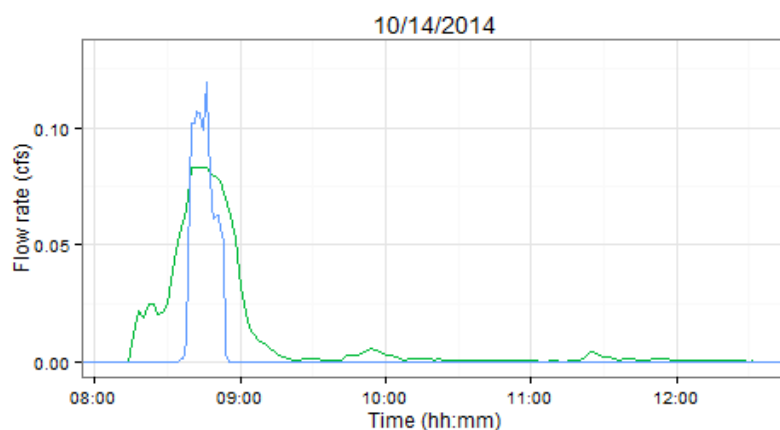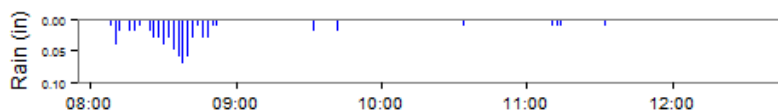
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.72		
Rainfall duration (h)	3.4		
Max 5-min intensity (in/h)	0.63		
Mean intensity (in/h)	0.21		
Antecedent dry period (h)	59.7		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	62		2.8		0.95
SSC	mg L^{-1}	85.66		1.78		0.98
TP	mg L^{-1}	0.0560		0.012		0.79
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.0120**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.94		0.37		0.61
NH$_{3/4}$-N	mg L^{-1}	0.56		0.0225		0.96
TN	mg L^{-1}	0.986		0.447		0.55
NO$_{2/3}$-N	mg L^{-1}	0.046		0.077		-0.67
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1096.8	Y[a]	496.3	0.458	-	-	Y
UNDERDRAIN	163.4	N	163.4	0.083	0.012	22.2	Y
BYPASS	77.8	N	77.8	0.102	-	-	-

[a]Backwater in weir observed

11/24/2014
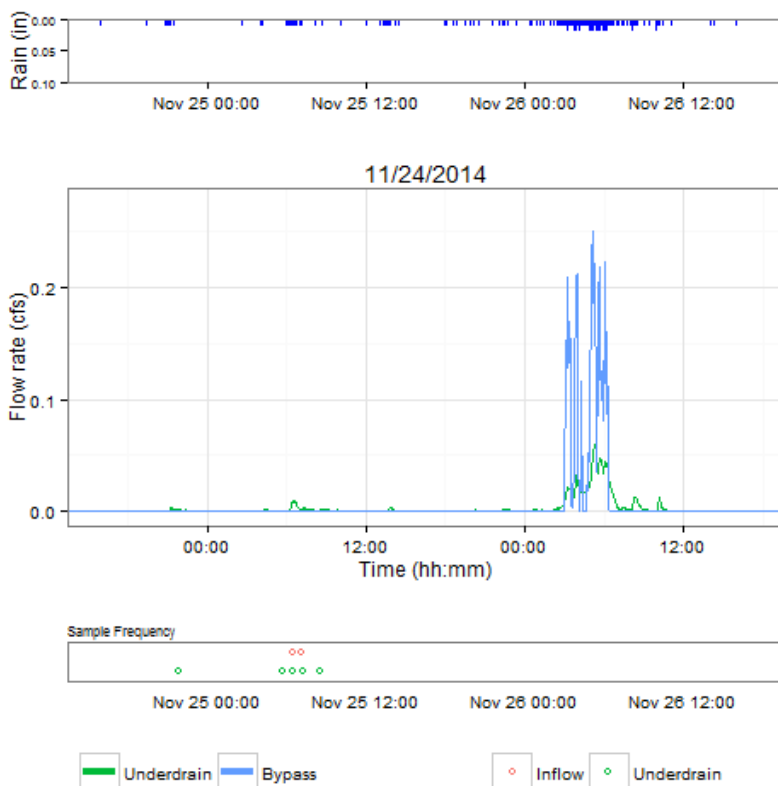
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.94		Storm not included in statistical analysis in body of report
Rainfall duration (h)	48.1		because it was sampled before a majority of the runoff
Max 5-min intensity (in/h)	0.41		occurred. Sample personnel were on-site, and all available
Mean intensity (in/h)	0.04		indication was that there would be no rain for at least six
Antecedent dry period (h)	15.5		hours, which did not occur.

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	160.0		2.0		0.99
SSC	mg L^{-1}	133.1		3.03		0.98
TP	mg L^{-1}	0.17		0.094		0.45
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.0650		0.076		-0.17
TKN	mg L^{-1}	0.85		0.50		0.41
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	0.903		0.588		0.35
NO$_{2/3}$-N	mg L^{-1}	0.0530		0.088		-0.66
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1259.5	Y[a]	1581.5	0.143	-	-	N
UNDERDRAIN	488.5	N	488.5	0.051	0.004	6.60	N
BYPASS	1295.0	N	1295.0	0.250	-	-	-

[a]Backwater in weir observed

12/06/2014
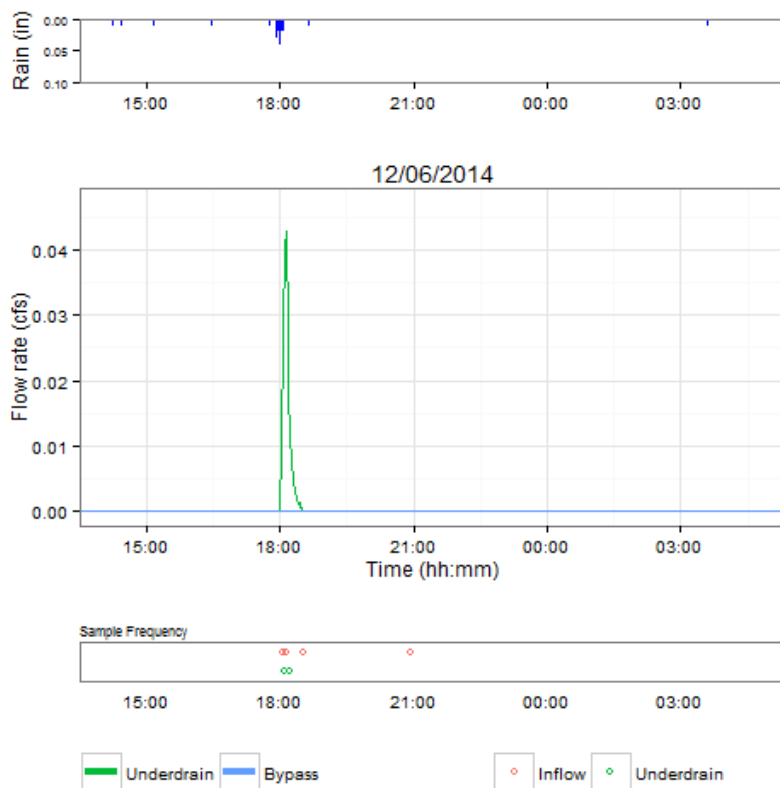
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.2		
Rainfall duration (h)	4.4		
Max 5-min intensity (in/h)	0.15		
Mean intensity (in/h)	0.045		
Antecedent dry period (h)	238.2		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	82		11		0.87
SSC	mg L^{-1}					
TP	mg L^{-1}	0.12		0.0560		0.53
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	0.037		-2.08
TKN	mg L^{-1}	1.0		0.78		0.22
NH$_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	0.045		-1.0
TN	mg L^{-1}	1.06		0.99		0.07
NO$_{2/3}$-N	mg L^{-1}	0.0590		0.21		-2.56
Cu	μg L^{-1}					
Zn	μg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	43.4	N	43.4	0.069	-	-	Y
UNDERDRAIN	24.0	N	24.0	0.043	0.007	12.0	Y
BYPASS	3.2	N	3.2	0.0	-	-	-

12/22/2014
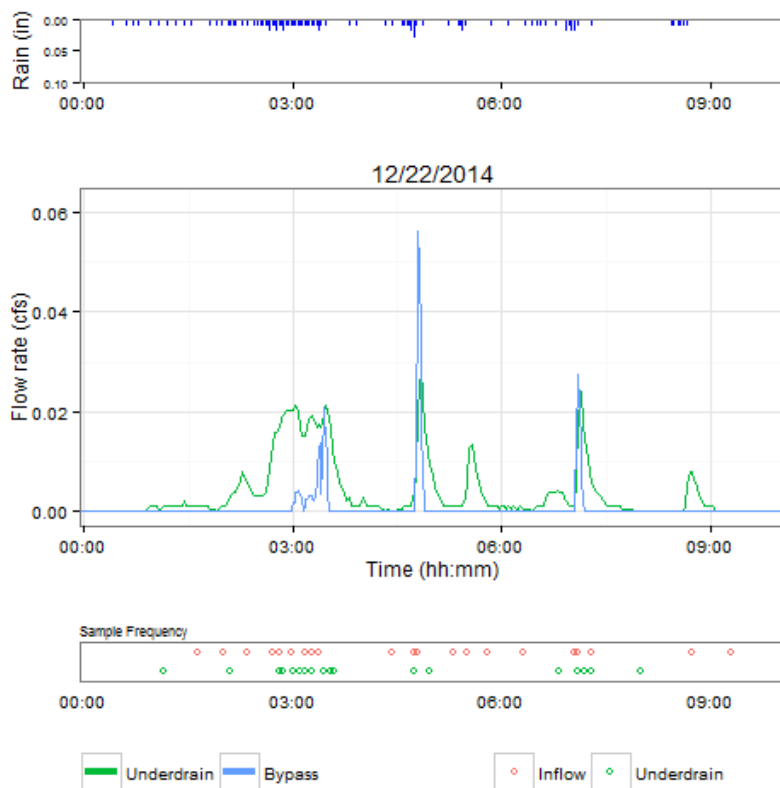
Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.97		
Rainfall duration (h)	13.8		
Max 5-min intensity (in/h)	0.33		
Mean intensity (in/h)	0.07		
Antecedent dry period (h)	365.8		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	33		3.60		0.89
SSC	mg L^{-1}					
TP	mg L^{-1}	0.12		0.025		0.79
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.490		**0.13**	0.26	0.73
NH$_{3/4}$-N	mg L^{-1}	0.065		**0.0225**	0.045	0.65
TN	mg L^{-1}	0.548		*0.26*		0.53
NO$_{2/3}$-N	mg L^{-1}	0.0580		0.13		-1.24
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	398.4	N	398.4	0.143	-	-	Y
UNDERDRAIN	135.1	N	135.1	0.020	0.005	8.5	Y
BYPASS	32.6	N	32.6	0.056	-	-	-

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Date 5 October 2017

Mr Michael Wicks
Technical Director
Stormwater 360, Australia

Dear Sir,

Please find attached a peer review report in relation to the applicability of Filterra®
Bioretention System as a stormwater improvement device under typical Australian urban
runoff conditions.

It has been found that Filterra® Bioretention System is highly likely to achieve hydrologic
and pollutant removal performances in typical Australian urban catchments (as required by
the local councils) at least at the same level found by the North Carolina State University,
Fayetteville, North Carolina, USA testing (reported in Anderson and Smolek, 2015).

This conclusion has been arrived mainly based on the review of field study and test results on
Filterra® carried out by North Carolina State University during 2013-14 (over 22 months) to
assess its hydrologic and pollutant removal performances and comparison with similar field
and laboratory testing of a number of bioretention systems in Australia.

Yours sincerely,

Associate Professor Ataur Rahman, PhD, FIE Aust., M. ASCE
Water and Environmental Engineering
Civil Engineering Department
School of Computing, Engineering and Mathematics
Western Sydney University, Australia

Peer Review: StormFilter® as a stormwater improvement device

1. Background

Urbanisation has major negative impacts including increased flood peak & volume and deteriorated water quality. A range of stormwater treatment technologies have been developed to reduce the negative impacts of urbanisation, for example, wetlands, sedimentation ponds, infiltration systems and, more recently, bioretention systems (e.g. Davis, 2005; Wong, 2006). Bioretention systems, also known as biofilters or raingardens, are the most widely used stormwater 'best management practice' in the US (Davis et al., 2009) and becoming quite popular in other countries like Australia (Wong, 2006).

Bioretention systems typically consist of small areas which are excavated and backfilled with a mixture of high-permeability soil and organic matter to maximize infiltration and vegetative growth and are covered with native vegetation (Roy-Poirier et al., 2010). The vegetation is selected to be resistant to environmental stresses and generally include small plants and shrubs. A layer of mulch is often added to cover the soil media and retain solids. An inlet structure is built to route urban runoff from the surrounding area to the unit, while an overflow structure bypasses flows above the ponding capacity of the unit. In regions having native soils of low permeability, an underdrain structure is constructed at the bottom of the facility to prevent water from standing in the unit for extended periods of time. Biofiltration system is a recommended and increasingly popular technology for stormwater management; however, there is a general lack of performance data for these systems, particularly at the field scale (Hatt et al., 2009).

The water quality performance of bioretention systems has mainly been assessed in laboratory conditions (e.g. Bratieres et al., 2008; Lucas and Greenway, 2008). These studies generally report high removals of sediments, heavy metals and phosphorus from synthetic stormwaters. The removal of nitrogen, and particularly nitrate, has been variable with the bioretention systems (Hatt et al., 2007). Recent studies have suggested that laboratory-scale filter columns do not satisfactorily replicate field-scale conditions leading to the needs for field evaluation of bioretention systems (Hatt et al., 2008).

This review focuses on Filterra® Bioretention Systems that offers a unique version of the typical flow-through filter by coupling high volume treatment with an engineered bioretention media (e.g. 140 in/hr, equivalent to 3556 mm/hr design infiltration rate) (Anderson and Smolek, 2015).

2. Review of Bioretention System

Bioretention system is an engineered stormwater control measure that provides soil and vegetation treatment to stormwater runoff. A variety of pollutants are present in stormwater sediments, which can be removed by physical processes such as sedimentation and filtration, provided by a bioretention system. Dissolved pollutant removal in traditional bioretention system occurs through a combination of processes such as adsorption, precipitation, ion exchange, and biological processes (Davis et al., 2009).

Removal of sediments in stormwater is generally high by bioretention system (54 to 99%) aided by filtration and sedimentation (Hatt et al., 2009). The top mulch layer in bioretention system has been shown to filter most of the TSS in the runoff (Hsieh and Davis, 2005).

Phosphorus removal rate by bioretention system has been reported to be in the range of 52 to 99% aided by filtration, sorption and plant uptake (Hunt et al., 2012). However, it is more difficult to remove dissolved phosphorus by traditional bioretention systems.

Nitrogen removal rate by bioretention system has been found to be in the range of 30 to 99% achieved by microbial metabolism, plant uptake and denitrification (Davis et al., 2009). However, aerobic bioretention conditions, which are common in flow-through media in bioretention can add nitrate-nitrogen rather than remove it. An anoxic condition is needed to convert nitrate to nitrogen gas. This can be achieved by adding an upturned elbow, anoxic zone, or internal water storage zone in bioretention systems.

Metal removal rate by bioretention system has been reported to be 54 to 99% aided by sorption, filtration, plant uptake, hydrolysis and precipitation (Passeport and Hunt, 2009). Most metal removal in bioretention system occurs in the top 5 to 20 cm of media and mulch (Davis et al., 2009).

3. **Filterra® System Components**

The Filterra® system is a high filtration rate stormwater treatment device that uses proprietary bioretention filtration media topped with mulch in combination with a planted tree species (Figure 1) (Anderson and Smolek, 2015). Stormwater runoff enters the system through a wide open-throated kerb inlet. Similar to conventional bioretention system, an underdrain surrounded by washed aggregate drains treated stormwater to the existing drainage infrastructure.

Figure 1. A typical Filterra site with overflow bypass pipe (Anderson and Smolek, 2015).

4. Review of Field Testing on Filterra® Bioretention System

A Filterra® Bioretention System was monitored by North Carolina State University, Fayetteville, North Carolina, USA as detailed in Anderson and Smolek (2015) during 2013-14 (for 22 months). An existing parking lot of an AmtrakTM train station was retrofitted with a 6-foot by 4-foot (i.e. 1.2 m×1.8 m approximately) Filterra® system, which treated 0.25 acres (about 1000 m^2) of impervious asphalt and concrete catchment (Figure 2). The Filterra® system area was approximately 0.22% of the catchment area. The maximum impervious drainage area for the 6-foot by 4-foot system installed in Fayetteville is 0.21 acres according to the Filterra® sizing chart for the region (for 1 inch design storm) (equivalent to 0.26% of the catchment area). Hence, the Filterra® system in the North Carolina State University testing was slightly undersized. The system was installed in September, 2012 and activated on 2nd October 2012 by Contech Engineered Solutions and performance data were obtained for 22 months during 2013-14. The site area on average receives 1049 mm of rainfall per year. The Filterra® system is shown in Figure 3.

Filterra® sizing utilizes a conservative design flow rate of about 3.5 m per hour. To design the Filterra® to treat the necessary (e.g. 25 to 40 mm) water quality volume, sizing chart for Filterra® is available, which was utilized to estimate maximum size drainage area for a Filterra® unit using a "worst case" 100% impervious drainage area.

Automatic water quality samplers were installed to collect influent and effluent samples. All rainfall at the site was measured using a tipping-bucket rain gauge. To obtain flow-weighted composite samples for each storm event, runoff was routed to the influent sampling location into a sharp-crested compound weir flow-measuring device. The sampling procedure generally meets the international standards (Anderson and Smolek, 2015).

The collected water quality samples were tested for event mean concentrations of total suspended solids (TSS), suspended sediment concentration (SSC), total ammoniacal nitrogen (TAN), nitrate/nitrite-nitrogen ($NO_{2,3}$-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), total copper (Cu), dissolved copper, total zinc (Zn), and dissolved zinc (Anderson and Smolek, 2015).

Figure 2. Location of Filterra® at city-owned AmtrakTM parking lot in Fayetteville, North Carolina (Anderson and Smolek, 2015).

Figure 3. Filterra® at city-owned AmtrakTM parking lot in Fayetteville (Anderson and Smolek, 2015).

Study results show that the Filterra® system reduced median peak flow by 56% for storms monitored in the study (0.10 to nearly 5 inches, equivalent to 2.54-127 mm, in depth) during the study period (2013-2014). About 72% of inflow volume was treated by the Filterra®, while the remainder was either bypass flow (22%) or a combination of soil storage and/or instrument error (6%). Filterra® was found to behave similarly to widely-used and approved BMPs in North Carolina (Anderson and Smolek, 2015). As reported by HEC (2009), substantial water losses were observed in the Filterra test systems at the Port of Tacoma between the influent and effluent monitoring stations during the start of the monitoring year in May and June 2008. This water loss ranged from 1.2 to 57 percent, with a median value of 27 percent. As reported in HEC (2009), a study performed by Filterra and Randolph-Macon College showed that volume storage capacity of the Filterra system increased as a function of system size and drying period, and would be ideal for capturing small, low intensity events and dry weather flows. Standard Filterra systems retained between 17.5 and 28.9 percent of the influent water volume based on a 0.1-inch rainfall intensity, which is the 80th percentile of the rainfall intensities measured in the Mid-Atlantic region of USA. Based on these results, the volume reduction in the Filterra® system may be taken as 6% as found in the North Carolina State University testing (given Filterra® system was undersized at 0.22% of the catchment area, if the system was sized at 0.3% of the catchment area, the water loss would have been higher).

Over a 22-month monitoring period, the Filterra® significantly reduced TSS concentrations with an efficiency ratio of 96%, a cumulative load reduction of 76%, and a median storm-by-storm TSS load reduction of 80%. Another sediment metric, Suspended Sediment Concentration (SSC), was also measured, resulting in a 97% significant efficiency ratio, a 77% cumulative load reduction, and a 77% median storm-by-storm load reduction. The 95% confidence interval of the mean TSS removal on a per storm event basis was estimated to be 90% - 94%.

Total phosphorus concentrations were notably reduced with an efficiency ratio of 64%, a cumulative load reduction of 54% and a 63% median storm-by-storm load reduction. Overall cumulative percent loading reduction was 54%, indicating excellent removal of phosphorus for bioretention without internal water storage. Concentrations of both total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) were very low both entering and leaving the system (below what is expected on an urban watershed).

Total nitrogen concentrations were significantly reduced with an efficiency ratio of 39%, a cumulative load reduction of 39% and a 45% median storm-by-storm load reduction. Although total nitrogen was reduced, likely due to filtration of particulate-bound N, nitrate export was witnessed. This finding was expected, and is typical in systems that do not have apparent mechanisms for denitrification.

Total zinc concentrations were also significantly reduced with an efficiency ratio of 69%. For the Filterra® system as a whole, cumulative percent load reductions for TSS, TP and TN were 76%, 54% and 39%, respectively. When only storms that did not produce bypass were considered, the cumulative percent load reduction increased to 96%, 75%, and 45% for TSS, TP and TN, respectively (Anderson and Smolek, 2015).

5. Field Testing on Filterra® Bioretention System in Fayetteville, North Carolina vs. Australian data

Birch et al. (2005) assessed the efficiency of stormwater infiltration basin to remove contaminants from urban stormwater runoff in eastern Sydney. They monitored seven rainfall events. The TSS removal efficiency of the stormwater infiltration basin was about 50% on average, whereas the removal efficiencies of Cu, Pb and Zn were on average 68%, 93% and 52%, respectively. The mean removal efficiencies for total phosphorus (TP) and total Kjeldahl Nitrogen (TKN) were found to be 51% and 65%, respectively.

Hatt et al. (2007) conducted a laboratory-scale gravel infiltration system in Monash University, Clayton, Victoria to test the pollutant removal under a range of water level regimes, including both constant and variable water levels. Gravel filters were found to be very effective for removal of sediment and heavy metals under all water level regimes, even as the system clogged over time. Despite the sediment particle size distribution being much smaller than the filter media pore size, sediment and its associated pollutants were effectively trapped in the top of the gravel filter, even when the water level was allowed to vary. A media depth of 0.5m was found to achieve adequate pollutant removal. The removal efficiencies for TSS, TP, TN and zinc were 92%, 53%, 44% and 38%.

Bratieres et al. (2008) conducted a large-scale column study in purpose built greenhouse in Melbourne to test the performance of biofilters for the removal of sediment, nitrogen and phosphorus from stormwater runoff. A variety of factors were tested, using 125 large

columns including plant species, filter media, filter depth, filter area and pollutant inflow concentration. The results demonstrate that vegetation selection is critical to performance for nitrogen removal (e.g. Carex appressa and Melaleuca ericifolia performed significantly better than other tested species). Whilst phosphorus removal was consistently very high (typically around 85%), biofilter soil media with added organic matter reduced the phosphorus treatment effectiveness. Biofilters built according to observed 'optimal specifications' can reliably remove both nutrients (up to 70% for nitrogen and 85% for phosphorus) and suspended solids (consistently over 95%).The optimally designed biofilter is at least 2% of its catchment area and possesses a sandy loam filter media, planted with C. appressa or M. ericifolia.

Hatt et al. (2009) investigated the hydrologic and pollutant removal performance of three field-scale biofiltration systems in Australia (one at Monash University, Clayton, Victoria and the other at McDowall, Queensland). They found that Biofilters effectively attenuated peak runoff flow rates by at least 80%. Performance assessment of a lined biofilter demonstrated that retention of inflow volumes by the filter media, for subsequent loss via evapotranspiration, reduced runoff volumes by 33% on average. Retention of water was found to be most influenced by inflow volumes, although only small to medium storms could be assessed. Vegetation was shown to be important for maintaining hydraulic capacity, because root growth and senescence countered compaction and clogging. Suspended solids and heavy metals were effectively removed, irrespective of the design configuration, with load reductions generally in excess of 90%. In contrast, nutrient retention was variable, and ranged from consistent leaching to effective and reliable removal, depending on the design. It was recommended that to ensure effective removal of phosphorus, a filter medium with low phosphorus content needs to be selected. They noted that nitrogen was more difficult to remove because it is highly soluble and strongly influenced by the variable wetting and drying regime that is inherent in biofilter operation.

Table 1 compares the pollutant removal efficiencies of Filterra® Bioretention System tested in Fayetteville, North Carolina with four Australian studies. It can be seen that TSS removal efficiency of Filterra® is 96%, which matches very well with the studies by Hatt et al. (2007) (92%), Bratieres et al. (2008) (95%) and Hatt et al. (2009) (90%) .

It can be seen that TP removal efficiency of Filterra® is 64%, which is higher than the value found by Hatt et al. (2007) (53%), but smaller than the value found by Bratieres et al. (2008) (85%). It should be noted that study by Bratieres et al. (2008) was greenhouse experiment but Fayetteville, North Carolina study with Filterra® was a field study.

Table 1. Comparison of Filterra® Bioretention System tested in Fayetteville, North Carolina vs. Australian data

Pollutant	Filterra® (field tested in North Carolina, USA) (Anderson and Smolek, 2015)	Other bioretention/ infiltration systems tested in Australia	Reference
TSS	96%	50%	Birch et al. (2005): field study site in eastern Sydney
		92%	Hatt et al. (2007): laboratory experiment at Monash University Clayton, Victoria
		95%	Bratieres et al. (2008): Greenhouse experiment, Melbourne, Victoria
		90%	Hatt et al. (2009): Monash University, Clayton, Victoria and McDowall, Queensland
TP	64%	51%	Birch et al. (2005): field study site in eastern Sydney
		53%	Hatt et al. (2007): laboratory experiment at Monash University Clayton, Victoria
		85%	Bratieres et al. (2008): Greenhouse experiment, Melbourne, Victoria
		Not available	Hatt et al. (2009): Monash University, Clayton, Victoria and McDowall, Queensland
TN	39%	65% (TKN)	Birch et al. (2005): field study site in eastern Sydney
		44%	Hatt et al. (2007): laboratory experiment at Monash University Clayton, Victoria
		Up to 70%	Bratieres et al. (2008): Greenhouse experiment, Melbourne, Victoria
		Not available	Hatt et al. (2009): Monash University, Clayton, Victoria and McDowall, Queensland
Zn	69%	52%	Birch et al. (2005): field study site in eastern Sydney
		38%	Hatt et al. (2007): laboratory experiment at Monash University Clayton, Victoria
		Not available	Bratieres et al. (2008): Greenhouse experiment, Melbourne, Victoria
		Not available	Hatt et al. (2009): Monash University, Clayton, Victoria and McDowall, Queensland

There are little published data on contaminants in runoff from carparks in Australia. The contaminant concentrations and load in the carpark runoff depend on factors such as traffic volume in the carpark, surrounding land use, adopted maintenance mode and frequency. The small catchment size of carpark is likely to show a first flush effect after the heavy rainfall events. Hence, comparison of contaminants in the carpark runoff from different studies located in different regions must be interpreted in light of the local conditions.

Fletcher et al. (2004) recommended the event mean concentrations (EMC) for a number of land uses in Australia, which are widely used in design (Table 2). It is found that contaminant concentrations for the case of Mitchell Community College carpark testing are much smaller than reported by Fletcher et al. (2004).

Table 2. EMC for different land uses in Australia (Fletcher et al., 2004) compared with Mitchell Community College carpark testing (values in parentheses indicate Fayetteville Filterra® Bioretention result)

Contaminant	Range (mg/L)	Typical value (mg/L)
Suspended solids	900 - 800	270
	(20 - 730)	(120)
Total Nitrogen	1.00 - 5.00	2.2
	(0.35 - 2.62)	(1.20)
Total Phosphorus	0.15 - 1.5	0.5
	(0.03 - 0.59)	(0.130)

In another study by Morison (2001) for St Martins Shopping Village carpark in Western Sydney using a rainfall simulator (calibrated for a 1 in six month storm of 15 minutes duration) showed a first flush effect for 10 minutes with an approximate EMC for a duration of 15 minutes of Suspended Solids (95 mg/L), Total Nitrogen (1.85 mg/L) and Total Phosphorus (0.15 mg/L). The results from Morison (2001) and Fletcher et al. (2004) when compared with Mitchell Community College carpark testing exhibit a large difference, which perhaps are due to different land use characteristics and traffic volume representing local conditions.

It should be highlighted that if the EMC in the influent is higher, the contaminant removal efficiency by a stormwater quality improvement device should be higher. Hence, it is highly likely that the efficiency ratio for Fayetteville Filterra® Bioretention system would be much higher if the influent EMCs were higher as reported in Australia.

6. Conclusion

Based on this literature review, the following conclusions can be made:

- The sampling and monitoring protocol of field testing of Filterra® Bioretention System by North Carolina State University, Fayetteville, North Carolina, USA as detailed in Anderson and Smolek (2015) generally follows the international and Australian standards of field testing. Hence, the test results from this study are deemed to be reliable.

- In the North Carolina State University testing, a 6-foot by 4-foot Filterra® was adopted for 0.25 acres of impervious asphalt and concrete catchment area, i.e. the Filterra® system area was approximately 0.22% of the catchment area. According to the local Filterra® sizing guideline, the treatment area should have been 0.21 acres (i.e. Filterra® system area should have been 0.26% of the catchment area). Based on these data, the minimum sizing criterion of Filterra® for Australia may be taken as 0.3 % of catchment area.

- Results from North Carolina State University testing show that the 1.2 m×1.8m Filterra® system reduced median peak flow by 56% for storms (2.54-127 mm in depth) monitored during the study period for treatable catchment area of about 1000 m^2. About 72% of inflow volume was treated by the Filterra®. The mean annual rainfall in the study area is 1049 mm. Depending on the local rainfall and given catchment area in Australia, the appropriate size of the Filterra® system needs to be calculated.

- Based on the results of the North Carolina State University testing and other similar studies, the volume reduction in the Filterra® system (due to factors such as storage and evapotranspiration) may be taken as 6% of rainfall volume (generally applicable for smaller rainfall events e.g. 3 mm or less), which is ideal for capturing small, low intensity rainfall events and dry weather flows.

- The pollution removal efficiencies of Filterra® Bioretention System in the North Carolina State University testing has been found to be about 96%, 64%, 39% and 69% for TSS, TP, TN and Zn. When only storms that did not produce bypass were considered, the cumulative percent load reduction increased to 96%, 75%, and 45% for TSS, TP and TN, respectively (Anderson and Smolek, 2015).These pollution removal efficiencies for Filterra® Bioretention System are likely to vary from site to site depending on the surrounding urban land use condition and rainfall characteristics; and these values are shown to match quite well with similar Australian studies with the bioretension systems. Hence, it is highly likely that Filterra® Bioretention System will achieve hydrologic and pollutant removal performances in typical Australian urban catchments (as required by the local councils) at least at the same level found by the North Carolina State University, Fayetteville, North Carolina, USA field testing as detailed in Anderson and Smolek (2015).

- Based on this review, for typical stormwater modelling (e.g. using MUSIC) in Australia using Filterra® Bioretention system, the following pollution removal efficiencies may be adopted: 96% (for TSS), 64% (for TP) and 39% (for TN) together with a volume reduction of 6%. It should be noted that the removal efficiencies recommended are less than the cumulative percent load reduction for storms (without bypass).

- It should be noted that TN removal efficiency is subject to greater uncertainty as bioretention systems do not have adequate mechanisms for denitrification. It is suggested that field testing of Filterra® Bioretention System should be conducted in typical Australian urban catchments of the discrete nutrient speciation (for N) removals to confirm above findings of this review.

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APPENDIX K1

STORMWATER QUANTITY AND QUALITY TREATMENT SYSTEM MONITORING AND MAINTENANCE SCHEDULE

General Notes:

1 - Maintenance is to be carried out with regard to relevant occupational health and safety guidelines and standards. This includes all confined space, traffic management, fall arrest and other requirments.

2 - Initial monitoring and inspections of the stormwater system post commissioning are to be carried out every 3 months for the first year of operation. The amount and type of debris is to be noted and recorded.

3 - The frequency of inspections shown in the stormwater maintenance schedule are the maximum periods. Inspection frequencies may be reduced upon completion of the initial monitoring and inspection program as noted in note 2.

4 - Blank copies of the maintenance schedule are to be made and filled out during each subsequent inspection with the details kept on site for future reference.

Inspected by: …………………………………………………………………………..

Date of Inspection: ………………………………………………………………… Date of Next Inspection: …………………………………………………………...

Item to be Inspected	Frequency	Performed by	Inspected Yes/No	Maintenance Required Yes/No	Maintenance Procedure	Maintenance Completed Date
General						
Eaves/Box Guttering System and Downpipes	Six Monthly/ After Major Storm	Owner / Maintenance Contractor			Inspect and remove any build up of sediment, debris, litter and vegetation within gutter system.	
Stormwater surface inlet and junction pits	Four Monthly/ After Major Storm	Owner / Maintenance Contractor			Remove grate and inspect internal walls and base, repair where required. Remove any collected sediment, debris, litter and vegetation. (e.g. Vacuum) Inspect and ensure grate is clear of sediment, debris, litter and vegetation. Ensure flush placement of grate on refitment.	
General visual inspection of entire stormwater drainage system	Bi-annually	Owner / Maintenance Contractor			Inspect all drainage structures noting any dilapidation, carrry out required repairs.	
Raingarden						
Filterra garden area and surrounding areas.	Four Monthly/ After Major Storm	Owner / Maintenance Contractor			Check the area of any rubbish and build up of dirt and silt. Collect and remove rubbish and dirt/silt.	
Plants health and remove weeds	Four Monthly/ After Major Storm	Owner / Maintenance Contractor			During long period of drought, check if the plants are in good health. If necessary provide irrigation or replace dead plants. Remove weeds or other plant species that are not suitable for raingarden.	
Filter media (Biofiltration, transition, drainage layers) clogging and constant ponding	6 Monthly	Owner / Maintenance Contractor			Inspect for surface clogging/ponding in filter media. If clogging or ponding present check subsoil drainge line for blockage and cleanout. If no blockage present in sub-soil drainge remove clogged filter media and replace with specified filter media.	
Evidence of surface erosion of Filterra garden	6 Monthly	Maintenance Contractor			Check for scour of filter media at inlet pit and overflow pit. If scour present rake back filter media and provide scour protection.	
Inlet pit, overflow pit and Filterra garden walls.	Annually	Owner / Maintenance Contractor			Inspect pit and wall/batter structure to ensure in good condition with no deterioration present. If required provide repairs.	
Permeable pavement at courtyard						
Permeable pavement (N/A)	Six Monthly/ After Major Storm	Owner / Council			Check if ponding on the pavement and stormwater could not infiltrate into the sand layer due to clogging. Remove any collected sediment, debris, litter and vegetation. Repair and unclog using vacuum if necessary.	