KINGSTON UNDERPASS

FLOOD RISK INVESTIGATION – ADDENDUM TO KINGSGATE ROAD RAILWAY BRIDGE FLOOD INVESTIGATION REPORT, 2013

THE ROYAL BOROUGH OF KINGSTON UPON THAMES

PREPARED FOR ROYAL BOROUGH OF KINGSTON

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EXECUTIVE SUMMARY

This flood risk investigation for the Kingston underpass was triggered due to multiple reports of flooding at the site. A Section 19 investigation was carried out in response to two flood events which occurred in July 2013. A third flood event occurred in June 2019, which triggered this flood risk investigation to be carried out as an addendum to the report for the July 2013 events.

The investigation established that the site is potentially at risk of flooding from surface water and sewer sources. A catchment analysis provided hydrological catchment and primary flow path outputs for the site. The defined catchment shows that the Kingston underpass site lies close to the primary flow path in the catchment. The catchment's primary overland flow path flows towards the west and outfalls in the River Thames.

The flood risk at the site is exacerbated due to several factors, including the site being located close to the primary flow path in the catchment and a history of failure of a Thames Water Utilities Limited (TWUL) pumping station close to the site. The urbanised nature of the hydrological catchment also increases the rate of runoff flowing through the catchment, increasing the risk of flooding from surface water.

The Risk Management Authorities (RMAs) who are responsible for managing the potential risks posed by flooding to the site are the Royal Borough of Kingston upon Thames (Kingston) and TWUL. Kingston carried out an emergency response to the flooding and have investigated the flood events as part of Section 19 investigations. The actions carried out by Kingston align with their roles and responsibilities. TWUL have attended the site to restart the pumps and remove the water in times of flooding. Further investigation is required to ascertain whether action to prevent failure of the pumping station has been undertaken.

The recommendation for Kingston from the 2013 *Kingsgate Road Railway Bridge Flood Investigation Report* is as follows:

- Put in place improved out of hours procedure to ensure liaison with Thames Water duty officer for all flood incidents in this location.

Following the flood risk investigation carried out for the Kingston underpass site, the following recommendations have been put forward:

- Further investigate and liaise with TWUL to determine if any action has been taken to prevent failure of the pumping station in the future, and produce an action plan which can be implemented if the pumping station fails again.

- Continue to collaborate with TWUL on the Drainage and Wastewater Management Plan investigations, to address flooding within the area.
- In the event of future flooding, investigate opportunities for introducing automated traffic diversions, signage, and alarms.
- Review the measures put in place following the 2013 *Kingsgate Road Railway Bridge Flood Investigation Report.*

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FIGURES AND TABLES

ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
DWMP	Drainage and Wastewater Management Plan
EA	Environment Agency
FWMA	Flood and Water Management Act 2010
Kingston	Royal Borough of Kingston upon Thames
LFRMS	Local Flood Risk Management Strategy
LLFA	Lead Local Flood Authority
LiDAR	Light Detection and Ranging
RMA	Risk Management Authority
RoFSW	Risk of Flooding from Surface Water
TBR	Tipping Bucket Raingauge
TfL	Transport for London
TWUL	Thames Water Utilities Limited

1 INTRODUCTION

1.1 Background Policy and Information

As a unitary authority, the Royal Borough of Kingston upon Thames (Kingston) is a Lead Local Flood Authority (LLFA). LLFAs are defined as a Risk Management Authority (RMA) under Section 6, Part 1 of the Flood and Water Management Act (FWMA) 2010. They are one of several parties who are responsible for managing the risks posed by flooding. Other RMAs as defined by the FWMA are:

- the Environment Agency (EA)
- a district council for an area for which there is no unitary authority
- an internal drainage board
- a water company, and
- a highway authority.

RMAs relevant within Kingston are found in *Chapter 4.* There are no district councils or internal drainage boards within Kingston.

As part of their role as an LLFA and an RMA under Section 19, Part 1 of the Act, Kingston is required to act when they become aware of flooding in the area. The FWMA 2010 states that:

> *A lead local flood authority must, to the extent that it considers it necessary or appropriate, investigate –*
>
> *a. which risk management authorities have relevant flood risk management functions, and*
>
> b. *whether each of those risk management authorities has exercised, or is proposing to exercise, those functions in response to the flood.*

For all flood investigations carried out under Section 19 of the FWMA 2010, Kingston must:

a. publish the results of its investigation, and

b. notify any relevant risk management authorities

There are certain threshold criteria defined in the Local Flood Risk Management Strategy (LFRMS) which if met, trigger Kingston to conduct a Section 19 investigation. These are:

- If internal flooding of one building has been experienced on more than one occasion
- Where internal flooding of five or more properties has been experienced during a single flood incident
- Where critical infrastructure (e.g. highways impassable to traffic) has been affected by flooding more than once within a 12 month period

Kingston conducted a Section 19 investigation following two flooding incidents in July 2013, where a section of Kingsgate Road flooded. This section, located under a railway bridge, is approximately 80m to the west of Kingston station and is referred to as the Kingston underpass. This location is shown in *Figure 1.1*. In July 2019, Kingston received a report of flooding at the Kingston underpass, in the same location as the 2013 flood incidents. LLFAs can, at their own discretion, investigate flood incidents which do not meet their criteria if it is deemed necessary. The multiple reports of flooding, combined with the flooding of critical infrastructure, has triggered Kingston to conduct another Section 19 investigation at this location.

This document is intended to be read as an addendum to the Kingsgate Road Railway Bridge Flood Investigation Report, 2013. The 2013 report stated that there was light rainfall which would not normally cause flooding, however the pumps at a nearby Thames Water Utilities Limited (TWUL) pumping station did not work as intended, contributing to the flooding.

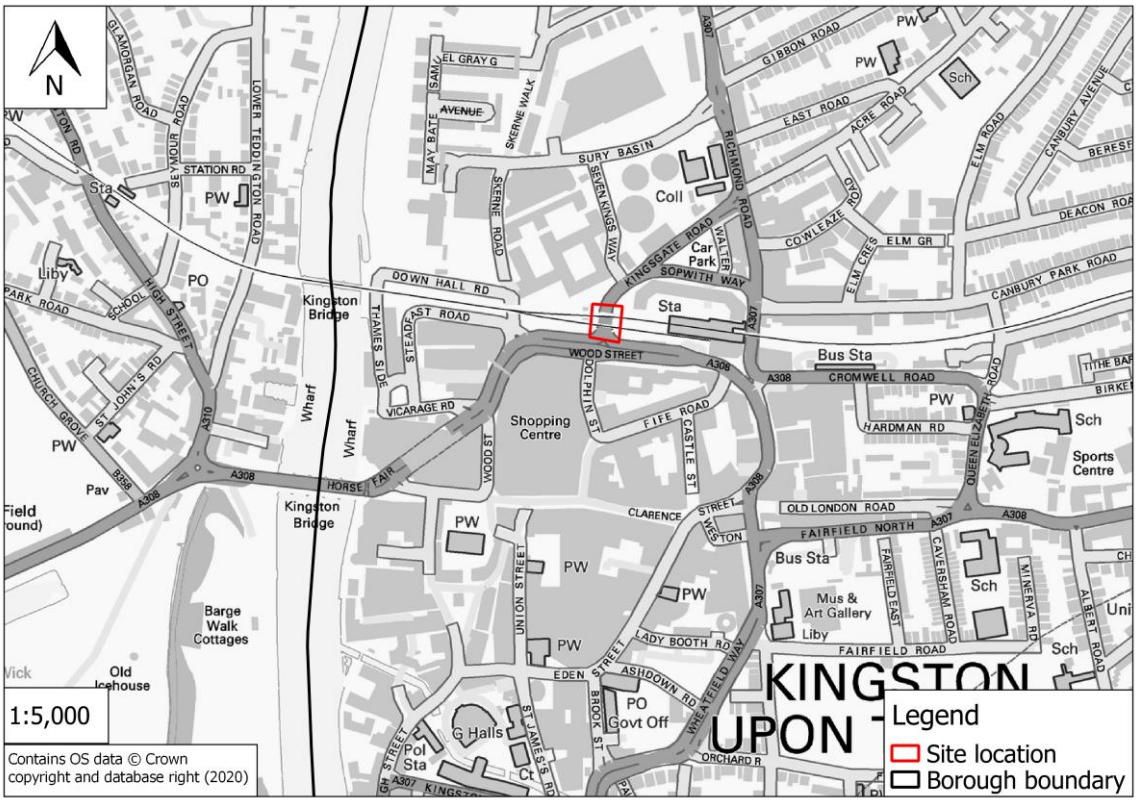

Figure 1.1 Location of Kingston underpass

1.2 Methodology

A method was developed and followed to facilitate the flood investigation. The first step was a data collection exercise. An identification task was carried out to identify the type of data that was required to inform the flood investigation. The data obtained is listed in *Table 1.1.*

Table 1.1. Data sources

Data	Source
Rainfall data for historic events	EA
Topography	EA
Watercourse locations	EA / Kingston
Historic flood records and OS Master Map	Kingston
OS Master Map	Kingston
Assets significant to flood risk	EA / Kingston / TWUL
Sewer network	TWUL / Kingston
Surface water, fluvial and artificial flood maps	EA
Ground water information	EA
Geology information	British Geological Survey
Social media/news reports	Various sources

The information collected was analysed in a desktop study to identify the flood mechanisms for the local area. The available historical, topographical, drainage, geological and land use data was used to explore how water might end up at the site. The data was also used to establish the hydrological catchment and the area's primary overland flow route(s), showing where water flows in the area in relation to the site. The different RMAs were then identified alongside their responsibilities for the different flood risks posed to the site. Further information on this can be found in *Chapter 4*.

Finally, the results of the investigation were compiled and are delivered in this report. Recommendations on flood risk mitigation and potential next steps are provided in *Chapter* ***Error! Reference source not found.***.

2 FLOOD INCIDENT DETAILS

The Kingston underpass site is located where the A308 carriageway runs under the railway line, to the west of Kingston Station (see *Chapter 2.1* in the 2013 *Kingsgate Road Railway Bridge Flood Investigation Report*). This is a topographical low point compared to the areas immediately surrounding the site.

There was heavy and prolonged rainfall leading up to the flood incident. Met Office observations show that the rainfall started in the morning and continued into the afternoon, increasing in intensity. Raingauge data taken from the River Hogsmill raingauge showed that the rainfall peaked at 17:15 and 20:45. More information can be found on this in *Chapter 3.2*.

Flooding of the underpass led to closure of the highway in the affected area and diversion of traffic in Kingston town centre. Kingston bridge (located over the River Thames, over 400m to the south west of the site) was also closed to prevent high sided vehicles from entering the diversion route in the town centre. Various local news websites confirmed that there was traffic disruption and delays within Kingston. Video clips on social media show members of the public pushing a vehicle out of the floodwater. Anecdotal evidence says that at the deepest point, the depth of flood water was greater than six feet. During the flood incident, the TWUL pumping station located close to the site failed (see *Chapter 4.3.2* for further details). Once the water had been removed, Kingston arranged for two abandoned vehicles to be removed. The highway was cleansed and re-opened in time for the morning rush hour on 11th July 2020. Photographs of the flooding incident are shown in *Figures 2.1* and *2.2*.

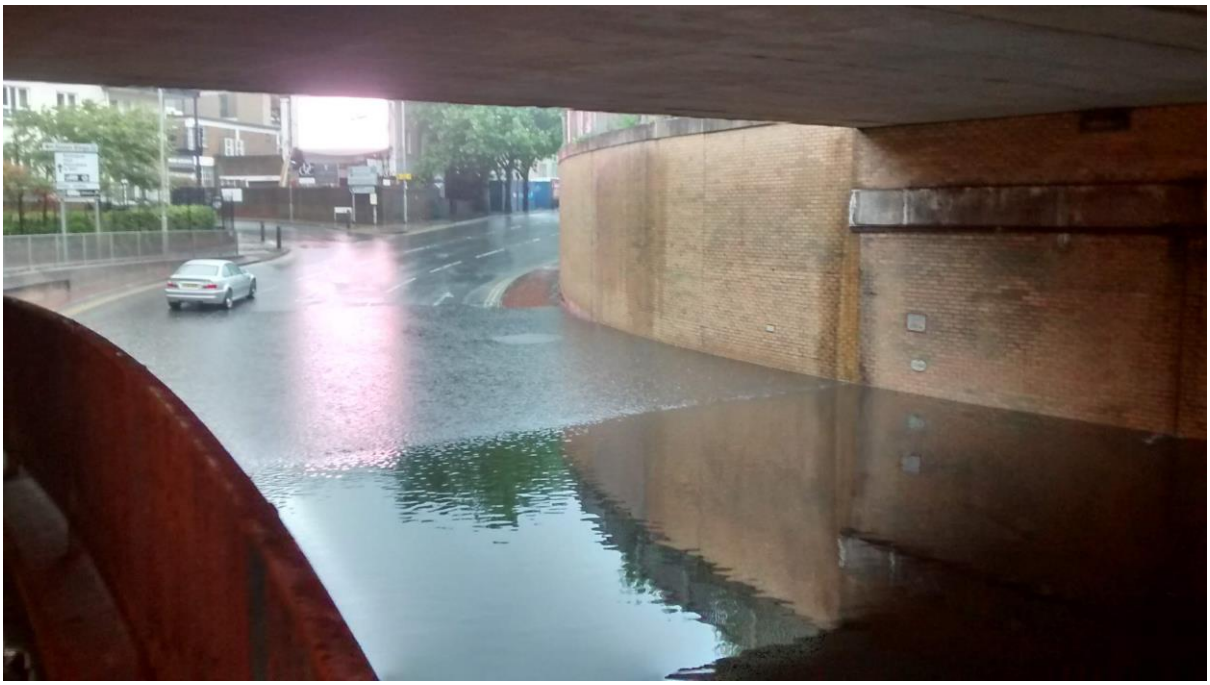

Figure 2.1 Flooding at the Kingston underpass site on 10th June 2019. Source: Kingston

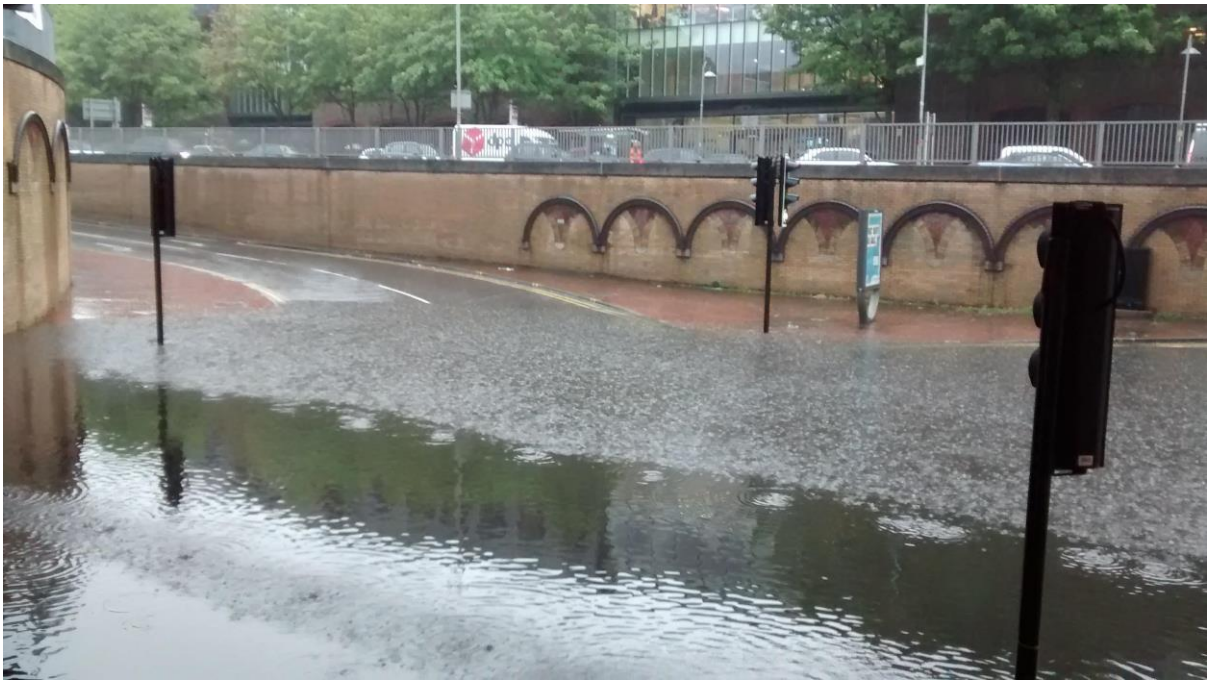

Figure 2.2. Flooding at the Kingston underpass site on 10th June 2019. Source: Kingston

3 FLOOD MECHANISMS

3.1 Potential Sources of Flooding

3.1.1 Hydrological catchment

To better understand the potential causes of flooding at the Kingston underpass site, the hydrological catchment area was defined. The catchment is an area of land where rain falls and drains towards the same waterbody, flow path (where water flows out of one catchment and into another) or topographical low point. There may be more than one topographical low point in a catchment and may be more than one catchment in the vicinity of the site. The hydrological catchment was established through an analysis of the wider area's topography using QGIS. Light Detection and Ranging (LiDAR) data was used to help define the catchment, a surveying method that measures distance to a target by using light and sensors to make 3-D representations of target areas.

Analysis of the area provided several outputs, including a defined hydrological catchment and a primary overland flow path for water (shown as 'Hydrological Stream' in ***Error! Reference source not found.***). The Kingston underpass site is situated close to the primary flow path in the catchment. This means that runoff from the topographically higher surrounding areas may flow towards the site and contribute to the surface water that reaches the site. The primary flow path is represented as the main overland flow route for surface water in the catchment. The topography indicates that rain falling on this catchment will flow from the north and east towards the River Thames. Further hydrological catchment and primary flow path (defined as the 'hydrological stream') information is presented in *Figure 3.1.*

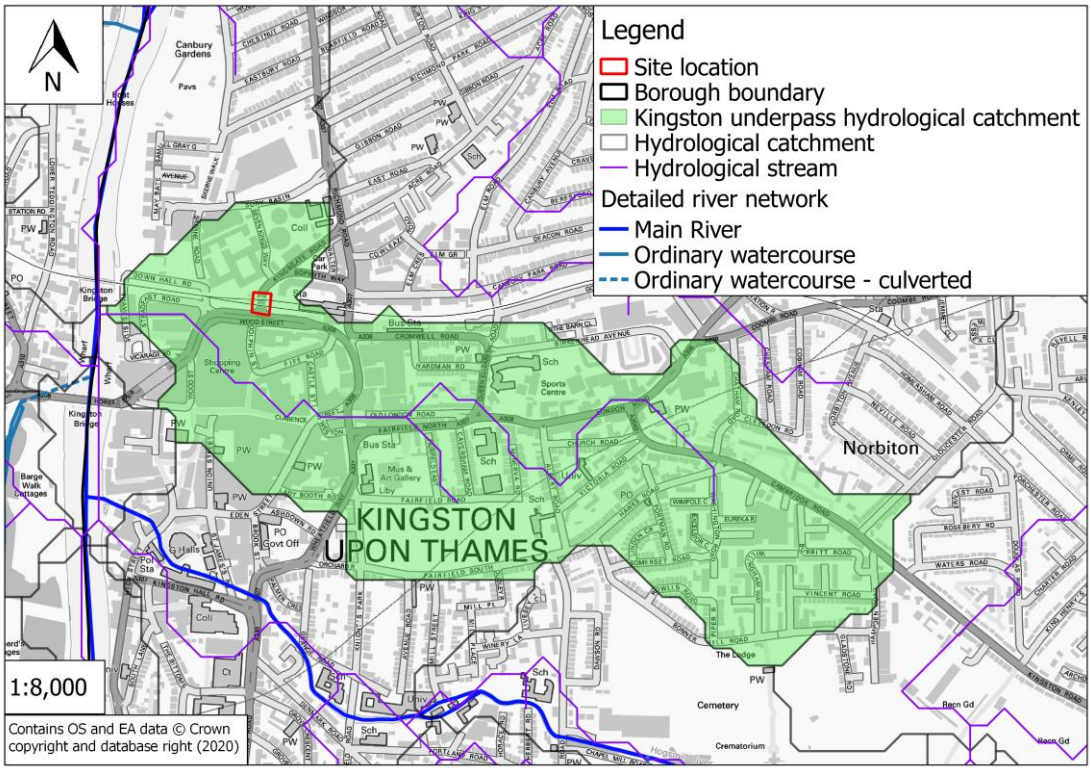

Figure 3.1 Hydrological catchment and primary flow path for the Kingston underpass site

3.1.2 Surface water flood risk

Surface water flooding arises due to the accumulation of water on the surface of the ground following heavy or prolonged periods of rainfall. Flooding is exacerbated when surface water cannot be drained away at a sufficient rate by a watercourse, sewer network or via infiltration.

The EA's Risk of Flooding from Surface Water (RoFSW) map shows the site to be at risk of surface water flooding from the 1 in 30, 1 in 100 and 1 in 1000 year rainfall events. The previous flood events in July 2013 were attributed to surface water flooding. The RoFSW map is shown in *Figure 3.2.* The urbanised nature of the area surrounding the site exacerbates the risk of flooding from surface water, as there is little infiltration potential for runoff to seep into the largely impermeable ground.

3.1.3 Ordinary watercourse flood risk

Flooding from ordinary watercourses can occur when heavy or prolonged periods of rain or other precipitation causes watercourses to exceed their hydraulic capacity. When watercourses rise above their banks or retaining structures, they can flow onto land and can cause flooding. Predicted flooding from ordinary watercourses is included within the EA's *RoFSW* map. There are no ordinary watercourses in the vicinity of the site, therefore the Kingston underpass is not at risk of flooding from ordinary watercourses.

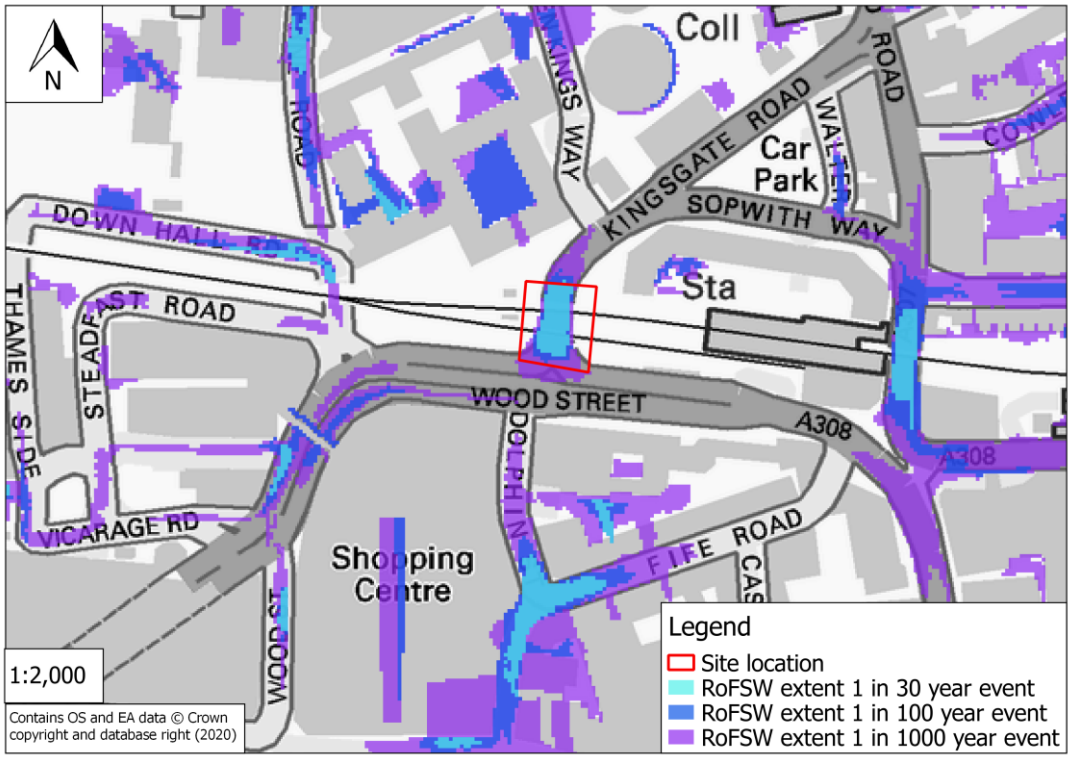

Figure 3.3 Risk of flooding from surface water at the Kingston underpass site

3.1.4 Fluvial flood risk

Fluvial flooding can arise as a result of heavy or excessive precipitation causing watercourses to exceed their hydraulic capacity. This source of flooding comes from watercourses that are designated as a Main River by the EA. The Kingston underpass is located in Flood Zone 3, and therefore is at high risk of fluvial flooding (greater than the 1 in 100 year annual probability of fluvial flooding). As no reports of fluvial flooding were reported in Kingston on 10th July 2019, it is unlikely that this flooding incident can be attributed to fluvial sources.

3.1.5 Groundwater flood risk

Groundwater flooding occurs when the underground water table rises. In extreme circumstances, water can emerge through the ground and cause flooding. This source of flooding tends to occur after extensive periods of heavy rainfall. The effects can be further exacerbated based on an area's ground composition and the presence of aquifers, which are significant influences on the potential rate of

groundwater flooding. Based on the EA's Areas Susceptible to Groundwater Flooding data, the Kingston underpass site falls within the '<25%' flood risk class. British Geological Survey mapping shows that the underlying geology is impermeable London Clay. The likelihood of this flooding incident being caused by groundwater influences is very low.

3.1.6 Sewer flood risk

Sewer flooding can occur as a result of heavy rainfall or precipitation causing an increased flow and volume of water to enter a sewer system. This increase can cause the sewer to exceed its hydraulic capacity, resulting in the system surcharging and flooding over land. Blockages in the sewer system can cause water to back up in the network and cause flooding.

There is historical evidence that the TWUL pumping station located close to the Kingston underpass site has failed on several previous occasions. Water from the surrounding area drains through the sewer network to a 30m deep sump located next to the pumping station. Water is then pumped through a rising main before entering a gravity drained sewer which carries flows towards the River Thames. Failure of the pumping station leads to blockages and a reduction in capacity of the sewer network. As the Kingston underpass is the lowest topographical point in the vicinity, it is at increased risk of sewer flooding. The location of the TWUL pumping station and surface water sewer network are shown in *Figure 3.3*.

Figure 3.4 TWUL surface water sewer system and pumping station

3.1.7 Flood risk from other sources

There are no artificial watercourses within the vicinity of the site. The EA's *Risk of Flooding from Reservoirs* map shows the site to be at risk of flooding from reservoirs (see *Figure 3.4*). However, there were no reservoir flood incidents that occurred at the time of the flood event. The nearest reservoir to the site is the Island Barn Reservoir, located approximately 4.5km to the south west. It is therefore unlikely that this flooding incident can be attributed to reservoir flood sources.

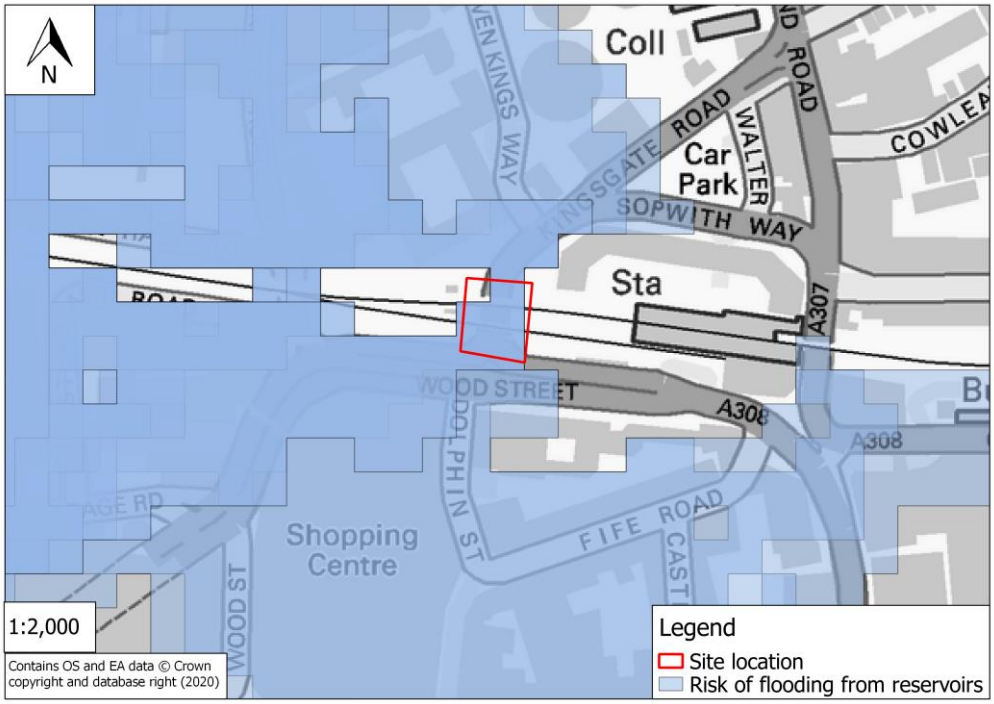

Figure 3.5 EA Risk of Flooding from Reservoirs extent

3.2 Raingauge data

Rainfall data from a Tipping Bucket Raingauge (TBR) at the River Hogsmill was used to assess the reported rainfall event which resulted in flooding at the site. This TBR is located within the borough boundary and is located approximately 2km south from the Kingston underpass site (see *Figure 3.5* for the approximate location). The TBR at the River Hogsmill is the most local gauge to the Kingston underpass site.

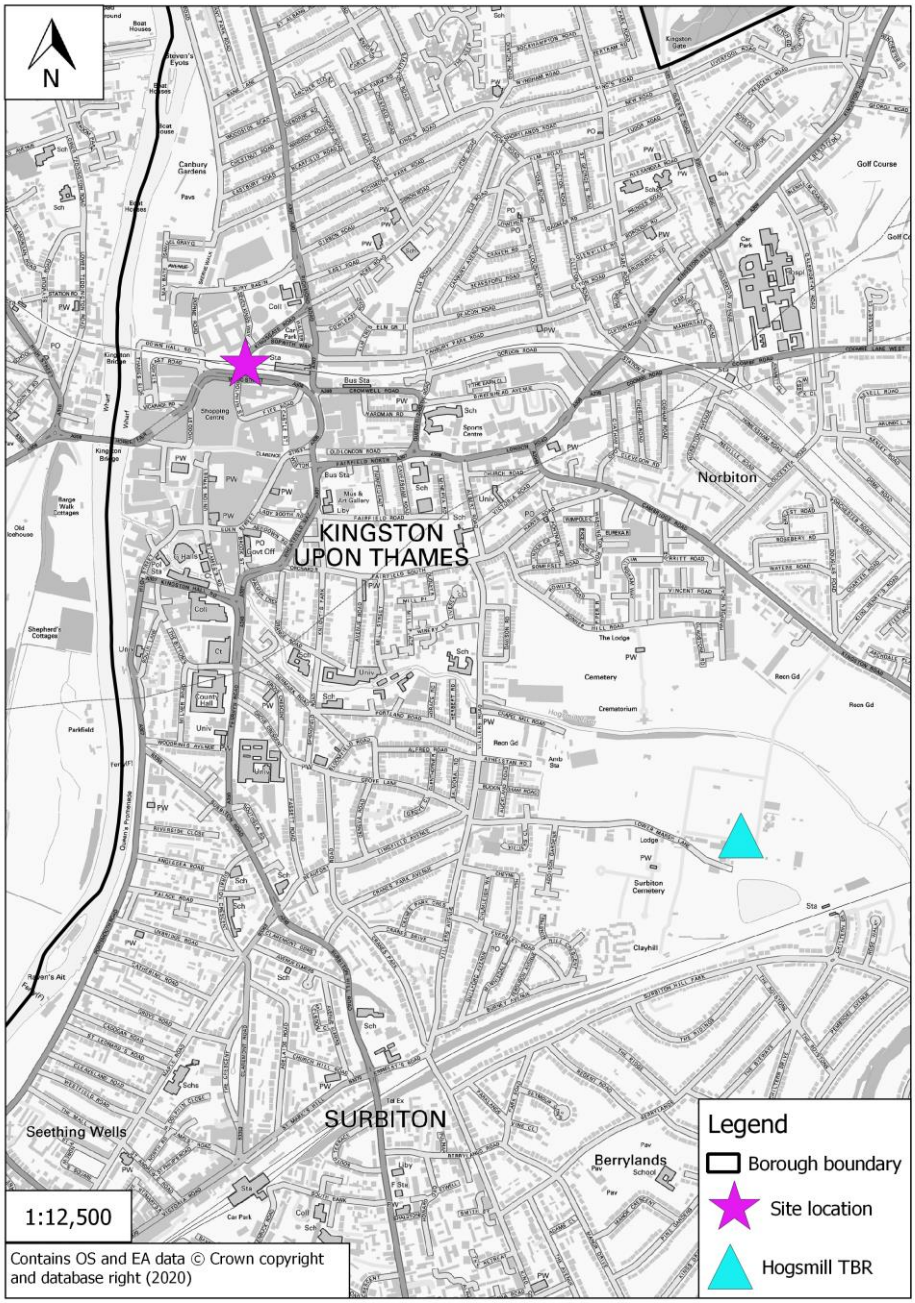

Figure 3.6 Location of Hogsmill TBR

The data analysed from the Hogsmill TBR shows the variation in rainfall over a 24-hour period for one rainfall event. The data recorded provides accumulated totals for each 15-minute period. *Table 3.1* provides a summary of the rainfall event investigated as part of this study. Rainfall event specific details on rainfall variation are shown in *Figure 3.6.*

Table 3.1. Summary of Rainfall Events

Rainfall Event	First Significant Rainfall Period	First Recorded Peak (mm)	Peak Time	Second Significant Rainfall Period	Second Recorded Peak (mm)	Peak Time
June 2019	00:00 to 17:15 GMT on 10th June	2.77	17:15	18:15 to 23:45 GMT on 10th June	3.07	20:45

The data for the June 2019 event indicates that the peak rainfall return period for this event approximates to a 1 in 5-year event (20% probability of rainfall of that intensity occurring each year). As the Kingston underpass is located at a local topographical low point, rainwater ponds at the site during flood events. Based on the severity of the flood event which occurred, the amount of water captured in the TBR is not as expected considering the nature of the recorded flood event. It is therefore possible that the flood event is greater than the 1 in 5-year event. The proximity of the Hogsmill TBR to the Kingston underpass site makes it the best TBR data source to approximate the rainfall return period for the catchment. The next nearest TBR to the site is located approximately 4.3km to the north west in Fulwell.

The TBR results for the June 2019 event have been labelled as “good and complete” by the EA. This means that the TBR was operational during the event to accurately record rainfall depth. Anecdotal evidence suggests that the total rainfall for the June 2019 event may have been greater than the amount recorded. Further information on the rainfall return period estimations can be found in Appendix A.

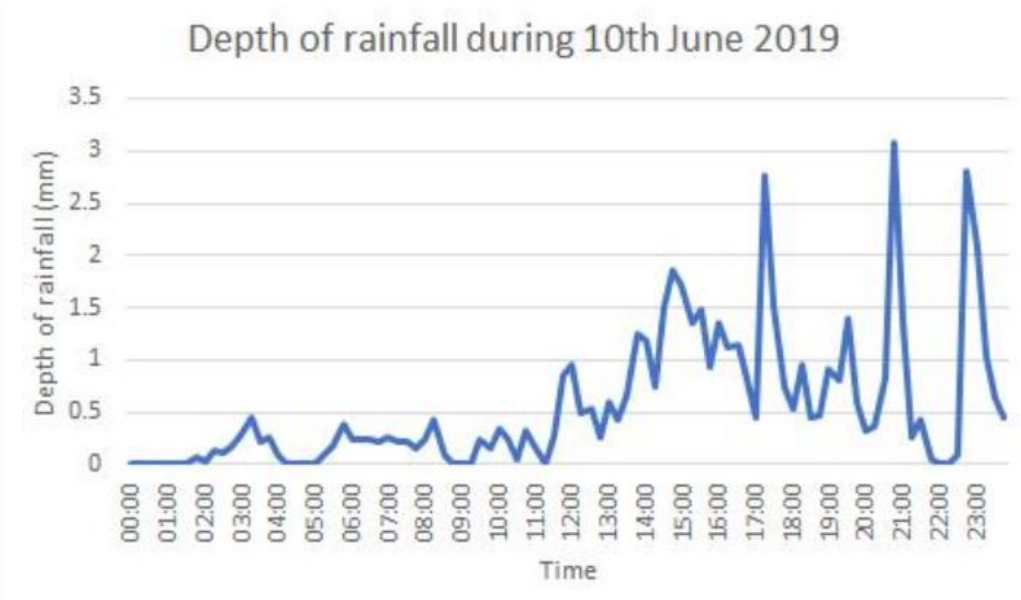

Figure 3.7 Rainfall depth on 10th June 2019

4 RISK MANAGEMENT AUTHORITIES

There are several RMAs who are responsible for managing the potential risks posed by flooding. *Table 4.1* lists them at a borough level, with further information provided in *Chapters 4.1* to *4.5*.

Table 4.1. Borough level Risk Management Authorities

Risk Management Authorities	Authority	Risk management responsibilities
EA	EA	Main Rivers and reservoirs
LLFA	Kingston	Surface water, ordinary watercourse, and groundwater sources
Water and sewerage company	TWUL	Surface water and foul / combined sewer systems
Highway Authority	Kingston	Highway drainage
Highway Authority	TfL	Highway drainage

4.1 Environment Agency

4.1.1 Responsibilities

The EA are the lead RMA in managing flood risk from designated Main Rivers and reservoirs. They have a range of powers and responsibilities including surveying, maintenance and improvement works to Main Rivers and the sea relating to flood and coastal erosion risk management. The EA plays a key role in advising planning authorities on the implications that proposed developments may have on flood risk, providing and operating flood warning systems, and improving the environment.

The identified flood risk sources for Kingston Underpass are not from fluvial sources. Therefore, the EA do not have direct RMA responsibilities to manage flood risk for the site.

4.1.2 Authority Contributing Action to Flood Incident

Before

The EA issued an amber weather warning for rain on the morning of 10th June 2019 for London and South East England, stating that flooding and transport disruption as a result of heavy rain was likely. The weather warning was in place for between 15:00-23:00. A Flood Guidance Statement issued by the Flood Forecasting Centre (a partnership between the EA and Met Office) on the morning of 10th June 2019 predicted that the impact of flooding would be 'significant', and the likelihood of flooding was 'medium' with urban areas at risk of flooding. The EA issued a Flood Alert in the afternoon which stated that flooding was possible for the Beverly Brook area in Kington upon Thames, and that flooding of highways and land was expected between 17:30-22:00 on 10th June 2019.

During

No known actions have been taken by the EA during the flood event.

After

No known actions have been taken by the EA after the flood event.

4.2 Royal Borough of Kingston upon Thames

4.2.1 Responsibilities

Kingston has different RMA roles as an LLFA, a Highway Authority and a landowner. As a unitary authority LLFA, Kingston has the lead responsibility for managing flood risk from surface water, ordinary watercourse, and groundwater sources. They are responsible for:

- Developing, applying, maintaining, and monitoring local flood risk management strategies.
- Maintaining a register of structures and features that have a significant effect on flood risk.
- Preparing and maintaining preliminary flood risk assessments, flood hazard maps, flood risk maps and flood risk management plans.
- Reviewing and consulting on surface water management plans for major developments.
- Undertaking Section 19 flood risk investigations as per the FWMA 2010.

Other RMAs have a duty to cooperate with LLFAs where necessary to undertake the above responsibilities. Kingston can also carry out work to help alleviate surface water, groundwater, and ordinary watercourse flooding in collaboration with other RMAs. Under the powers granted to them, Kingston can make by-laws to ensure that flood risk management work is effective.

As a Highway Authority, Kingston is responsible for providing and managing highway drainage that is not managed by Transport for London (TfL) or Highways England. Part of their responsibility is to manage highway flooding on and from highways, reducing the wider flood risk that may be presented from highways through routine works such as gully cleansing.

As a landowner, Kingston have a responsibility to safeguard their own land and property against flooding. Common law also requires that they do not increase the risk of flooding to a neighbouring property through carrying out tasks such as drain clearing and maintaining any existing flood defences. Kingston is the landowner of the Kingston underpass section.

4.2.2 Authority Contributing Action to Flood Incident

Before

No known actions were taken by Kingston before the flood event.

During

Kingston closed the highway under the railway bridge and put a diversion route in place. Kingston bridge (which is situated across the River Thames) was also closed to stop high sided vehicles entering Kingston

town centre and accessing the diversion route. Kingston LLFA also kept an on-the-day record of Met Office rainfall observations.

After

There were two abandoned vehicles left at the underpass site by their owners. Kingston arranged for these vehicles to be moved by 4:00am on 11th July 2020 and for the highway to be cleansed and reopened in time for the morning rush hour.

4.3 Thames Water Utilities Limited

4.3.1 Responsibilities

TWUL is the water and sewerage company responsible for managing public surface water, foul, and combined sewer systems. They are responsible for any maintenance and repair work on their drainage assets. When there are wet winters and high groundwater levels, TWUL investigate where the water may be forcing its way into the sewer network. TWUL use CCTV, Impermeable Area Surveys, flow monitors, and manhole surveys to identify problem areas. TWUL may also investigate potential flood impacts if a report has been submitted to highlight internal property flooding. In each of their Asset Management Periods (which operates on a five-yearly cycle), investment is put into TWUL's business plan for flood alleviation. The location of flood alleviation schemes are prioritised based on frequency and severity of flooding, as well as environmental and customer impact. It is for this reason why it is important that sewer-related flooding incidents are reported to TWUL.

The Kingston underpass site is served by separate TWUL surface water and foul sewer networks. There is a TWUL pumping station located approximately 85m to the west of the site. The 2013 *Kingsgate Road Railway Bridge Flood Investigation Report* concluded that this pumping station failed during the 2013 flood event.

4.3.2 Authority Contributing Action to Flood Incident

Before

No known actions have been taken by TWUL before the flood event.

During

No known actions have been taken by TWUL during the flood event.

After

A TWUL engineer attended the site and re-started the pumping station at approximately 02:00 on 11th June 2019. The Kingston underpass site falls within a risk area which will be included in the TWUL Drainage and Wastewater Management Plan (DWMP) investigations. The DWMP aims to prioritise interventions for areas which have the biggest drainage and wastewater management issues. TWUL and Kingston are collaborating on this at the time of writing of this report.

4.4 Landowners

4.4.1 Responsibilities

Landowners have the primary responsibility of safeguarding their own land and property against flooding. Under common law they are also required to ensure that they do not use their property in a way that increases the risk of flooding to a neighbouring property. Common law also enables landowners to take reasonable measures to protect their property from flooding, provided the measures do not cause harm to others.

4.4.2 Authority Contributing Action to Flood Incident

Kingston is the landowner of the A308, and therefore take the necessary actions in response to the flood incident for its entire stretch. The response and actions undertaken by Kingston are outlined in *Chapter 4.2.2*.

4.5 Other Authorities

4.5.1 Transport for London

The highways surrounding the Kingston underpass site are not on TfL's highway network and do not fall within the same hydrological catchment as a TfL managed highway. TfL do not have responsibilities as an RMA to provide or manage drainage for the site.

4.5.2 Category One Responders

Blue light emergency services are categorised as Category One Responders under the Civil Contingencies Act (2004). They are emergency services at the core of responding to most emergencies. Services such as the Metropolitan Police Service and the London Fire Brigade are the most relevant responders with regards to flood incidents. It is unknown if any actions have been taken by Category One Responders.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This flood risk investigation for the Kingston underpass was triggered due to multiple flooding reports received at the site. A Section 19 investigation was carried out in response to two flood events which occurred in July 2013. A third flood event occurred in June 2019, which triggered this flood risk investigation to be written as an addendum to the report for the July 2013 events.

The investigation established that the site is potentially at risk of flooding from surface water and sewer sources. A catchment analysis provided hydrological catchment and primary flow path outputs for the site. The defined catchment shows that the Kingston underpass site lies close to the primary flow path in the catchment. The primary flow path flows towards the west and outfalls in the River Thames.

The 2013 *Kingsgate Road Railway Bridge Flood Investigation Report* states that the TWUL pumping station failed during the 2013 flood event. Due to this history of failure and the fact that TWUL had to re-start the pumps for the June 2019 event, it is concluded that the pumping station failed during the June 2019 event also.

The flood risk at the site is exacerbated due to several factors, including:

- The site being close to the primary flow path in the catchment.
- The history of failure of the TWUL pumping station close to the site.
- The urbanised nature of the hydrological catchment.

The RMAs who are responsible for managing the potential risks posed by flooding to the site are Kingston (to manage the risks posed by surface water and highway drainage) and TWUL (to manage and maintain the sewer network and drainage assets). Landowners also have a degree of responsibility (Kingston is also the landowner of the site).

Kingston carried out an emergency response in terms of highway closures and diversions in the town centre. They have also investigated the flooding in this location as part of this Section 19 investigation and the previous investigation relating to the July 2013 flooding events. The actions carried out by Kingston align with their roles and responsibilities. TWUL have attended the site to re-start the pumps and remove the water in times of flooding. Further investigation is required to ascertain whether action to prevent the repeated failure of the pumping station has been undertaken.

5.2 Recommendations

The recommendation for Kingston from the 2013 *Kingsgate Road Railway Bridge Flood Investigation Report* is as follows:

- Put in place improved out of hours procedure to ensure liaison with Thames Water duty officer for all flood incidents in this location.

Following the flood risk investigation carried out for the Kingston underpass site, it is recommended that the following actions are carried out by the LLFA:

- Further investigate and liaise with TWUL to determine if any action has been taken to prevent failure of the pumping station in the future, and produce an action plan which can be implemented if the pumping station fails again.
- Continue to collaborate with TWUL on the DWMP investigations, to address flooding within the area.
- In the event of future flooding, investigate opportunities for introducing automated traffic diversions, signage, and alarms.
- Review the measures put in place following the 2013 *Kingsgate Road Railway Bridge Flood Investigation Report.*

APPENDICES

Appendix A – Rainfall Return Period Estimations

Rainfall Return Period Estimations

Time of Concentration - Kerby Method

$$t_c = 0.83\left(\frac{Ln}{S^{0.5}}\right)^{0.467}$$

Where:

L = Length of overland flow (ft, m)
S = Average catchment slope (ft/ft, m/m)
n = Retardance Roughness
Smooth pavement 0.02
Poor grass, bare soil 0.30
Average grass 0.40
Dense grass 0.80

n = **0.15**

Top of catchment to Kingston Underpass (m) = **14.63**
Length of overland flow (m) = **1550**
Slope = **0.009439**

Tc to Kingston Underpass (min) = **31.41**

For a critical duration period of 15 minutes (Kingston Underpass FEH)						
Minute	5 Year	10 Year	20 Year	30 Year	40 Year	100 Year
1	17.05	22.01	28.11	32.37	35.75	48.95
2	18.74	24.20	30.91	35.59	39.31	53.83
3	21.35	27.56	35.21	40.54	44.78	61.32
4	25.63	33.09	42.27	48.67	53.75	73.61
5	34.02	43.91	56.10	64.59	71.34	97.69
6	58.28	75.24	96.12	110.66	122.22	167.37
7	115.35	148.91	190.23	219.02	241.90	331.25
8	179.03	231.11	295.25	339.93	375.43	514.12
9	115.35	148.91	190.23	219.02	241.90	331.25
10	58.28	75.24	96.12	110.66	122.22	167.37
11	34.02	43.91	56.10	64.59	71.34	97.69
12	25.63	33.09	42.27	48.67	53.75	73.61
13	21.35	27.56	35.21	40.54	44.78	61.32
14	18.74	24.20	30.91	35.59	39.31	53.83
15	17.05	22.01	28.11	32.37	35.75	48.95
Mean rainfall over the 15 minute period (mm/hr)	**50.66**	**65.40**	**83.55**	**96.19**	**106.23**	**145.48**

For a critical duration period of 30 minutes (Kingston Underpass FEH)						
Minute	5 Year	10 Year	20 Year	30 Year	40 Year	100 Year
1	10.24	13.06	16.48	18.85	20.72	27.94
2	10.77	13.74	17.34	19.82	21.79	29.38
3	11.30	14.41	18.19	20.80	22.86	30.83
4	11.80	15.05	19.00	21.72	23.87	32.19
5	12.65	16.12	20.35	23.27	25.58	34.49
6	13.68	17.44	22.01	25.17	27.66	37.30
7	14.99	19.11	24.12	27.58	30.32	40.88
8	16.61	21.18	26.74	30.57	33.60	45.31
9	18.89	24.09	30.40	34.77	38.21	51.53
10	23.05	29.38	37.09	42.41	46.61	62.85
11	29.92	38.14	48.14	55.05	60.50	81.59
12	41.94	53.47	67.49	77.17	84.82	114.38
13	60.14	76.68	96.79	110.67	121.64	164.04
14	82.07	104.63	132.07	151.01	165.98	223.82
15	110.36	140.69	177.60	203.07	223.20	300.99
16	110.36	140.69	177.60	203.07	223.20	300.99
17	82.07	104.63	132.07	151.01	165.98	223.82
18	60.14	76.68	96.79	110.67	121.64	164.04
19	41.94	53.47	67.49	77.17	84.82	114.38
20	29.92	38.14	48.14	55.05	60.50	81.59
21	23.05	29.38	37.09	42.41	46.61	62.85
22	18.89	24.09	30.40	34.77	38.21	51.53
23	16.61	21.18	26.74	30.57	33.60	45.31
24	14.99	19.11	24.12	27.58	30.32	40.88
25	13.68	17.44	22.01	25.17	27.66	37.30
26	12.65	16.12	20.35	23.27	25.58	34.49
27	11.80	15.05	19.00	21.72	23.87	32.19
28	11.30	14.41	18.19	20.80	22.86	30.83
29	10.77	13.73	17.34	19.82	21.79	29.38
30	10.24	13.06	16.48	18.85	20.72	27.94
Mean rainfall over peak 15 minute period (mm/hr)	**49.96**	**63.69**	**80.40**	**91.93**	**101.03**	**136.25**

Mean of the means (mm/hr)	**50.31**	**64.54**	**81.97**	**94.06**	**103.63**	**140.86**
Depth in a 15 minute period (mm)	**12.58**	**16.14**	**20.49**	**23.51**	**25.91**	**35.22**

Rainfail TBR Data (Every 15 Minutes)
June 2019 Peak Rainfall Gauge Depth (mm) = **3.07**

Therefore:
June 2019 Event (Approximately) = **Under 1 in 5 Year**