

Highgate School MSC 4-Phase

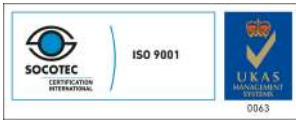
Surface Water Modelling Report



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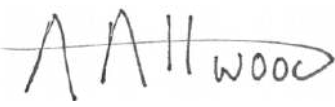
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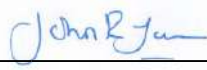


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Glossary of Terms

+CC – Return period inclusive for the predicted effects of Climate Change

1D – One-Dimensional

2D – Two-Dimensional

AOD – Above Ordnance Datum (0m sea level, Newlyn, UK)

Channel Cross Section – A profile view of a river channel, normally obtained by surveying a line across the watercourse

Critical Storm – A storm that produces peak run off in the watershed

Culvert – A device used to channel water, similar to a pipe though may be larger

ESTRY Software – One-Dimensional hydraulic model – Representation of watercourses

FEH – Flood Estimation Handbook

Fluvial – Referring to the processes associated with rivers and streams

FRA – Flood Risk Assessment

GIS – Geographic Information System

Hydraulic Model – The mathematical process of analysing the interaction of water and the connected environment

Hydrology – The calculation of catchment based flow rates

Inflow – Source of water within a modelled domain

ESTRY-TUFLOW – Hydraulic program that dynamically links ISIS and TUFLOW (1D-2D)

LiDAR – Light Detection And Ranging, remote sensing technology to measure distance typically used to obtain topographic data over a large area

Outflow – The method by which water may leave a modelled area

Q100 – 1% annual probability fluvial event

Q1000 – 0.1% annual probability fluvial event

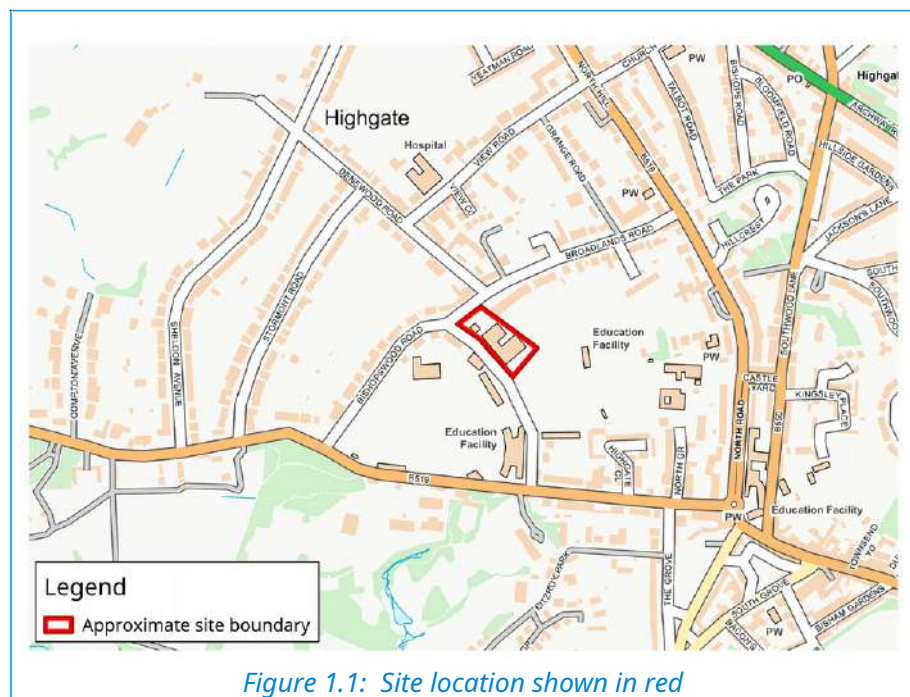
Q100CC – 1% annual probability fluvial event with an allowance for the predicted effects of climate change

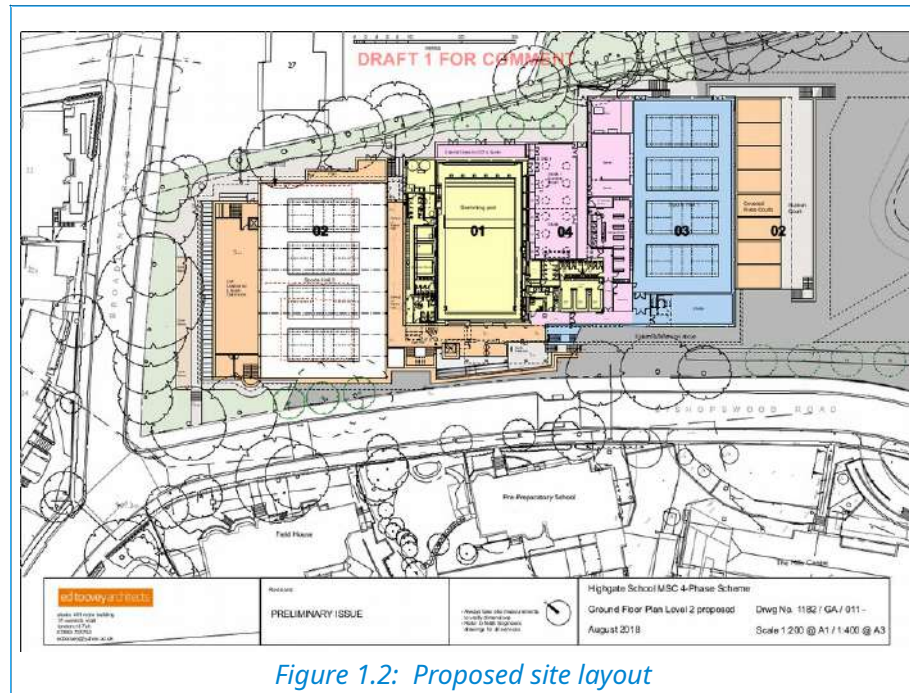
TUFLOW Software – Two-Dimensional hydraulic model – Representation of floodplain

1 Introduction

1.1 Overview

- 1.1.1 Flood modelling is used to inform risk associated with proposed developments. By using standardised techniques, comparative analysis of risk at different sites can be undertaken. Such analyses can also be used in the planning system to ensure that proposed developments conform to certain requirements with regards to flood risk.
- 1.1.2 This hydraulic modelling work has been undertaken to support the Flood Risk Assessment (FRA) for Capital Projects as part of a planning application relating to the Mallinson Sports Centre redevelopment
- 1.1.3 The site is located on Bishopswood Road, Highgate, London within the Highgate catchment Figure 1.1 with the proposed development shown in Figure 1.2, or detailed description of proposed developments refer to the Planning Statement. There are no watercourses in the immediate vicinity and the site lies in Environment Agency flood zone 1.





1.2 Study overview

- 1.2.1 Hydraulic modelling using TUFLOW software has been undertaken, which incorporates site specific details such as topographic survey and the local drainage network.
- 1.2.2 This allows the derivation of more representative surface water flood levels on site, compared to the Environment Agency surface water mapping which does not include these details.
- 1.2.3 The updated modelling allows more suitable threshold levels to be determined for the development as well as the modelling of flood mitigation options.
- 1.2.4 Existing flood risk at the site has been assessed by running the existing condition for three storm durations (3.5 hr, 4.5 hr and 5.5 hrs.) and the standard return periods for rainfall required by the local authority; 1 in 10 year, 1 in 30 year, 1 in 100 year, 1 in 100 year with a 20% allowance for climate change, 1 in 100 with a 40% allowance for climate change year and 1 in 1000 year.
- 1.2.5 In addition, a further modelling exercise has been undertaken to assess the flood risk at the site for the development of the sports facilities and flood mitigation options. There will be particular focus on the 1 in 100 year event with a 20% allowance for climate change as this is to be considered the design case.

2 Available data

2.1 Existing modelling

- 2.1.1 No pre-existing modelling of this area is available for use, though the area is covered by the EA surface water flood mapping. A new model has been built from component data with no elements from previous models incorporated.

2.2 Elevation data

- 2.2.1 LiDAR data was obtained from the Environment Agency. For the study area 2m and 1m DTMs were available and 1m resolution was selected.

2.3 Topographic survey

- 2.3.1 Topographic survey was undertaken for the purposes of this study by Randall Surveys in 2016. The survey included information pertaining to surface water sewers, foul sewers and the topography of the site. This survey can be found in Appendix A.

2.4 MasterMap data

- 2.4.1 Land-use data in vector format was derived from the national coverage provided by Ordnance Survey MasterMap. This was supplied with sufficient coverage for the full model extent. See section 4.3 for further details.

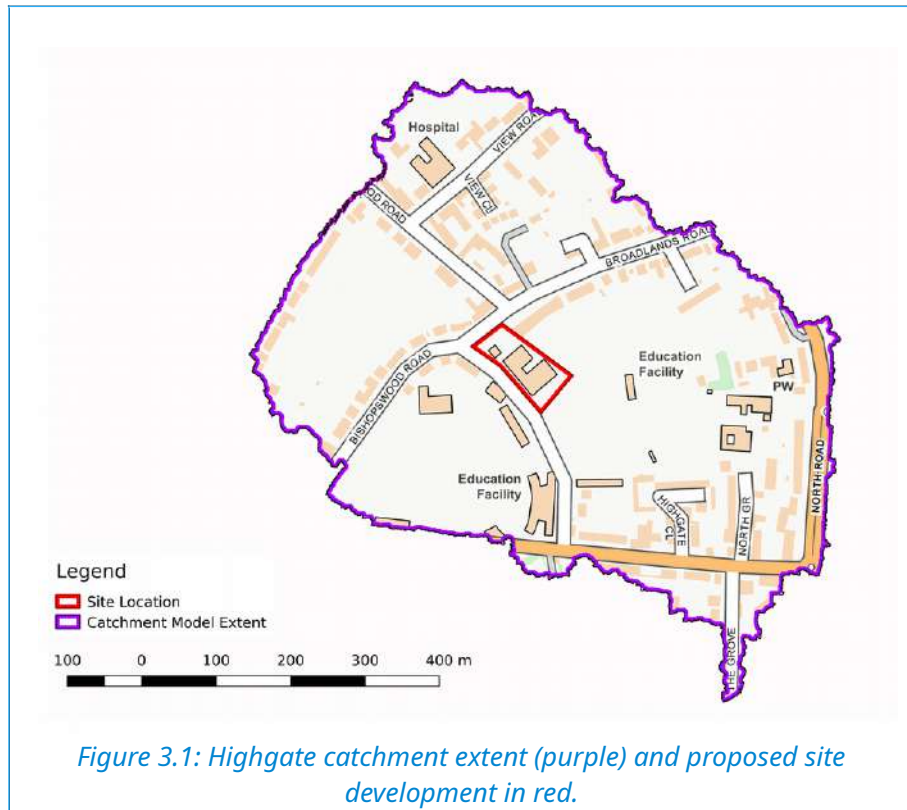
2.5 Hydrological data

- 2.5.1 ReFH2.2 software was used in combination with the FEH web service in order to provide data for hydrological analysis. See section 3 for further details.

3 Hydrological analysis

3.1 Introduction

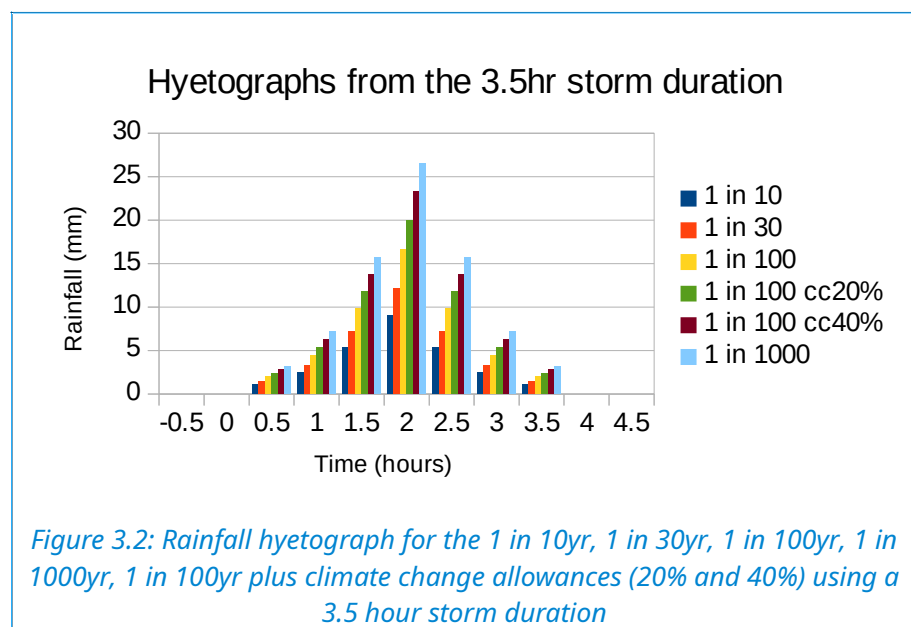
- 3.1.1 A hydrological assessment was undertaken for the Highgate catchment surrounding the development site shown in Figure 3.1.



- 3.1.2 The rainfall boundary was set over the entire 2D model area, which has been configured to be larger than the FEH catchment area to ensure that any errors in the delineation of the FEH catchment are excluded.

3.2 Storm durations

- 3.2.1 The rainfall hyetograph shown in Figure 3.2 has been based on gross rainfall derived from the ReFH2 using DDF2013 data.
- 3.2.2 The rainfall hyetograph shown is for the 1 in 10, 1 in 30, 1 in 100, 1 in 1000 as well as the 1 in 100 plus 20% and 40% climate change.
- 3.2.3 Additionally, several storm durations were run, including 3.5 hour (which is the critical storm duration for the catchment), 4.5 hour and 5.5 hour durations (which is the critical storm drainage duration).
- 3.2.4 This approach means that there is explicit representation of both storage and infiltration losses within the hydraulic model.



3.3 Climate change allowances

- 3.3.1 Regarding the climate change allowances, the EA recommends in the 2016 document “Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities” to increase the total rainfall by an upper estimate of 40% and a central estimate of 20% for the total potential change anticipated for the ‘2080s’ (2070-2115), when events rarer than 1 in 5 year return period are considered. For the purpose of this study both estimates have been modelled.

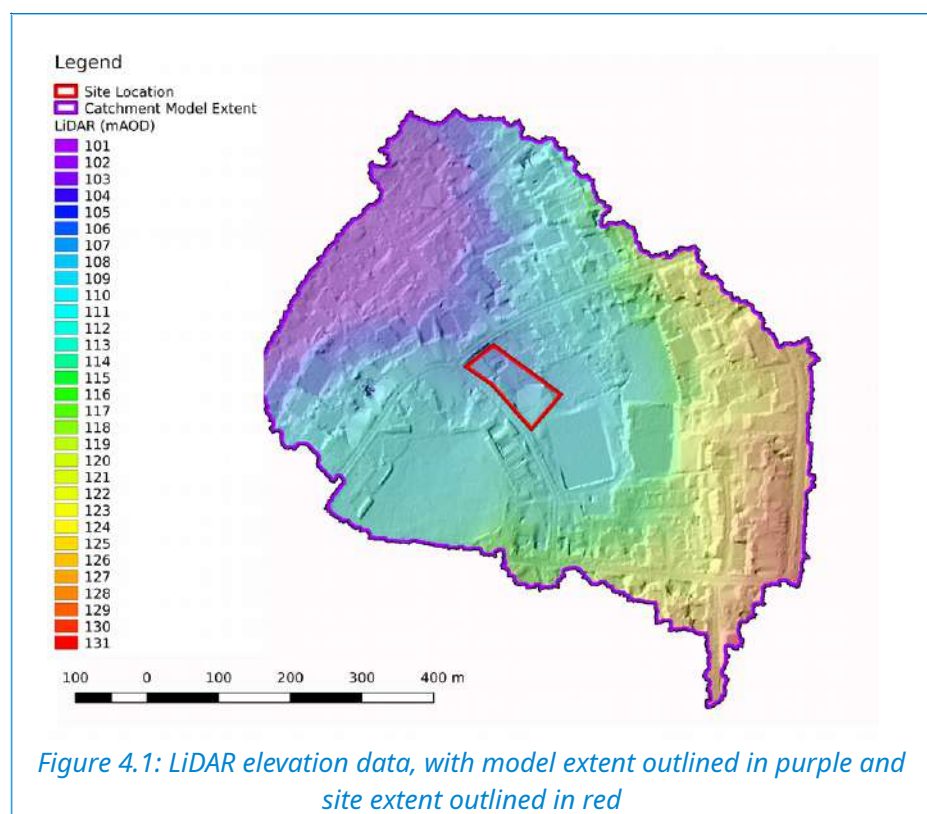
4 Hydraulic simulation

4.1 Software

- 4.1.1 The scheme was modelled using the widely-adopted TUFLOW HPC software. TUFLOW has been in wide use in the UK for over 10 years and is a stable and extensively tested two-dimensional (2D) modelling package. It incorporates a one-dimensional (1D) model, ESTRY, for the simulation of surface water pipe network.
- 4.1.2 The 1D and 2D solvers may be coupled and run simultaneously, exchanging data throughout the simulation, permitting utilisation of the strengths of both 1D (best for channels, structures and pipe networks) and 2D (best for floodplains and complex flood paths).
- 4.1.3 One of the key advantages of the software is its use of standardised and open input and output formats (ASC, SHP, CSV, TXT). This means that model data can be both prepared and inspected/reviewed without a copy of the software and the data can be readily extracted and processed using other, unrelated programs.
- 4.1.4 The latest version of the software was applied, specifically build 2018-03-AC-iSP-w64.

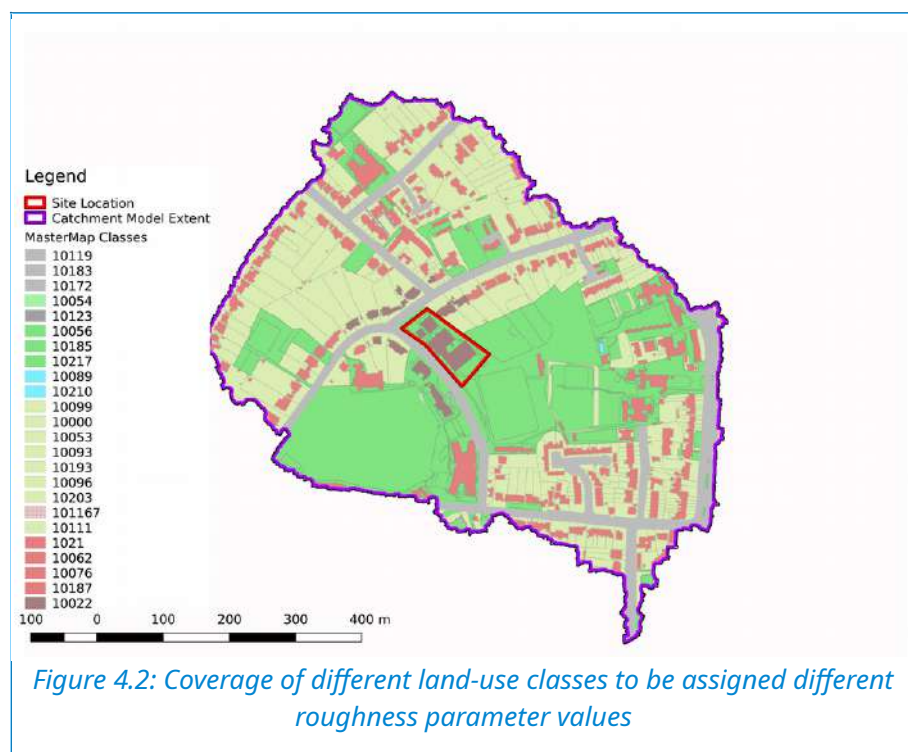
4.2 Terrain

- 4.2.1 Represented using the 2D portion of the model, the wider floodplain is split into square elements referred to as 'cells'. The cell size should be small enough to represent flow routes with sufficient detail, however, larger cell sizes are favourable as increases to the number of cells also increases the computational effort in undertaking simulations (halving the cell size results in simulations taking approximately 8 times longer to run).
- 4.2.2 In this instance a 1m resolution was selected as there are fine detailed features that need representing in 2D and this still permits runs to complete in suitable time.
- 4.2.3 The majority of elevations across the terrain were obtained by inspection of the LiDAR data. Figure 4.1 below shows the Extent of LiDAR coverage around the modelled area.
- 4.2.4 LiDAR was sufficiently recent and of sufficient quality that no further refinements were considered necessary.



4.3 Surface roughness:

- 4.3.1 Roughness has been spatially assigned using MasterMap data, with different classes (also known as feature codes) being assigned different Manning's n roughness parameters (the industry standard parametrisation of roughness). The values selected are typical values for floodplains in the UK.
- 4.3.2 Figure 4.2 below shows the coverage of the different classes, while Table 1 below shows the roughness parameters applied to the different classes.



MasterMap class	Description	Manning's 'n' roughness parameter
10021	Buildings	1
10022	Buildings	1
10053	Land	0.08
10054	Land	0.02
10056	Land	0.05
10062	Buildings	0.1
10089	Water	0.03
10096	Land	0.055
10111	Land	0.1
10172	Roads	0.022
10123	Roads	0.022
10183	Roads	0.04
10193	Structures	0.055
10217	Land	0.08

Table 1 – Roughness parameters applied to MasterMap classes

4.4 Surface permeability:

4.4.1 Soils data has been based on the freely available European Soil Database¹.

4.4.2 The Highgate catchment model extent falls under the soil category loam, this soil was specified using TUFLOW default values for the Green-Ampt Infiltration Method.

¹ <https://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data>

4.5 Surface water drainage

- 4.5.1 Surface water drainage features are included in this modelling including a pipe network with pits that allow transfer of water from cover levels of manholes to the surface water sewer network beneath. The network is based on the topographic survey in Appendix A.
- 4.5.2 The pipe network has entrance and exit losses applied as recommended within the TUFLOW manual.

4.6 Boundary conditions

4.6.1 Inflows and outflows:

- 4.6.2 The rainfall boundary was set over the entire 2D model area, which has been configured to be larger than the FEH catchment area to ensure that any errors in the delineation of the FEH catchment are excluded.
- 4.6.3 Head/time boundaries have been applied at the downstream extent of both pipe exits that drain to the north west of the catchment in the 1D domain. The elevations of both of these boundaries have been set to be just above the soffit level of the pipes (9803a at 103.83mAOD and 8805 at 103.34mAOD). This allows representation of a full pipe as the downstream boundary condition, in order to provide a conservative estimate of flows on the site.
- 4.6.4 A head/flow boundary has been applied at the North-western boundary of the catchment to drain the flow as it will continue to flow down the slope. An average gradient was calculated and applied.

4.7 Initial conditions

- 4.7.1 The 2D domain starts completely dry.
- 4.7.2 The 1D downstream water level boundaries have been set so the pipes are full.

4.8 Simulation parameters

- 4.8.1 All simulation parameters have been left at their default values. The model time-step has been set to be 0.5 seconds for the 2D domain and 0.25 seconds for the 1D domain. This is in-line with the TUFLOW manual recommendations on appropriate time-steps (which states that "2D time-step in seconds should be somewhere between 1/2 to 1/5 of the 2D cell size in metres" and the 1D time-step is recommended as being half that of the 2D domain in linked simulations).

4.9 Model sensitivity runs

- 4.9.1 In any modelling exercise there are associated uncertainties. Often it is desirable to calibrate/verify the model to observed data, in order to either refine the selected schematisation/parameters or to demonstrate that they produce reasonable results by showing fit to the observed data.

- 4.9.2 In this instance there is no observed data to fit for either calibration or verification. Instead, a number of sensitivities have been undertaken in order to assess the impact upon results that selecting different parameters or schematisation might have. It should be stressed that reasonable values and schematisation have been selected in all cases as the baseline case, in line with best practice; however, by adjusting these values a measure of confidence in the outputs might be obtained in the face of uncertainties.

4.9.3 Storm durations

- 4.9.4 The sensitivities applied in this model are to run different storm durations to see how this impacts upon the results of the model.

5 Modelled scenarios

5.1 Baseline model scenario

- 5.1.1 The baseline model is a representation of the existing school sports facilities.
- 5.1.2 It includes all the parameters described in sections 3 and 4, with the existing sports centre facilities represented using finished floor levels based on the plan drawings.

5.2 Post development model scenario

- 5.2.1 The post development model is a representation of the proposed sports facilities and proposed flood mitigation options.
- 5.2.2 It includes all the parameters described in sections 3 and 4, with the proposed sports centre facilities represented using finished floor levels based on the proposed plans. The lowest finished floor level in the proposed most northerly building is 106.4mAOD.
- 5.2.3 The flood mitigation options for this scenario are shown in Figure 5.1 and include:
- An amphitheatre which doubles as a flood storage attenuation area with ground levels set to 107.5mAOD at the lowest level.
 - A bund set to 110mAOD surrounding the southerly sports facility buildings in order to prevent the main flow route from the south-east flooding the buildings.
 - Ground levels around the most northerly buildings are set to 106.00mAOD as indicate by the architectural plans. There is a proposed extra gully to help drain this area.
 - An existing swale has been diverted through the proposed all weather sports pitch area.

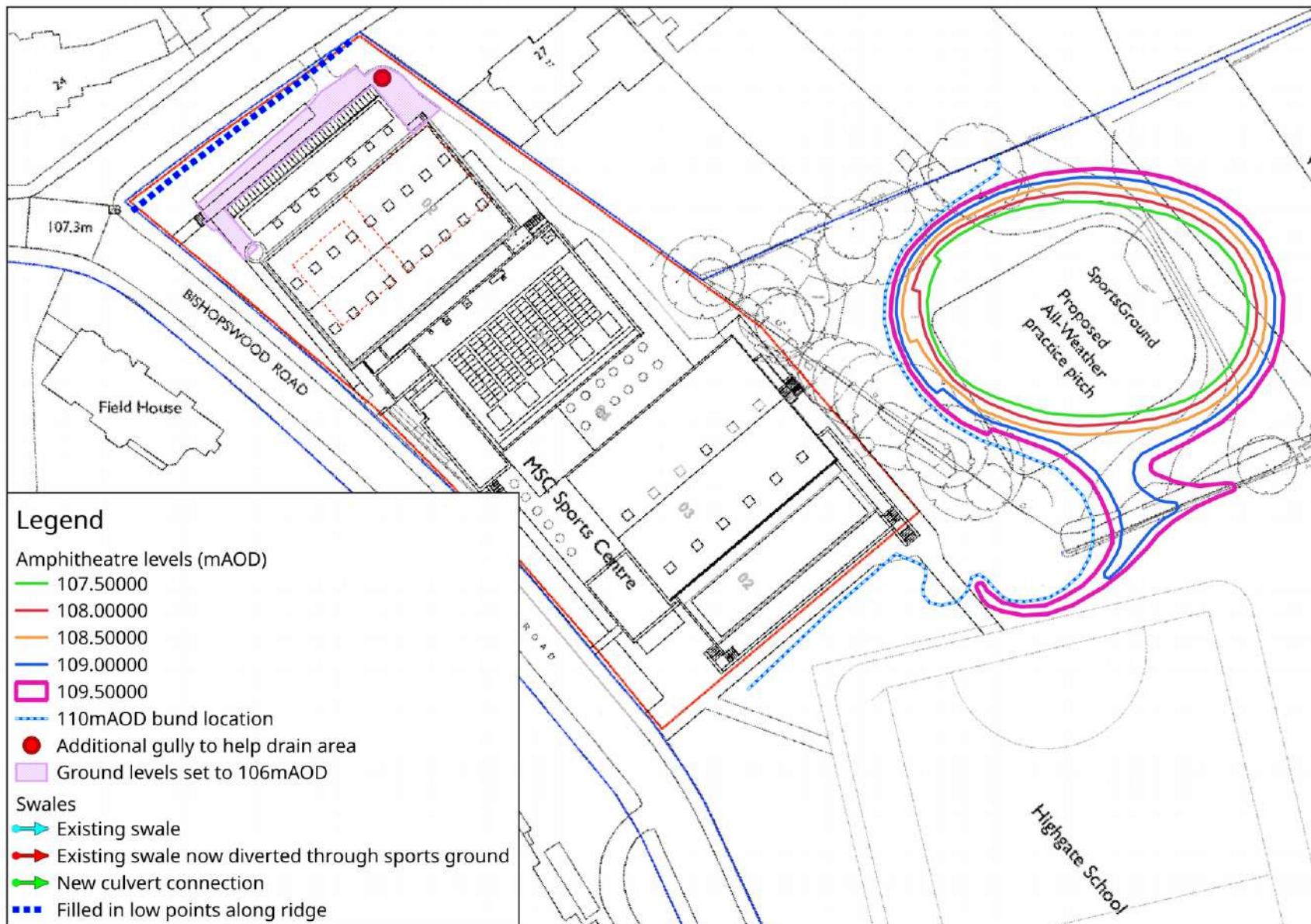


Figure 5.1: Proposed flood mitigation measures

6 Model strengths and limitations

6.1 Strengths

- 6.1.1 The model has been built in line with current best practice, including undergoing model review. A range of sensitivities on storm duration have been undertaken to assess the impact of changing such parameters to see if they have any significant effect on model results which could alter the conclusions of the study.
- 6.1.2 These show that storm duration is not a critical issue in terms of evaluating flood depths for the 3.5 hour, 4.5 hour and 5.5 hour rainfall events. The maximum change in depth in the site of interest is between a 3.5 hour and 5.5 hour simulation is less than 0.1m.

6.2 Limitations

- 6.2.1 The modelling includes simplifications associated with the schematisation of the astro-turf sports pitch. This is considered conservative, as a more accurate representation of the astro-turf drainage would account for additional flood storage volume.
- 6.2.2 Certain surface water pipes shown on the topographic survey are stated as “assumed connection from records”. As no diameter or invert levels were recorded, the modelling has assumed their diameters as the same as any pipes they are connected to. As an example, modelled pipes SW8805 and SWSTN102d are assumed as being 450mm in diameter (based on the known connecting pipes), with invert levels based on nearest known inverts.

7 Results

7.1 Overview

- 7.1.1 The following sections focus on the mapping results for the 1 in 100 year + 20% climate change design event with a 5.5 hour critical storm drainage duration.
- 7.1.2 As this is a rainfall model, all depth mapping uses a 10cm “cut off” depth which means depths below 10cm are not shown.
- 7.1.3 Flood depth and hazard mapping for all the remaining modelled return periods for the pre and post development scenarios are shown in Appendix B.
- 7.1.4 The sensitivity results are shown in Appendix C.
- 7.1.5 When there is discussion on water level sample points, the location of sample point 1 is shown below in Figure 7.1:

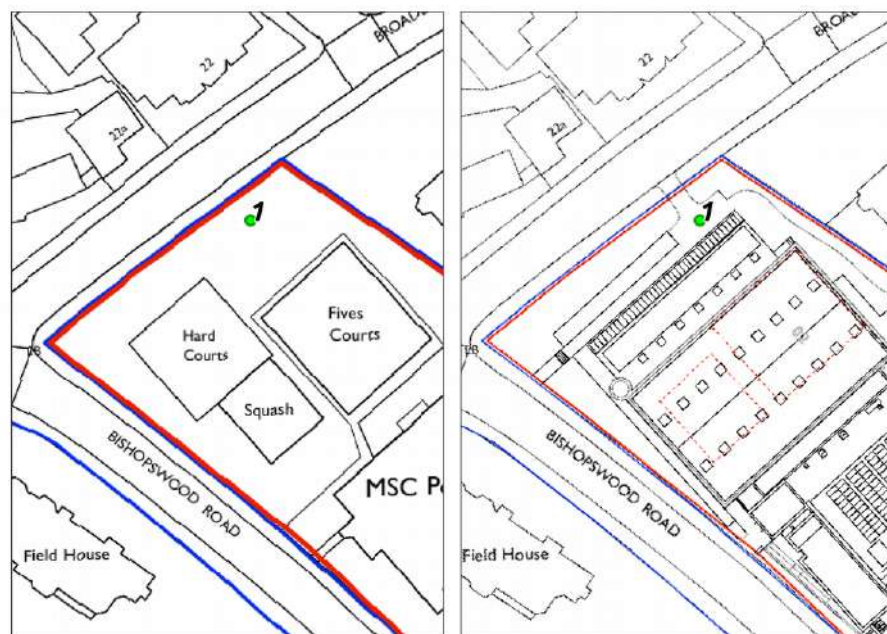
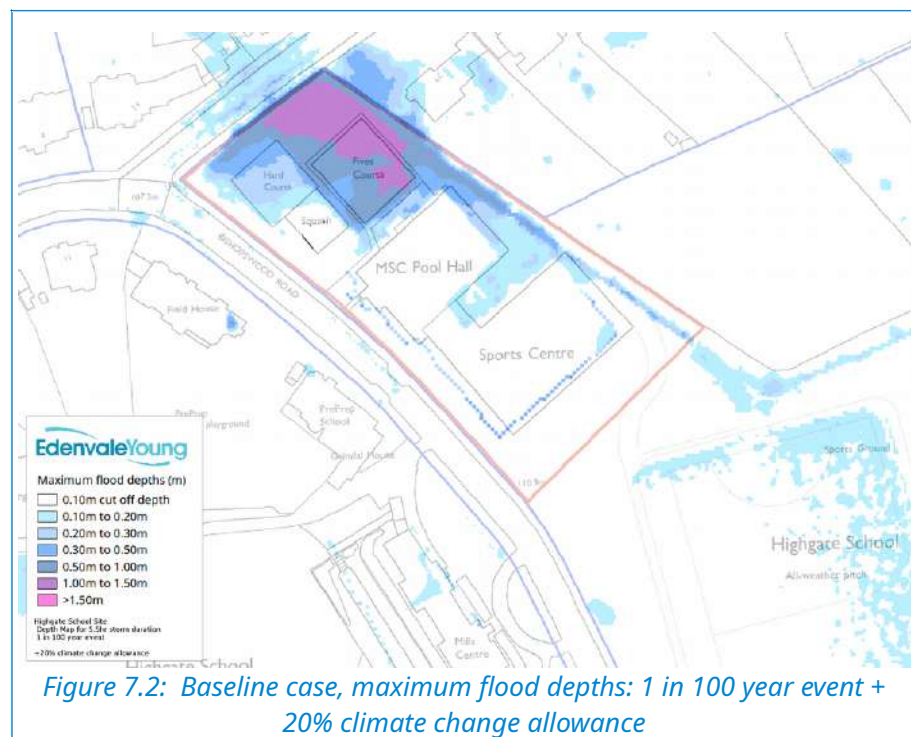


Figure 7.1: Point sample location 1

7.2 Baseline scenario

7.2.1 The modelling indicates that surface water run-off flows from the east and south-east towards the Sports Hall, accumulates in the depression upstream of Broadlands Road and that parts of the existing development are vulnerable to surface water flooding in all modelled return periods.

7.2.2 Figure 7.2 shows the modelled flood depths at the site for the 1 in 100 year event with climate change allowances of 20%. The modelling indicates that the maximum depth is approximately 1.27m for this event, with an equivalent water level of 106.89mAOD at sample point 1.



7.2.3 Flood depth maps for the 1 in 30, 1 in 100 year event, 1 in 100 year event with 40% climate change allowance and 1 in 1000 year event are presented in Appendix B. The modelled water levels and depths at sample point 1 are given in the following table:

Event	Maximum modelled flood level (mAOD)	Maximum modelled depth (m)
1 in 30	105.99	0.38
1 in 100	106.78	1.16
1 in 100 +20% CC	106.89	1.27
1 in 100 +40% CC	106.95	1.33
1 in 1000	106.99	1.37

Table 7.1: Modelled flood levels and depths at sample point 1

7.2.4

The survey drawings indicate that the finished floor levels in the existing swimming pool are 106.86mAOD and there is no risk to the existing swimming pool at 1 in 30 years but if the threshold levels at the entrance are less than the peak water levels shown in the table then there could be a risk of inundation at higher return periods.

7.3 Post development scenario

- 7.3.1 The proposed flood mitigation measures intercept the surface water run-off and direct it to be stored in amphitheatre.
- 7.3.2 Figure 7.3 shows the modelled flood depths at the site for the 1 in 100 year event with climate change allowances of 20%. The modelling indicates that the maximum depth is approximately 0.40m for this event, with an equivalent water level of 106.40mAOD at sample point 1.
- 7.3.3 This is below the proposed finished floor level of 106.40mAOD and therefore the proposed new development should be free from flooding in this event.

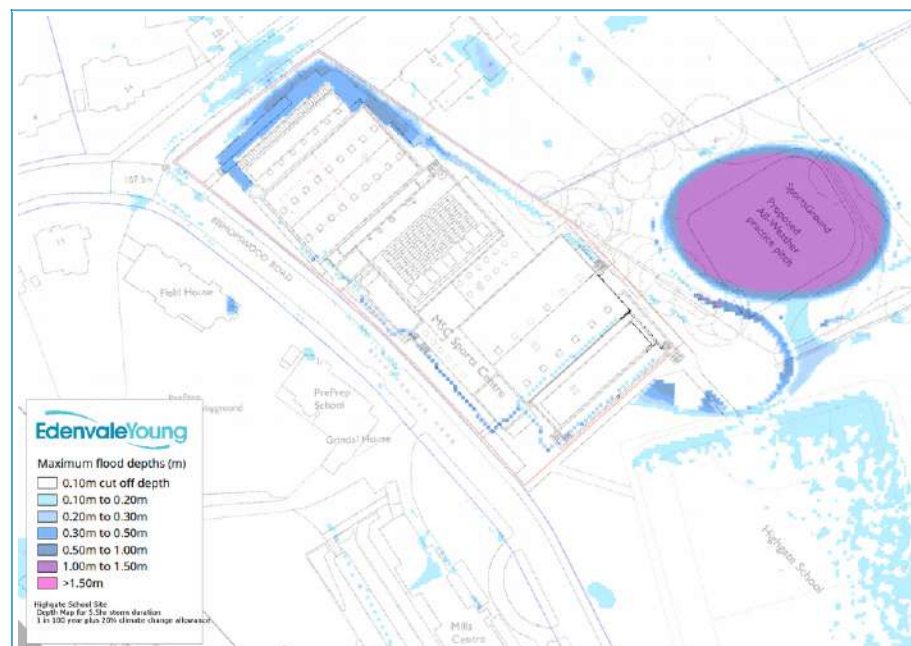


Figure 7.3: Post development scenario, maximum flood depths: 1 in 100 year event + 20% climate change allowance

- 7.3.4 Flood depth maps for the 1 in 30, 1 in 100 year event, 1 in 100 year event with 40% climate change allowance and 1 in 1000 year event are presented in Appendix B. The modelled water levels and depths at sample point 1 are given in the following table:

Event	Maximum modelled flood level (mAOD)	Maximum modelled depth (m)
1 in 30	106.05	0.05
1 in 100	106.22	0.23
1 in 100 +20% CC	106.40	0.40
1 in 100 +40% CC	106.62	0.62
1 in 1000	106.77	0.77

Table 7.2: Modelled flood levels and depths at sample point 1

7.3.5 Despite the extensive mitigation measures, the modelled water levels indicate that the proposed sports centre will be at risk of internal flooding in a 1 in 100 year event with 40% climate change allowance and a 1 in 1000 year event, as the flood levels are above the finished floor level of 106.4mAOD.

7.3.6 The downstream flood impact of the proposed new sports facilities and mitigation measures have also been assessed for the 1 in 100 year +20% climate change design event. The result has been presented as 'water level difference' map between the proposed post development scenario and the modelled existing condition (see Figure 7.4). On the mapping the colours indicate:

- Blue to green shows a reduction in peak flood level as a result of the mitigation options.
- Yellow to red shows an increase in peak flood level as a result of the mitigation options.
- White indicates "No change".

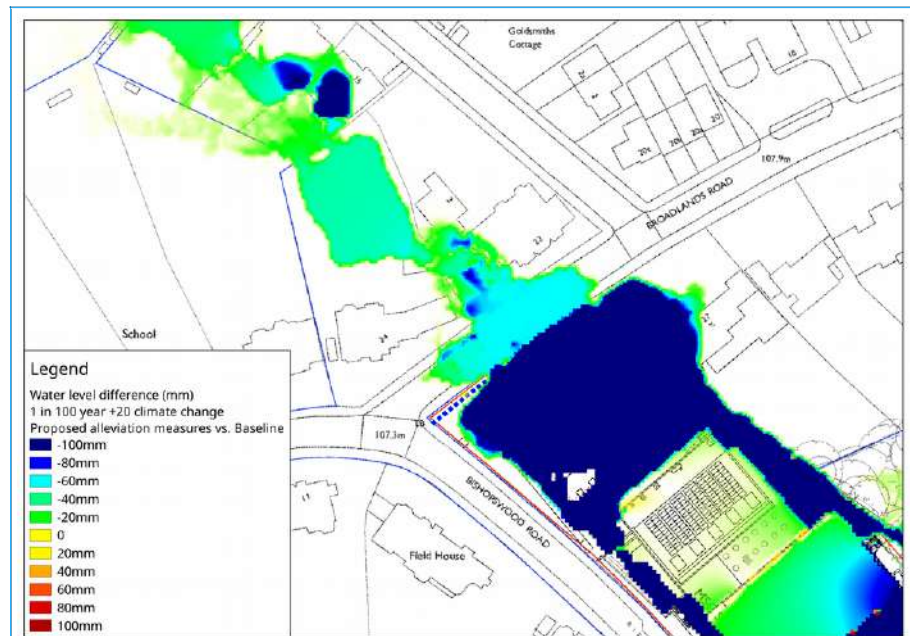


Figure 7.4: Water level difference mapping between the proposed post development scenario and existing case

- 7.3.7 As shown above, the proposed mitigation options not only benefit the school but also those downstream, through reducing flood depths by up to 100mm in the 1 in 100 year +20% climate change event.

7.4 Sensitivity results

- 7.4.1 The depth and hazard mapping can be found in Appendix C.
- 7.4.2 The water levels for the 3 modelled storm durations for the 1 in 100 year event are shown in the table below:

Storm duration	Baseline Water level (mAOD)	Proposed water level (mAOD)
3.5	106.66	106.06
4.5	106.74	106.07
5.5	106.78	106.07

Table 7.3: Storm duration sensitivity

- 7.4.3 The model is not very sensitive to storm duration, as shown above.

8 Conclusions and recommendations

8.1 Conclusions

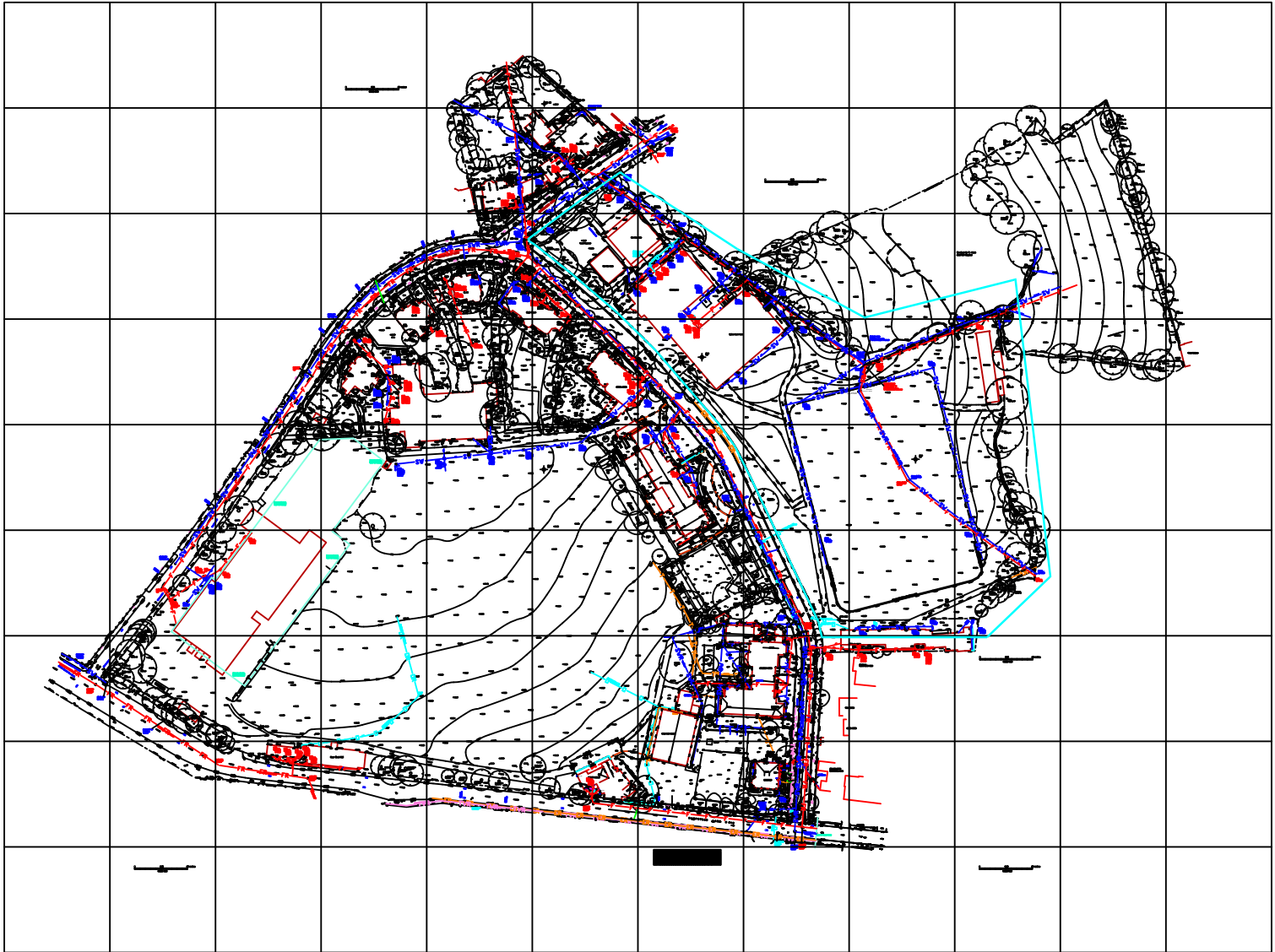
- 8.1.1 A hydraulic model has been constructed of the Highgate school catchment using industry standard ESTRY TUFLOW software to assess surface water flooding at the existing sports facilities and for the proposed sports facilities.
- 8.1.2 As part of the new sports facility development, various flood mitigation options have been proposed, which include:
- An amphitheatre which doubles as a flood storage attenuation area with ground levels set to 107.5mAOD at the lowest level.
 - A bund set to 110mAOD surrounding the southerly sports facility buildings to protect them from surface water run-off
 - Ground levels around the most northerly buildings are set to 106.00mAOD as indicated by the plans. There is a proposed extra gully to help drain this area.
 - An existing swale has been diverted through the proposed all weather sports pitch area.
- 8.1.3 The latest modelling has demonstrated that:
- The modelled flood mitigation options are effective at preventing internal flooding to the school up to and including the 1 in 100 year design event + 20% climate change. They also provide a benefit for those downstream of the school, with a reduction in flood level of up to 100mm.
 - The flood level for the 1 in 100 year design event + 20% climate change is 106.40mAOD at the northern end of the site. This is the same as the proposed finished floor level of 106.40mAOD, so there is no internal flooding for this event.
 - The proposed sports facilities are at risk of flooding in the 1 in 100 year event + 40% climate change and the 1 in 1000 year event.

8.2 Recommendations

- 8.2.1 The following recommendations are considered appropriate:
- If possible, lowering the ground levels below 106.00mAOD around the northern proposed buildings would be effective in providing more freeboard between the finished floor level of 106.40mAOD and the design flood level.
 - Provision of flood doors at the entrance to buildings in conjunction with ensuring that the building is sealed at pipe entrance points will provide further flood resilience.

Appendix A

Topographic survey undertaken by Randall Surveys LLP in January 2016.



Appendix B

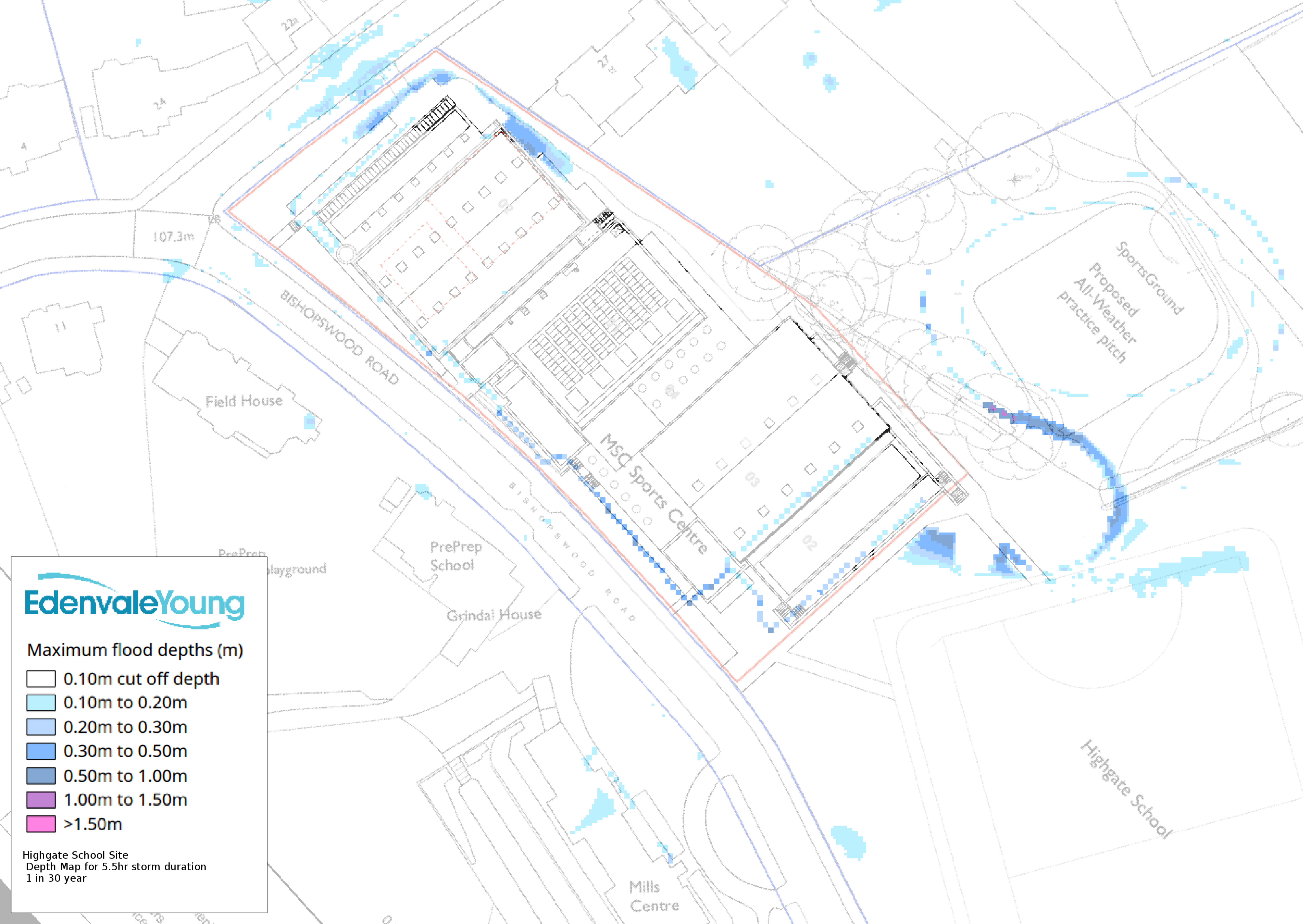
Flood depth and hazard mapping.



Maximum flood depths (m)

- 0.10m cut off depth
- 0.10m to 0.20m
- 0.20m to 0.30m
- 0.30m to 0.50m
- 0.50m to 1.00m
- 1.00m to 1.50m
- >1.50m

Highgate School Site
Depth Map for 5.5hr storm duration
1 in 30 year

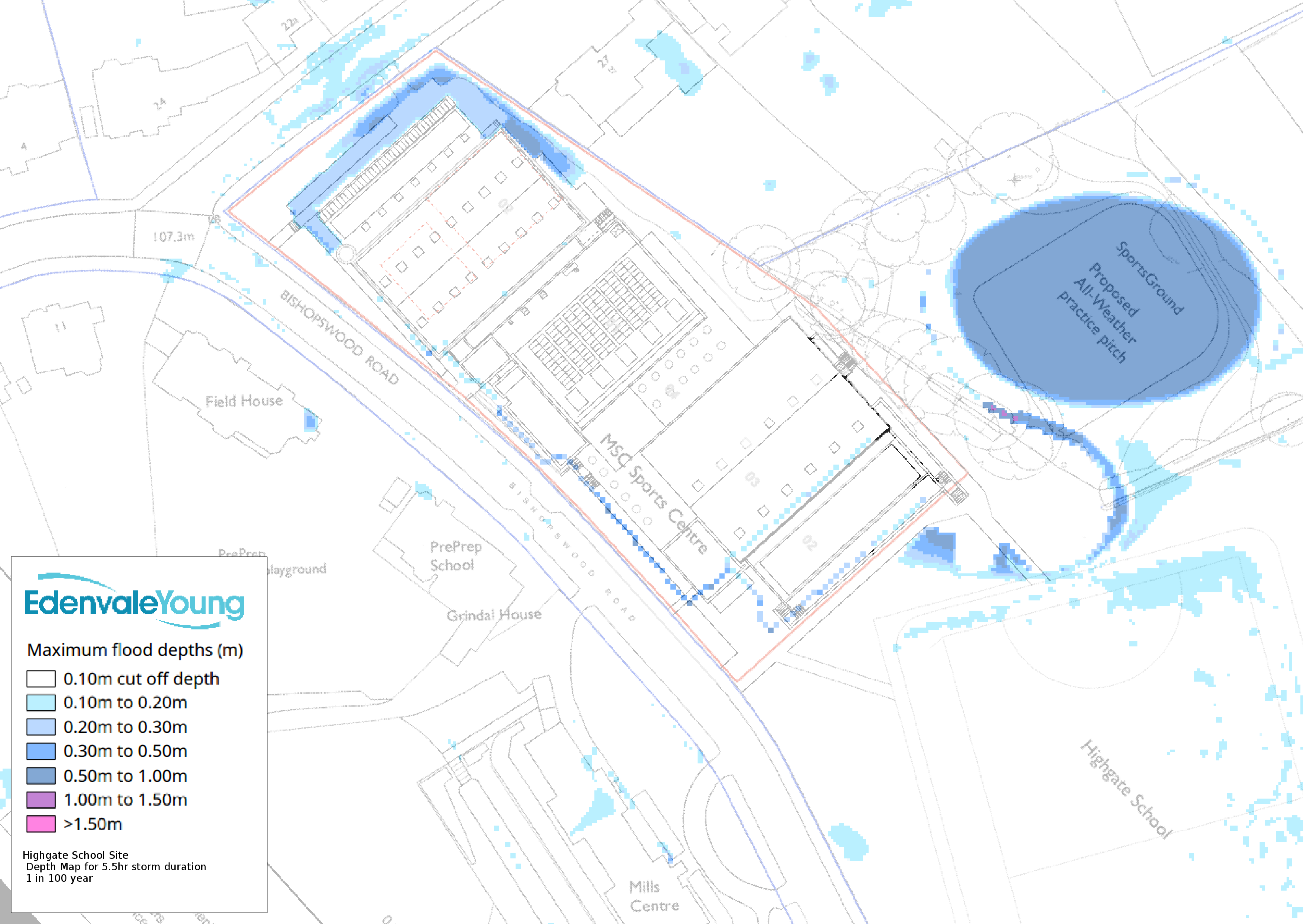




Maximum flood depths (m)

- 0.10m cut off depth
- 0.10m to 0.20m
- 0.20m to 0.30m
- 0.30m to 0.50m
- 0.50m to 1.00m
- 1.00m to 1.50m
- >1.50m

Highgate School Site
Depth Map for 5.5hr storm duration
1 in 100 year

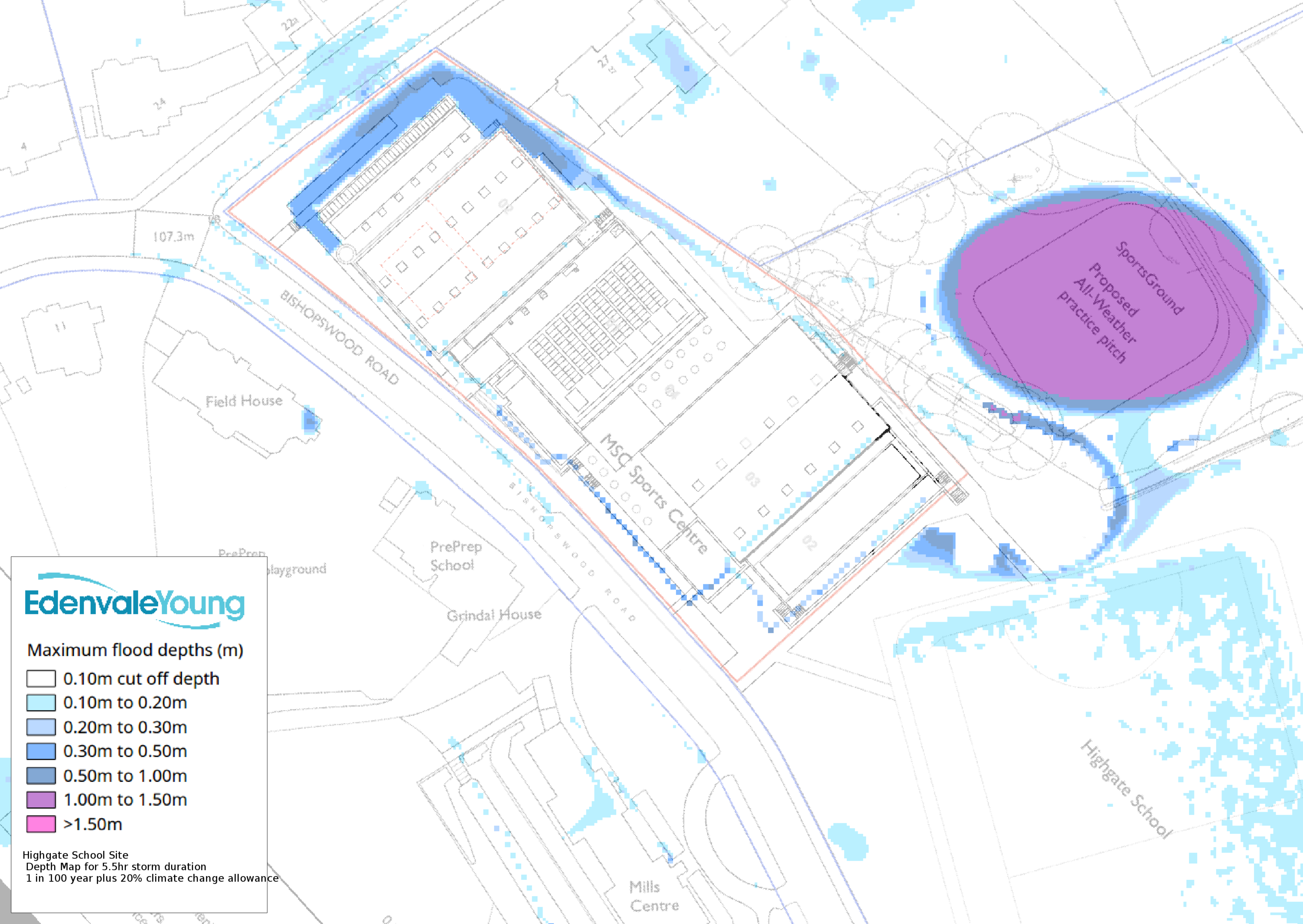


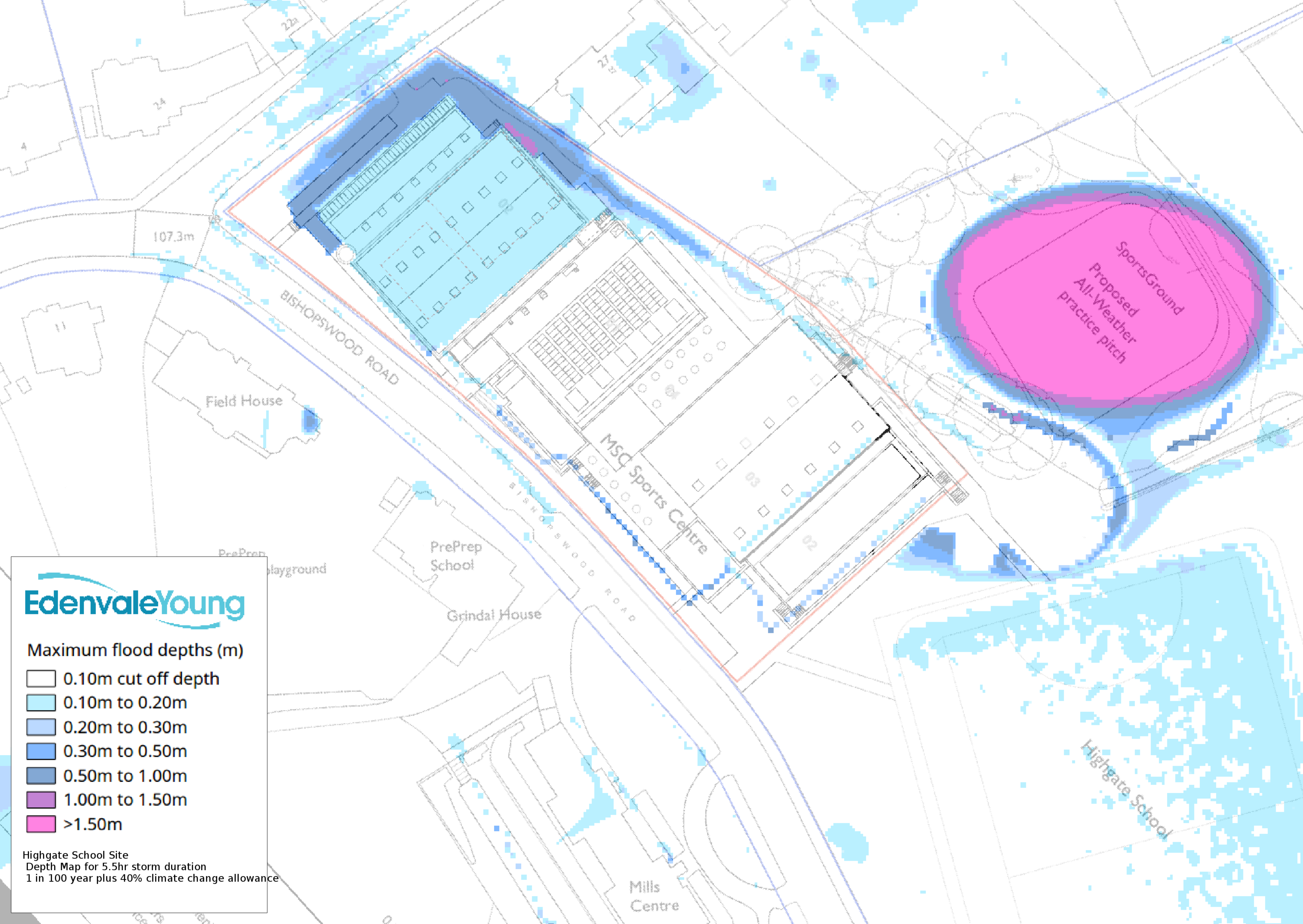


Maximum flood depths (m)

- 0.10m cut off depth
- 0.10m to 0.20m
- 0.20m to 0.30m
- 0.30m to 0.50m
- 0.50m to 1.00m
- 1.00m to 1.50m
- >1.50m

Highgate School Site
Depth Map for 5.5hr storm duration
1 in 100 year plus 20% climate change allowance





Maximum flood depths (m)

- 0.10m cut off depth
- 0.10m to 0.20m
- 0.20m to 0.30m
- 0.30m to 0.50m
- 0.50m to 1.00m
- 1.00m to 1.50m
- >1.50m

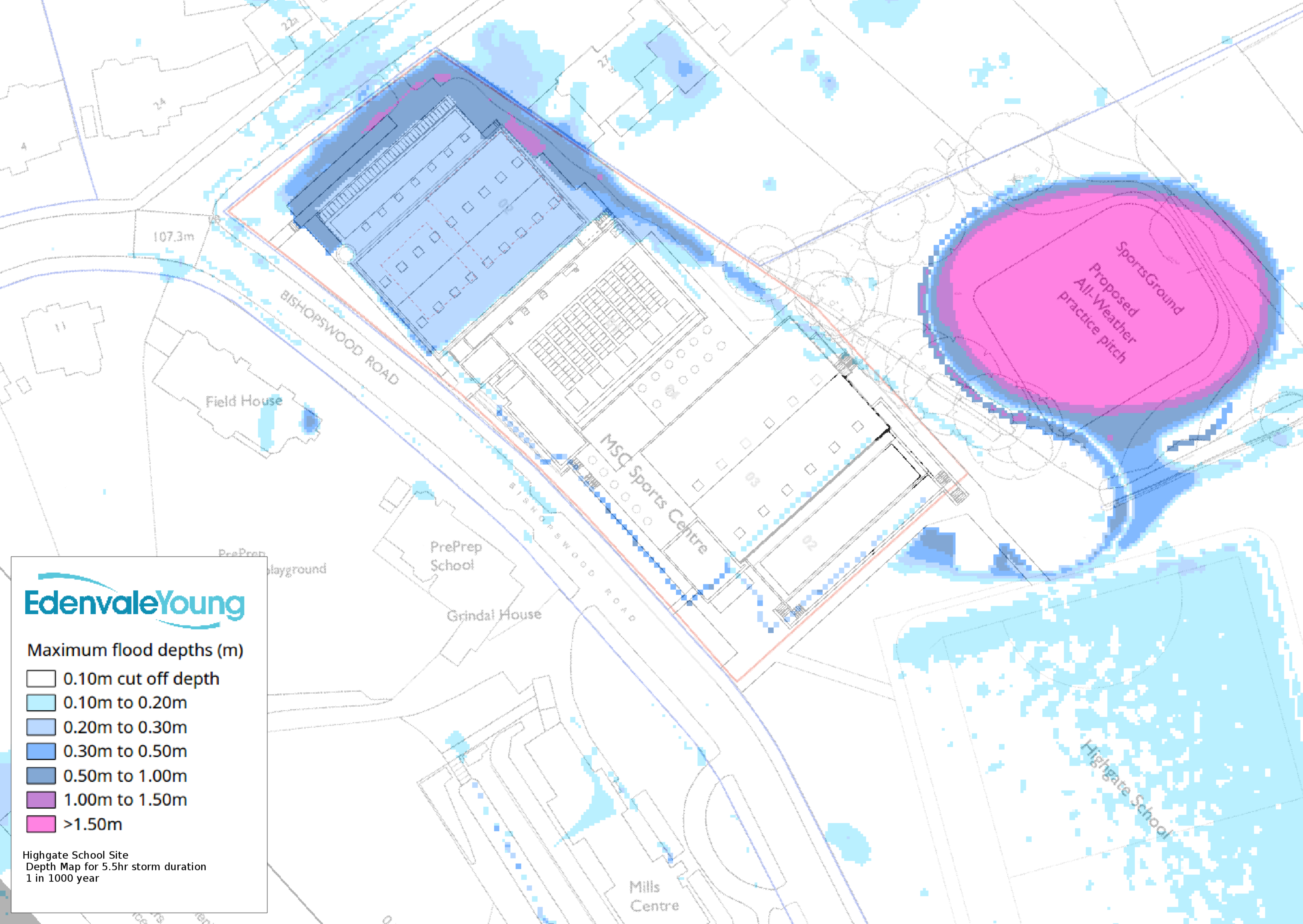
Highgate School Site
Depth Map for 5.5hr storm duration
1 in 100 year plus 40% climate change allowance

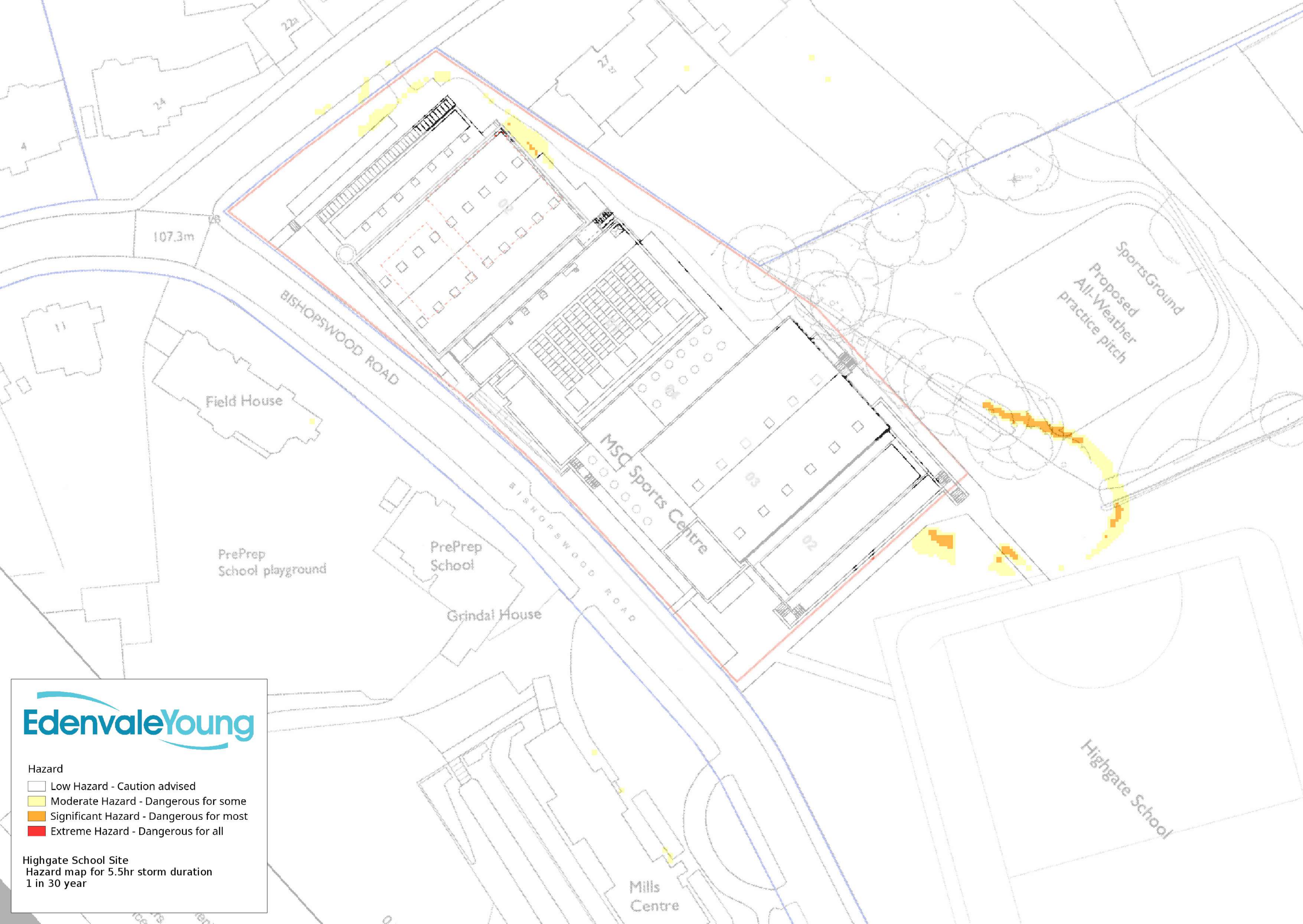


Maximum flood depths (m)

- 0.10m cut off depth
- 0.10m to 0.20m
- 0.20m to 0.30m
- 0.30m to 0.50m
- 0.50m to 1.00m
- 1.00m to 1.50m
- >1.50m

Highgate School Site
Depth Map for 5.5hr storm duration
1 in 1000 year



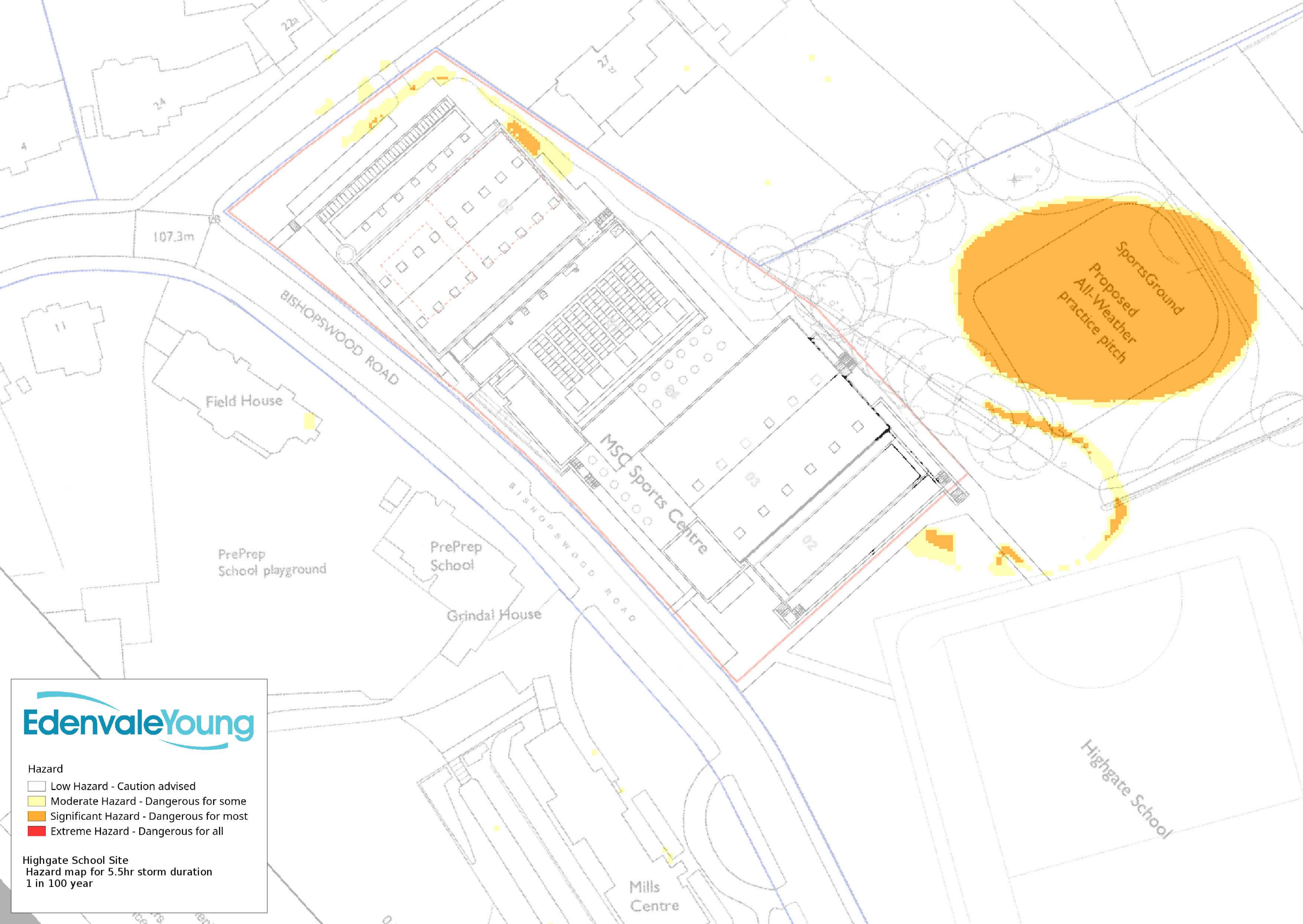


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Hazard

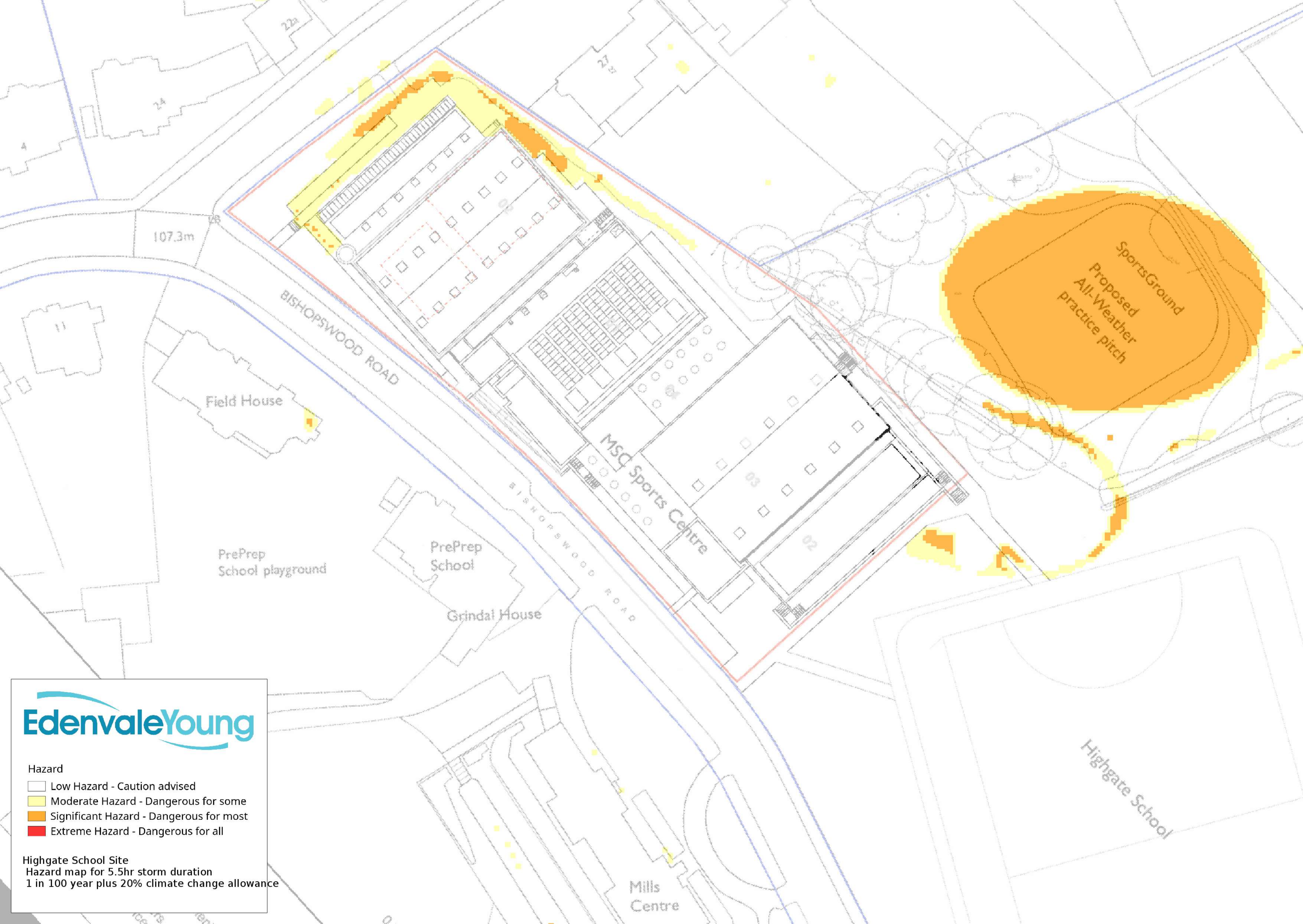
- Low Hazard - Caution advised
- Moderate Hazard - Dangerous for some
- Significant Hazard - Dangerous for most
- Extreme Hazard - Dangerous for all

Highgate School Site
Hazard map for 5.5hr storm duration
1 in 30 year



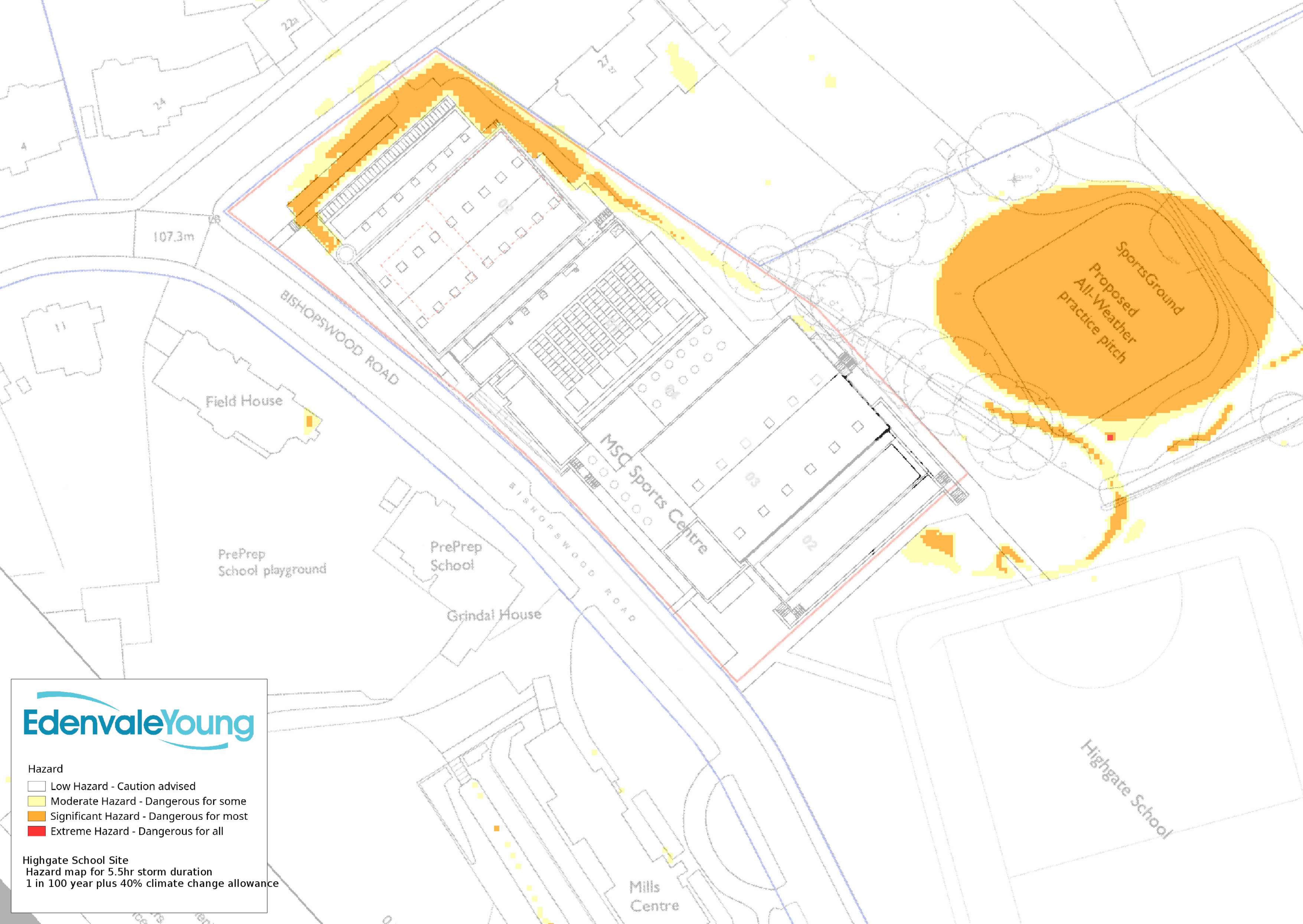
- Hazard
- Low Hazard - Caution advised
 - Moderate Hazard - Dangerous for some
 - Significant Hazard - Dangerous for most
 - Extreme Hazard - Dangerous for all

Highgate School Site
Hazard map for 5.5hr storm duration
1 in 100 year



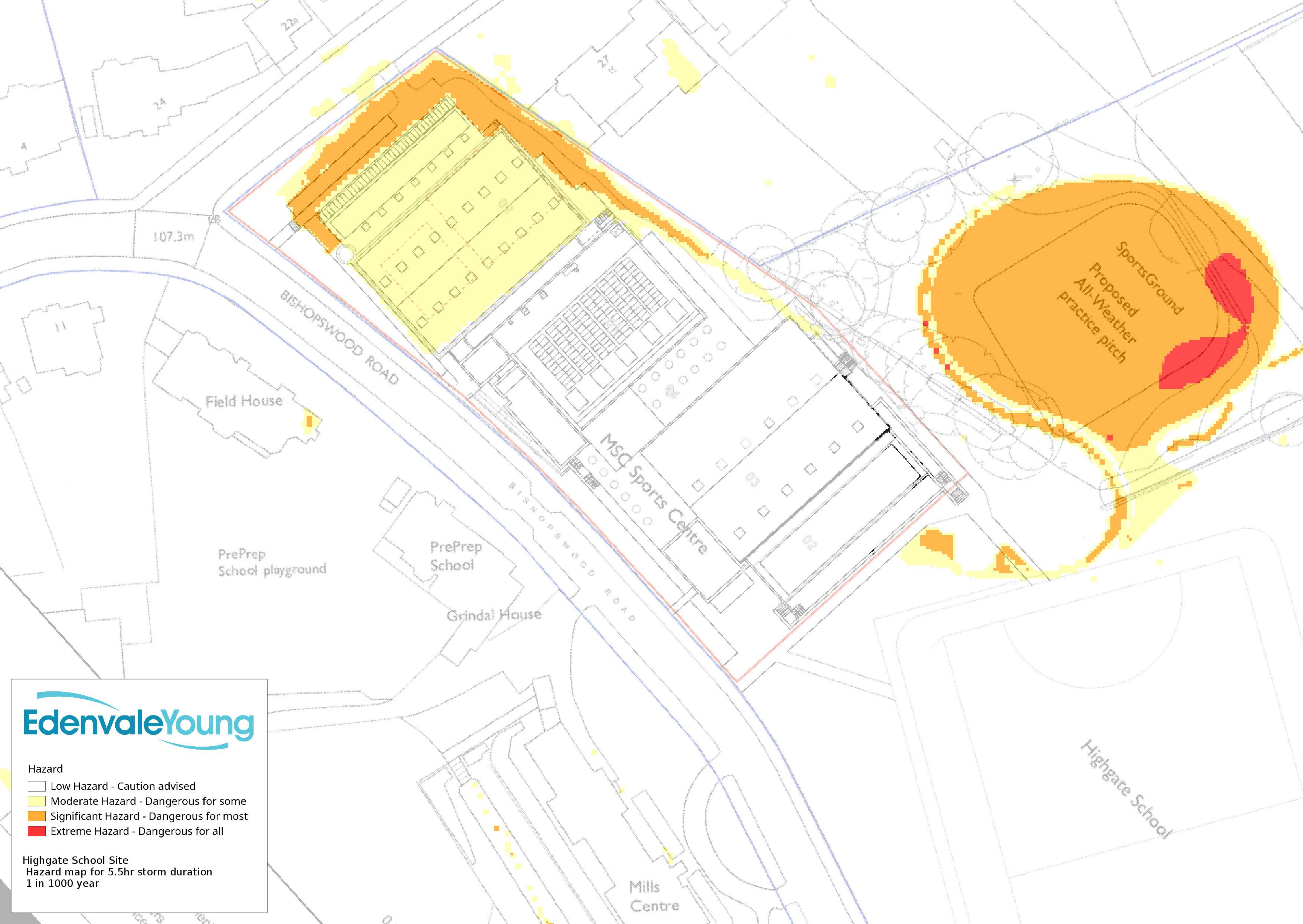
- Hazard
- Low Hazard - Caution advised
 - Moderate Hazard - Dangerous for some
 - Significant Hazard - Dangerous for most
 - Extreme Hazard - Dangerous for all

Highgate School Site
Hazard map for 5.5hr storm duration
1 in 100 year plus 20% climate change allowance



- Hazard
- Low Hazard - Caution advised
 - Moderate Hazard - Dangerous for some
 - Significant Hazard - Dangerous for most
 - Extreme Hazard - Dangerous for all

Highgate School Site
Hazard map for 5.5hr storm duration
1 in 100 year plus 40% climate change allowance



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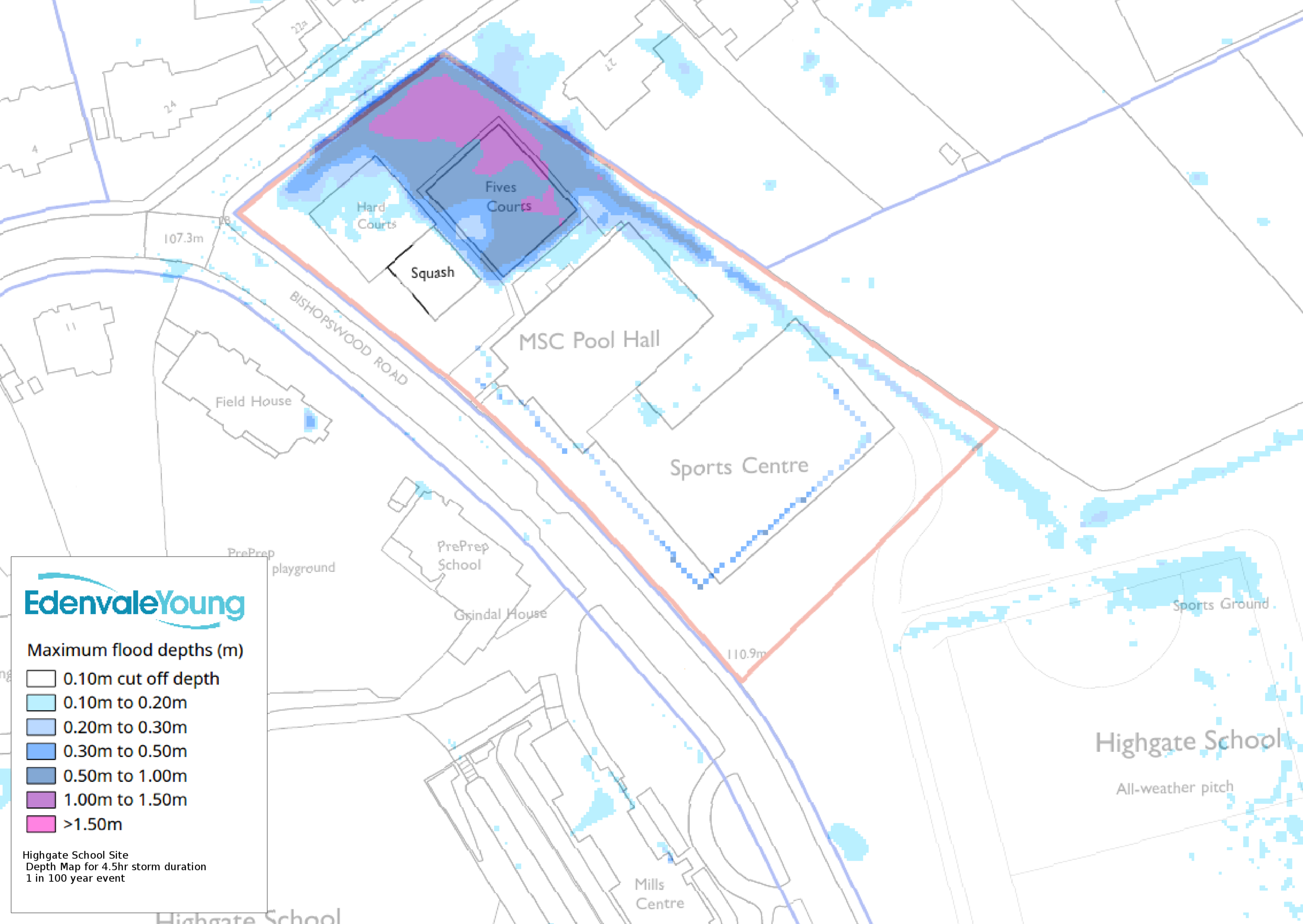
- Hazard
- Low Hazard - Caution advised
 - Moderate Hazard - Dangerous for some
 - Significant Hazard - Dangerous for most
 - Extreme Hazard - Dangerous for all

Highgate School Site
Hazard map for 5.5hr storm duration
1 in 1000 year

Appendix C

Sensitivity results.



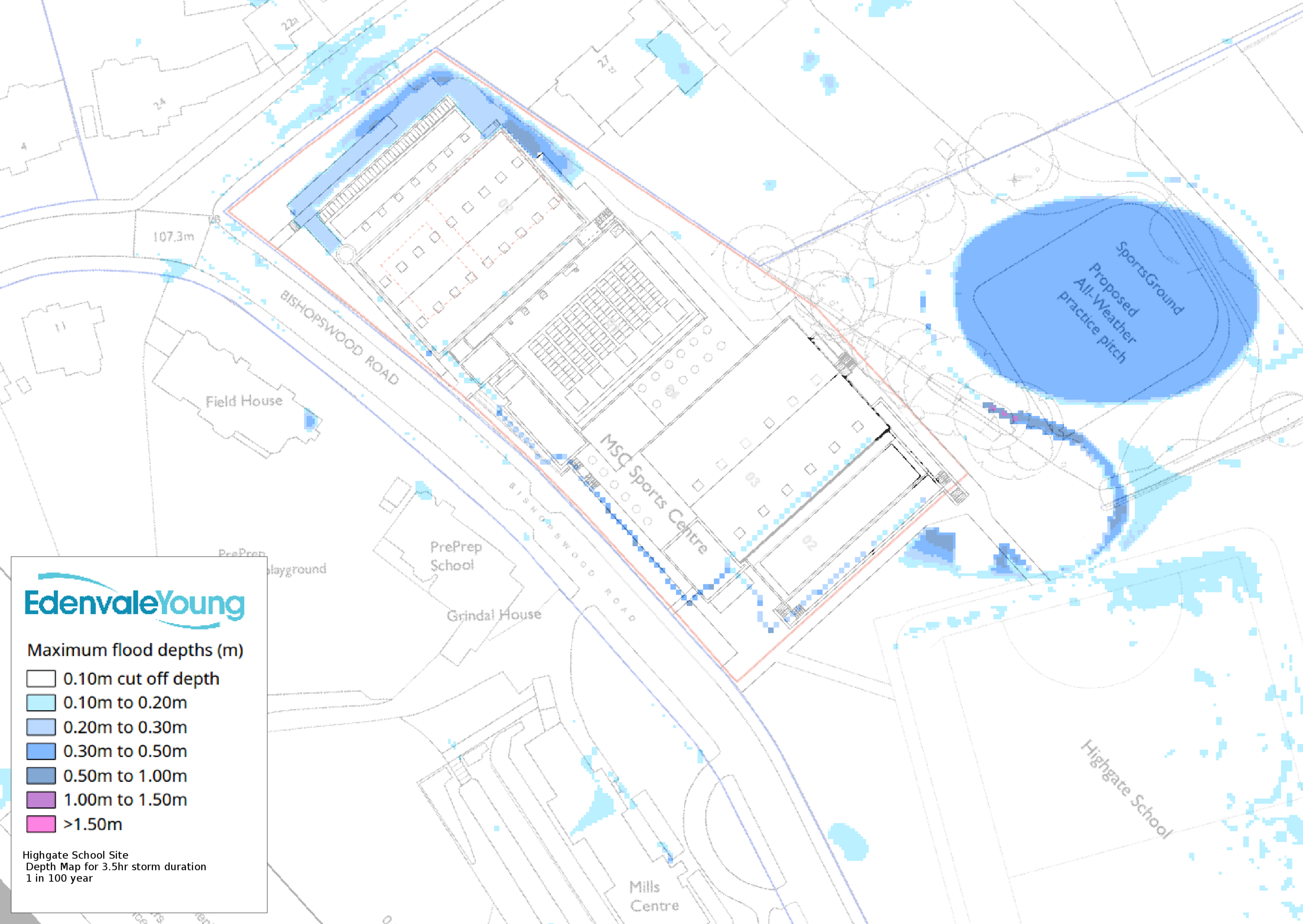




Maximum flood depths (m)

- 0.10m cut off depth
- 0.10m to 0.20m
- 0.20m to 0.30m
- 0.30m to 0.50m
- 0.50m to 1.00m
- 1.00m to 1.50m
- >1.50m

Highgate School Site
Depth Map for 3.5hr storm duration
1 in 100 year

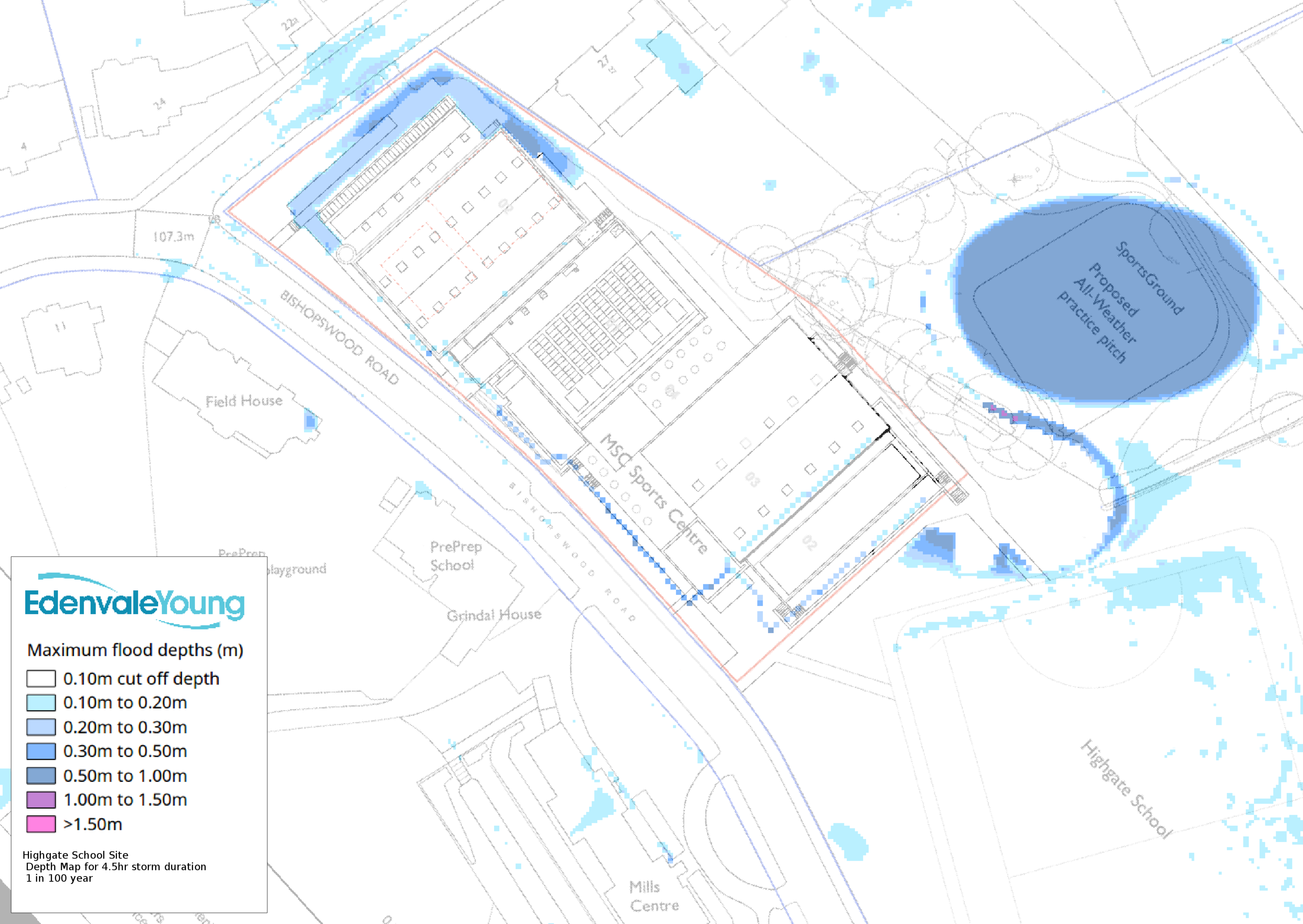




Maximum flood depths (m)

- 0.10m cut off depth
- 0.10m to 0.20m
- 0.20m to 0.30m
- 0.30m to 0.50m
- 0.50m to 1.00m
- 1.00m to 1.50m
- >1.50m

Highgate School Site
Depth Map for 4.5hr storm duration
1 in 100 year



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