

## **Appendix B Typical Year Rainfall Analysis**

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**London**  
CANADA

# **City of London Pollution Prevention Control Plan (PPCP) Update**

**Typical Year Rainfall Analysis Review and Update**

Prepared by GM BluePlan Engineering Ltd.

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## Version Updates

The following is a record of the changes/updates that have occurred on this document:

| Version | Changes / Updates | Author       | Reviewer          | Approved        | Date              |
|---------|-------------------|--------------|-------------------|-----------------|-------------------|
| 1       | Draft Document    | Ali Ghandour | Jonathan Brickman | James Jorgensen | October 15, 2023  |
| 2       | Draft Document    | Ali Ghandour | Jonathan Brickman | James Jorgensen | November 15, 2023 |
| 3       | Draft Document    | Ali Ghandour | Jonathan Brickman | James Jorgensen | December 12, 2023 |
| 4       | Final Document    | Ali Ghandour | Jonathan Brickman | James Jorgensen | January 08, 2024  |
| 5       | Final Document    | Ali Ghandour | Jonathan Brickman | James Jorgensen | March 1, 2024     |

## 1. Introduction

Typical or average year rainfall is used with a hydraulic model to estimate overflow discharges and to determine compliance with Ontario's regulation for "Levels of Treatment for Municipal and Private Sewage Treatment Works Discharging to Surface Waters"<sup>1</sup>. The City of London currently uses 2010 as its typical year of rainfall. The 2010 rainfall data set is used in City of London InfoWorks ICM hydraulic models to assess F-5-5 analysis and was used to assess the City's collection system through the previous Pollution Prevention Control Plan (PPCP). Due to changing precipitation patterns (rainfall frequency, intensity, and volume) in the City over time, the historic rainfall recorded in 2010 may no longer be considered "typical" and representative of current annual precipitation conditions.

The City of London has identified the need to review the current 20-year period of rainfall records to complete a review and to identify a new typical year of rainfall, in order to update the City of London's PPCP. This updated typical year of rainfall will be used to assess the City's wastewater system, to demonstrate that it meets the requirements of minimum overflow controls set out by the Ministry of the Environment, Conservation, and Parks (MECP) Procedure F-5-5.

### 1.1 Aims and Objectives

The aim of this analysis is to identify a representative typical or average year by reviewing the long-term rainfall record in a comprehensive and statistically detailed manner, considering recent years of rainfall data since the previous typical year selection.

To achieve this aim, the following key objectives have been identified:

- Review long-term rainfall data for a 20+ year period (2000 to 2023);
- Determine statistically "typical" rainfall year based on key metrics including average annual rainfall depth (volume), number of discrete rainfall events (frequency), and average peak intensity (intensity); and,
- Re-run hydraulic model using new typical year rainfall series (if it differs from current year).

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<sup>1</sup> <https://www.ontario.ca/page/f-5-5-determination-treatment-requirements-municipal-and-private-combined>

## 2. Typical Year Rainfall Analysis

### 2.1 Background

The typical year rainfall approach is used to evaluate CSO and SSO discharges as per the Ministry of the Environment, Conservation, and Parks Procedure F-5-5. The Ontario's regulation defines an "average year" as:

- Long-term average of flow based on at least twenty years of rainfall data; and/or,
- A year in which rainfall intensity, volume, and frequency are consistent with long-term mean of the area; and/or,
- A year in which rainfall runoff rate, volume, and frequency is consistent with long-term mean of the area.

### 2.2 Data Source

Historical rainfall data was provided by the City of London from nine (9) rain gauges within the City of London. The locations of the rain gauges are shown in **Figure 1**. The data was provided in a 5-minute interval for all years, except for year 2023 where the data was provided at an hourly time step. **Table 1** provides a summary of all rain gauges' location and period of data collection. Data was then reviewed and underwent a QA/QC review to identify and resolve data gaps before importing the data into GM BluePlan's in-house Rainfall Analyzer. Refer to **Section 2.3** below for more details on the Rainfall Analyzer.

Table 1: City of London Precipitation Stations (2000 to 2023)

| Rain Gauge                   | Address                 | Start of Date | End of Date |
|------------------------------|-------------------------|---------------|-------------|
| A. J. Tyler Operation Centre | 665 Bathurst Street     | 10/25/2011    | 6/14/2023   |
| Lambeth Arena                | 7112 Beattie Street     | 3/3/2009      | 6/15/2023   |
| London Public Library        | 2016 Dundas St          | 1/1/2002      | 6/15/2023   |
| Medway Arena                 | 1045 Wonderland Road N. | 11/7/2000     | 6/15/2023   |
| Northridge Community Pool    | 15 McLean Drive         | 3/1/2003      | 6/15/2023   |
| Oxford WWTP                  | 1570 Oxford Street W.   | 7/5/2000      | 6/15/2023   |
| South crest Community Pool   | 10 Hazelwood Avenue     | 11/1/2011     | 6/15/2023   |
| Ecole Saint jean de Brebeuf  | 270 Chelton Road        | 11/1/2011     | 6/15/2023   |
| Former Westminster WWTP      | 3225 Dingman Drive      | 1/1/2000      | 6/15/2023   |

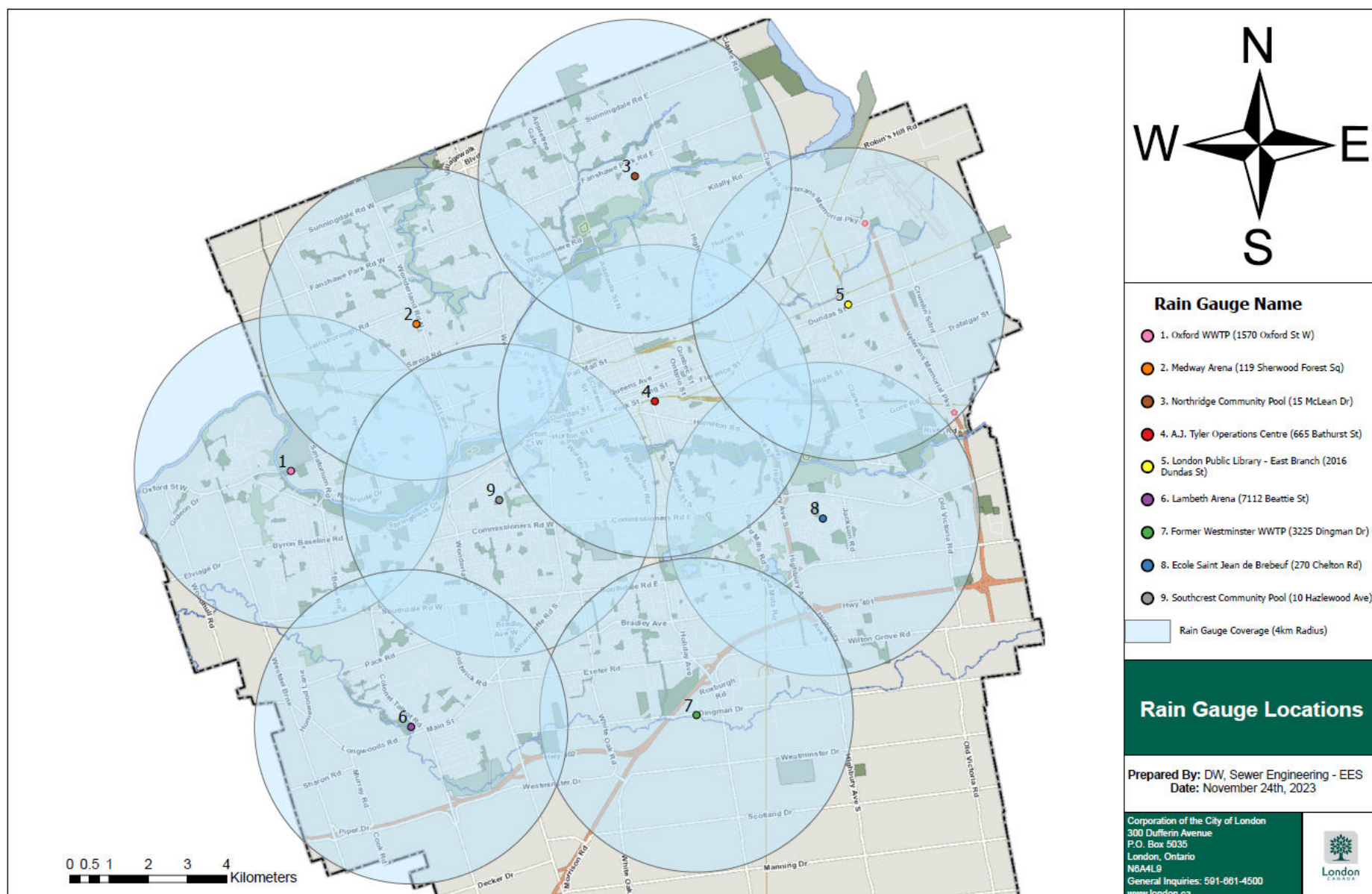


Figure 1: Rain Gauge Locations

## 2.3 Analysis Methodology

The full 22-year period (2001 to 2022) was selected as the long-term rainfall period for analysis. This period includes enough annual rainfall data to derive a typical year which is representative of the entire period.

The rainfall data was processed through GM BluePlan's Wastewater Inflow & Infiltration Flow Analysis Tool (WiiFAT) Rainfall Analyzer, which discretized individual rainfall events for each rain gauge. Once the 5-minute rainfall data was run through the WiiFAT Rainfall Analyzer, key metrics were generated for each rain gauge, for each year of rainfall, over the entire 20+ year period. A threshold of 5mm minimum rainfall depth was used to identify rainfall events, in order to minimize noise in the raw data. The use of this criterion is a common industry practice for evaluating rainfall events' effect on sanitary sewer systems, as noted in the Waste Water Planning Users Group (WaPUG) User Note No 6<sup>2</sup>.

Per F-5-5 guidelines, only the April to November period of the typical year of rainfall is used for analysis; therefore, the following analysis is limited to the period spanning April to November of each year when calculating number of events, total rainfall depth, etc.

The methodology to selecting a typical year of rainfall is as follows:

- The typical year should closely match the average number of rainfall events per year for the 22-year period;
- The typical year should closely match the average total annual rainfall depth for the 22-year period; and,
- The typical year should show a maximum peak rainfall intensity (5-minute and 1-hour) which is closely matched with the average of all maximum peak rainfall intensities for all years over the 22-year period.

### 2.3.1 Rain Gauge Selection

All rain gauges were first processed and analyzed to define all discrete rainfall events. A spatial analysis was completed to assess if there were any rainfall trends, in terms of volume or intensity across the City. A summary of the gauge data, by year is provided in **Appendix A**. Whilst there was significant variation in annual rainfall totals between rain gauges, there was no notable trend in spatial variation of total annual rainfall volume across the catchment. The **Oxford WWTP** rain gauge was ultimately chosen as the only rain gauge to be used for rainfall analysis over the analysis period for the following reasons:

1. The Oxford WWTP rain gauge had the most complete data coverage of all rain gauges throughout the 22-year period.

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[https://www.ciwem.org/assets/pdf/Special%20Interest%20Groups/Urban%20Drainage%20Group/WAPUG\\_User\\_Note\\_06.pdf](https://www.ciwem.org/assets/pdf/Special%20Interest%20Groups/Urban%20Drainage%20Group/WAPUG_User_Note_06.pdf)

2. A review of rainfall metrics, considering the number of events and total depth across all rain gauges, indicated that the Oxford gauge data is representative. Some spatial variation was observed among rain gauges located within the city boundaries, as shown in **Appendix A**.

Additionally, it is worth noting that the Oxford WWTP rain gauge was used to select the previous typical year of rainfall (2010), allowing for a more consistent approach to the F-5-5 analysis and system assessment.

A comprehensive analysis was undertaken for data collected at the Oxford WWTP rain gauge to determine the most typical, representative year of rainfall for the entire dataset.

The total number of rainfall events and total depth of rainfall for each year were compared to the averages. The standard deviation was calculated for both parameters to evaluate closeness of each year to the averages (qualifying years were within  $\pm 1$  standard deviation from both the average number of rainfall events and average total annual depth).

Additional statistics were calculated for analysis including:

- Maximum 1-hr peak intensity for all events in a given year
- Maximum 5-min peak intensity for all events in a given year

**Table 2** below summarizes the typical year rainfall statistical analysis for Oxford PCP rain gauge.

*Table 2: Annual Rainfall Analysis Table (April to November only)*

| Year | Rain Gauge  | Total Rainfall Depth (mm) | # Of Rainfall Events | Max of Peak 1-Hour Intensity (mm/hr) | Max of Peak 5-minute Intensity (mm/hr) |
|------|-------------|---------------------------|----------------------|--------------------------------------|----------------------------------------|
| 2001 | Oxford WWTP | 540                       | 50                   | 15                                   | 69                                     |
| 2002 | Oxford WWTP | 333                       | 43                   | 1                                    | 60                                     |
| 2003 | Oxford WWTP | 529                       | 53                   | 14                                   | 93                                     |
| 2004 | Oxford WWTP | 543                       | 50                   | 21                                   | 78                                     |
| 2005 | Oxford WWTP | 414                       | 41                   | 30                                   | 102                                    |
| 2006 | Oxford WWTP | 698                       | 52                   | 20                                   | 60                                     |
| 2007 | Oxford WWTP | 263                       | 46                   | 21                                   | 60                                     |
| 2008 | Oxford WWTP | 611                       | 59                   | 16                                   | 81                                     |
| 2009 | Oxford WWTP | 620                       | 51                   | 40                                   | 96                                     |
| 2010 | Oxford WWTP | 543                       | 50                   | 21                                   | 126                                    |
| 2011 | Oxford WWTP | 714                       | 51                   | 44                                   | 111                                    |

| Year | Rain Gauge  | Total Rainfall Depth (mm) | # Of Rainfall Events | Max of Peak 1-Hour Intensity (mm/hr) | Max of Peak 5-minute Intensity (mm/hr) |
|------|-------------|---------------------------|----------------------|--------------------------------------|----------------------------------------|
| 2012 | Oxford WWTP | 517                       | 50                   | 23                                   | 102                                    |
| 2013 | Oxford WWTP | 756                       | 56                   | 35                                   | 111                                    |
| 2014 | Oxford WWTP | 613                       | 49                   | 43                                   | 72                                     |
| 2015 | Oxford WWTP | 634                       | 55                   | 67                                   | 114                                    |
| 2016 | Oxford WWTP | 490                       | 46                   | 30                                   | 93                                     |
| 2017 | Oxford WWTP | 575                       | 54                   | 23                                   | 99                                     |
| 2018 | Oxford WWTP | 611                       | 51                   | 26                                   | 90                                     |
| 2019 | Oxford WWTP | 656                       | 60                   | 20                                   | 141                                    |
| 2020 | Oxford WWTP | 516                       | 52                   | 20                                   | 84                                     |
| 2021 | Oxford WWTP | 438                       | 30                   | 29                                   | 105                                    |
| 2022 | Oxford WWTP | 460                       | 50                   | 32                                   | 81                                     |

### 3. Results

#### 3.1 Analysis Results

The average annual total precipitation depth for all rainfall events over the 22-year period was 549 mm, with an average of 50 rainfall events per year for the 2001 to 2022 period using data from April up until November.

Based on the annual rainfall depth statistical analysis, there are several years which are considered a good representation for the typical year rainfall which are: 2001, 2003, 2004, 2010, 2012, 2014, 2017, 2018. The long-term trend shows a slightly increasing volume trend. Because of this it was decided that a year more recent would be preferable and representative of a typical year. As such the following is the shortlist of years based on rainfall depth (volume): 2014, 2017, 2018.

Annual rainfall depth totals per year are shown in **Figure 2**.

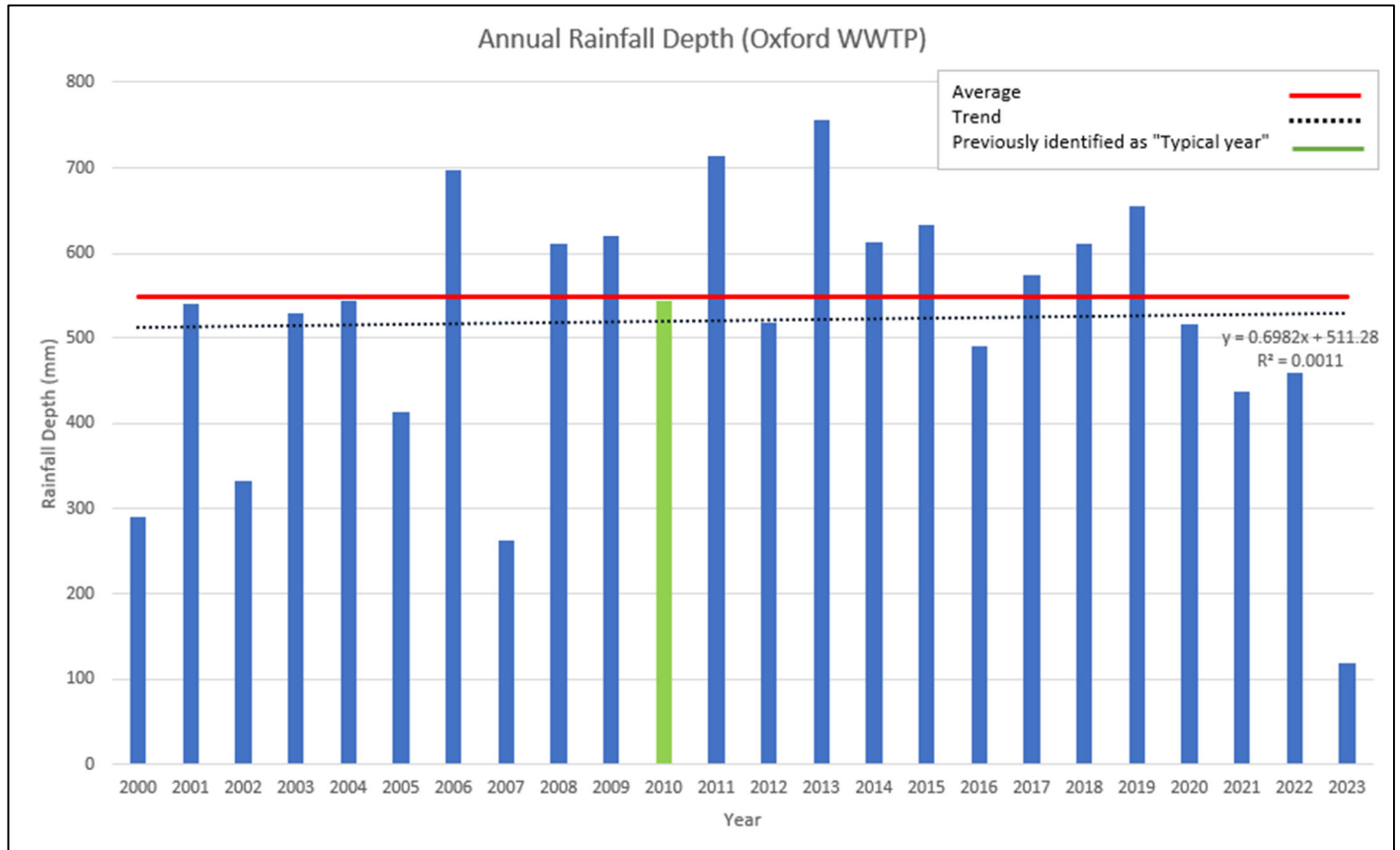


Figure 2: Annual Rainfall Depth

The next analysis criteria was the annual max peak 1-hour intensity. **Figure 3** below suggests that the trendline has been generally increasing throughout the years. Based on the max peak 1-hour intensity, year 2016, 2018, and 2021 were considered a good representation of a typical year rainfall. Looking at the past ten years, 2016, 2018, and 2021 are the closest to the average annual max peak intensity.

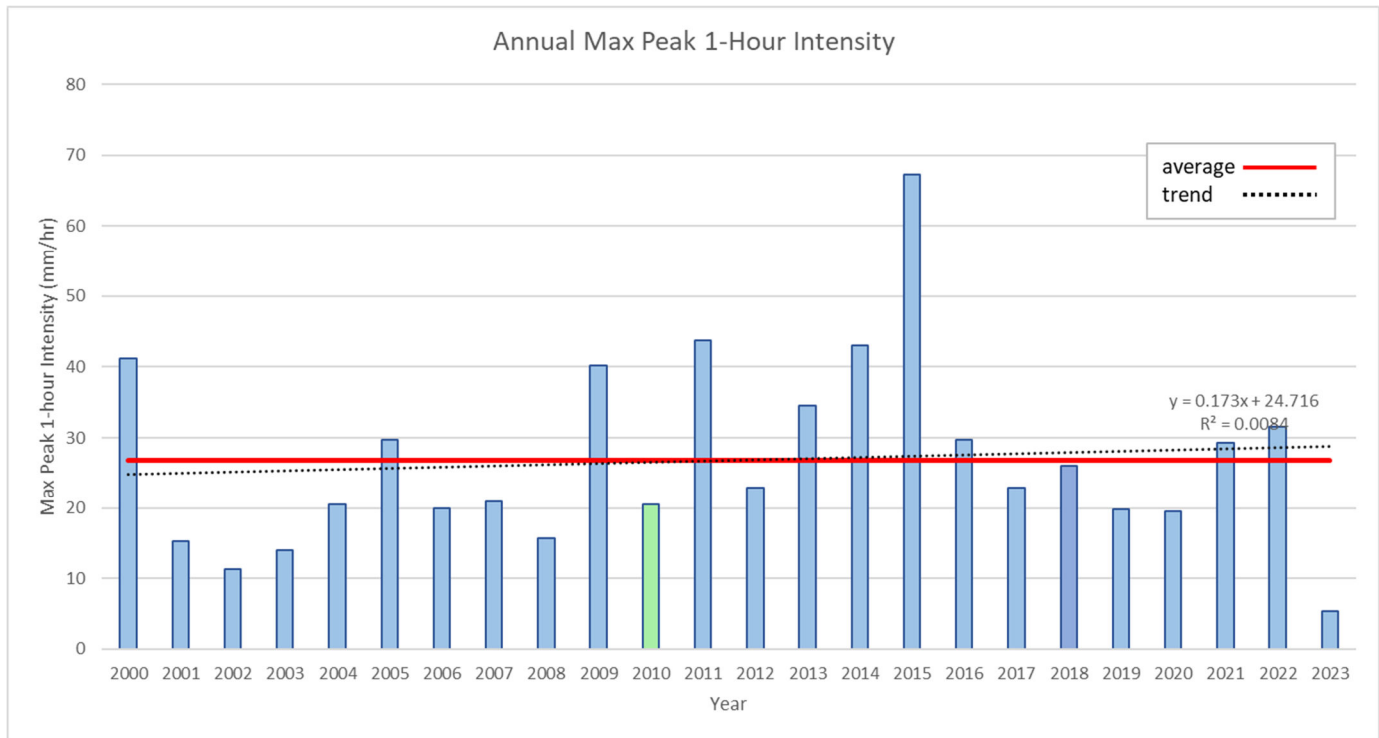


Figure 3: Annual Max Peak 1-Hour Intensity

The next criteria in the rainfall evaluation was to assess the rainfall intensity at the Oxford PCP rain gauge by year, by assessing the exceedance frequency for each selected intensity all rainfall events per year. This method helps understand the range of rainfall event intensities that occur during a given year. The analysis assessed the average number of events within the following peak 1-hour intensity ranges and then ranked the results for each range and then overall:

- # events over 5mm/hr
- # events over 10mm/hr
- # events over 15mm/hr
- # events over 20mm/hr

To capture more recent trends after the last PPCP study was conducted, the analysis was completed on year 2010 to 2022 using all intensity ranges mentioned above. Full table of results is provided in **Appendix A**.

This analysis ensures that a year is selected that has a typical range of event intensities. 2018 had the most typical number of events for every intensity range and therefore ranked #1 overall as well. The graph below **Figure 4** shows graphically how intensity ranges change for each year (2014 to 2021) and how some years, such as 2014 and 2015 have one very high intensity event with the next event much lower – this type of pattern is not typical. (note: the full data set was not graphed to maintain clarity).

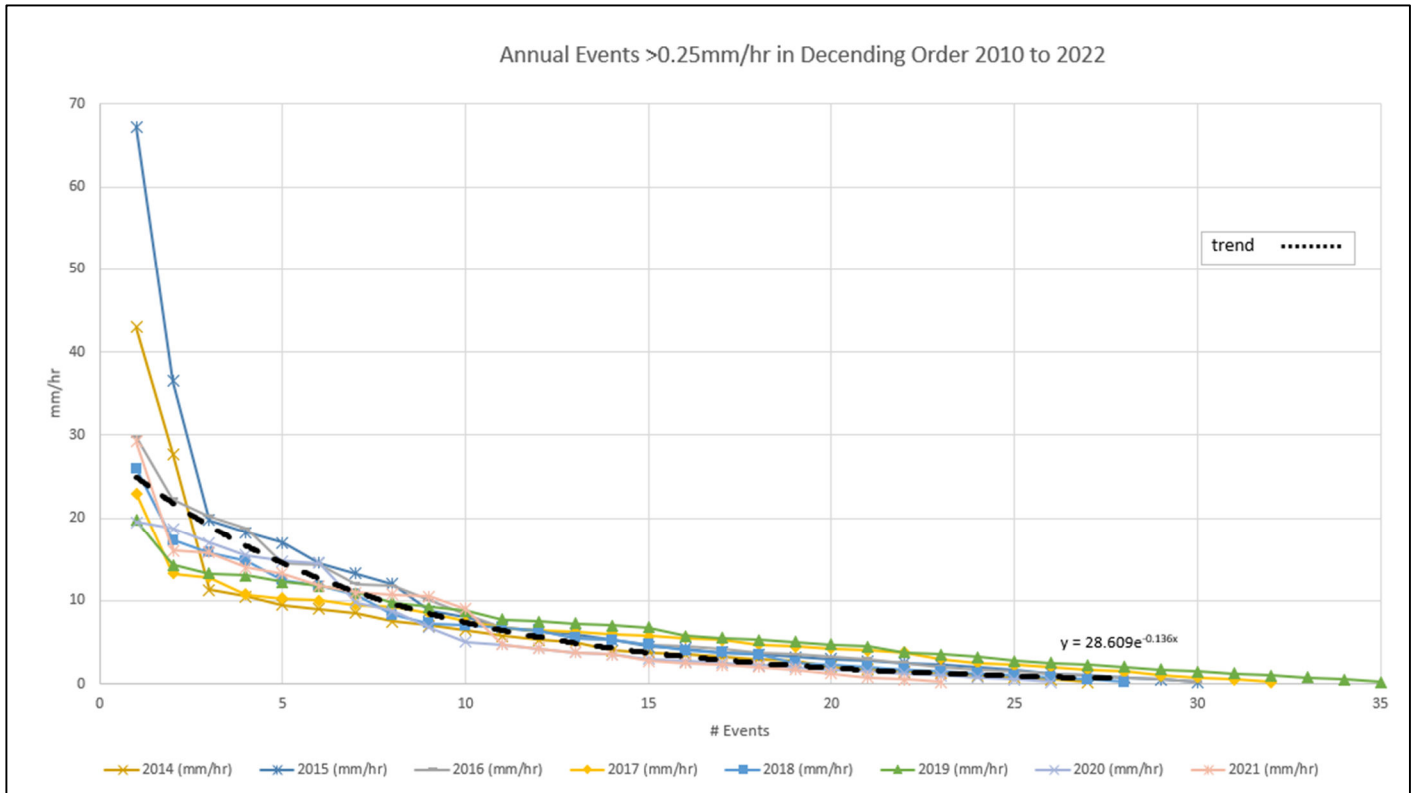


Figure 4: Annual Events Based on Intensity and Event Count

### 3.2 Peak Event Return Period

The highest return period events in 2018 was calculated using the City of London IDF curve. The two highest intensity events captured in 2018 are shown in **Figure 5** and **Table 3**.

Table 3: Peak Event Return Period using the City IDF Curve

| Event Date | Event Start   | Event End     | Total Duration (hh:mm) | Total Volume (mm) | Max 3-Hr Volume (mm) | Peak 5-min Intensity (mm/h) | Return Period |
|------------|---------------|---------------|------------------------|-------------------|----------------------|-----------------------------|---------------|
| 5-Jul-18   | 7/5/18 13:05  | 7/5/18 19:10  | 6:05                   | 29                | 26.75                | 90                          | 2 Year        |
| 16-Jul-18  | 7/16/18 15:25 | 7/16/18 19:00 | 3:35                   | 26                | 24.25                | 81                          | < 2 Year      |

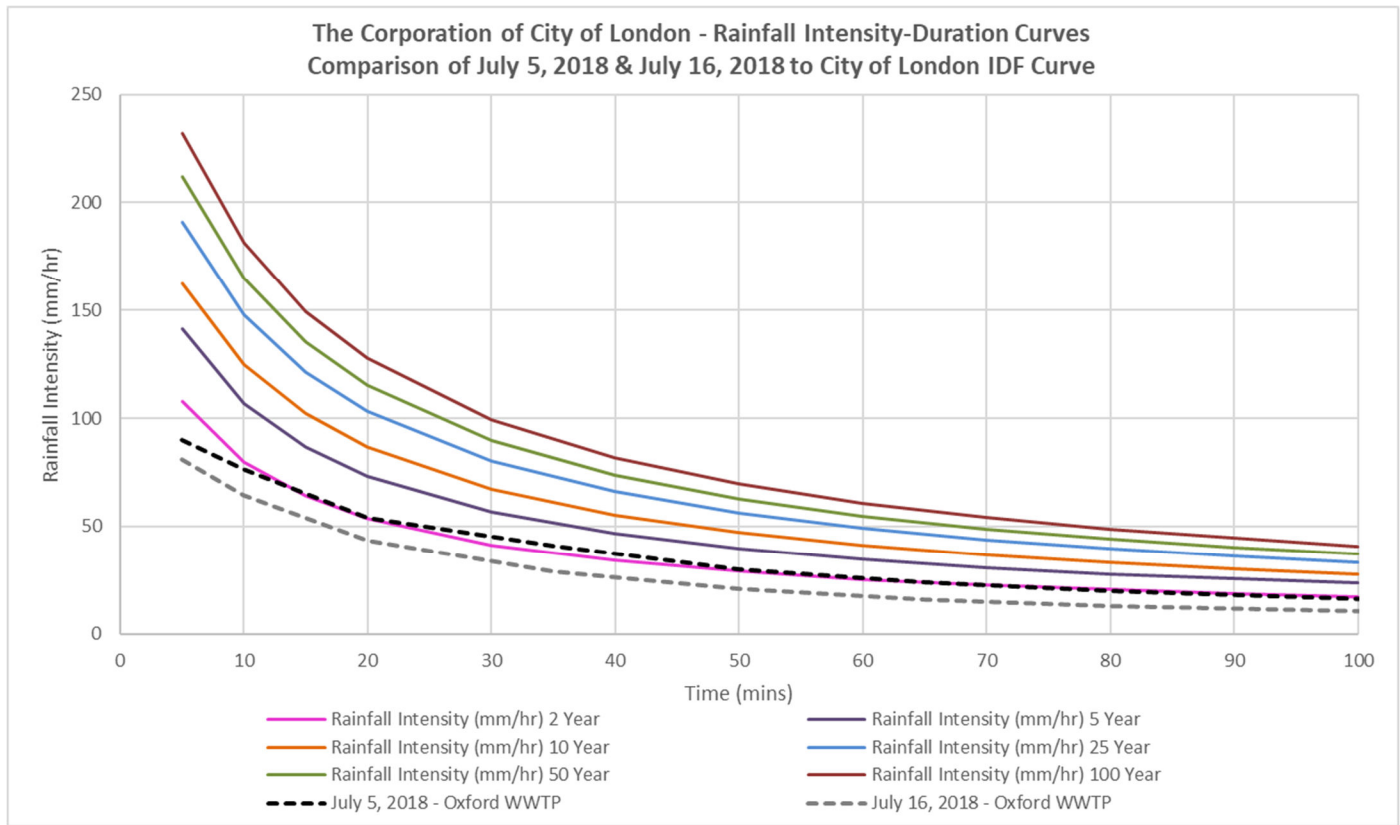


Figure 5: 2018 Return Period IDF

As an additional analysis, the return period was also calculated using the Bilham formula (as modified by Holland, 1967):  $X = t(0.0394R)^n$ . The results are shown in **Table 4**.

Table 4: Peak Event Return Period using the Bilham Formula

| Event Date | Event Start   | Event End     | Total Duration (hh:mm) | Total Volume (mm) | Max 3-Hr Volume (mm) | Peak 5-min Intensity (mm/h) | Return Period  |
|------------|---------------|---------------|------------------------|-------------------|----------------------|-----------------------------|----------------|
| 5-Jul-18   | 7/5/18 13:05  | 7/5/18 19:10  | 6:05                   | 29                | 26.75                | 90                          | 1 in 2.53 Year |
| 16-Jul-18  | 7/16/18 15:25 | 7/16/18 19:00 | 3:35                   | 26                | 24.25                | 81                          | 1 in 2.95 Year |

#### 4. Conclusion & Recommendation

Based on the results of this typical year rainfall assessment, 2018 is considered the average year rainfall: In summary:

- The 2018 year closely matches the average number of rainfall events per year for the 22-year period;
- The 2018 year closely matches the average total annual rainfall depth for the 22-year period;
- The 2018 year showed average peak rainfall intensities (5-minute and 1-hour) which were closely matched with the average of all peak rainfall intensities for all years over the 22-year period.
- The 2018 year had the most typical rainfall events by intensity ranges.

The average year rainfall data will serve as the basis for evaluating system performance through ongoing simulations using the InfoWorks ICM hydraulic model.

It is noted that modelled overflows statistics will likely change with the adoption of a new typical year of rainfall. These changes are expected and can occur for a variety of reasons as outlined below:

- The modelled (predicted) overflows for a given typical year are heavily dependent on that year's individual rainfall event characteristics.
- Certain overflow facilities may not be activated by small rainfall events (number of rainfall events may not be proportional to number of overflows).
- Certain overflow facilities may show discharge volumes which are disproportionately caused by a significant rainfall event (e.g., 50% of the total annual discharge volume being the result of one rainfall event).
- Because each year of rainfall has such a unique distribution of discrete rainfall events, it is not appropriate to directly compare modelled overflow discharges from the 2010 year of rainfall with those from the 2018 year of rainfall; however, 2018 is considered representative of rainfall patterns over the past 20+ years of observed data and as such is recommended to be used to assess overflow frequency and volume in the 2023 PPCP.

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## Appendix A

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## Appendix A: Raingauge Summary by Year and Gauge

| Row Labels      | Sum of Total Depth (mm) | Count of Start of Rain | Sum of Peak 1-Hour Intensity (mm/hr) | Sum of Peak 5-Minute Intensity (mm/hr) |
|-----------------|-------------------------|------------------------|--------------------------------------|----------------------------------------|
| <b>2001</b>     | <b>1757.5</b>           | <b>143</b>             | <b>569.25</b>                        | <b>2394</b>                            |
| Argyle Arena    | 594.25                  | 47                     | 205.5                                | 879                                    |
| Oxford WWTP     | 540.5                   | 50                     | 167.25                               | 675                                    |
| Westminster PCP | 622.75                  | 46                     | 196.5                                | 840                                    |
| <b>2002</b>     | <b>1410.75</b>          | <b>159</b>             | <b>613.5</b>                         | <b>2658</b>                            |
| Argyle Arena    | 441.25                  | 45                     | 194.5                                | 903                                    |
| MedwayArena     | 100                     | 13                     | 41.5                                 | 183                                    |
| Oxford WWTP     | 332.5                   | 43                     | 146.5                                | 552                                    |
| WestminsterPCP  | 438                     | 44                     | 196.25                               | 867                                    |
| WROC            | 99                      | 14                     | 34.75                                | 153                                    |
| <b>2003</b>     | <b>3752.75</b>          | <b>323</b>             | <b>1530.25</b>                       | <b>5805</b>                            |
| Argyle Arena    | 596.75                  | 54                     | 247.25                               | 1020                                   |
| LondonHydro     | 454.5                   | 38                     | 197.5                                | 738                                    |
| MedwayArena     | 557.5                   | 46                     | 220.25                               | 702                                    |
| NorthridgePool  | 592.25                  | 42                     | 257.25                               | 1365                                   |
| Oxford WWTP     | 528.5                   | 53                     | 207.5                                | 747                                    |
| WestminsterPCP  | 523                     | 44                     | 199                                  | 606                                    |
| WROC            | 500.25                  | 46                     | 201.5                                | 627                                    |
| <b>2004</b>     | <b>4074</b>             | <b>347</b>             | <b>1640</b>                          | <b>6504</b>                            |
| Argyle Arena    | 530.75                  | 51                     | 228                                  | 948                                    |
| LondonHydro     | 600                     | 51                     | 243.5                                | 900                                    |
| MedwayArena     | 654                     | 47                     | 268                                  | 1050                                   |
| NorthridgePool  | 609.25                  | 47                     | 245.25                               | 1005                                   |
| Oxford WWTP     | 543                     | 50                     | 205.5                                | 798                                    |
| WestminsterPCP  | 585                     | 52                     | 225.75                               | 915                                    |
| WROC            | 552                     | 49                     | 224                                  | 888                                    |
| <b>2005</b>     | <b>3021</b>             | <b>280</b>             | <b>1408.5</b>                        | <b>5862</b>                            |
| Argyle Arena    | 442.75                  | 38                     | 205.25                               | 858                                    |
| LondonHydro     | 461.25                  | 36                     | 204.25                               | 855                                    |
| MedwayArena     | 353                     | 33                     | 157                                  | 729                                    |
| NorthridgePool  | 456.75                  | 40                     | 212                                  | 858                                    |
| Oxford WWTP     | 414                     | 41                     | 198.5                                | 849                                    |
| WestminsterPCP  | 508.75                  | 46                     | 244                                  | 951                                    |
| WROC            | 384.5                   | 46                     | 187.5                                | 762                                    |
| <b>2006</b>     | <b>5320.25</b>          | <b>365</b>             | <b>2299.75</b>                       | <b>8103</b>                            |
| Argyle Arena    | 714.25                  | 52                     | 333.25                               | 1245                                   |
| LondonHydro     | 763.25                  | 53                     | 326                                  | 1218                                   |
| MedwayArena     | 795                     | 52                     | 350.75                               | 1146                                   |
| NorthridgePool  | 794.25                  | 52                     | 340.5                                | 1227                                   |
| Oxford WWTP     | 698                     | 52                     | 281.75                               | 891                                    |
| WestminsterPCP  | 836.75                  | 53                     | 340.75                               | 1182                                   |
| WROC            | 718.75                  | 51                     | 326.75                               | 1194                                   |
| <b>2007</b>     | <b>2624.25</b>          | <b>339</b>             | <b>1284</b>                          | <b>4956</b>                            |
| Argyle Arena    | 298.5                   | 44                     | 157.75                               | 597                                    |
| LondonHydro     | 385                     | 42                     | 193.75                               | 771                                    |
| MedwayArena     | 380.25                  | 46                     | 176.25                               | 747                                    |
| NorthridgePool  | 422.75                  | 54                     | 202                                  | 789                                    |
| Oxford WWTP     | 263.25                  | 46                     | 114                                  | 417                                    |
| WestminsterPCP  | 446.25                  | 55                     | 215.75                               | 792                                    |
| WROC            | 428.25                  | 52                     | 224.5                                | 843                                    |
| <b>2008</b>     | <b>4246.75</b>          | <b>372</b>             | <b>1775.25</b>                       | <b>7536</b>                            |
| Argyle Arena    | 480.75                  | 51                     | 202.5                                | 951                                    |
| LondonHydro     | 624                     | 51                     | 254                                  | 1002                                   |
| MedwayArena     | 691.75                  | 57                     | 286                                  | 1248                                   |
| NorthridgePool  | 606.25                  | 53                     | 238.75                               | 1059                                   |
| Oxford WWTP     | 611                     | 59                     | 258                                  | 1119                                   |
| WestminsterPCP  | 624.5                   | 47                     | 257                                  | 1062                                   |
| WROC            | 608.5                   | 54                     | 279                                  | 1095                                   |
| <b>2009</b>     | <b>4321.25</b>          | <b>342</b>             | <b>1931</b>                          | <b>7269</b>                            |
| AquaticCentre   | 708.25                  | 51                     | 315                                  | 1074                                   |
| Argyle Arena    | 470.75                  | 48                     | 215.25                               | 954                                    |
| LambethArena    | 623.5                   | 47                     | 276.25                               | 1107                                   |
| LondonHydro     | 570.25                  | 45                     | 249.25                               | 945                                    |
| NorthridgePool  | 653.75                  | 51                     | 287.5                                | 996                                    |
| Oxford WWTP     | 619.75                  | 51                     | 279.25                               | 1005                                   |
| WestminsterPCP  | 675                     | 49                     | 308.5                                | 1188                                   |
| <b>2010</b>     | <b>4191.25</b>          | <b>365</b>             | <b>2036.25</b>                       | <b>7143</b>                            |
| AquaticCentre   | 650                     | 52                     | 317.25                               | 1056                                   |
| Argyle Arena    | 581                     | 51                     | 305.5                                | 1026                                   |

|                     |                |            |                |                |
|---------------------|----------------|------------|----------------|----------------|
| LambethArena        | 548.25         | 51         | 245.5          | 876            |
| LondonHydro         | 603            | 50         | 295            | 1071           |
| NorthridgePool      | 656.25         | 52         | 326            | 1167           |
| Oxford WWTP         | 542.75         | 50         | 257.5          | 915            |
| WestminsterPCP      | 610            | 59         | 289.5          | 1032           |
| <b>2011</b>         | <b>5356.35</b> | <b>328</b> | <b>2487.79</b> | <b>8478.72</b> |
| AJTylarCentre PPCP  | 6              | 2          | 1.5            | 6              |
| AquaticCentre       | 840            | 45         | 402.75         | 1305           |
| Argyle Arena        | 659.5          | 47         | 308            | 1074           |
| LambethArena        | 777            | 50         | 352            | 1296           |
| LondonHydro         | 726.25         | 39         | 318.75         | 912            |
| NorthridgePool      | 793.4          | 43         | 373.43         | 1232.76        |
| Oxford WWTP         | 714.07         | 51         | 346.56         | 1219.2         |
| StjeandeBrebeu      | 0.25           | 1          | 0.25           | 3              |
| WestminsterPCP      | 839.88         | 50         | 384.55         | 1430.76        |
| <b>2012</b>         | <b>4585.75</b> | <b>423</b> | <b>1688</b>    | <b>5937</b>    |
| AJTylarCentre PPCP  | 507            | 49         | 172            | 576            |
| AquaticCentre       | 545.25         | 47         | 189.25         | 618            |
| Argyle Arena        | 233.75         | 28         | 111.5          | 405            |
| LambethArena        | 586.75         | 49         | 224.75         | 759            |
| NorthridgePool      | 551.25         | 48         | 204            | 723            |
| Oxford WWTP         | 517.25         | 50         | 180.5          | 741            |
| SouthcrestPool PPCP | 556.75         | 51         | 200.5          | 762            |
| StjeandeBrebeu      | 533            | 51         | 193            | 681            |
| WestminsterPCP      | 554.75         | 50         | 212.5          | 672            |
| <b>2013</b>         | <b>6850</b>    | <b>440</b> | <b>2615.25</b> | <b>9525</b>    |
| AJTylarCentre PPCP  | 889.5          | 56         | 346.5          | 1296           |
| AquaticCentre       | 863            | 55         | 314.5          | 1149           |
| Argyle Arena        | 830.75         | 55         | 322.75         | 1179           |
| LambethArena        | 864.75         | 55         | 349.25         | 1296           |
| NorthridgePool      | 974.5          | 53         | 355.5          | 1383           |
| Oxford WWTP         | 755.75         | 56         | 278            | 957            |
| SouthcrestPool PPCP | 847            | 56         | 319.25         | 1110           |
| StjeandeBrebeu      | 824.75         | 54         | 329.5          | 1155           |
| <b>2014</b>         | <b>6231.75</b> | <b>450</b> | <b>2778.25</b> | <b>9954</b>    |
| AJTylarCentre PPCP  | 715.75         | 54         | 315            | 1092           |
| AquaticCentre       | 664            | 48         | 284            | 1059           |
| Argyle Arena        | 659.25         | 51         | 286.25         | 987            |
| LambethArena        | 718            | 48         | 311            | 1212           |
| NorthridgePool      | 748.5          | 55         | 326.5          | 1218           |
| Oxford WWTP         | 612.5          | 49         | 259            | 903            |
| SouthcrestPool PPCP | 713.75         | 49         | 324            | 1101           |
| StjeandeBrebeu      | 662.5          | 50         | 318.25         | 1116           |
| WestminsterPCP      | 737.5          | 46         | 354.25         | 1266           |
| <b>2015</b>         | <b>5895.5</b>  | <b>476</b> | <b>2888.5</b>  | <b>9651</b>    |
| AJTylarCentre PPCP  | 620.25         | 52         | 309.75         | 972            |
| AquaticCentre       | 591.5          | 51         | 270            | 918            |
| Argyle Arena        | 546.75         | 50         | 263.75         | 807            |
| LambethArena        | 724            | 54         | 360.5          | 1347           |
| NorthridgePool      | 620.75         | 53         | 291.75         | 1137           |
| Oxford WWTP         | 633.75         | 55         | 327.5          | 957            |
| SouthcrestPool PPCP | 747            | 53         | 361.25         | 1191           |
| StjeandeBrebeu      | 672.5          | 55         | 305.5          | 1086           |
| WestminsterPCP      | 739            | 53         | 398.5          | 1236           |
| <b>2016</b>         | <b>4738.5</b>  | <b>407</b> | <b>2313.75</b> | <b>8583</b>    |
| AJTylarCentre PPCP  | 550.5          | 44         | 268.75         | 978            |
| AquaticCentre       | 568.25         | 49         | 255.25         | 930            |
| Argyle Arena        | 458.75         | 44         | 228.75         | 912            |
| LambethArena        | 453.5          | 40         | 218.5          | 744            |
| NorthridgePool      | 587.25         | 44         | 248.5          | 906            |
| Oxford WWTP         | 489.75         | 46         | 248.75         | 918            |
| SouthcrestPool PPCP | 621.25         | 46         | 314.5          | 1047           |
| StjeandeBrebeu      | 489            | 47         | 251.75         | 1050           |
| WestminsterPCP      | 520.25         | 47         | 279            | 1098           |
| <b>2017</b>         | <b>5434.5</b>  | <b>449</b> | <b>2267.5</b>  | <b>9357</b>    |
| AJTylarCentre PPCP  | 629.5          | 52         | 268            | 1191           |
| AquaticCentre       | 502.5          | 46         | 210.75         | 903            |
| Argyle Arena        | 585.75         | 48         | 221            | 936            |
| LambethArena        | 636.25         | 54         | 259            | 1101           |
| NorthridgePool      | 566.25         | 41         | 237            | 948            |
| Oxford WWTP         | 574.75         | 54         | 243            | 1041           |
| SouthcrestPool PPCP | 642            | 52         | 272            | 1056           |
| StjeandeBrebeu      | 666.75         | 50         | 284.25         | 1080           |

|                     |                  |             |                 |                  |
|---------------------|------------------|-------------|-----------------|------------------|
| WestminsterPCP      | 630.75           | 52          | 272.5           | 1101             |
| <b>2018</b>         | <b>6063.75</b>   | <b>457</b>  | <b>2370</b>     | <b>9759</b>      |
| AJTylarCentre PPCP  | 630.5            | 50          | 242.75          | 903              |
| DundasLibrary       | 723.25           | 50          | 289.25          | 1506             |
| LambethArena        | 655.25           | 52          | 244.25          | 963              |
| MedwayArena         | 711.5            | 50          | 305.25          | 1059             |
| NorthridgePool      | 748              | 50          | 307.5           | 1203             |
| Oxford WWTP         | 610.75           | 51          | 243.25          | 990              |
| SouthcrestPool PPCP | 705.5            | 50          | 273             | 1143             |
| StjeandeBrebeu      | 628.5            | 52          | 230.25          | 975              |
| WestminsterPCP      | 650.5            | 52          | 234.5           | 1017             |
| <b>2019</b>         | <b>6232.5</b>    | <b>547</b>  | <b>2683.25</b>  | <b>10956</b>     |
| AJTylarCentre PPCP  | 692.25           | 64          | 289.25          | 1098             |
| DundasLibrary       | 770.5            | 64          | 325             | 1545             |
| LambethArena        | 761.75           | 66          | 348.5           | 1287             |
| MedwayArena         | 733.25           | 59          | 294.5           | 1197             |
| NorthridgePool      | 744              | 55          | 297.75          | 1296             |
| Oxford WWTP         | 655.5            | 60          | 290.75          | 1290             |
| SouthcrestPool PPCP | 628.25           | 57          | 292             | 1113             |
| StjeandeBrebeu      | 541              | 58          | 235.75          | 927              |
| WestminsterPCP      | 706              | 64          | 309.75          | 1203             |
| <b>2020</b>         | <b>4686.75</b>   | <b>412</b>  | <b>2242.25</b>  | <b>7770</b>      |
| AJTylarCentre PPCP  | 613.5            | 50          | 303.25          | 1143             |
| DundasLibrary       | 594.5            | 48          | 283             | 963              |
| LambethArena        | 622              | 51          | 306.25          | 1086             |
| MedwayArena         | 467              | 49          | 215.25          | 780              |
| NorthridgePool      | 176.25           | 21          | 96              | 384              |
| Oxford WWTP         | 515.75           | 52          | 213.25          | 786              |
| SouthcrestPool PPCP | 644.5            | 49          | 298             | 966              |
| StjeandeBrebeu      | 598              | 48          | 296             | 891              |
| WestminsterPCP      | 455.25           | 44          | 231.25          | 771              |
| <b>2021</b>         | <b>6228.5</b>    | <b>414</b>  | <b>2708.5</b>   | <b>11055</b>     |
| AJTylarCentre PPCP  | 808              | 52          | 353.75          | 1449             |
| DundasLibrary       | 837.75           | 58          | 388.5           | 1827             |
| LambethArena        | 811.75           | 56          | 343             | 1248             |
| MedwayArena         | 768.25           | 52          | 345.5           | 1413             |
| NorthridgePool      | 438.75           | 23          | 185             | 669              |
| Oxford WWTP         | 437.5            | 30          | 184.25          | 768              |
| SouthcrestPool PPCP | 810              | 57          | 336.75          | 1305             |
| StjeandeBrebeu      | 784.25           | 56          | 344             | 1374             |
| WestminsterPCP      | 532.25           | 30          | 227.75          | 1002             |
| <b>2022</b>         | <b>4037.82</b>   | <b>430</b>  | <b>2028.14</b>  | <b>9136.8</b>    |
| AJTylarCentre PPCP  | 373.46           | 41          | 185.41          | 840.24           |
| DundasLibrary       | 485.66           | 55          | 277.02          | 1430.04          |
| LambethArena        | 447.23           | 50          | 199.39          | 762.96           |
| MedwayArena         | 478.47           | 48          | 238.56          | 1064.04          |
| NorthridgePool      | 471.97           | 41          | 249.55          | 1016.28          |
| Oxford WWTP         | 459.67           | 50          | 234.59          | 934.92           |
| SouthcrestPool PPCP | 484.44           | 50          | 244.44          | 1340.88          |
| StjeandeBrebeu      | 394.71           | 48          | 192.59          | 780.72           |
| WestminsterPCP      | 442.21           | 47          | 206.59          | 966.72           |
| <b>Grand Total</b>  | <b>101061.42</b> | <b>8268</b> | <b>44158.93</b> | <b>168392.52</b> |

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## Appendix B

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Appendix B: Rainfall Event Intensities by Year with Intensity Range Rankings

| Year/Event                     | 2010 (mm/hr) | 2011 (mm/hr) | 2012 (mm/hr) | 2013 (mm/hr) | 2014 (mm/hr) | 2015 (mm/hr) | 2016 (mm/hr) | 2017 (mm/hr) | 2018 (mm/hr) | 2019 (mm/hr) | 2020 (mm/hr) | 2021 (mm/hr) | 2022 (mm/hr) |
|--------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|                                | 20.5         | 43.75        | 23           | 34.5         | 43           | 67.25        | 29.75        | 23           | 26           | 19.75        | 19.5         | 29.25        | 31.5         |
|                                | 19.25        | 34.5         | 9.75         | 24.5         | 27.75        | 36.5         | 22.25        | 13.25        | 17.25        | 14.25        | 18.75        | 16           | 14.25        |
|                                | 19           | 25           | 9            | 18.25        | 11.25        | 19.75        | 20.25        | 12.75        | 15.75        | 13.25        | 17           | 15.75        | 13           |
|                                | 18.75        | 23           | 8.25         | 17.75        | 10.5         | 18.25        | 18.75        | 10.75        | 14.75        | 13           | 15.5         | 14           | 12.75        |
|                                | 18.5         | 19.75        | 8            | 15.25        | 9.5          | 17           | 14.5         | 10.25        | 12.5         | 12.25        | 14.75        | 13.25        | 11.75        |
|                                | 12           | 15           | 7.75         | 14.75        | 9            | 14.5         | 14.25        | 10           | 11.75        | 11.75        | 14.5         | 11.75        | 11.68        |
|                                | 11.5         | 14           | 7.25         | 14.5         | 8.5          | 13.25        | 12           | 9.5          | 10.75        | 11           | 9.75         | 11           | 8.75         |
|                                | 9.75         | 12.75        | 6.75         | 14           | 7.5          | 12           | 11.75        | 9.25         | 8.25         | 9.75         | 8.75         | 10.75        | 8.25         |
|                                | 9.5          | 12.5         | 6.5          | 9.75         | 7            | 8.75         | 10           | 8.5          | 7.25         | 9.25         | 6.75         | 10.5         | 7.63         |
|                                | 8            | 10.66        | 6.25         | 8.25         | 6.5          | 8            | 8.25         | 7.5          | 7            | 8.75         | 5            | 9            | 7.61         |
|                                | 7            | 9.5          | 6            | 7.5          | 5.75         | 6.75         | 6.75         | 6.75         | 6.75         | 7.75         | 4.75         | 4.75         | 7.5          |
|                                | 6.5          | 9.25         | 5.25         | 6.5          | 5.25         | 6.25         | 6.5          | 6.5          | 6.5          | 7.5          | 4.25         | 4.25         | 7.25         |
|                                | 6.25         | 9.13         | 4.75         | 6            | 5            | 6            | 5.5          | 6.25         | 5.5          | 7.25         | 3.75         | 3.75         | 5.75         |
|                                | 6            | 7.5          | 4.5          | 5.5          | 4            | 5.25         | 5.25         | 6            | 5.25         | 7            | 3.5          | 3.5          | 5.25         |
|                                | 5.75         | 6.75         | 3.75         | 4.5          | 3.75         | 4.5          | 4.75         | 5.75         | 4.75         | 6.75         | 3            | 2.75         | 5            |
|                                | 5            | 6.5          | 3.25         | 4            | 3.5          | 4.25         | 4.5          | 5.5          | 4            | 5.75         | 2.75         | 2.5          | 4.31         |
|                                | 4.25         | 6.25         | 3            | 3.75         | 3.25         | 3.75         | 4.25         | 5.25         | 3.75         | 5.5          | 2.5          | 2.25         | 4.25         |
|                                | 4            | 6            | 2.75         | 3.5          | 3            | 3.5          | 3.75         | 4.75         | 3.5          | 5.25         | 2.25         | 2            | 3.75         |
|                                | 3.5          | 5.75         | 2.5          | 3.25         | 2.75         | 3.25         | 3.5          | 4.5          | 2.5          | 5            | 2            | 1.75         | 3.28         |
|                                | 3            | 5.5          | 2.25         | 3            | 2            | 3            | 3.25         | 4.25         | 2.25         | 4.75         | 1.75         | 1.25         | 3.25         |
|                                | 2.75         | 5.25         | 2            | 2.5          | 1.75         | 2.75         | 3            | 4            | 2            | 4.5          | 1.5          | 0.75         | 3.04         |
|                                | 2.25         | 5            | 1.75         | 2.25         | 1.5          | 2.5          | 2.5          | 3.75         | 1.75         | 3.75         | 1.25         | 0.5          | 3.03         |
|                                | 2            | 3.75         | 1.5          | 2            | 1.25         | 2.25         | 2            | 3            | 1.5          | 3.5          | 1            | 0.25         | 3            |
|                                | 1.75         | 3.5          | 1.25         | 1.75         | 1            | 2            | 1.75         | 2.5          | 1.25         | 3.25         | 0.75         |              | 2.75         |
|                                | 1.5          | 3            | 1            | 1.5          | 0.75         | 1.75         | 1.5          | 2.25         | 1            | 2.75         | 0.5          |              | 2.25         |
|                                | 1.25         | 2.52         | 0.75         | 1.25         | 0.5          | 1.25         | 1.25         | 2            | 0.75         | 2.5          | 0.25         |              | 2            |
|                                | 1            | 2            | 0.5          | 1            | 0.25         | 1            | 1            | 1.75         | 0.5          | 2.25         |              |              | 1.75         |
|                                | 0.75         | 1.75         | 0.25         | 0.75         |              | 0.75         | 0.75         | 1.5          | 0.25         | 2            |              |              | 1.5          |
|                                | 0.5          | 1.5          |              | 0.5          |              | 0.5          | 0.5          | 1            |              | 1.75         |              |              | 1.26         |
|                                | 0.25         | 1.25         |              | 0.25         |              | 0.25         | 0.25         | 0.75         |              | 1.5          |              |              | 1.25         |
|                                |              | 1            |              |              |              |              |              | 0.5          |              | 1.25         |              |              | 1            |
|                                |              | 0.75         |              |              |              |              |              | 0.25         |              | 1            |              |              | 0.75         |
|                                |              | 0.5          |              |              |              |              |              |              |              | 0.75         |              |              | 0.5          |
|                                |              | 0.25         |              |              |              |              |              |              |              | 0.5          |              |              | 0.25         |
|                                |              |              |              |              |              |              |              |              |              | 0.25         |              |              |              |
|                                |              |              |              |              |              |              |              |              |              |              |              |              |              |
| AVERAGES                       |              |              |              |              |              |              |              |              |              |              |              |              |              |
| # events over 5mm/hr           | 15           | 21           | 12           | 14           | 12           | 14           | 14           | 17           | 14           | 18           | 9            | 10           | 14           |
| # events over 10mm/hr          | 7            | 10           | 1            | 8            | 4            | 8            | 8            | 5            | 7            | 7            | 6            | 9            | 6            |
| # events over 15mm/hr          | 5            | 5            | 2            | 5            | 2            | 5            | 4            | 1            | 3            | 1            | 4            | 3            | 1            |
| # events over 20mm/hr          | 1            | 4            | 1            | 2            | 2            | 2            | 3            | 1            | 1            | 0            | 0            | 1            | 1            |
|                                |              |              |              |              |              |              |              |              |              |              |              |              |              |
| variation from average 5mm/hr  | 0.85         | 6.85         | 2.15         | 0.15         | 2.15         | 0.15         | 0.15         | 2.85         | 0.15         | 3.85         | 5.15         | 4.15         | 0.15         |
| variation from average 10mm/hr | 0.38         | 3.38         | 5.62         | 1.38         | 2.62         | 1.38         | 1.38         | 1.62         | 0.38         | 0.38         | 0.62         | 2.38         | 0.62         |
| variation from average 15mm/hr | 1.92         | 1.92         | 2.08         | 1.92         | 1.08         | 1.92         | 0.92         | 2.08         | 0.08         | 2.08         | 0.92         | 0.08         | 2.08         |
| variation from average 20mm/hr | 0.46         | 2.54         | 0.46         | 0.54         | 0.54         | 0.54         | 1.54         | 0.46         | 0.46         | 1.46         | 1.46         | 0.46         | 0.46         |
|                                |              |              |              |              |              |              |              |              |              |              |              |              |              |
| Rank 5mm/hr                    | 6            | 13           | 7            | 1            | 7            | 1            | 1            | 9            | 1            | 10           | 12           | 11           | 1            |
| Rank 10mm/hr                   | 1            | 12           | 13           | 6            | 11           | 6            | 6            | 9            | 1            | 1            | 4            | 10           | 4            |
| Rank 15mm/hr                   | 6            | 6            | 10           | 6            | 5            | 6            | 3            | 10           | 1            | 10           | 3            | 1            | 10           |
| Rank 20mm/hr                   | 1            | 13           | 1            | 7            | 7            | 7            | 12           | 1            | 1            | 10           | 10           | 1            | 1            |
| Rank TOTAL                     | 14           | 44           | 31           | 20           | 30           | 20           | 22           | 29           | 4            | 31           | 29           | 23           | 16           |
| FINAL RANK                     | 2            | 13           | 11           | 4            | 10           | 4            | 6            | 8            | 1            | 11           | 8            | 7            | 3            |