APPENDIX F

Micro drainage storage estimate outputs with 40% climate change allowance and 50% drain down time

Drainage Zone	Drainage Sub-Zone	Infiltration Rate (m/hr)	Average Attenuation Storage Requirement, including 40% climate change allowance (m^3)		SuDS Space Requirement with 1.0m Average Depth (ha)		Available Strategic SuDS Space on Site (ha)	SuDS Area Surplus/ Shortfall for 1 in 100 annual chance(ha)	1 in 100 annual chance 50% Drain-down Time (hrs)
			1 in 100 annual chance	1 in 30 annual chance	1 in 100 annual chance	1 in 30 annual chance			
Westenhanger	DR-WH1	0.00000	16,436	12,374	2.14	1.61	4.80	2.66	23.2
	DR-WH2	0.00000	27,765	20,896	3.61	2.72	2.83	-0.78	42.2
	DR-WH3	0.00000	10,927	8,235	1.42	1.07	1.55	0.13	49.5
	DR-WH4	0.00000	8,168	6,151	1.06	0.80	2.03	0.97	23.9
	DR-WH5	0.00000	7,540	5,677	0.98	0.74	0.91	-0.07	41.5
East Otterpool	DR-EO1	0.00763	14,284	10,245	1.86	1.33	2.86	1.00	16.6
	DR-E02	0.00156	6,343	4,427	0.82	0.58	1.98	1.15	19.8
	DR-EO3	0.00156	4,391	30,69	0.57	0.40	0.73	0.16	15.1
	DR-EO4	0.00156	8,260	5,771	1.07	0.75	1.74	0.67	48.5
	DR-EO5	0.00763	0	0	0.00	0.00		0.00	0.0
West Newingreen	DR-WN1	0.00000	12,667	9,543	1.65	1.24	0.85	-0.80	32.7
	DR-WN2	0.00000	7,779	5,864	1.01	0.76	0.64	-0.37	55.0
East Triangle	DR-ET1	0.00006	6,658	5,009	0.87	0.65	0.80	-0.07	35.5
	DR-ET2	0.00006	29,890	22,477	3.89	2.92	3.52	-0.36	43.9

Drainage Zone	Drainage Sub-Zone	Infiltration Rate (m/hr)	Average Attenuation Storage Requirement, including 40% climate change allowance (m^3)		SuDS Space Requirement with 1.0m Average Depth (ha)		Available Strategic SuDS Space on Site (ha)	SuDS Area Surplus/ Shortfall for 1 in 100 annual chance(ha)	1 in 100 annual chance 50% Drain-down Time (hrs)
			1 in 100 annual chance	1 in 30 annual chance	1 in 100 annual chance	1 in 30 annual chance			
East Triangle South	DR-ETS	0.00006	7,348	5,526	0.96	0.72	0.89	-0.07	36.3
South Otterpool	DR-S01	0.00763	8,907	6,391	1.16	0.83	2.35	1.19	15.8
	DR-SO2	0.00763	15,731	11,292	2.05	1.47	2.90	0.85	19.2
	DR-S03	0.00763	3,751	2,693	0.49	0.35	0.80	0.31	18.4
	DR-S04	0.00763	4,984	3,574	0.65	0.46	0.32	-0.33	26.9
	DR-S05	0.00763	2,082	1,498	0.27	0.19	0.78	0.51	11.9
	DR-S06	0.00763	0	0	0.00	0.00		0.00	0.0
West Otterpool	DR-WO1	0.00075	20,452	14,143	2.66	1.84	3.07	0.41	45.9
	DR-W02	0.00075	16,081	11,123	2.09	1.45	1.69	-0.41	49.3
	DR-W03	0.00075	18,326	12,668	2.38	1.65	5.39	3.01	45.9
	DR-W04	0.00075	8,293	57,26	1.08	0.74	1.01	-0.07	77.1
Barrow Hill	DR-BH1	0.01555	3,404	2,431	0.44	0.32	0.98	0.54	7.1
	DR-BH2	0.01555	2,838	2,023	0.37	0.26	0.32	-0.05	10.0
	DR-BH3	0.01555	12,147	8,669	1.58	1.13	2.62	1.04	10.9
	DR-BH4	0.01555	6,008	4,285	0.78	0.56	1.44	0.66	8.0
	DR-BH5	0.01555	1,176	840	0.15	0.11	0.01	-0.15	6.3
	DR-BH6	0.01555	11,082	7,908	1.44	1.03	2.33	0.89	11.1
	DR-BH7	0.01555	4,643	3,314	0.60	0.43	1.57	0.97	6.8

Drainage Zone	Drainage Sub-Zone	Infiltration Rate (m/hr)	Average Attenuation Storage Requirement, including 40% climate change allowance (m^3)		SuDS Space Requirement with 1.0m Average Depth (ha)		Available Strategic SuDS Space on Site (ha)	SuDS Area Surplus/ Shortfall for 1 in 100 annual chance(ha)	1 in 100 annual chance 50% Drain-down Time (hrs)
			1 in 100 annual chance	1 in 30 annual chance	1 in 100 annual chance	1 in 30 annual chance			
	DR-BH8	0.01555	0	0	0.00	0.00	0.04	0.04	0.0
	DR-BH9	0.00000	1,508	1,074	0.30	0.14	0.25	0.06	4.3
River Stour	DR-RS1	0.00000	14,238	10,721	1.85	1.39	1.11	-0.75	51.8
	DR-RS2	0.00000	2,583	1,940	0.34	0.25	0.98	0.64	13.9
	DR-RS3	0.00000	9,777	7,359	1.27	0.96	2.93	1.66	37.2
	DR-RS4	0.00000	1,942	1,466	0.25	0.19	0.56	0.31	40.0
	DR-RS5	0.00000	18,780	14,142	2.44	1.84	4.61	2.17	44.7
TOTAL* SITE	**N/A**	**N/A**	**351,177**	**260,536**	**46.43**	**33.87**	**64.15**	**17.72**	**N/A**

* Totals are slightly different to sums of individual values due to rounding effects not shown

APPENDIX G

Drainage strategy summary proforma

1. Site details	
Sie/ development name	Otterpool Park
Address including post code	Stone St, Westenhanger, Hythe CT21 4HX
Grid reference	TR 112 365
LPA reference	Y19/2057/FH
Type of application	Outline ☒ Full ☐ Discharge of Conditions ☐ Other ☐
Has pre-application advice been sought from KCC? If so, KCC Reference Number: Pre-application Meeting Date:	Yes ☒ No ☐ TBC Numerous - first meeting was held on 21/06/2017
Site Condition	Greenfield ☒ Brownfield ☐

2. Existing drainage			Document/ Plan where information is stated:
Total site area (ha)	589		This FRA and DS Document
Impermeable area (ha)	20		
Final discharge location	Infiltration ☒ Watercourse ☒ Sewer ☐ Tidal reach/sea ☐		
Where applicable specify catchment runoff rates:	Greenfield runoff rates (l/s)	Existing brownfield runoff rates (l/s)	
QBAR (l/s)	N/A	N/A	
1 in 1 year (l/s)	0.9	N/A	
1 in 30 year (l/s)	2.1	N/A	
1 in 100 year (l/s)	3.0	N/A	

3. Proposed drainage areas	Document/ Plan where information is stated:

Impermeable area (ha)	Roof	223	
	Highway/road	30	
	Other paved areas	N/A - Included within roof figure above.	
	Total	253	
Permeable area (ha)	Open space	271.0	
	Other permeable areas	65.0	
	Total	336.0	
Final discharge location	Infiltration ☒ Average infiltration rate of all drainage sub-zones given in Appendix F = 0.005088 m/hr Watercourse ☒ Sewer ☐ Tidal reach/sea ☐		This FRA and DS Document
Climate change allowance included within design	20% ☐ 30% ☐ 40% ☒ (this is applied to the rainfall for the purpose of SuDS strategy)		This FRA and DS Document
4. Post-Development Discharge rates, with mitigation			**Document/ Plan where information is stated:**
Describe development drainage strategy in general terms: The surface water drainage strategy consists of a comprehensive SuDS scheme (e.g. soakaways, permeable paving, raingardens, swales, storage ponds, wetlands, detention Basins and infiltration basins) to intercept, treat, convey, infiltrate, store and discharge surface water. This will ensure natural drainage routes are utilised as part of the surface water management strategy.			This FRA and DS Document
(a) Soil type and discharge	Sewer ☐ No off-site discharge i.e. infiltration ☐	Semi-permeable ☒ Infiltration maximised, QBAR off-site ☐	Impermeable ☐ Staged discharge ☒
(b) Controlled developed discharge rates (l/s)	1 in 1 year	Average: 0.9 l/s/ha	This FRA and DS Document
	1 in 30 year	Average: 2.1 l/s/ha	
	1 in 100 year	Average: 3.0 l/s/ha	

	1 in 100 year + CC	Average: 3.0 l/s/ha	
5. Discharge volumes			Document/ Plan where information is stated:
	Existing volume (m³)	Proposed volume (m³)	This FRA and DS Document (volumes are quoted at the Harringe Lane Bridge on River East Stour (NGR 609400, 137700)
1 in 1 year	13,630	TBC - at detail design/detail WCS stage	
1 in 30 year	35,460	TBC - at detail design/detail WCS stage	
1 in 100 year	51,520	TBC - at detail design/detail WCS stage	
1 in 100 year + CC	72,128* *simply increased 1 in 100 year volume by 40%	TBC - at detail design/detail WCS stage	
6. Plans/Drawings			Document/ Plan where information is stated:
A schematic of the drainage strategy has been included? Yes ☒ No ☐ A schematic of the drainage network model has been included? Yes ☐ No ☒			This FRA and DS Document

Form completed by	Renuka Gunasekara
Qualifications	BEng, CEng, MCIWEM, C.WEM, MICE, FCIWEM
Company	Arcadis Consulting (UK)
Telephone	07793187700
Email	renuka.gunasekara@arcadis.com
On behalf of (Client's details)	Otterpool Park LLP
Date	15/03/22

APPENDIX H

Baseline river modelling

OTTERPOOL PARK

Flood Modelling Report

10029956-AUK-XX-XX-RP-CW-0021-P2

MARCH 2021

VERSION CONTROL

Version	Date	Author	Checker	Approver	Changes
P1	20/08/20	Matt Langdon	Claire Gibson	Renuka Gunasekara	First Issue
P2	11/03/21	Michael Grogan	Claire Gibson	Renuka Gunasekara	Updated baseline flood extent drawings Final Issue

CONTENTS

FIGURES

TABLES

APPENDICES

APPENDIX A

FEH Calculation Record

APPENDIX B

Baseline Modelled Flood Extents

1 Introduction

Arcadis has been appointed by Folkestone and Hythe District Council (FHDC) to support updating the masterplan and associated Outline Planning Application (OPA) documentation for a new garden town settlement located in Kent, known as Otterpool Park. The proposed development is located on 585.2ha of land and the application for planning permission relates to an OPA that has already been submitted under planning reference Y19/0275/FH.

A Flood Risk Assessment (FRA) and Surface Water Drainage Strategy has also been prepared to support the revised OPA for the proposed development in accordance with the National Planning Policy Framework (NPPF) and the associated Flood Risk & Coastal Change planning practice guidance (PPG) and local guidance. The East Stour River, which flows through the application site, has had Flood Zones 2 and 3 mapped by the Environment Agency (EA) using a broad-scale national mapping study (JFLOW). The information available is not suitable for informing site-specific Flood Risk Assessments (FRA) and, therefore, a detailed flood model has been constructed to inform the revised FRA.

Specifically, the Flood Map for Planning does not include an allowance for climate change and, therefore, one of the primary purposes of this study is to assess the effects of climate change to the proposed development and ensure a robust sequential approach is adopted to manage flood risk over its design life as per the NPPF requirements.

Additionally, the flood model will be used to assess the impact of the proposed development on offsite flood risk and demonstrate that the proposed measures can adequately mitigate any negative impacts. A comparison of the hydrographs and levels from the baseline and post-development scenario will be made at the downstream boundary of the model to assess any downstream flood risk impacts.

Furthermore, there are three key ordinary watercourses that flow through the application site which have not been mapped by the Environment Agency (EA). These are referred to as Harringe Brook, North Lympne Drain and Racecourse Drain. To understand the risk posed by these watercourses and ensure that the proposed development is safe it is necessary to include these within the flood model.

This report summaries the methodology used to estimate flood flows, build a linked 1D-2D hydraulic model of the watercourses and floodplain, calculate flood levels and derive flood extents for the baseline condition. The aim of this document is solely to advise the EA of the modelling process adopted, to facilitate their model review. The FRA will contain discussion of the model results in relation to national and local planning policy, which will be submitted with the revised OPA.

2 Approach and Data Collection

2.1 Modelling Approach

The study area and four modelled watercourses are shown in

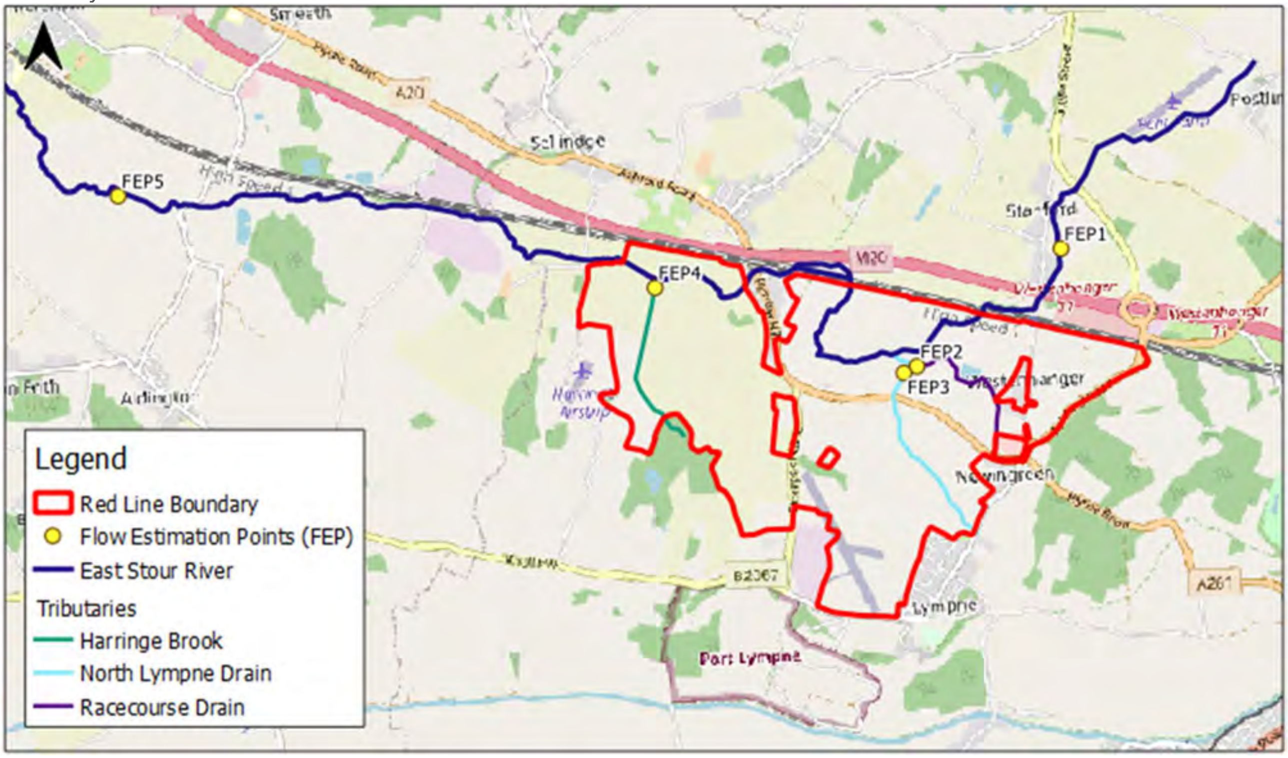


Figure 1, which includes the locations of the Flow Estimation Points (FEPs). At the model scoping stage, the downstream boundary was originally envisaged to be located downstream of the Aldington Flood Storage Area (FSA) at FEP5, this would have allowed any effect of the proposed development on the FSA to have been explicitly modelled.

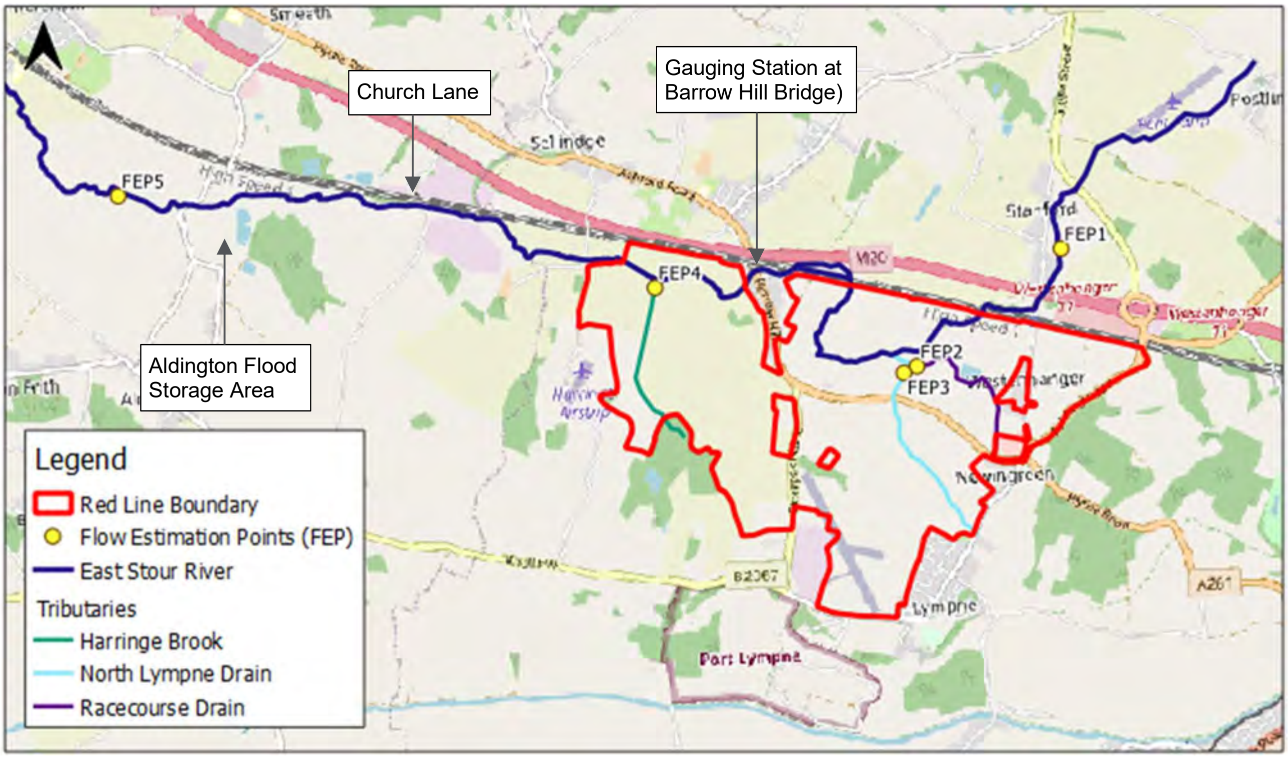


Figure 1: Plan of study area and watercourses (© OpenStreetMap contributors)

During the model development, it was identified that inclusion of the FSA within the model would introduce significant difficulty and uncertainty as information on the construction details and how the facility operates are currently restricted due to public safety and national security concerns. Additionally, there are several catchments which flow into the FSA further downstream of the Otterpool Park site and it is expected that the behaviour of the flood storage area would be dependent on the timing of the different peak flows from these catchments. This will involve development of a complex hydrological and hydraulic model, which is not within the current project scope.

Therefore, the downstream boundary of the model has been moved to Church Lane, upstream of the Aldington FSA, but far enough downstream of the application site that any uncertainty around the downstream boundary conditions is unlikely to affect the results at the site. As discussed in Section 3, FEP5 has still been used to apply a series of lateral inflows to the model by apportioning the peak flow according to contributing areas at key locations (such as upstream of significant structures or the location of confluences).

The upstream boundary of the East Stour River has been selected to ensure that any storage of flood water upstream of the M20 culvert is accounted for in the model. The upstream boundaries of the three tributaries to the East Stour River have been located upstream of the site red line boundary to ensure that the application site is fully mapped and at a location where flows are likely to be well constrained.

A linked 1D-2D approach has been selected as there is potential or significant floodplain flow and storage along the East Stour River. Flood Modeller Pro (FMP) has been selected as the preferred 1D software package as there are a large number of structures within the model extents and the options for structure representation in FMP are broad. TUFLOW has been selected as the 2D software package as the ability to make alterations to the topography to represent development scenarios is very versatile and well-understood.

2.2 Data Collection

This study has been informed by:

- Survey Data (including photographs)
- Lidar Data

- Ordnance Survey Mapping

2.2.1 Survey Data

Maltby Land Surveys Ltd (MLS) were commissioned to gather channel and structure survey data to inform the model. MLS had previously undertaken survey for the East Stour River on behalf of the EA and via consultation with the EA geomatics team, this survey was made available to Arcadis. New survey data was acquired for the three tributaries and this and the survey data for the East Stour River was used to build the 1D FMP component of the hydraulic model.

2.2.2 Lidar Data

The 2D model domain has been created using 2m resolution, filtered Lidar data downloaded from Defra Data Services Platform in January 2020. The Lidar data has been sampled to create a 2D model domain with a grid cell size of 4m. This is sufficiently small to include floodplain features influencing hydraulic behaviour, whilst ensuring that model run times are not too onerous.

2.2.3 Ordnance Survey Mapping

Ordnance Survey (OS) MasterMap data has been acquired to define the land use type within the 2D model domain. Roughness coefficients are within the 2D domain are assigned according to the land use type as discussed further in Section 4.

3 Hydrological Assessment

This section summarises the Flood Estimation Handbook (FEH) Calculation Record which contains full details regarding the calculations and decisions made during the flood estimation. This is included as Appendix A and has been reviewed and approved by the EA.

3.1 Design Flood Events

Peak flows were estimated at the FEPs shown in in Figure 1 for the following flood events:

- 5% Annual Exceedance Probability (AEP) (1 in 20 annual chance);
- 1% AEP (1 in 100 annual chance);
- 1% AEP +45CC (1 in 100 annual chance plus a 45% allowance for climate change);
- 1% AEP +105CC (1 in 100 annual chance plus a 105% allowance for climate change); and
- 0.1% AEP (1 in 1,000 annual chance).

Note that the FEH Calculation Record did not report on the 5% AEP as this was added as a requirement at a later stage in the project to define the functional floodplain (Flood Zone 3b). Nonetheless, the same method and growth curves were used to define it.

3.2 Climate Change

In accordance with the EA's latest guidelines on climate change[1], the higher central allowance to 2115 (45%) will be used to assess the risk to the proposed development. The upper end allowance to 2115 (105%) will be used as a sensitivity test for the effects of climate change.

3.3 Hydrological Approach

The catchment area to the downstream boundary of the model is 19.5km^2 and receives an average annual rainfall of 773mm. The catchment is essentially rural, with only the sub-catchment of the North Lympne Drain characterised as slightly urbanised due to the presence of the village. The catchment is considered to be permeable but not highly permeable and therefore no adjustment for permeability is considered necessary.

Flows were estimated using both the Statistical and ReFH2 methods. Given the presence of gauged data records downstream on the Great Stour the Statistical method was preferred. The hydrographs generated by the ReFH2 method were scaled to match the peak flow estimates from the Statistical method for use as inflows to the hydraulic model.

3.4 Application of Flood Flows to the Hydraulic Model

As discussed in Section 2.1, the downstream boundary was originally envisaged to be downstream of Aldington FSA. As the project progressed, it was decided to relocate this upstream of the FSA, but not before the FEH Calculation Record was originally prepared. Nonetheless, in consultation with the EA the peak flows originally defined for FEP5 have been apportioned to provide additional inflows for the hydraulic model and this is detailed further in Appendix A within the approved FEH Calculation Record.

A total of 6 inflows have been applied to the model, including 4 lumped catchment (FEPs 1-4) and two intervening areas which have been apportioned from FEP5 and distributed across the model as lateral inflows. A summary of the peaks flows for the six model inflows is provided in Table 1 and the hydrographs for the 1% AEP event included in Figure 2.

[1] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

Table 1: Summary of peak flows.

Location	5% AEP	1% AEP	1% AEP +45%	1% AEP + 105%	0.1% AEP
East Stour US (FEP1)	1.71	2.51	3.64	5.15	5.09
Racecourse Drain (FEP2)	0.20	0.28	0.42	0.60	0.58
North Lympne Drain (FEP3)	0.52	0.75	1.09	1.54	1.47
Harringe Brook (FEP4)	0.58	0.86	1.25	1.76	1.68
East Stour Lat1	0.74	0.95	1.37	1.94	1.83
East Stour Lat2	1.00	1.29	1.87	2.64	2.49

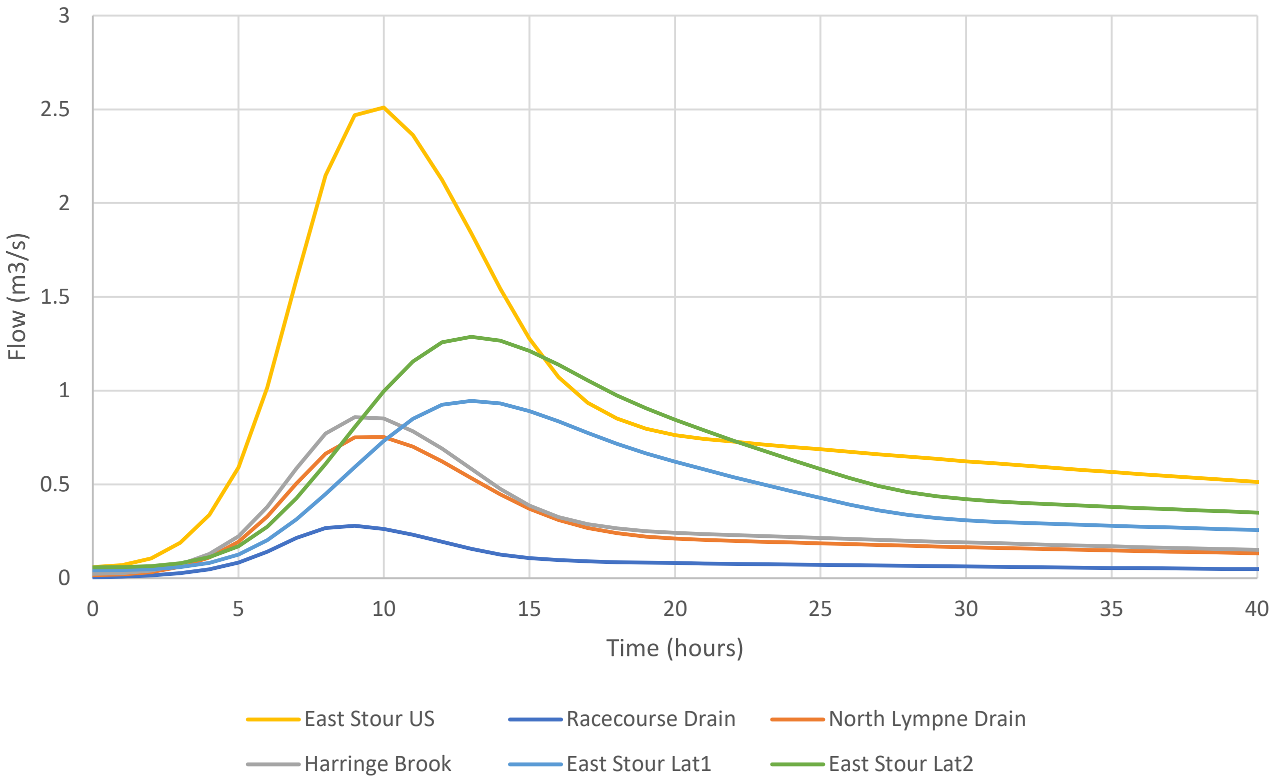


Figure 2: 1% AEP hydrograph of the model inflows.

4 Hydraulic Modelling

The assessment of fluvial flood risk has been undertaken using a newly built FMP TUFLOW model in accordance with EA guidelines and best practice. A linked 1D-2D model approach has been taken since it combines the complementary strengths of 1D models (e.g. accurate representation of in-bank flows and channel features such as bridges and culverts) and 2D models (e.g. simulation of complex floodplain flows). The modelling has been undertaken using FMP version 4.5.1.6163 and TUFLOW build 2018-03-AE-iDP-w64.

4.1 Model Geometry

The model represents a 7.4km long reach of the East Stour River from approximately 360m upstream of the M20 to Church Lane, which is approximately 1.4km downstream of the site red line boundary. Three tributaries of the East Stour, referred to as the Racecourse Drain, North Lympne Drain and Harringe Brook have been included in the 1D domain for lengths of 1.4km, 1.7km and 1.1km respectively. The model extent is shown in Figure 3.

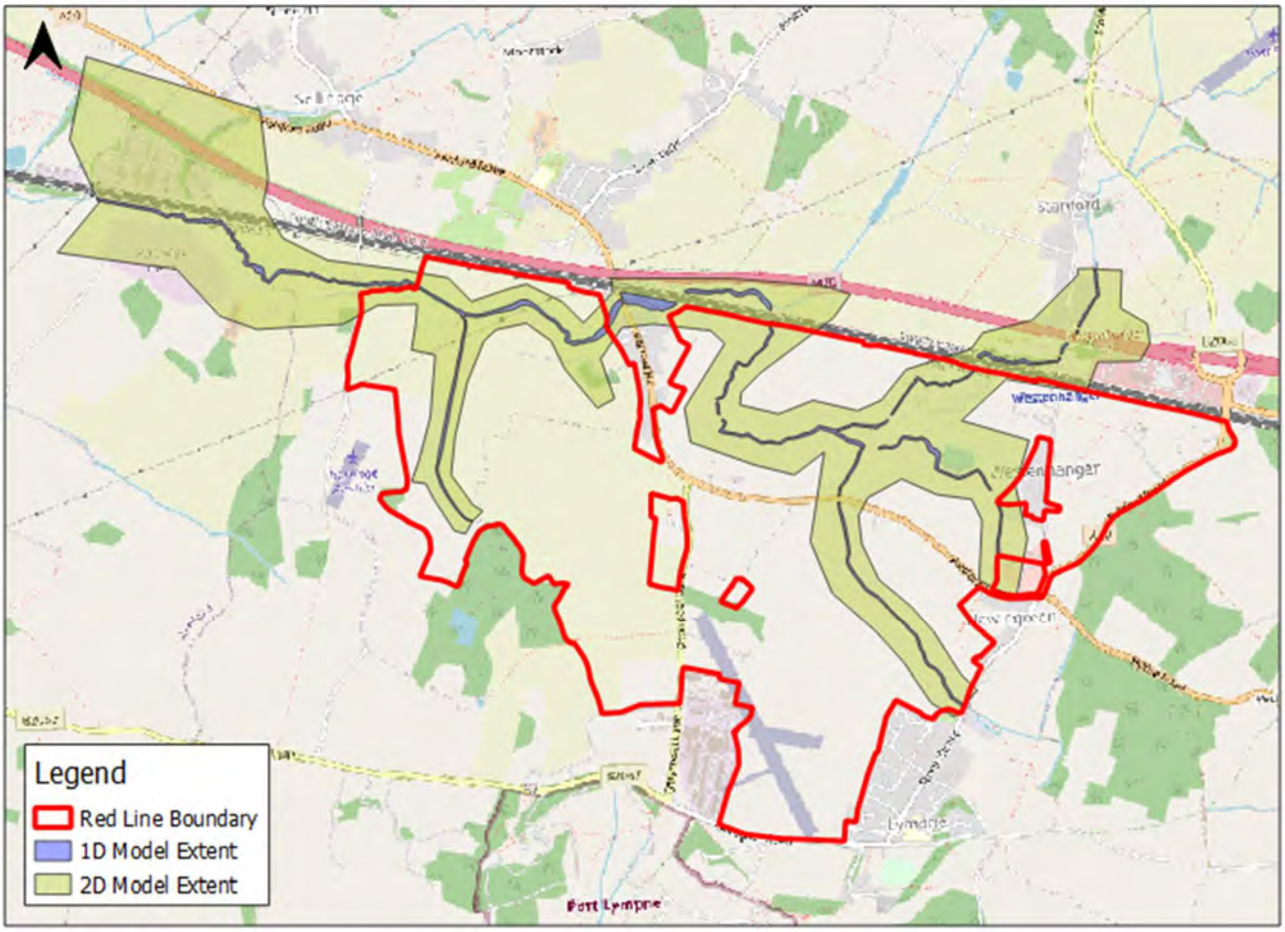


Figure 3: Hydraulic model extent. (© OpenStreetMap contributors)

The 1D channel geometry is based on surveyed cross-sections which is linked to a 2D model domain which uses Lidar data to define the topography. Structures, such as weirs, bridges and culverts have been included within the 1D model domain.

4.2 Roughness

The channel survey and photographs of in-channel bed and bank conditions show the East Stour River to be wide enough to be reasonably clear of overhanging vegetation. The survey photographs recorded the presence of weed growth in places and so a Manning's 'n' value of 0.04 has generally been used; but this has been adjusted where the survey photos show the channel to be notably different. The tributaries are narrower and were observed to be more vegetated than the East Stour River; therefore, a ‘n’ value of 0.05 has generally been used for the channel, with adjustments where necessary.

The OS MasterMap data was used to classify the different land uses and assign appropriate Manning’s ‘n’ values to represent the variation of roughness within the floodplain.

4.3 Boundary Conditions

Six inflow boundaries have been applied as flow-time units in the FMP model. Four of these were applied at the upstream boundaries of the East Stour and three tributaries, whilst the remaining two inflows have been applied as lateral inflows and distributed within the model.

The 1D downstream boundary is defined using an FMP normal depth boundary. The surveyed channel gradient of 1 in 1,000 has been used to define the slope used in the automatic generation of the flow-head relationship. All modelled events remain in-channel at this location and, therefore a downstream boundary for the 2D domain is not necessary.

4.4 Model Validation and Sensitivity Testing

4.4.1 Model Validation

It is common practice to calibrate and verify hydraulic models with anecdotal accounts of flooding within a study area, in order to ensure that the model gives the best possible representation of the physical characteristics which control the flood conditions. It is likely that the rural nature of the subject watercourses and the absence of key receptors is the reason why anecdotal information on out of bank flooding is not available in this location. However, there is a river level gauge on the East Stour at Barrow Hill Bridge which although it only has a 4.5 year record, can provide some context for the modelled flood levels. The gauge corresponds to model node ESTO01_15396; Figure 4 shows the recorded levels relative to modelled and surveyed water levels.

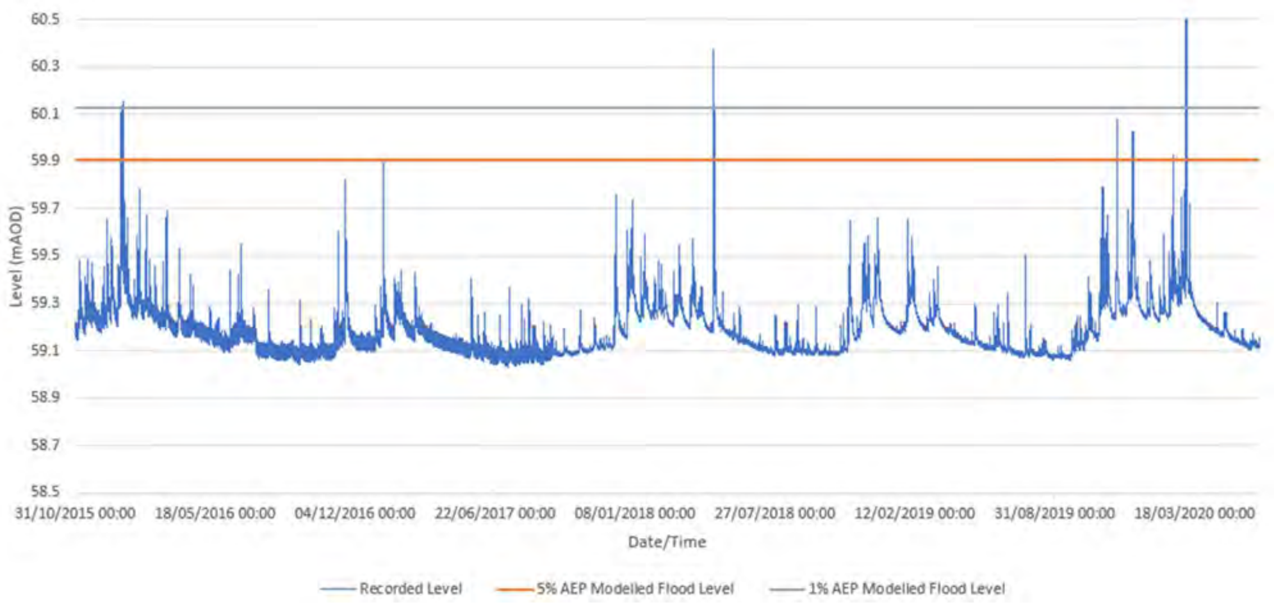


Figure 4: Comparison of East Stour gauge record with modelled flood levels.

Figure 4 indicates that the modelled 1% AEP level has been exceeded on three occasions since the gauge record began in October 2015. This suggests that the model may be under predicting water levels in this location. This issue has been previously raised with the EA although no comments on draft modelled flood extents or any anecdotal flood records related to the modelled river reach have been received to date. The hydrology was also reviewed and approved by the EA as fit for use in this modelling exercise.

4.4.2 Mass Balance and Model Stability

In addition to the validation discussions above, a review of key model health indicators and model sensitivity testing has been undertaken.

The mass balance errors reported by FMP and TUFLOW have been reviewed for the 1% AEP event including a 45% allowance for climate change. FMP reports a mass balance error of -0.21% which is well within the generally accepted tolerance limits of ±1% and only 0.12% of the simulation failed to converge on a solution. Of the timesteps which failed to converge, 52% are associated with node HAR010049OU, a small culvert on the Harringe Brook. Detailed review of the results in this location confirms that the stage plots upstream and downstream of the culvert are stable. A further 46% are associated with node ESTO01_16322 with the remaining 2% are associated with node EST1_17959cd, a culvert on the East Stour. Stage plots at both these locations are stable.

The TUFLOW model reports a cumulative mass balance error at the start of the simulation of +2.26% which quickly settles down and then reaches an absolute peak of -0.94% at approximately 14.5 hours into the simulation. The final cumulative mass balance error is -0.74% and this is within the tolerance limits of ±1% and therefore the simulations are considered acceptable.

A review of the results across the model confirm that the stage and flow hydrographs are generally stable and free of oscillation. The key exception to this is culvert RCD010869C on the Racecourse Drain which exhibits some instability due to the combination of the upstream weir and narrow culvert entrance. Investigations have confirmed that, despite the oscillation in stage upstream, water levels are sufficiently above bank to cause flooding and therefore it is considered that the overland flow path predicted gives a conservative representation of flooding in this area.

4.4.3 Sensitivity Tests

Sensitivity of the model to the selected roughness coefficients and to the downstream boundary condition was assessed for the 1% AEP event.

Increasing the roughness coefficients by 20% gave an average (median) increase in the peak water level of 60mm. The impact on modelled flood extents as a result of increasing roughness is predominantly minor; the two main exceptions to this are downstream of ESTO01_18447 and ESTO01_17350 where additional out of bank flood pathways are predicted.

A reduction in roughness coefficients of 20% caused the model to become unstable. Investigations into the reasons for this concluded that neither a reduction in coefficients of 10% nor a reduction only within channel would run stably. It is therefore concluded that the model is sensitive to a reduction in roughness coefficient. However detailed investigations into the source of this are not necessary given the generally limited out of bank flooding and the small impact on modelled flood extents observer for the increase roughness test.

The slope used to model the downstream boundary was varied by plus / minus 20%. Results demonstrate that the impact of this change extends for 460m upstream of the model boundary. This is downstream of the site boundary and is therefore acceptable.

4.5 Flood Extents

The model outputs from TUFLOW have been imported to GIS software and used to map the flood extents, which are included in Appendix B.

For the East Stour River, the 5% AEP event remains entirely within channel, only entering the 2D domain of the model where there are secondary channels. This also remains mostly the case for the 1% AEP event, where the only notable water on the floodplain is:

- just north of Westenhanger Castle;
- on the left bank of where the East Stour flows south to north under High Speed 1and the Eastern Main Line; and
- just upstream of Barrow Hill.

5 Assumption and Limitations

The following assumptions and limitations in estimating the flood flows are acknowledged:

- Catchment descriptors derived for the FEPs are suitably representative of the corresponding catchment conditions.
- Use of the 40022 Great Stour @ Chart Leacon gauging station as a donor station for the purpose of data transfer is appropriate for the sites in this study.
- The Statistical method is intended principally for AEP events between 50% and 0.5% years. Given the typically short length of river gauge records, there are significant uncertainties associated with applying the method to more extreme events. However, the Hybrid method was used to derive flood peaks for events greater than the 1% AEP event.
- Catchment wetness has been modelled using the standard FEH catchment descriptors, however as the subject catchments are relatively permeable there is potential for them to have a different runoff response if rain falls when they already saturated.

The following assumptions and limitations in the hydraulic modelling are acknowledge:

- The model geometry is based on a combination of survey data for the channels and in channel structures and lidar for the floodplain. The accuracy of the model is therefore subject to any inherent inaccuracies in the data supplied.
- The highly vegetated nature of the upper reaches of the Racecourse Drain, limited the extent to which the survey could be completed and therefore there is some uncertainty as to the exact location of the channel.
- Model cross sections have been surveyed at regular intervals however cost implications of obtaining surveys mean that not all changes in the channel geometry will be picked up. Lidar data has therefore been used to assist in highlighting locations where the channel does change and to generate 'synthesised' channel sections to add more detail.
- Sensitivity testing has demonstrated that the model results in the vicinity of the site are not influenced by the choice of downstream boundary gradient.
- A best assessment of roughness coefficients has been made based on site photos and aerial photography. Sensitivity testing has been used to assess the implications of this choice and highlighted only two locations where the flood extents / mechanisms change significantly. This will not change the overall conclusions of the wider study.
- No anecdotal evidence of flooding on the site was available for model validation. Therefore, an assessment has been made using 4.5 years' worth of gauge data. This indicates that the model may be under predicting flood levels although further discussion with the EA is required on this.

6 Conclusions

The aim of this report is to document the flood modelling methodology to facilitate review by the Environment Agency. It does not constitute a Flood Risk Assessment, which will be prepared separately.

This hydraulic modelling study has determined the baseline flood extents for five design events on the East Stour River at its three tributaries. Modelled flood levels and mapped flood extents will be used to inform the design of the Otterpool Park Garden Town Masterplan and preparation of the OPA documentation.

Sensitivity testing carried out during this study indicates that the impact of changing roughness and the downstream boundary condition does not have a significant impact on the modelled flood extents.

Comparison of modelled flood levels with a limited period of gauge record within the model extent suggests that the model may be under predicting flood levels and further discussion with EA is required to resolve this.

Once formally approved, these baseline flood mapping outputs are intended to replace the published Environment Agency flood outlines as they are derived from a more detailed modelling study than that currently used. As such, they will be used to inform the sequential approach in allocating specific land uses within the masterplan and inform the FRA preparation.

The approved baseline model can then be used to test the proposed bridge crossings over the East Stour and develop suitable mitigation options in consultation with the Environment Agency.

APPENDIX A

FEH Calculation Record

Flood estimation calculation record

Introduction

This document is a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at multiple locations.

Contents

Approval

	Signature	Name and qualifications	For Environment Agency staff: Competence level (see below)
Calculations prepared by:	[redacted]	Emma Coward MESci	Level 1
Calculations checked by:		Lisa Driscoll	Level 3
Calculations approved by:		Lisa Driscoll	Level 3

Environment Agency competence levels are covered in Section 2.1 of the flood estimation guidelines:

- Level 1 – Hydrologist with minimum approved experience in flood estimation
- Level 2 – Senior Hydrologist
- Level 3 – Senior Hydrologist with extensive experience of flood estimation

ABBREVIATIONS

AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

1 Method statement

1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: • Purpose of study • Approx. no. of flood estimates required • Peak flows or hydrographs? • Range of return periods and locations • Approx. *time* available	Arcadis Consulting Ltd. (Arcadis) have been commissioned to produce flow estimates, required to inform the hydraulic modelling of the East Stour and three of its tributaries that flow through the proposed development herein referred to as 'Otterpool Park'. The hydraulic model is being developed to test the effects of climate change on the currently mapped Environment Agency (EA) flood zones, as well as to produce evidence to demonstrate the proposed development would not impact on flood risk downstream. No existing hydraulic modelling of the subject watercourses is available from the Environment Agency (EA). Therefore, a new hydraulic model is being developed using existing survey data provided by Maltby Surveys for the East Stour, on behalf of the EA. No survey data is available for the tributaries of interest that flow through the proposed development site (Harringe Brook, Racecourse Drain and North Lympne Drain). At this stage of the assessment, the flow estimates derived for the tributaries will be input into the East Stour model as point inflows. Five Flow Estimation Points (FEPs) are required to inform the model at the locations shown in Appendix A.6.2 (Figure 1). Peak flows and hydrographs have been produced for the following Annual Exceedance Probability (AEP) storm events: 1%, 1% plus climate change (+CC) allowance of 45% (higher central to 2115), 1%+105CC (upper end to 2115) and 0.1%. These allowances have been used in line with the latest guidance available at https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances. In view of the lack of gauges on the subject watercourses, a hydrograph shape for each FEP was generated from a catchment-descriptor based rainfall runoff model applied in ReFH v2.3 and scaled to the selected flow peaks.

1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The catchment area to the downstream boundary of the model is approximately 50km^2. The catchment receives an average annual rainfall of 773mm and is considered essentially rural. The component sub-catchments of the Harringe Brook and Racecourse Drain are also considered essentially rural. Whilst the catchment draining to the North Lympne drain is characterised as slightly urbanised (URBEXT1990 >0.025 but < 0.05), owing to the inclusion of the village of Lympne in the headwaters of the catchment.

1.3 Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 8 (September 2019)

1.4 Gauging stations (flow or level)

(at the sites of flood estimates or nearby at potential donor sites)

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catch-ment area (km²)	Type (rated / ultrasonic / level…)	Start and end of flow record
Great Stour	Chart Leacon	N/A	40022	TQ992422	72.5	Velocity-area station	01/1967 to Current

Note: 40023 East Stour at South Willesborough is situated on the subject watercourse just downstream of the study reach, however there is no peak flow data record published for this station in the National River Flow Archive.

1.5 Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	**Other comments on station and flow data quality** – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
Chart Leacon	01/1967	N/A	Yes – Gauged above QMED. Scatter in gaugings evident.	No – Few high flow gaugings. Rating can not be validated beyond QMED.	No	Gauge is located 3.5km upstream of the confluence with the East Stour. The weir does not conform to British Standard as the downstream slope is inadequate and the approach channel is not straight and uniform. Flow becomes non-modular at stages. The low modular limit, Singleton Lake outflows and backwater effects from the B2229 road bridge hinder the gauges effectiveness at high flows. Vegetation and channel siltation problems. The 2002 review suggests that these may reduce the effectiveness of the gauge at moderate flows. Gaugings taken by wading with rods, which can result in an underestimation of flow through the gauge. Some upstream regulation: Hothfield flood retention reservoir upstream has a major impact on flood flows - designed to limit d/s flows to <6m³/s.
Give link/reference to any further data quality checks carried out			n/a			

1.6 Rating equations

Station name	**Type of rating** e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	**Reasons** – e.g. availability of recent flow gaugings, amount of scatter in the rating.
40022 Great Stour @ Chart Leacon	Theoretical rating / Velocity area calibration for high flows	N/A	Two peak flow ratings applied across period of records, the most recent is valid from October 1979 when weir was constructed. Rating extended to 1.8m by hydraulic modelling but low confidence beyond 1.13m as out of bank.
Give link/reference to any rating reviews carried out		N/A	

1.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available ?	Source of data and licence reference if from EA	Date obtained	Details
Check flow gaugings (if planned to review ratings)					
Historic flood data – give link to historic review if carried out.	No				No historical flood data is available relevant to this study.
Flow data for events					
Rainfall data for events					
Potential evaporation data					
Results from previous studies					
Other data or information (e.g. groundwater, tides)					

1.8 Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	Yes, application of the FEH Statistical and ReFH2.3 methods are considered appropriate.
Outline the conceptual model, addressing questions such as: • Where are the main sites of interest? • What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) • Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? • Is there a need to consider temporary debris dams that could collapse?	The main area of interest is the land comprising the proposed development of Otterpool Park, including key watercourses that cross it, i.e. the Racecourse Drain, Harringe Brook and North Lympne Drain. The other main site of interest is downstream, in particular Ashford, where concerns were raised in pre-application consultation relating to the potential for increased risk of flooding from the East Stour as a result of the proposed development. The likely cause of flooding for these subject watercourses is due to peak flows exceeding channel capacity.
Any unusual catchment features to take into account? e.g. • highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% • highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments • pumped watercourse – consider lowland	The study catchments BFIHOST parameter values are indicative of relatively permeable soils and geology, with values exceeding 0.65. However, SPRHOST values for the FEPS exceed 20% so no adjustment for permeability has been made in the FEH Statistical method. The performance of ReFH 2 across both permeable and impermeable catchments within the NRFA Peak Flows dataset is evaluated in ReFH2 Science Report: Evaluation of the Rural Design Event Model. This demonstrates that the ReFH 2 permeable catchment performance is a considerable improvement on the original ReFH method. This is particularly the case when

catchment version of rainfall-runoff method • major reservoir influence (FARL<0.90) – consider flood routing • extensive floodplain storage – consider choice of method carefully	used with the FEH13 rainfall model, where performance is comparable to the current FEH statistical method. The study catchments are not significantly urbanised. There are several small ponds / reservoirs within the lumped downstream catchment of the East Stour. However, there is deemed to be no major flood attenuation effect as demonstrated by the FARL values >0.90 in Table 2.2. The watercourses have no tidal influence. It is considered that there are no other unusual catchment characteristics to take into consideration as part of the hydrological assessment.
Initial choice of method(s) and reasons Will the catchment be split into subcatchments? If so, how?	FEH methods are deemed appropriate, so flows have been estimated through application of both the ReFH[2.3] and FEH Statistical methods for comparison.
Software to be used (with version numbers)	FEH Web Service WINFAP [4] ReFH [2.3]

2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
FEP1	East Stour	Upstream model boundary limit	613050	137800	6.72	-
FEP2	Racecourse Drain	-	611950	136900	0.87	-
FEP3	North Lympne watercourse	-	611850	136850	2.23	-
FEP4	Harringe Brook	-	609950	137500	2.49	-
FEP5	East Stour	Downstream model boundary limit	605850	138200	50.01	-
Reasons for choosing above locations		These subject sites have been defined to represent key inflows including at the upstream model boundary and from minor tributaries or land drains within the lumped catchment that cross the Otterpool Park site, as well as a check flow at the downstream model boundary.				

2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST [1995]	BFIHOST [2019]	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT 2000 (*)	FPEXT
FEP1	0.998	0.340	0.728	0.754	2.39	66.90	797	21.23	0.0062	0.0493
FEP2	0.9480	0.340	0.755	0.686	0.87	26.60	768	25.36	0.00	0.2034
FEP3	1.00	0.340	0.783	0.685	1.55	26.00	760	24.16	0.0631	0.0539
FEP4	0.9660	0.340	0.724	0.624	1.69	45.40	757	26.71	0.00	0.0472
FEP5	0.9960	0.340	0.660	0.642	7.38	47.40	773	28.05	0.0165	0.0889
	(*) Updated to 2020 Given that runoff from the new development at Otterpool Park will be managed to ensure no increase in peak rainfall runoff volumes or rates of discharge to the East Stour further updates to the URBEXT2000 parameter are not required. The surface water management proposals are detailed in the Otterpool Park Flood Risk Assessment and Drainage Strategy (10029956-AUK-XX-XX-RP-CW-0010).									

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	OS mapping, contour and LiDAR data were utilised to check the catchment boundaries identified from the FEH Web Service for each of the FEPs. No changes were deemed necessary as the catchment boundaries were represented correctly.

Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	FEH catchment descriptors describing catchment soils and geology (SPRHOST and BFIHOST) were checked using the Soil Survey of England and Wales 1:25,000 mapping and method set out in the Institute of Hydrology Report No.126 (See Annex 6.3 Additional Supporting Information Table 2). Other features such as reservoirs/lakes which influence FARL, for example were checked using OS mapping. No changes to the FEH catchment descriptors were necessary following a review.
Source of URBEXT	URBEXT2000 (updated to URBEXT2020)
Method for updating of URBEXT	CPRE formula from FEH Volume 4

3 Statistical method

3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: • Number of potential donor sites available • Distances from subject site • Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	Donor sites were investigated for each of the catchments draining to their applicable FEP. A search radius of 25km was adopted (based on centroid distance). One potential donor site was identified in WINFAP-FEH (using OK for QMED stations in the September 2019 release of the Peak Flow Data (HiFlows) database): **40005 Beult @ Stilebridge**. This station was immediately discounted owing to the size of its catchment area [278.05km^2], significantly larger than the subject catchments. The FEH Web Service identified the following two gauging stations within the search radius: 40023 East Stour @ South Willesborough 40022 Great Stour @ Chart Leacon. The 40023 gauging station is characterised as not suitable for QMED and therefore was also immediately discounted. The 40022 gauging station was not suggested as a potential donor in WINFAP4 owing to the default URBEXT value being set to <0.030 to satisfy the preference for selected donors that are essentially rural. Upon further investigation this gauging station was noted to have an URBEXT value of 0.035, only marginally exceeding the threshold. It was deemed appropriate to consider this station in further detail as a potential donor for data transfer to improve QMED estimates for the subject watercourses in this study. QMED based on observed flow estimates at this gauging station are higher than the empirical estimates. Data transfer using this station as a donor would therefore have an overall effect of uplifting the flows derived for the subject FEPs, which is considered a precautionary approach when it comes to deriving the modelling outcomes of this study i.e. assessing flood risk downstream and the impact of climate change on the flood zones. Given the emphasis in best practice guidance on geographical proximity when selecting a donor, it was also concluded that the choice of 40022 as a suitable donor station is appropriate (at a centroid distance of approximately 14km).

3.2 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjust-ment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjust-ment ratio (A/B)
40022	See Section 3.1 above	AM	No	5.12	3.92	1.31
Which version of the urban adjustment was used for QMED at donor sites, and why? Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).				The WINFAP4 urban adjustment method (based on Kjeldsen, 2010) in line with best practice.		

3.3 Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of QMED [rural] (m^3/s)	Data transfer						Final estimate of QMED [urban adjusted] (m^3/s)
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d_{ij} (km)	Power term, a	Moderated QMED adjustment factor, $(A/B)^a$	If more than one donor		
							Weight	Weighted average adjustment factor	
FEP1	DT	0.79	40022	21.11	0.30	-	-	-	0.87
FEP2		0.09		20.62	0.30	-	-	-	0.10
FEP3		0.21		20.56	0.30	-	--	-	0.27
FEP4		0.27		18.61	0.30	-	-	-	0.30
FEP5		5.30		14.92	0.34	-	-	-	6.06
Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?						Yes, values of QMED are consistent. QMED values increase moving downstream on the East Stour and QMED values are typically higher for larger catchments.			
Which version of the urban adjustment was used for QMED, and why?						Kjeldsen (2010) – in WINFAP			

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone.

When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added.

When QMED is estimated from catchment descriptors, the revised 2008 equation from Science Report SC050050Error! Bookmark not defined. should be used. If the original FEH equation has been used, say so and give the reason why.

The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8). The adjustment method used in WINFAP-FEH v3.0.003 is likely to overestimate adjustment factors for such catchments. In this case the only reliable flood estimates are likely to be derived from local flow data.

The data transfer procedure is from Science Report SC050050. The QMED adjustment factor A/B for each donor site is given in Table 3.3. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is $(A/B)^a$ times the initial estimate from catchment descriptors.

If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column.

3.4 Derivation of pooling groups

The composition of the pooling groups is given in the Annex.

Name of group	**Site code from whose descriptors group was derived**	**Subject site treated as gauged?** (enhanced single site analysis)	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Weighted average L-moments**, L-CV and L-skew, (before urban adjustment)
P_GROUP1	FEP1	No	The default pooling group contains 14 stations and 500 station years. The pooling group is possibly heterogeneous (H2=1.6074) and a review of the pooling group is optional. Upon review of the pooling group the following stations were removed: **27032 Hebden Beck @ Hebden** – removed owing to unresponsive behaviour and flows influenced by old mine workings. **44008 South Winterbourne @ Winterbourne Steepleton** – removed owing to the occurrence of bypassing and runoff that is influenced by abstraction within the catchment. **26802 Gypsey Race @ Kirby Grindalythe** – removed owing to children interfering with weir causing fluctuations. **47022 Tory rook @ Newnham Park** – removed owing to china clay works having affected the river flow regime in the catchment. **28033 Dove @ Hollinsclough** – removed owing to difficulties in gauging higher flows and largest flow suggests rating underestimates flows. **49005 Bolingey Stream @ Bolingey Cocks Bridge** – removed owing to difference in flood seasonality compared to pooling group. **71003 Croasdale Beck @ Croasdale Flume** – removed owing to disparity in range of high flows and lack of high flow gaugings. The following stations were added to restore the total station years to around 500 in line with best practice: 76011 Coal Burn @ Coalburn 49003 De Lank @ De Lank 72014 Conder @ Galgate 54022 Severn @ Plynlimon Flume 41020 Bevern Stream @ Clappers Bridge The final pooling group contains 12 stations and 507 station years. The pooling group is acceptably homogeneous (H2=0.7023) and a review of the pooling group is not required.	Default Pooling Group: L-CV: 0.256 L-SKEW: 0.261 Final Pooling Group: L-CV: 0.226 L-SKEW: 0.241

Name of group	**Site code from whose descriptors group was derived**	**Subject site treated as gauged?** (enhanced single site analysis)	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Weighted average L-moments**, L-CV and L-skew, (before urban adjustment)
P_GROUP2	FEP2		The default pooling group contains 15 stations and 518 station years. The pooling group is heterogeneous (H2=2.1871) and a review of the pooling group is desirable. Upon review of the pooling group the following stations were removed: **26802 Gypsey Race @ Kirby Grindalythe** – removed owing to children interfering with weir causing fluctuations. **47022 Tory rook @ Newnham Park** – removed owing to china clay works having affected the river flow regime in the catchment. **28033 Dove @ Hollinsclough** – removed owing to difficulties in gauging higher flows and largest flow suggests rating underestimates flows. **71003 Croasdale Beck @ Croasdale Flume** – removed owing to disparity in range of high flows and lack of high flow gaugings. **91802 Allt Leachdach @ Intake** – removed owing to use with caution in pooling based on FSR quality grade of A2. **76011 Coal Burn @ Coalburn** – removed owing to potential for underestimation of flows and further research required associated with this. The following stations were added to restore the total station years to around 500, in line with best practice: 28041 Hamps @ Waterhouses 47021 Kensey @ Launceston Newport 72014 Conder @ Galgate 49003 De Lank @ De Lank The final pooling group contains 14 stations and 510 station years. The pooling group is possibly heterogeneous (H2=1.1772) and a review of the pooling group is optional.	Default Pooling Group: L-CV: 0.225 L-SKEW: 0.238 Final Pooling Group: L-CV: 0.228 L-SKEW: 0.211

Name of group	**Site code from whose descriptors group was derived**	**Subject site treated as gauged?** (enhanced single site analysis)	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Weighted average L-moments**, L-CV and L-skew, (before urban adjustment)
P_GROUP3	FEP3		The default pooling group contains 15 stations and 518 station years. The pooling group is heterogeneous (H2=2.1006) and a review of the pooling group is desirable. Upon review of the pooling group the following stations were removed: **26802 Gypsey Race @ Kirby Grindalythe** – removed owing to children interfering with weir causing fluctuations. **91802 Allt Leachdach @ Intake** – removed owing to use with caution in pooling based on FSR quality grade of A2. **28033 Dove @ Hollinsclough** – removed owing to difficulties in gauging higher flows and largest flow suggests rating underestimates flows. **47022 Tory rook @ Newnham Park** – removed owing to china clay works having affected the river flow regime in the catchment. **71003 Croasdale Beck @ Croasdale Flume** – removed owing to disparity in range of high flows and lack of high flow gaugings. The following stations were added to restore the total station years to around 500 in line with best practice: 72014 Conder @ Galgate 73015 Keer @ High Keer Weir 49003 De Lank @ De Lank 27010 Hodge Beck @ Bransdale Weir The final pooling group contains 14 stations and 530 station years. The pooling group is possibly heterogenous (H2=1.5912) and a review of the pooling group is optional.	Default Pooling Group: L-CV: 0.226 L-SKEW: 0.239 Final Pooling Group: L-CV: 0.221 L-SKEW: 0.229

Name of group	**Site code from whose descriptors group was derived**	**Subject site treated as gauged?** (enhanced single site analysis)	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Weighted average L-moments**, L-CV and L-skew, (before urban adjustment)
P_GROUP4	FEP4		The default pooling group contains 15 stations and 511 station years. The pooling group is possibly heterogeneous (H2=1.3157) and a review of the pooling group is optional. Upon review of the pooling group the following stations were removed: **91802 Allt Leachdach @ Intake** – removed owing to use with caution in pooling based on FSR quality grade of A2 **26802 Gypsey Race @ Kirby Grindalythe** – removed owing to children interfering with weir causing fluctuations. **47022 Tory rook @ Newnham Park** – removed owing to china clay works having affected the river flow regime in the catchment. The following stations were added to restore the total station years to around 500 in line with best practice: 49003 De Lank @ De Lank 206006 Annalong @ Recorder The final pooling group contains 14 stations and 533 station years. The pooling group is possibly heterogeneous (H2=1.4366) and a review of the pooling group is optional.	Default Pooling Group: L-CV: 0.228 L-SKEW: 0.257 Final Pooling Group: L-CV: 0.222 L-SKEW: 0.248

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
P_GROUP5	FEP5		The default pooling group contains 12 stations and 528 station years. The pooling group is possibly heterogeneous (H2=1.6627) and a review of the pooling group is optional. Upon review of the pooling group the following stations were removed: **36004 Chad Brook @ Long Melford** – removed owing to runoff influenced by industrial groundwater abstraction, station experiences some bypassing and poorly maintained channel influencing the modular limit. **76019 Roe Beck @ Stockdalewath –** removed owing to difference of flood seasonality and L-moments to group. **53017 Boyd @ Bitton** – removed owing to theoretical rating unconfirmed and flows affected by abstractions and diversions. **39042 Leach @ Priory Mill Lechlade** – removed owing to bypassing occurring at this station. **26003 Foston Beck @ Foston Mill** – removed owing to flows being susceptible to damming on occasions. The following stations were added to restore the total station years to around 500 in line with best practice: 44011 Asker @ East Bridge Bridport 440033 Asker @ Bridport 20007 Gifford Water @ Lennoxlove 43014 East Avon @ Upavon 53023 Sherston Avon @ Fosseway 36007 Belchamp Brook @ Bardfield Bridge The final pooling group contains 13 stations and 534 station years. The pooling group is possibly heterogeneous (H2=1.2908) and a review of the pooling group is optional. The following station was investigated but retained in the group: **26013 Driffield Trout Stream @ Driffield** - had a high discordancy. This was possibly owing to only 8 years of data. No clear reasons for discordancy or to remove from pooling group. FEH guidelines (2015) state that stations should only be removed if stations years are <8.	Default Pooling Group: L-CV: 0.253 L-SKEW: 0.121 Final Pooling Group: L-CV: 0.263 L-SKEW: 0.134

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
Notes Pooling groups were derived using the revised procedures from Science Report SC050050 (2008). The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.				

3.5 Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group (3.4)	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments	Growth factor for 100-year return period
FEP1	P	PG1	General Logistic (GL) – WINFAP4 recommended	Urban adjustment in WINFAP4	Location: 1.00 Scale: 0.223 Shape: -0.242	2.88
FEP2	P	PG2	General Logistic (GL) – WINFAP4 recommended		Location: 1.00 Scale: 0.23 Shape: -0.211	2.78
FEP3	P	PG3	General Logistic (GL) – WINFAP4 recommended		Location: 1.00 Scale: 0.211 Shape: -0.24	2.77
FEP4	P	PG4	General Logistic (GL) – WINFAP4 recommended		Location: 1.00 Scale: 0.22 Shape: -0.248	2.88
FEP5	P	PG5	GEV - WINFAP4 recommended		Location: 0.847 Scale: 0.421 Shape: 0.053	2.57
Further information on the choice of distribution is provided in Annex 6.3 Additional Supporting Information.						
Notes Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters. Urban adjustments to growth curves should use the version 3 option in WINFAP-FEH: Kjeldsen (2010). Growth curves were derived using the revised procedures from Science Report SC050050 (2008).						

3.6 Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)			
	100	100+45%CC	100+105CC	1000*
FEP1	2.51	3.64	5.15	5.09
FEP2	0.28	0.42	0.60	0.58
FEP3	0.75	1.09	1.54	1.47
FEP4	0.86	1.25	1.76	1.68
FEP5	15.56	22.56	31.90	30.13
*Hybrid method				

4 Revitalised flood hydrograph (ReFH) 2.3 method

4.1 Parameters for ReFH model

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	C_{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
FEP1	CD	2.84	790.13	51.75	2.99
FEP2	CD	2.14	662.2	39.2	2.68
FEP3	CD	2.99	660.48	44.42	2.68
FEP4	CD	2.63	563.7	42.78	2.41
FEP5	CD	6.04	590.68	60.02	2.48

Brief description of any flood event analysis carried out (further details should be given below or in a project report)	No flood event analysis was carried out.

4.2 Design events for ReFH method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
FEP1	Urban	Winter	11	-
FEP2	Urban	Winter		-
FEP3	Urban	Winter		-
FEP4	Urban	Winter		-
FEP5	Urban	Winter		-

Whilst the URBEXT values identify the catchments as essentially rural, the use of the Urban model as opposed to the Rural model is justified to account for small areas of existing development within the study catchments.
The winter rainfall profile is considered appropriate as per the ReFH2.3 Technical Guidance which notes that the summer profile should be applied when either URBEXT2000 is >0.30 or URBEXT2000 >0.15 to <0.30 and BFIHOST >0.65.

Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?	A uniform storm duration was applied to all FEPs based on the critical storm duration (11Hr) of the lumped catchment of the East Stour to the downstream model boundary (FEP5). A sensitivity run was carried out, in which a uniform storm duration was applied to all FEPs based on the shortest critical storm duration (3.5Hr) of the subject catchments (i.e. Racecourse Drain), to test the effects on the peak flow. The results of this run can be viewed in Appendix 6.2 Table 1.

4.3 Flood estimates from the ReFH method

Site code	Flood peak (m^3/s) for the following return periods (in years)			
	100	100+45%CC	100+105%CC	1000

Site code	Flood peak (m^3/s) for the following return periods (in years)			
	100	**100+45%CC**	**100+105%CC**	**1000**
FEP1	2.39	3.96	6.53	4.85
FEP2	0.45	0.74	1.22	0.90
FEP3	1.08	1.75	2.83	2.11
FEP4	1.43	2.31	3.75	2.79
FEP5	16.74	26.89	43.20	32.42

5 Discussion and summary of results

5.1 Comparison of results from different methods

This table compares peak flows from the ReFH method with those from the FEH Statistical method for the 1 in 100 year (1% AEP) return period event.

Site Code	Return period 100 years (1% AEP)		
	Statistical	ReFH2	Ratio (ReFH / Statistical)
FEP1	2.51	2.39	0.95
FEP2	0.29	0.45	1.55
FEP3	0.75	1.08	1.44
FEP4	0.86	1.43	1.66
FEP5	15.56	16.74	1.08

5.2 Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	The flows on the East Stour derived from the two methods (FEH Statistical and ReFH2.3) are very similar. However, on the tributaries of the East Stour (represented by FEP2, FEP3 and FEP4) the FEH Statistical method produces lower flow estimates compared to those produced using ReFH2.3. It is considered that this may be influenced by the differences between the BFIHOST2019 and BFIHOST1995 values, most notable in the tributaries compared to the East Stour. The BFI2019 values used in ReFH2.3 are lower than the BFIHOST1995 values for each FEP, indicating less permeable soils which would generate higher flows in ReFH2.3 compared to FEH Statistical (which uses BFIHOST1995). Given the presence of the data records from the 40022 Great Stour @ Chart Leacon gauging station to utilise in data transfer, flow estimates from the FEH Statistical method are preferred. This is because data transfer from a suitable donor is considered to improve the estimate of QMED. The Hybrid Method has been utilised in line with best practice to derive the 1 in 1000 year (0.1% AEP) peak flow estimates. Hydrographs have been produced using ReFH2.3 and scaled to the FEH Statistical peak for input into the hydraulic model at the point of each corresponding FEP. For further details see Annex 6.2 Additional Supporting Information.

5.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	1. Catchment descriptors derived for the FEPs are suitably representative of the corresponding catchment conditions. 2. Use of the 40022 Great Stour @ Chart Leacon gauging station as a donor station for the purpose of data transfer is appropriate for the sites in this study.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	The following limitations are acknowledged: 1000 year flows – the Statistical method is intended principally for return periods between 2 and 200 years (Reed, 1999). Given the typically short length of river gauge records, there are significant uncertainties associated with applying the method to long return periods of floods. However, the Hybrid method was used to derive flood peaks for return periods greater than the 100 year.

	Catchment wetness – modelled using FEH descriptors, however as the subject catchments are relatively permeable there is potential for them to have a different runoff response if rained on when already saturated.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH **3** 12.5 or the factorial standard error from Science Report SC050050 (2008).	Although a local donor station was used to improve QMED estimates, the absence of local flow data records on the study reaches increases the uncertainty in the flow estimates, particularly for the small tributary streams assessed. Natural uncertainty from the inherent variability of the climate tends to be the largest source of uncertainty in flood estimates for long return periods such as for the 100, 200, 500 and 1000 year, because these are derived from flood data series that rarely exceed 50 years in length. Upper and lower bound confidence limits (95% interval) in the QMED estimates at the subject sites are presented in the table below:
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	A thorough treatment has been given to the flow frequency of the study watercourses, based on the best available data at this time. However, future analysts should satisfy themselves that no new data can be obtained that could be used to refine the estimates.
Give any other comments on the study, for example suggestions for additional work.	To increase confidence in the flow frequency estimates, a short period of flow data record would be very valuable in improving the median annual flood flow estimates (QMED).

Site	Lower Bound – Confidence Limit (m^3/s)	Upper Bound – Confidence Limit (m^3/s)
FEP1	0.43	1.77
FEP2	0.05	0.20
FEP3	0.13	0.55
FEP4	0.15	0.61
FEP5	2.97	12.36

5.4 Checks

Are the results consistent, for example at confluences?	Yes, the results appear consistent.
What do the results imply regarding the return periods of floods during the period of record?	There are no gauged flow records of previous flood events for the subject watercourses.
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	The 100 year growth factors from the FEH Statistical method lie within the range of 2.57 to 2.88. This is within the typical range.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	The Hybrid method was used to derive flood peaks for return periods greater than 100 years. The ratios range from 1.94 to 2.03.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Based on design flows from the FEH Statistical method, specific discharges in a 1 in 100 year return period (1% AEP) range from:

	100 Years
	Statistical (l/s/ha)
FEP1	3.7

	<table><tr><td>**FEP2**</td><td>3.3</td></tr><tr><td>**FEP3**</td><td>3.4</td></tr><tr><td>**FEP4**</td><td>5.3</td></tr><tr><td>**FEP5**</td><td>3.1</td></tr></table> There are no apparent inconsistencies.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	No other studies available.
Are the results compatible with the longer-term flood history?	No further checks undertaken.
Describe any other checks on the results	None.

5.5 Final results

Site code	Flood peak (m^3/s) for the following return periods (in years)			
	100	**100+45%CC**	**100+105%CC**	**1000**
FEP1	2.51	3.64	5.15	5.09
FEP2	0.28	0.42	0.60	0.58
FEP3	0.75	1.09	1.54	1.47
FEP4	0.86	1.25	1.76	1.68
FEP5	15.56	22.56	31.90	30.13

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	IED files saved here: \\UKCA2FS02\Modelling_Data\10029956_OttepoolPark\E-OurDrawings Please see Annex 6.2 Additional Supporting Information for hydrographs produced in ReFH2 and scaled to the FEH Statistical peak.

6 Annex - supporting information

6.1 Pooling group composition

PG1_DEFAULT POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27051 (Crimple @ Burn Bridge)	0.505	46	4.539	0.219	0.148	0.338
45816 (Haddeo @ Upton)	0.904	25	3.456	0.306	0.399	0.628
28033 (Dove @ Hollinsclough)	1.129	43	4.205	0.231	0.369	0.553
25019 (Leven @ Easby)	1.181	40	5.384	0.343	0.378	0.895
26802 (Gypsey Race @ Kirby Grindalythe)	1.222	19	0.109	0.309	0.183	0.537
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	1.357	8	6.511	0.262	0.049	2.729
47022 (Tory Brook @ Newnham Park)	1.522	25	6.18	0.273	0.149	0.428
25011 (Langdon Beck @ Langdon)	1.525	32	15.533	0.235	0.334	1.242
27010 (Hodge Beck @ Bransdale Weir)	1.561	41	9.42	0.224	0.293	0.175
44008 (South Winterbourne @ Winterbourne Steepleton)	1.648	39	0.448	0.411	0.328	2.047
71003 (Croasdale Beck @ Croasdale Flume)	1.805	37	10.9	0.212	0.323	0.389
25003 (Trout Beck @ Moor House)	1.824	45	15.12	0.167	0.302	0.925
206006 (Annalong @ Recorder)	1.83	48	15.33	0.189	0.052	2.714
27032 (Hebden Beck @ Hebden)	2.04	52	3.923	0.207	0.244	0.401
Total		500				
Weighted means				0.256	0.261	

PG1_FINAL POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27051 (Crimple @ Burn Bridge)	0.504	46	4.539	0.219	0.148	1.017
45816 (Haddeo @ Upton)	0.904	25	3.456	0.306	0.399	1.097
25019 (Leven @ Easby)	1.181	40	5.384	0.343	0.378	2.165
25011 (Langdon Beck @ Langdon)	1.525	32	15.533	0.235	0.334	1.598
27010 (Hodge Beck @ Bransdale Weir)	1.561	41	9.42	0.224	0.293	0.121
25003 (Trout Beck @ Moor House)	1.824	45	15.12	0.167	0.302	0.948
206006 (Annalong @ Recorder)	1.83	48	15.33	0.189	0.052	1.694
76011 (Coal Burn @ Coalburn)	2.089	41	1.84	0.165	0.315	1.278

49003 (de Lank @ de Lank)	2.134	52	13.985	0.223	0.209	0.335
72014 (Conder @ Galgate)	2.213	50	16.465	0.233	0.162	0.646
54022 (Severn @ Plynlimon Flume)	2.245	38	14.988	0.156	0.171	0.86
41020 (Bevern Stream @ Clappers Bridge)	2.353	49	13.66	0.203	0.181	0.241
Total		507				
Weighted means				0.226	0.241	

PG2_DEFAULT POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
76011 (Coal Burn @ Coalburn)	1.856	41	1.84	0.165	0.315	0.692
27073 (Brompton Beck @ Snainton Ings)	3.154	37	0.82	0.2	0.047	0.802
45816 (Haddeo @ Upton)	3.707	25	3.456	0.306	0.399	1.034
27051 (Crimple @ Burn Bridge)	3.803	46	4.539	0.219	0.148	0.167
28033 (Dove @ Hollinsclough)	3.948	43	4.205	0.231	0.369	0.523
91802 (Allt Leachdach @ Intake)	4.279	34	6.35	0.153	0.257	0.887
25003 (Trout Beck @ Moor House)	4.399	45	15.12	0.167	0.302	0.652
71003 (Croasdale Beck @ Croasdale Flume)	4.442	37	10.9	0.212	0.323	0.256
47022 (Tory Brook @ Newnham Park)	4.474	25	6.18	0.273	0.149	0.468
54022 (Severn @ Plynlimon Flume)	4.497	38	14.988	0.156	0.171	0.987
25019 (Leven @ Easby)	4.501	40	5.384	0.343	0.378	1.823
25011 (Langdon Beck @ Langdon)	4.505	32	15.533	0.235	0.334	1.09
26802 (Gypsey Race @ Kirby Grindalythe)	4.505	19	0.109	0.309	0.183	0.96
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	4.594	8	6.511	0.262	0.049	2.454
206006 (Annalong @ Recorder)	4.674	48	15.33	0.189	0.052	2.205
Total		518				
Weighted means				0.225	0.238	

PG2_FINAL POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27073 (Brompton Beck @ Snainton Ings)	3.154	37	0.82	0.2	0.047	0.708
45816 (Haddeo @ Upton)	3.707	25	3.456	0.306	0.399	1.22
27051 (Crimple @ Burn Bridge)	3.803	46	4.539	0.219	0.148	0.124

25003 (Trout Beck @ Moor House)	4.399	45	15.12	0.167	0.302	1.389
54022 (Severn @ Plynlimon Flume)	4.497	38	14.988	0.156	0.171	0.968
25019 (Leven @ Easby)	4.501	40	5.384	0.343	0.378	2.016
25011 (Langdon Beck @ Langdon)	4.505	32	15.533	0.235	0.334	0.981
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	4.594	8	6.511	0.262	0.049	2.528
206006 (Annalong @ Recorder)	4.674	48	15.33	0.189	0.052	1.108
49003 (de Lank @ de Lank)	4.976	52	13.985	0.223	0.209	0.038
72014 (Conder @ Galgate)	5.153	50	16.465	0.233	0.162	0.074
72007 (Brock @ Upstream of a6)	5.413	40	28.964	0.199	0.218	0.405
28041 (Hamps @ Waterhouses)	5.627	33	26.126	0.223	0.291	0.588
47021 (Kensey @ Launceston Newport)	5.641	16	13.685	0.253	0.118	1.854
Total		510				
Weighted means				0.228	0.211	

PG3_DEFAULT POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
76011 (Coal Burn @ Coalburn)	0.854	41	1.84	0.165	0.315	0.692
45816 (Haddeo @ Upton)	1.857	25	3.456	0.306	0.399	1.034
27051 (Crimple @ Burn Bridge)	1.884	46	4.539	0.219	0.148	0.167
28033 (Dove @ Hollinsclough)	2.145	43	4.205	0.231	0.369	0.523
25019 (Leven @ Easby)	2.705	40	5.384	0.343	0.378	1.823
27073 (Brompton Beck @ Snainton Ings)	2.727	37	0.82	0.2	0.047	0.802
26802 (Gypsey Race @ Kirby Grindalythe)	2.753	19	0.109	0.309	0.183	0.96
25011 (Langdon Beck @ Langdon)	2.782	32	15.533	0.235	0.334	1.09
47022 (Tory Brook @ Newnham Park)	2.815	25	6.18	0.273	0.149	0.468
91802 (Allt Leachdach @ Intake)	2.82	34	6.35	0.153	0.257	0.887
71003 (Croasdale Beck @ Croasdale Flume)	2.826	37	10.9	0.212	0.323	0.256
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.849	8	6.511	0.262	0.049	2.454
25003 (Trout Beck @ Moor House)	2.882	45	15.12	0.167	0.302	0.652
54022 (Severn @ Plynlimon Flume)	3.001	38	14.988	0.156	0.171	0.987
206006 (Annalong @ Recorder)	3.055	48	15.33	0.189	0.052	2.205
Total		518				
Weighted means				0.226	0.239	

PG3_FINAL POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
76011 (Coal Burn @ Coalburn)	0.853	41	1.84	0.165	0.315	0.99
45816 (Haddeo @ Upton)	1.86	25	3.456	0.306	0.399	1.221
27051 (Crimple @ Burn Bridge)	1.887	46	4.539	0.219	0.148	0.157
25019 (Leven @ Easby)	2.708	40	5.384	0.343	0.378	2.465
27073 (Brompton Beck @ Snainton Ings)	2.73	37	0.82	0.2	0.047	0.784
25011 (Langdon Beck @ Langdon)	2.785	32	15.533	0.235	0.334	1.208
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.852	8	6.511	0.262	0.049	2.656
25003 (Trout Beck @ Moor House)	2.884	45	15.12	0.167	0.302	0.989
54022 (Severn @ Plynlimon Flume)	3.003	38	14.988	0.156	0.171	0.898
206006 (Annalong @ Recorder)	3.057	48	15.33	0.189	0.052	2.114
27010 (Hodge Beck @ Bransdale Weir)	3.066	41	9.42	0.224	0.293	0.142
49003 (de Lank @ de Lank)	3.497	52	13.985	0.223	0.209	0.016
72014 (Conder @ Galgate)	3.703	50	16.465	0.233	0.162	0.172
73015 (Keer @ High Keer Weir)	3.736	27	12.33	0.205	0.281	0.186
Total		530				
Weighted means				0.221	0.229	

PG4_DEFAULT POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
76011 (Coal Burn @ Coalburn)	0.992	41	1.84	0.165	0.315	0.657
45816 (Haddeo @ Upton)	1.728	25	3.456	0.306	0.399	1.064
27051 (Crimple @ Burn Bridge)	1.732	46	4.539	0.219	0.148	0.291
28033 (Dove @ Hollinsclough)	2.017	43	4.205	0.231	0.369	0.466
25019 (Leven @ Easby)	2.552	40	5.384	0.343	0.378	1.781
26802 (Gypsey Race @ Kirby Grindalythe)	2.602	19	0.109	0.309	0.183	1.193
25011 (Langdon Beck @ Langdon)	2.648	32	15.533	0.235	0.334	1.645
47022 (Tory Brook @ Newnham Park)	2.652	25	6.18	0.273	0.149	0.52
27073 (Brompton Beck @ Snainton Ings)	2.696	37	0.82	0.2	0.047	1.166
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.697	8	6.511	0.262	0.049	2.528
71003 (Croasdale Beck @ Croasdale Flume)	2.711	37	10.9	0.212	0.323	0.213
91802 (Allt Leachdach @ Intake)	2.737	34	6.35	0.153	0.257	0.881
25003 (Trout Beck @ Moor House)	2.772	45	15.12	0.167	0.302	0.616
54022 (Severn @ Plynlimon Flume)	2.907	38	14.988	0.156	0.171	1.878
27010 (Hodge Beck @ Bransdale	2.911	41	9.42	0.224	0.293	0.102

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
Weir)						
Total		511				
Weighted means				0.228	0.257	

PG4_FINAL POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
76011 (Coal Burn @ Coalburn)	0.991	41	1.84	0.165	0.315	0.859
45816 (Haddeo @ Upton)	1.729	25	3.456	0.306	0.399	1.079
27051 (Crimple @ Burn Bridge)	1.734	46	4.539	0.219	0.148	0.213
28033 (Dove @ Hollinsclough)	2.018	43	4.205	0.231	0.369	0.427
25019 (Leven @ Easby)	2.554	40	5.384	0.343	0.378	2.382
25011 (Langdon Beck @ Langdon)	2.649	32	15.533	0.235	0.334	1.152
27073 (Brompton Beck @ Snainton Ings)	2.697	37	0.82	0.2	0.047	0.853
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.698	8	6.511	0.262	0.049	2.647
71003 (Croasdale Beck @ Croasdale Flume)	2.712	37	10.9	0.212	0.323	0.23
25003 (Trout Beck @ Moor House)	2.773	45	15.12	0.167	0.302	0.897
54022 (Severn @ Plynlimon Flume)	2.908	38	14.988	0.156	0.171	0.901
27010 (Hodge Beck @ Bransdale Weir)	2.912	41	9.42	0.224	0.293	0.073
206006 (Annalong @ Recorder)	2.92	48	15.33	0.189	0.052	2.251
49003 (de Lank @ de Lank)	3.368	52	13.985	0.223	0.209	0.036
Total		533				
Weighted means				0.222	0.248	

PG5_DEFAULT POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
26013 (Driffield Trout Stream @ Driffield)	0.24	8	2.78	0.29	0.218	2.822
26003 (Foston Beck @ Foston Mill)	0.372	57	1.76	0.248	-0.009	0.928
33032 (Heacham @ Heacham)	0.418	50	0.442	0.304	0.124	0.562
53017 (Boyd @ Bitton)	0.445	45	13.87	0.241	0.088	0.115
41022 (Lod @ Halfway Bridge)	0.469	48	15.86	0.298	0.187	0.447
30004 (Lymn @ Partney Mill)	0.48	56	6.983	0.229	0.046	0.452
33054 (Babingley @ Castle Rising)	0.52	42	1.132	0.201	0.08	0.585
41020 (Bevern Stream @ Clappers Bridge)	0.566	49	13.66	0.203	0.181	0.957
76019 (Roe Beck @ Stockdalewath)	0.573	19	39.9	0.231	0.337	2.075
36004 (Chad Brook @ Long	0.585	51	5.186	0.294	0.182	1.189

Melford)						
36003 (Box @ Polstead)	0.624	57	3.91	0.305	0.089	1.072
39042 (Leach @ Priory Mill Lechlade)	0.645	46	3.085	0.193	0.065	0.797
Total		528				
Weighted means				0.253	0.121	

PG5_FINAL POOLING GROUP

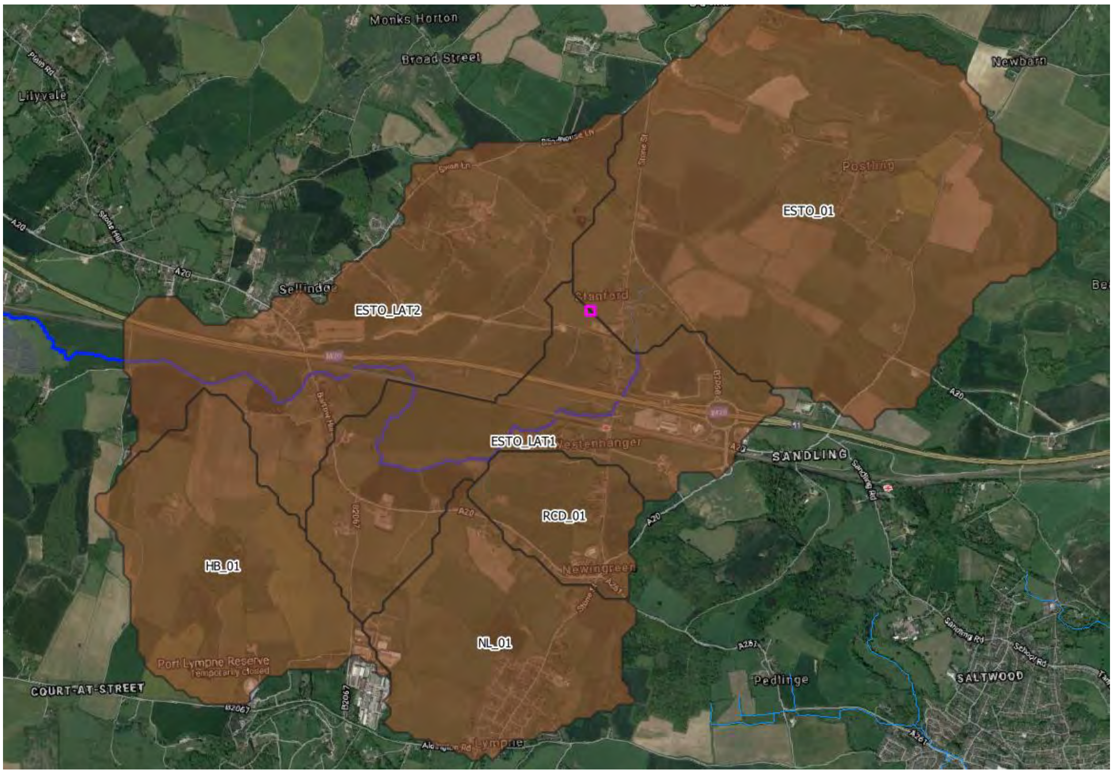
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
26013 (Driffield Trout Stream @ Driffield)	0.24	8	2.78	0.29	0.218	3.059
33032 (Heacham @ Heacham)	0.418	50	0.442	0.304	0.124	0.28
41022 (Lod @ Halfway Bridge)	0.469	48	15.86	0.298	0.187	0.351
30004 (Lymn @ Partney Mill)	0.48	56	6.983	0.229	0.046	1.202
33054 (Babingley @ Castle Rising)	0.52	42	1.132	0.201	0.08	0.706
41020 (Bevern Stream @ Clappers Bridge)	0.566	49	13.66	0.203	0.181	1.039
36003 (Box @ Polstead)	0.624	57	3.91	0.305	0.089	0.845
36007 (Belchamp Brook @ Bardfield Bridge)	0.661	53	4.63	0.371	0.119	1.692
53023 (Sherston Avon @ Fosseway)	0.668	42	7.332	0.225	0.193	0.657
43014 (East Avon @ Upavon)	0.785	47	3.729	0.208	0.08	0.774
44011 (Asker @ East Bridge Bridport)	0.794	23	16.566	0.228	0.12	0.326
44003 (Asker @ Bridport)	0.794	14	12.354	0.224	0.17	1.185
20007 (Gifford Water @ Lennoxlove)	0.798	45	16.19	0.323	0.2	0.885
Total		534				
Weighted means		534		0.263	0.134	

6.2 Hydrographs

During the model development it was identified that inclusion of the Aldington Flood Storage Area (FSA) within the model would introduce significant difficulty and uncertainty as information release on the construction details and how the facility operates are currently restricted due to public safety and national security concerns. Additionally, there are several catchments which flow into the FSA further downstream of the Otterpool Park site and it is expected that the behaviour of the flood storage area would be dependent on the timing of the different peak flows from these catchments. This will involve development of a complex hydrological and hydraulic model, which is not within the current project scope.

The primary purpose of this study is to assess the flood risk from the effects of climate change to the proposed development and ensure a robust sequential approach is adopted to manage flood risk over its design life as per the NPPF requirements. Additionally, the model will be used to assess the impact of the proposed development on offsite flood risk and demonstrate that the proposed measures can adequately mitigate any negative impacts. A comparison of the hydrographs and levels from the baseline and post-development scenario will be made at the downstream boundary of the model to assess any downstream flood risk impacts.

As such, the downstream boundary of the model has been moved to Church Lane, upstream of the Aldington FSA. FEP5 would have been used to apply a series of lateral inflows to the model by apportioning the peak flow according to contributing areas at key locations (such as upstream of significant structures or the location of confluences). FEP5 has still been used in this way, but only with the two intervening areas ESTO_LAT1 and ESTO_LAT2 as presented in the below image. These intervening areas cover 6.1% and 8.3% of the total catchment area of FEP5 and the hydrograph for FEP5 has been scaled accordingly to provide lateral inflows for the model.



Time	FEP1 (ESTO_01)				FEP2 (RCD_01)				FEP3 (NL01)				FEP4 (HB01)				ESTO_LAT1				ESTO_LAT2			
(hrs)	100	100 +45%	100 +105%	1000	100	100 +45%	100 +105%	1000	100	100 +45%	100 +105%	1000	100	100 +45%	100 +105%	1000	100	100 +45%	100 +105%	1000	100	100 +45%	100 +105%	1000
0	0.06	0.05	0.05	0.06	0.01	0.01	0.00	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.04	0.04	0.03	0.04	0.06	0.05	0.05	0.06
1	0.07	0.07	0.06	0.08	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.04	0.04	0.04	0.04	0.06	0.05	0.05	0.06
2	0.11	0.11	0.12	0.14	0.01	0.02	0.02	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.05	0.07	0.06	0.06	0.07
3	0.19	0.22	0.25	0.28	0.03	0.03	0.04	0.04	0.06	0.07	0.09	0.09	0.07	0.09	0.10	0.11	0.06	0.06	0.06	0.07	0.08	0.08	0.09	0.10
4	0.34	0.42	0.50	0.55	0.05	0.06	0.08	0.08	0.11	0.14	0.17	0.18	0.13	0.16	0.20	0.21	0.08	0.09	0.10	0.11	0.11	0.13	0.14	0.15
5	0.59	0.76	0.96	1.02	0.08	0.11	0.14	0.15	0.19	0.25	0.32	0.33	0.22	0.29	0.37	0.38	0.13	0.15	0.18	0.19	0.17	0.21	0.25	0.26
6	1.02	1.36	1.78	1.85	0.14	0.20	0.27	0.27	0.33	0.44	0.58	0.58	0.38	0.52	0.68	0.68	0.20	0.26	0.33	0.33	0.27	0.35	0.45	0.45
7	1.59	2.20	2.97	3.02	0.21	0.31	0.43	0.42	0.50	0.70	0.94	0.92	0.59	0.82	1.11	1.09	0.31	0.42	0.55	0.54	0.43	0.57	0.75	0.74
8	2.15	3.03	4.18	4.20	0.27	0.40	0.56	0.54	0.66	0.94	1.29	1.25	0.77	1.11	1.52	1.47	0.45	0.62	0.83	0.80	0.61	0.84	1.12	1.09
9	2.47	3.54	4.96	4.93	0.28	0.42	0.60	0.58	0.75	1.07	1.50	1.44	0.86	1.25	1.75	1.68	0.59	0.83	1.13	1.09	0.81	1.13	1.54	1.48
10	2.51	3.64	5.15	5.09	0.26	0.40	0.57	0.55	0.75	1.09	1.54	1.47	0.85	1.25	1.76	1.68	0.73	1.04	1.43	1.37	1.00	1.41	1.95	1.86
11	2.36	3.45	4.91	4.84	0.23	0.35	0.51	0.49	0.70	1.02	1.46	1.39	0.78	1.16	1.64	1.56	0.85	1.22	1.70	1.61	1.16	1.65	2.31	2.20
12	2.12	3.11	4.45	4.37	0.19	0.30	0.43	0.41	0.62	0.91	1.31	1.24	0.69	1.02	1.45	1.38	0.92	1.33	1.87	1.78	1.26	1.81	2.55	2.41
13	1.84	2.70	3.86	3.79	0.16	0.24	0.34	0.33	0.53	0.79	1.13	1.07	0.58	0.86	1.23	1.17	0.95	1.37	1.94	1.83	1.29	1.87	2.64	2.49
14	1.54	2.26	3.24	3.18	0.13	0.19	0.27	0.26	0.45	0.66	0.95	0.89	0.48	0.70	0.99	0.95	0.93	1.36	1.92	1.81	1.27	1.84	2.62	2.47
15	1.28	1.87	2.66	2.62	0.11	0.16	0.23	0.22	0.37	0.54	0.78	0.74	0.39	0.57	0.80	0.76	0.89	1.30	1.85	1.74	1.21	1.77	2.51	2.37
16	1.07	1.56	2.22	2.18	0.10	0.14	0.20	0.20	0.31	0.45	0.65	0.62	0.33	0.48	0.66	0.64	0.84	1.22	1.74	1.63	1.14	1.66	2.36	2.22
17	0.94	1.35	1.91	1.89	0.09	0.13	0.19	0.18	0.27	0.39	0.56	0.53	0.29	0.42	0.58	0.56	0.78	1.13	1.61	1.51	1.05	1.54	2.19	2.06
18	0.85	1.22	1.72	1.71	0.09	0.13	0.18	0.17	0.24	0.35	0.50	0.47	0.27	0.38	0.53	0.51	0.72	1.04	1.49	1.40	0.97	1.42	2.02	1.90
19	0.80	1.14	1.60	1.59	0.08	0.12	0.17	0.17	0.22	0.32	0.46	0.44	0.25	0.36	0.49	0.48	0.67	0.97	1.38	1.30	0.91	1.32	1.87	1.76
20	0.76	1.09	1.53	1.52	0.08	0.12	0.17	0.16	0.21	0.31	0.43	0.41	0.24	0.35	0.47	0.46	0.62	0.90	1.28	1.21	0.84	1.23	1.75	1.64
21	0.74	1.06	1.49	1.48	0.08	0.12	0.16	0.16	0.20	0.30	0.42	0.40	0.24	0.34	0.46	0.45	0.58	0.84	1.20	1.13	0.79	1.15	1.63	1.53
22	0.73	1.04	1.46	1.45	0.08	0.11	0.16	0.16	0.20	0.29	0.41	0.39	0.23	0.33	0.45	0.44	0.54	0.78	1.11	1.05	0.73	1.07	1.52	1.43
23	0.71	1.02	1.43	1.42	0.07	0.11	0.15	0.15	0.19	0.28	0.40	0.38	0.22	0.32	0.44	0.43	0.50	0.73	1.03	0.97	0.68	0.99	1.41	1.32
24	0.70	1.00	1.40	1.39	0.07	0.11	0.15	0.15	0.19	0.27	0.39	0.37	0.22	0.31	0.43	0.42	0.46	0.67	0.96	0.90	0.63	0.92	1.30	1.22
25	0.69	0.98	1.38	1.37	0.07	0.10	0.15	0.14	0.19	0.27	0.38	0.36	0.21	0.31	0.42	0.41	0.43	0.62	0.88	0.83	0.58	0.84	1.20	1.13
26	0.67	0.96	1.35	1.34	0.07	0.10	0.14	0.14	0.18	0.26	0.37	0.36	0.21	0.30	0.41	0.40	0.39	0.57	0.80	0.76	0.53	0.77	1.09	1.03
27	0.66	0.94	1.32	1.31	0.07	0.10	0.14	0.14	0.18	0.26	0.36	0.35	0.20	0.29	0.40	0.39	0.36	0.52	0.74	0.70	0.49	0.71	1.00	0.95
28	0.65	0.93	1.30	1.29	0.07	0.10	0.14	0.13	0.17	0.25	0.36	0.34	0.20	0.29	0.39	0.38	0.34	0.49	0.68	0.65	0.46	0.66	0.93	0.88
29	0.64	0.91	1.27	1.27	0.06	0.09	0.13	0.13	0.17	0.25	0.35	0.33	0.19	0.28	0.38	0.37	0.32	0.46	0.65	0.61	0.44	0.63	0.88	0.83
30	0.62	0.89	1.25	1.24	0.06	0.09	0.13	0.13	0.17	0.24	0.34	0.32	0.19	0.27	0.37	0.36	0.31	0.44	0.62	0.59	0.42	0.60	0.85	0.80
31	0.61	0.87	1.23	1.22	0.06	0.09	0.13	0.12	0.16	0.24	0.33	0.32	0.19	0.27	0.37	0.36	0.30	0.43	0.60	0.57	0.41	0.58	0.82	0.78
32	0.60	0.86	1.20	1.19	0.06	0.09	0.12	0.12	0.16	0.23	0.33	0.31	0.18	0.26	0.36	0.35	0.29	0.42	0.59	0.56	0.40	0.57	0.80	0.76
33	0.59	0.84	1.18	1.17	0.06	0.09	0.12	0.12	0.15	0.22	0.32	0.30	0.18	0.25	0.35	0.34	0.29	0.41	0.58	0.55	0.39	0.56	0.79	0.75
34	0.58	0.82	1.16	1.15	0.06	0.08	0.12	0.11	0.15	0.22	0.31	0.30	0.17	0.25	0.34	0.33	0.28	0.41	0.57	0.54	0.39	0.55	0.78	0.73
35	0.57	0.81	1.13	1.13	0.05	0.08	0.11	0.11	0.15	0.21	0.30	0.29	0.17	0.24	0.33	0.32	0.28	0.40	0.56	0.53	0.38	0.54	0.76	0.72
36	0.56	0.79	1.11	1.11	0.05	0.08	0.11	0.11	0.15	0.21	0.30	0.28	0.17	0.24	0.33	0.32	0.27	0.39	0.55	0.52	0.37	0.53	0.75	0.71
37	0.54	0.78	1.09	1.08	0.05	0.08	0.11	0.11	0.14	0.21	0.29	0.28	0.16	0.23	0.32	0.31	0.27	0.39	0.54	0.51	0.37	0.53	0.74	0.70
38	0.53	0.76	1.07	1.06	0.05	0.08	0.11	0.10	0.14	0.20	0.28	0.27	0.16	0.23	0.31	0.30	0.27	0.38	0.53	0.51	0.36	0.52	0.73	0.69
39	0.52	0.75	1.05	1.04	0.05	0.07	0.10	0.10	0.14	0.20	0.28	0.26	0.15	0.22	0.30	0.30	0.26	0.37	0.52	0.50	0.36	0.51	0.71	0.68
40	0.51	0.73	1.03	1.02	0.05	0.07	0.10	0.10	0.13	0.19	0.27	0.26	0.15	0.22	0.30	0.29	0.26	0.37	0.52	0.49	0.35	0.50	0.70	0.67

6.3 Additional supporting information

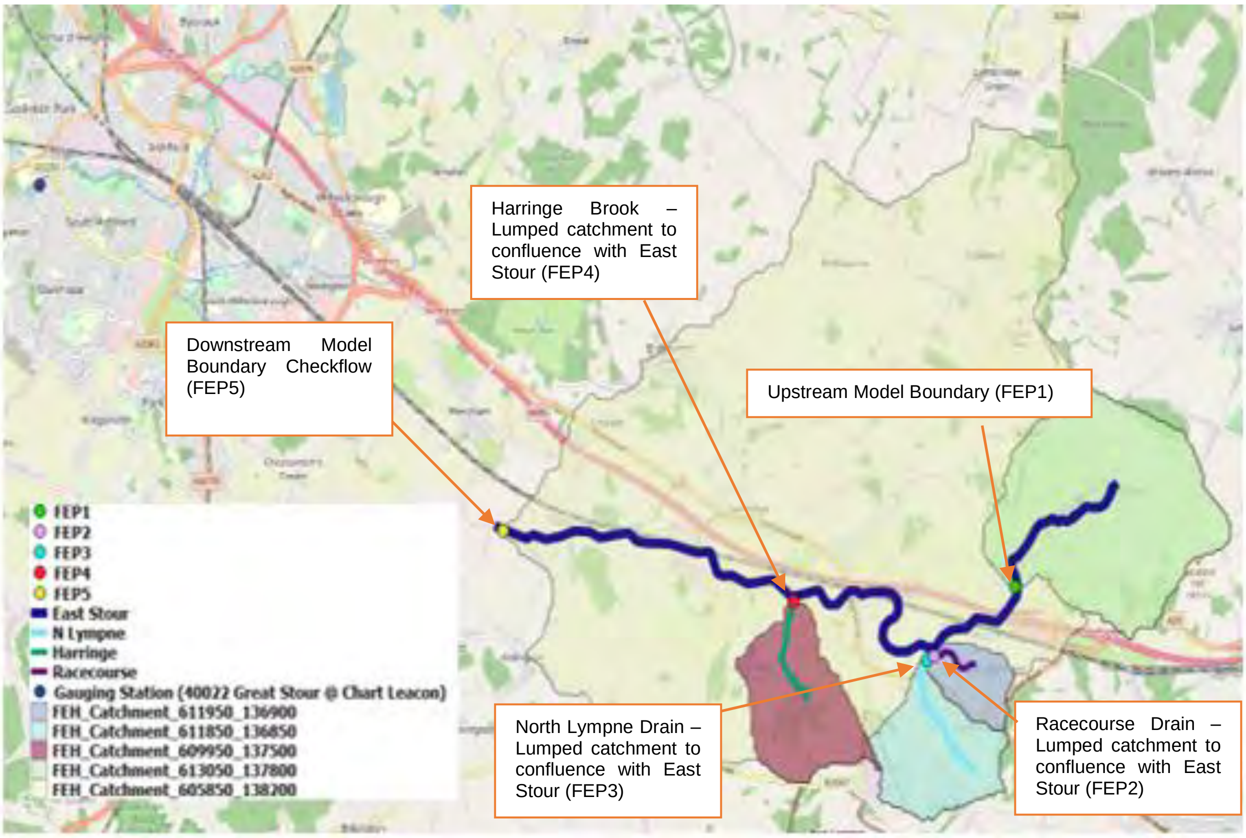


Figure 1: FEPs, subject watercourses and gauging station (40022 Great Stour @ Chart Leacon)

Table 1: Results of the sensitivity run for 3.5hr storm duration applied to all FEPs

	REFH2 (11 HR SD)			
FEP/Year	*100*	*100+45%*	*100+105%*	*1000*
DS(FEP5)	16.74	26.89	43.20	32.42
US (FEP1)	2.39	3.96	6.53	4.85
HARRINGE (FEP4)	1.43	2.31	3.75	2.79
N.LYMPNE (FEP3)	1.08	1.75	2.83	2.11
RACECOURSE (FEP2)	0.45	0.74	1.22	0.90
	REFH2 (3.5 HR SD)			
FEP/Year	*100*	*100+45%*	*100+105%*	*1000*
DS(FEP5)	10.44	16.02	24.61	18.91
US (FEP1)	1.77	2.79	4.40	3.31
HARRINGE (FEP4)	1.11	1.74	2.71	2.07
N.LYMPNE (FEP3)	0.84	1.31	2.02	1.56
RACECOURSE (FEP2)	0.37	0.58	0.91	0.69

Table 2: Comparison of FEH catchment descriptors (FEH Web Service) with manual checks using method in Institute of Hydrology Report No.126

FEP	*BFIHOST*			*SPRHOST*		
	FEH CDs	**Checks**	**Difference**	**FEH CDs**	**Checks**	**Difference**
FEP1 (US)	0.728	0.621	17.2%	21.23	22.3	-4.8%
FEP2 (RACE)	0.755	0.679	11.2%	25.36	28.949	-12.4%
FEP3 (N. LYMPNE)	0.783	0.655	19.5%	24.16	24.495	-1.4%
FEP4 (HARRINGE)	0.724	0.609	18.19%	26.71	24.906	7.2%
FEP5 (DS)	0.66	0.519	17.2%	28.05	16.297	-4.8%

Table 3: Comparison of Z values for choice of distribution for each FEP

FEP	GL	GEV	Comment
FEP1 (US)	-0.7193	-2.2127	Lowest absolute Z-value indicates best fit. Distribution gives an acceptable fit where the absolute Z-value < 1.645
FEP2 (RACE)	0.3903	-1.3642	
FEP3 (N. LYMPNE)	0.2693	-1.2604	
FEP4 (HARRINGE)	-0.3013	-1.7196	
FEP5 (DS)	3.4727	0.5781	

APPENDIX I

Baseline Hydrology Update

SUBJECT
Otterpool Park - East Stour Baseline Hydrology Update

DATE
15th March 2022

DEPARTMENT
Arcadis - Water Management and Resilience

COPIES TO
Lisa Driscoll (Arcadis)
Renuka Gunasekara (Arcadis)
Hywel Roberts (Arcadis)

TO
Jennifer Wilson (F&HDC)
James Farrar (F&HDC)

OUR REF
10029956-AUK-XX-XX-FN-CW-0045-P3

PROJECT NUMBER
10029956

FROM
Michael Grogan (Arcadis)
T +44 (0) 1483 803061
E Michael.Grogan@arcadis.com

1. Introduction

Following on from the previously issued East Stour Flow Sensitivity Test report (10029956-AUK-XX-XX-RP-CW-0028-P1-Flow Sensitivity Test), this memo details the outcome of further investigation of the runoff response of the East Stour catchment under different antecedent conditions. The previous report detailed the results of a sensitivity test to analyse the effects of an exceptionally wet antecedent period on flows in the catchment. The results of the test indicated that flows in the East Stour are responsive, and the tested combination of antecedent wetness and design rainfall resulted in modelled water levels that were higher than indicated in the gauge record at Barrowhill Bridge.

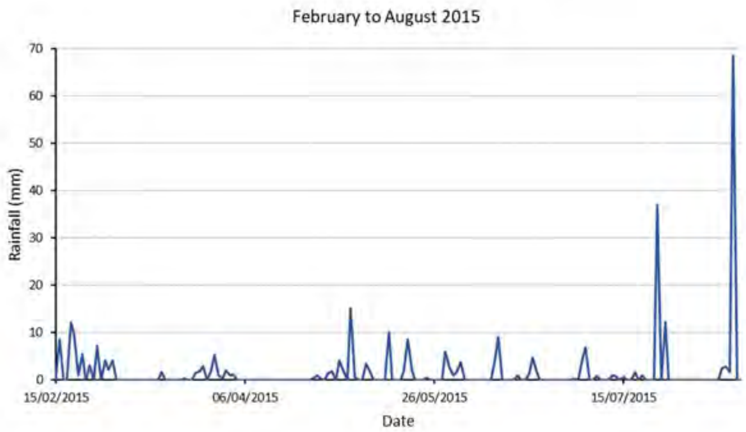
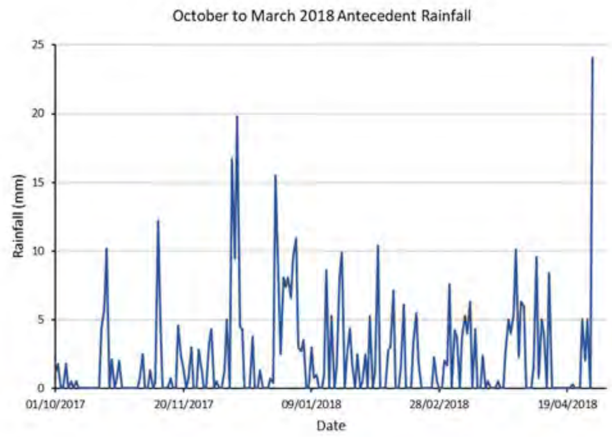
Further analysis of historical rainfall data has been undertaken to identify antecedent conditions that are more typical, such that when combined with design rainfall modelled water levels are more representative of observed levels.

2. Hydrology

2.1 Cini Updates

To test a range of antecedent conditions, the Cini parameter (representing initial soil moisture) within ReFH models of the East Stour and key tributaries that flow through the proposed development site, has been generated from observed rainfall data records. Following analysis of rainfall records from the Silver Spray storage rain gauge located in Sellindge, at NGR: TR 10250 38130, two 6-month periods of rainfall from February to August 2015 and October to March 2018 were identified as representing typical wet periods. A comparison of the two observed rainfall periods selected for analysis is shown Table 2-1.

Table 2-1: Antecedent Rainfall Event Summary

Rainfall Event	August 2015 Period	March 2018 Period
Total Antecedent Rainfall (mm)	312	489
Peak rainfall (mm)	67	24
Rain Profile		

The daily rainfall total for these two 6-month periods were applied in the ReFH models to generate Cini values for each period. Design rainfall events, for the 1% and 5% Annual Exceedance Probability (AEP) storms, were then applied to the catchments, combined with the updated Cini values to generate flow hydrographs. The peak flows produced at each Flow Estimation Point (FEP), are detailed in Table 2-2. The table includes the baseline peak flows, derived from the ReFH catchment descriptor modelled Cini values, the sensitivity test peak flows, based upon a Cini value derived from 6 months of rainfall data during an exceptionally wet period from October 2000 to February 2001, and the peak flows produced from modelling the August 2015 and March 2018 antecedent periods.

Table 2-2: Peak Flows derived from updated Cini value for each Flow Estimation Point (FEP)

FEP	Watercourse	ReFH Modelled Cini (Baseline)	Sensitivity test (Cini Oct 2000*)	Cini derived Aug 2015*	Cini derived Mar 2018*	Storm Duration	1% AEP Baseline peak flow (m^3/s)	1% AEP Sensitivity test peak flow (m^3/s)	1% AEP peak flow Aug 2015*	1% AEP peak flow Mar 2018*
FEP 1	East Stour (US)	65.13	163.59	87.35	154.96	11 Hours	2.39	5.02	2.99	4.80
FEP 2	Racecourse Drain	72.40	140.06	83.94	131.47		0.45	0.76	0.50	0.72
FEP 3	N/ Lympne	72.51	139.74	83.89	131.16		1.08	1.75	1.20	1.67
FEP 4	Harringe Brook	79.73	121.93	81.35	113.39		1.43	2.01	1.45	1.90
FEP 5	East Stour (DS Lumped Catchment)	77.52	126.90	16.11	118.34		16.74	25.11	7.28	23.66

*Cini value derived from 6 months period of daily rainfall total data preceding the specified date

2.2 Climate Change allowance updates

The Environment Agency (EA) released new peak river flow climate change allowances in July 2021[1], in line with these updates. The climate change allowances previously applied in the modelling study (10029956-AUK-XX-XX-RP-CW-0021-P2-Flood Modelling Report), have been updated. Table 2-3 shows the previous climate change allowances for the central, higher central and upper end estimates alongside the updated values for the Stour catchment.

Table 2-3: EA Peak River Flow Climate Change Allowances

Climate change allowance 2080s epoch (2070 to 2125)	Previous Allowance	Updated Allowance
Central	35%	38%
Higher Central	45%	55%
Upper End	105%	101%

The new guidance indicates that the central allowance is now applicable to inform future flood risk for 'more vulnerable' developments, including residential developments. Previously the guidance required the Higher Central estimate to be applied. This was confirmed through consultation with the EA in October 2021[2], as such the model has been run with a climate change allowance of 38%, with a sensitivity test for the upper end allowance of 101%.

3. River Modelling Results

The hydraulic model was run for the 5%, 1%, 0.1%, 1% + Central (38%) Climate Change allowance and 1% + Upper End (101%) Climate Change allowance events, using the hydrographs generated from the ReFH runs. The results of the modelling (peak water levels) for the 1% and 5% AEP events were compared against the previously modelled baseline water levels. The 1% AEP event was used to compare against the EA flood map, Flood Zone 3.

Based on these results, as described below, the antecedent conditions represented by modelling the March 2018 observed rainfall were taken forward.

3.1 Peak Modelled Water Levels

For the 5% AEP event the updated Cini value has resulted in an increase in peak modelled water level at the Barrowhill Bridge gauge of 0.6m, from 59.91mAOD in the original baseline to 60.51mAOD. For the 1% AEP event has water levels have increased by 1.03m, from 60.13mAOD to 61.16mAOD.

The peak water levels modelled are lower for both the 5% and 1% AEP events relative to the previous sensitivity test by 0.24m and 0.36m respectively.

The modelled 5% AEP water level lies between the two highest recorded levels at Barrowhill Bridge (60.349mAOD and 60.797mAOD) and the modelled water level for the 1% AEP event is very similar to the highest recorded level – see Figure 1.

[1] Environment Agency, Climate change allowances for peak river flow in England, Based on 1981-2000 baseline. June 2021, accessed via: https://environment.data.gov.uk/hydrology/climate-change-allowances

[2] Email correspondence with the EA dated 5th October 2021.

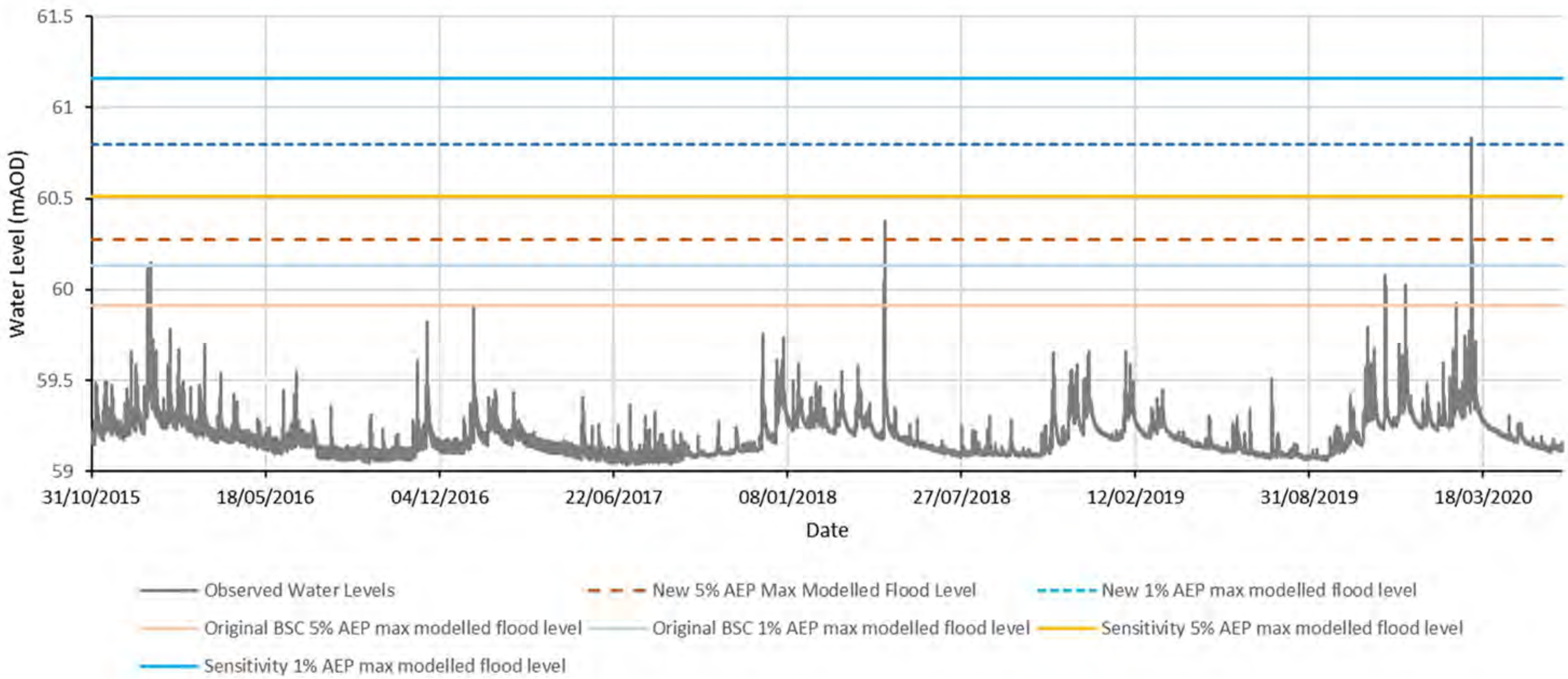


Figure 1: Comparison of observed water levels with modelled water levels in the baseline (BSC), sensitivity and updated runs.

3.2 Downstream Flood Conditions

A comparison of stage and flow at the downstream end of the proposed development site indicates that the peak stage and flows have increased in the updated baseline for both the 1% and 5% AEP events relative to the original baseline. Peak flow for the 1% AEP event has increased by 6.94m^3/s with stage increasing by 46mm. For the 5% AEP event flow increased by 3.95m^3/s and stage by 30mm. Figure 2 to Figure 5 below present comparisons between the stage and flow hydrographs at a model node downstream of the site boundary (ESTO01_13794), just upstream of the bridge at Harringe Lane.

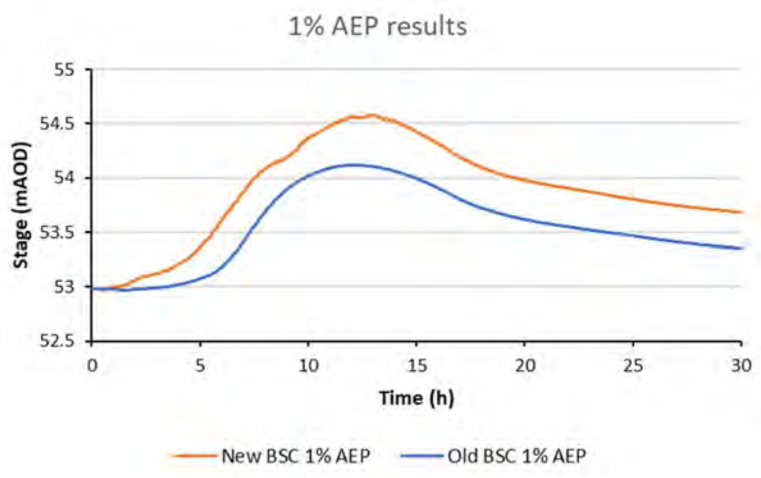


Figure 2: 1% AEP modelled stage, new baseline vs old baseline

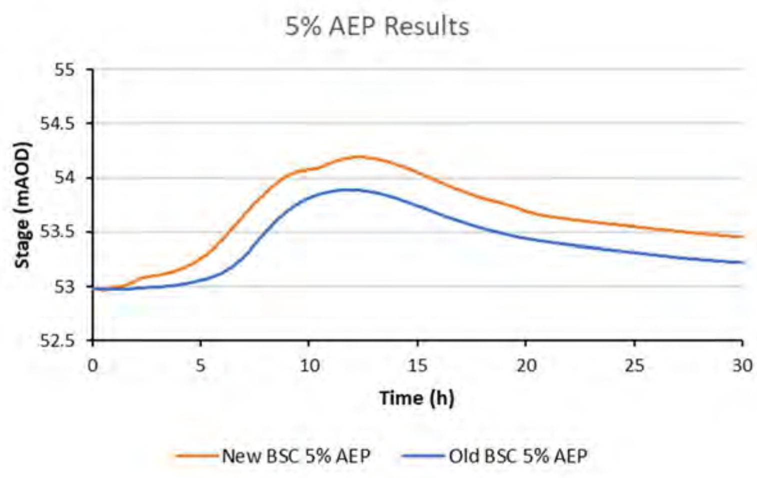


Figure 3: 5% AEP modelled stage, new baseline vs old baseline

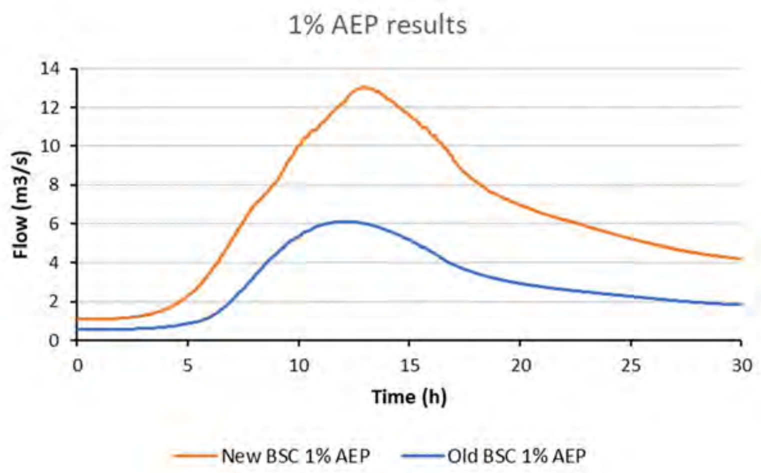


Figure 4: 1% AEP modelled flow, new baseline vs old baseline

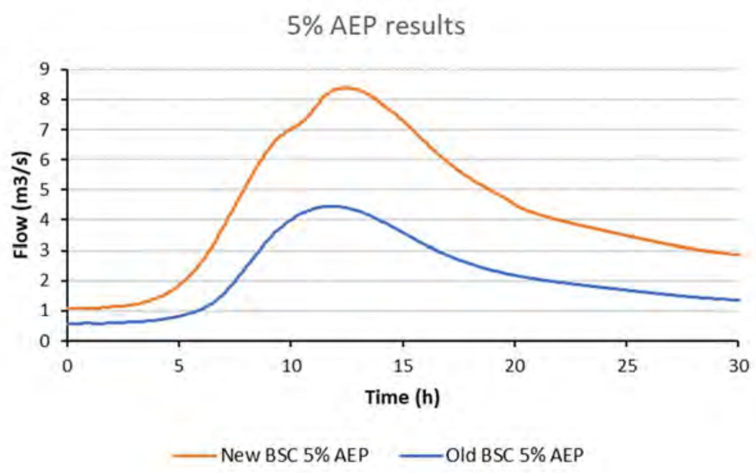


Figure 5: 5% AEP modelled flow, new baseline vs old baseline

3.3 On site flood extents

The mapped flood extents for the 1% and 5% AEP events for the new baseline along with the EA's Flood Zone 3 extent are shown in Figure 6 and Figure 7 respectively below.

For the 1% AEP event modelled extents now closely match Flood Zone 3 in most areas of the model within the site however the extents are smaller in other areas. The largest differences in flood extents can be seen at the western part of the site.

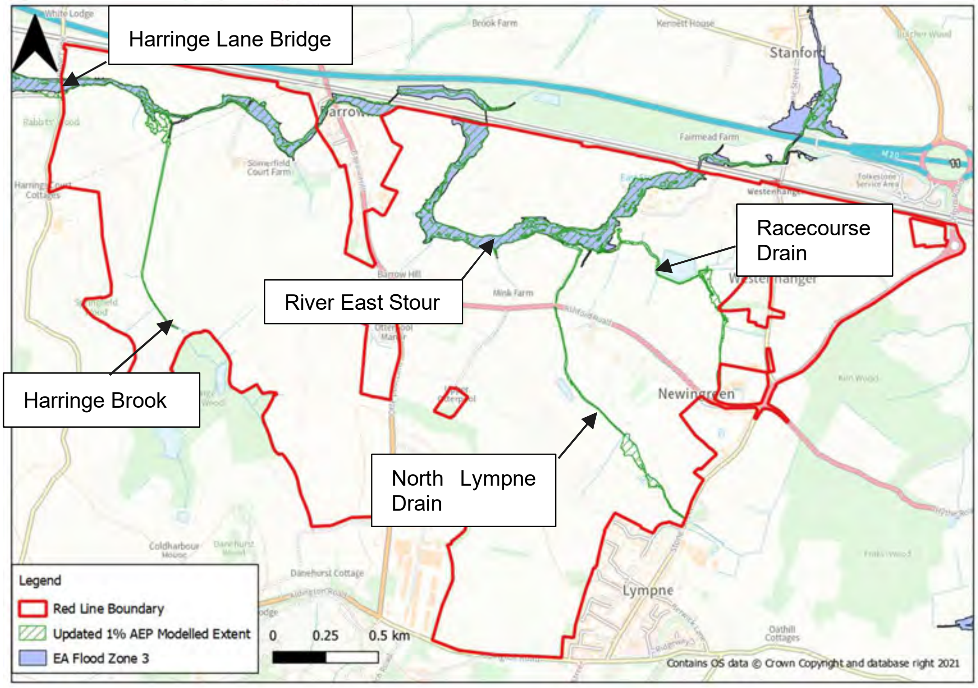


Figure 6: New 1% AEP Baseline Flood Extent shown with EA Flood Zone 3 mapping

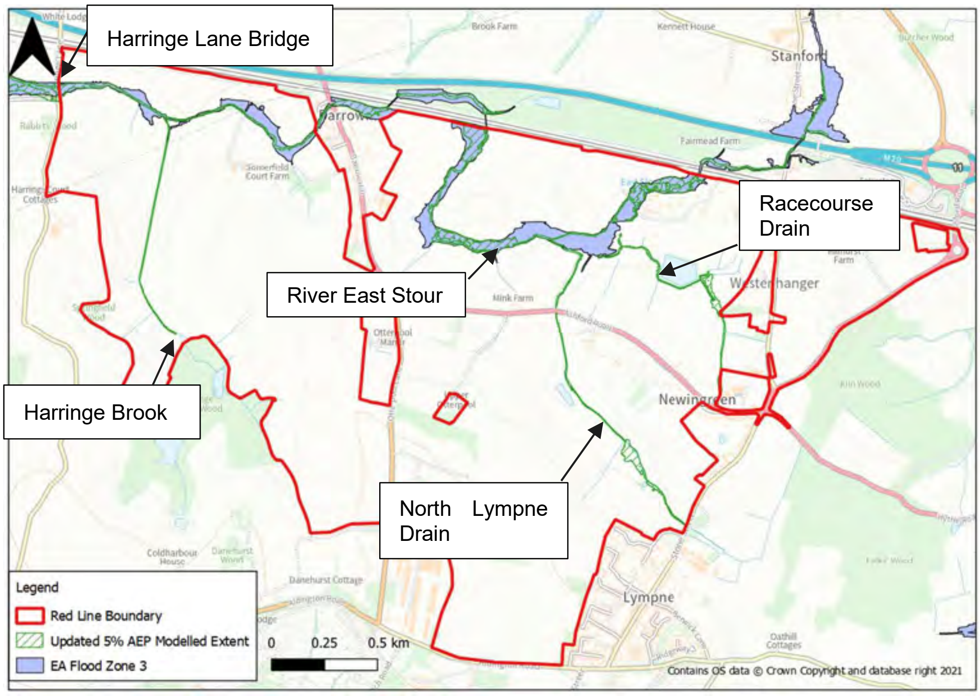


Figure 7: New 5% AEP Baseline Flood Extent shown with EA flood zone 3 mapping

Figure 8 to Figure 13 show comparisons of the previous and updated baseline model runs.

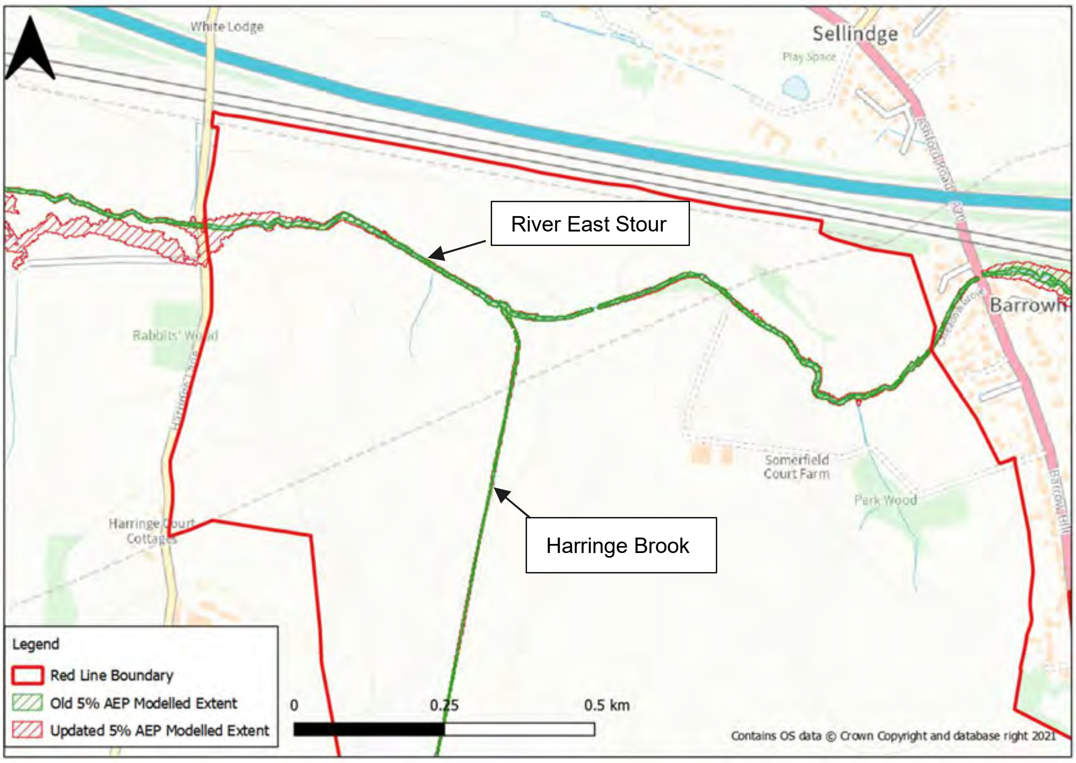


Figure 8: Comparison of new and old baseline model extents for the 5% AEP event at the confluence of the River East Stour and Harringe Brook

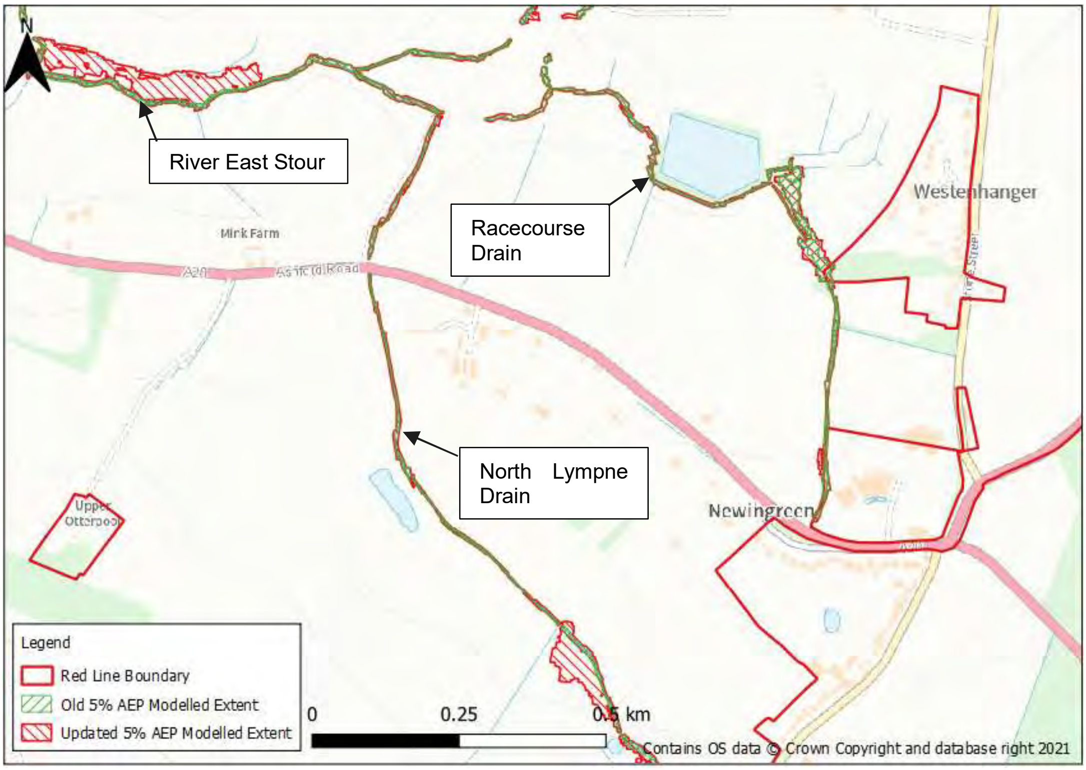


Figure 9: Comparison of new and old baseline model extents for the 5% AEP event on the upper reaches of the Racecourse Drain and North Lympne Drain

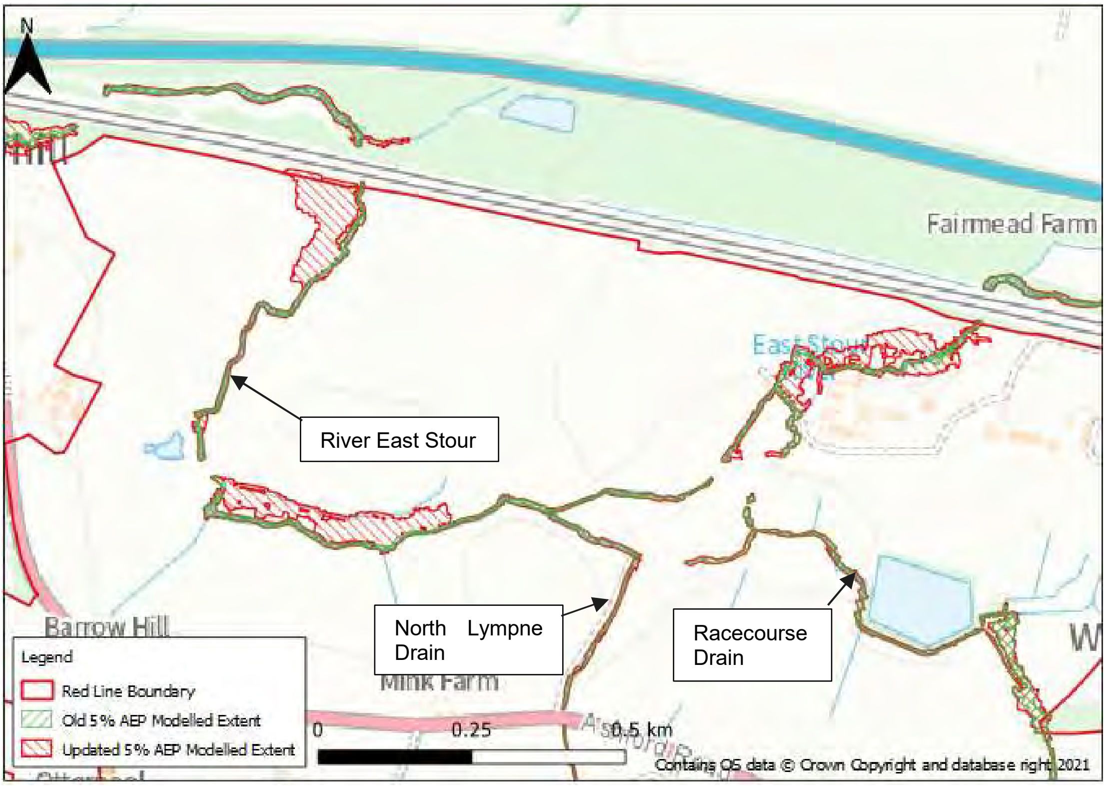


Figure 10: Comparison of new and old baseline model extents for the 5% AEP event at the confluence of the River East Stour with the North Lympne Drain and Racecourse Drain

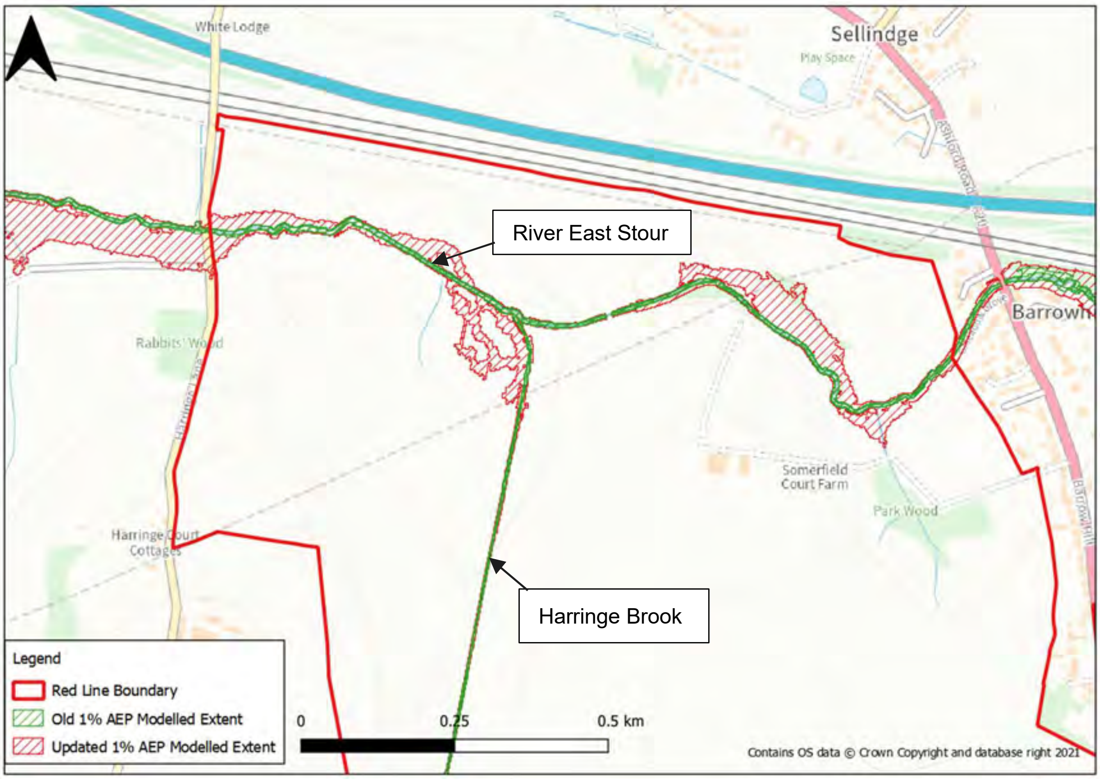


Figure 11: Comparison of new and old baseline model extents for the 1% AEP event at the confluence of the River East Stour and Harringe Brook

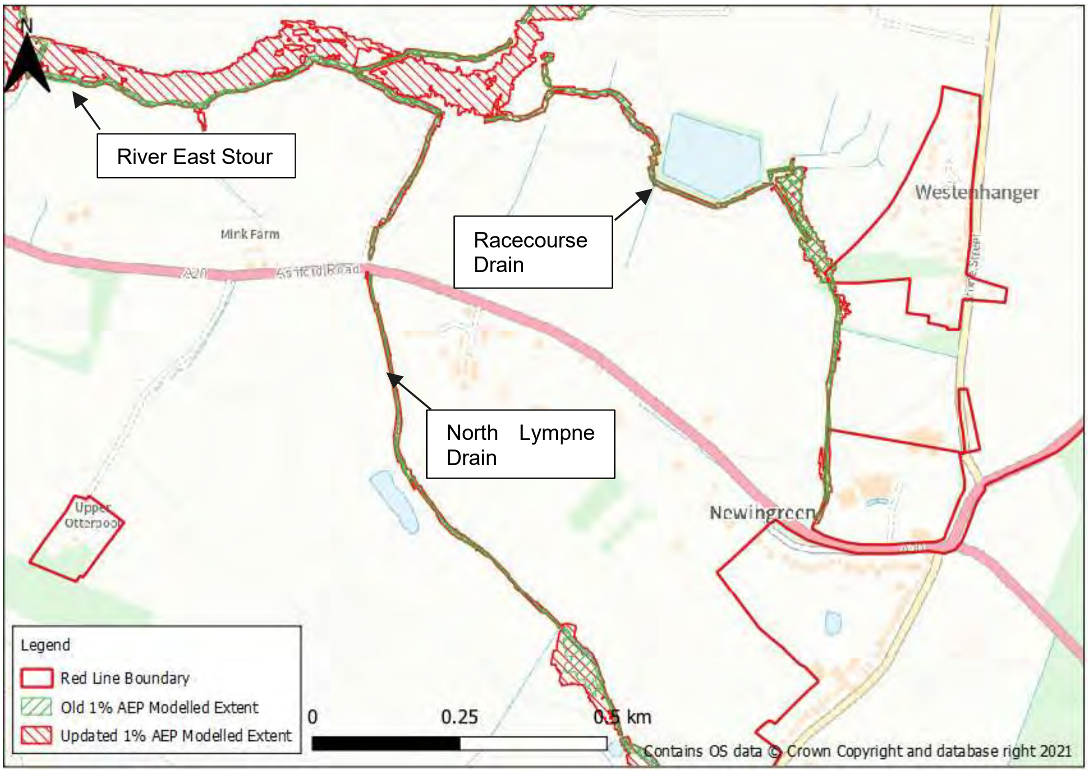


Figure 12: Comparison of new and old baseline model extents for the 1% AEP event on the upper reaches of the Racecourse Drain and North Lympne Drain

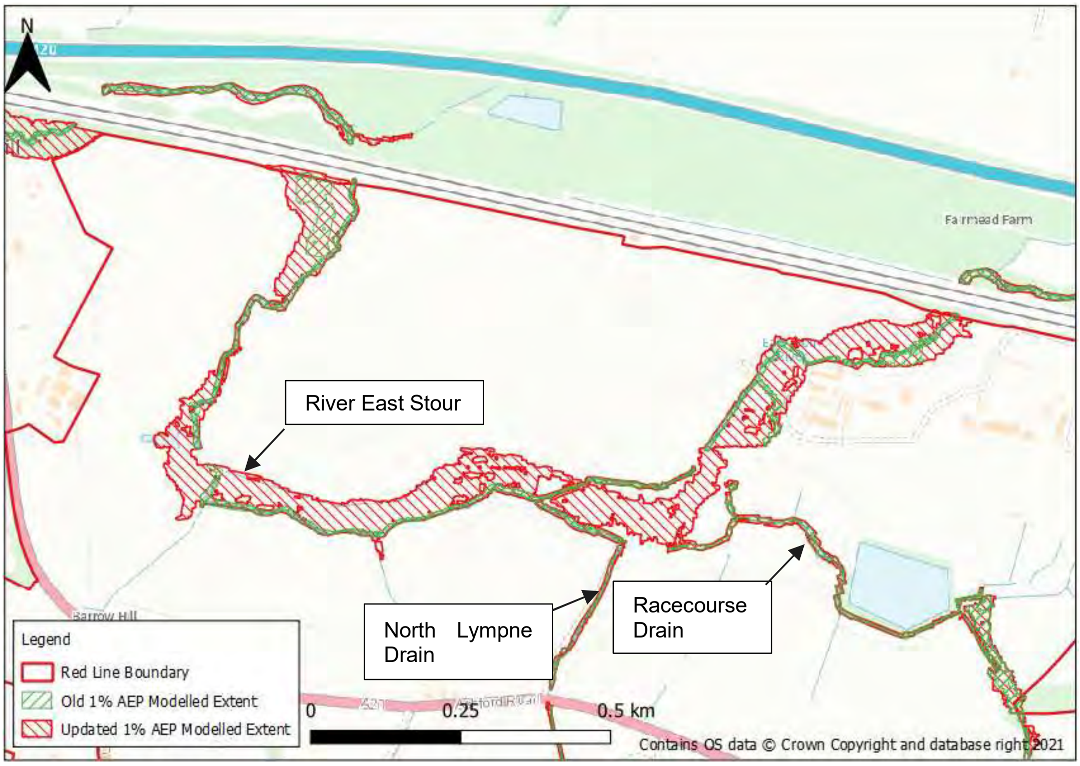


Figure 13: Comparison of new and old baseline model extents for the 1% AEP event at the confluence of the River East Stour with the North Lympne Drain and Racecourse Drain

3.4 Mass Balance and Model Stability

A review of the updated baseline key model health indicators and model sensitivity testing has been undertaken. The mass balance errors reported by FMP and TUFLOW have been reviewed for the 1% AEP event including a 38% climate change allowance. FMP reports a mass balance error of -0.33% which is well within the generally accepted tolerance limits of ±1% and only 1.05% of the simulation failed to converge on a solution. Of the timesteps with poor model convergence, 88% are associated with node EST1_16998 where a spill unit is present. A detailed review of the results in this location confirms that the stage plots upstream and downstream of the culvert are stable.

The TUFLOW model reports a cumulative mass balance error of -0.28%, this lies within the tolerance limits of ±1% and therefore the simulation is considered acceptable. The TUFLOW messages layer identifies only three warning / check messages, of which the majority refer to a check for repeat application of a HX boundary, which is acceptable at the locations at which it occurs. The remaining warnings are not significant. The model is deemed stable and suitable for informing flood risk to the development area.

3.5 Sensitivity Tests

Sensitivity of the model to the selected roughness coefficients and to the downstream boundary condition was assessed for the 1% AEP event.

Globally increasing the roughness coefficients by 20%, in both 1D and 2D, gave an average (median) increase in the peak water level of 66mm and a maximum increase of 188mm. The impact on the modelled flood extents is visible across the model domain in line with the increases in modelled water level within the 1D channel. A review of the extents and modelled levels indicates increases of approximately 40-60mm in flood depth in the 2D domain. The maximum modelled flood extent remains similar across most of the domain (excluding areas to the north of Partridge Farm, to the east of Harringe Lane, and to east of Stone Street), however, dry islands within this extent become infilled in the sensitivity test.

A reduction in roughness coefficients of 20% caused the model to become unstable. Further testing was undertaken which showed that the stability of the model is sensitive to a reduction in roughness coefficient. However, detailed investigations into the source of this instability are not considered necessary given the small impact on modelled flood extents observed for the increase roughness test.

The slope used to model the downstream boundary was varied by plus / minus 20%. Results demonstrate this change does not impact upon modelled water levels within the majority of the 1D watercourse, with impact only seen to extend for approximately 500m upstream of the model boundary. Similarly, there are no changes within the modelled 2D flood extend upstream of 500m of the model boundary. This is downstream of the site boundary and is, therefore, acceptable.

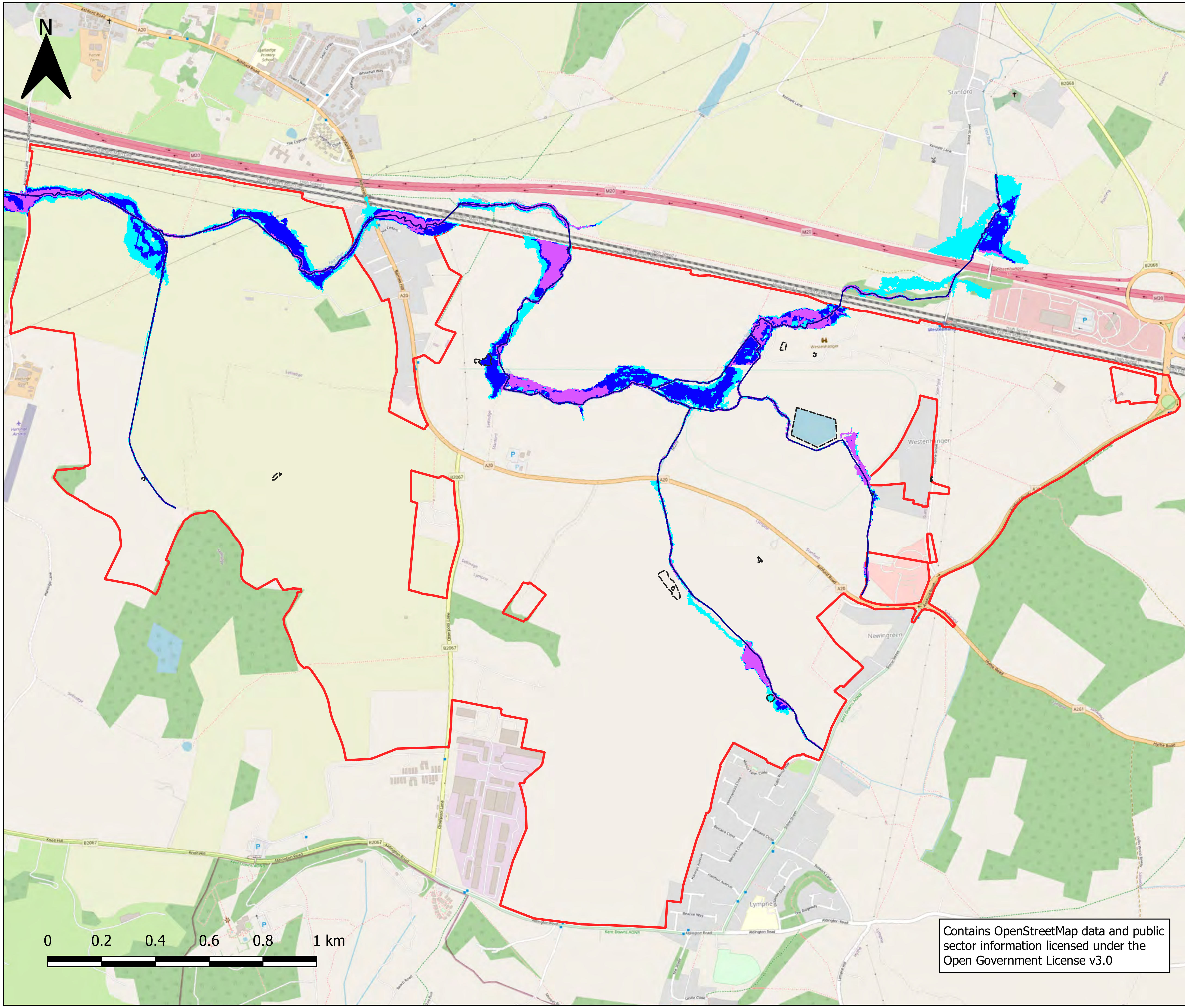
4. Conclusions

The previous sensitivity testing demonstrated that a greater flow response was induced when rainstorms coincide with saturated antecedent conditions in the East Stour catchment. However, the antecedent period previously modelled was exception, rather than typical, and the flows produced were likely to be overestimated based on comparison of modelled and observed water level data records at Barrowhill Bridge. As such a revised Cini value has been produced, utilising a more typical observed 6-month period of antecedent rainfall, to update the design flow estimates.

The model results indicate that the updated flows produce flood extents for the 1% AEP event that closely match the EA's Flood Zone 3 mapping within the site boundary. Furthermore, the modelled peak stages within the 1D sections correspond closely to the observed levels.

The updated Cini value is concluded to represent antecedent conditions more suitably in the catchment and the revised hydrology based on this parameter will be adopted going forwards.

Sensitivity testing carried out during this study indicates that the impact of changing roughness and the downstream boundary condition does not have a significant impact on the modelled flood extents.



Legend

- Modelled Watercourses
- Existing Ponds/ Lakes
- Baseline 5% AEP Flood Extent
- Baseline 1% AEP Flood Extent
- Baseline 0.1% AEP Flood Extent
- OPA Site Boundary

Note:

1. Flood outlines are for present-day scenario and do not include an allowance for climate change. Allowance for climate change is mapped in a separate drawing (10029956-AUK-XX-XX-DR-CW-0019-P5).

2. The baseline model build methodology is fully described in Flood Modelling Report 10029956-AUK-XX-XX-RP-CW-0021-P2

3. The latest hydrology is described in the Baseline Hydrology Update 10029956-AUK-XX-XX-FN-CW-0045-P3

Version	Date	Status	Author	Checker	Approver
P5	13/03/2022	FINAL	MG	CG	RG

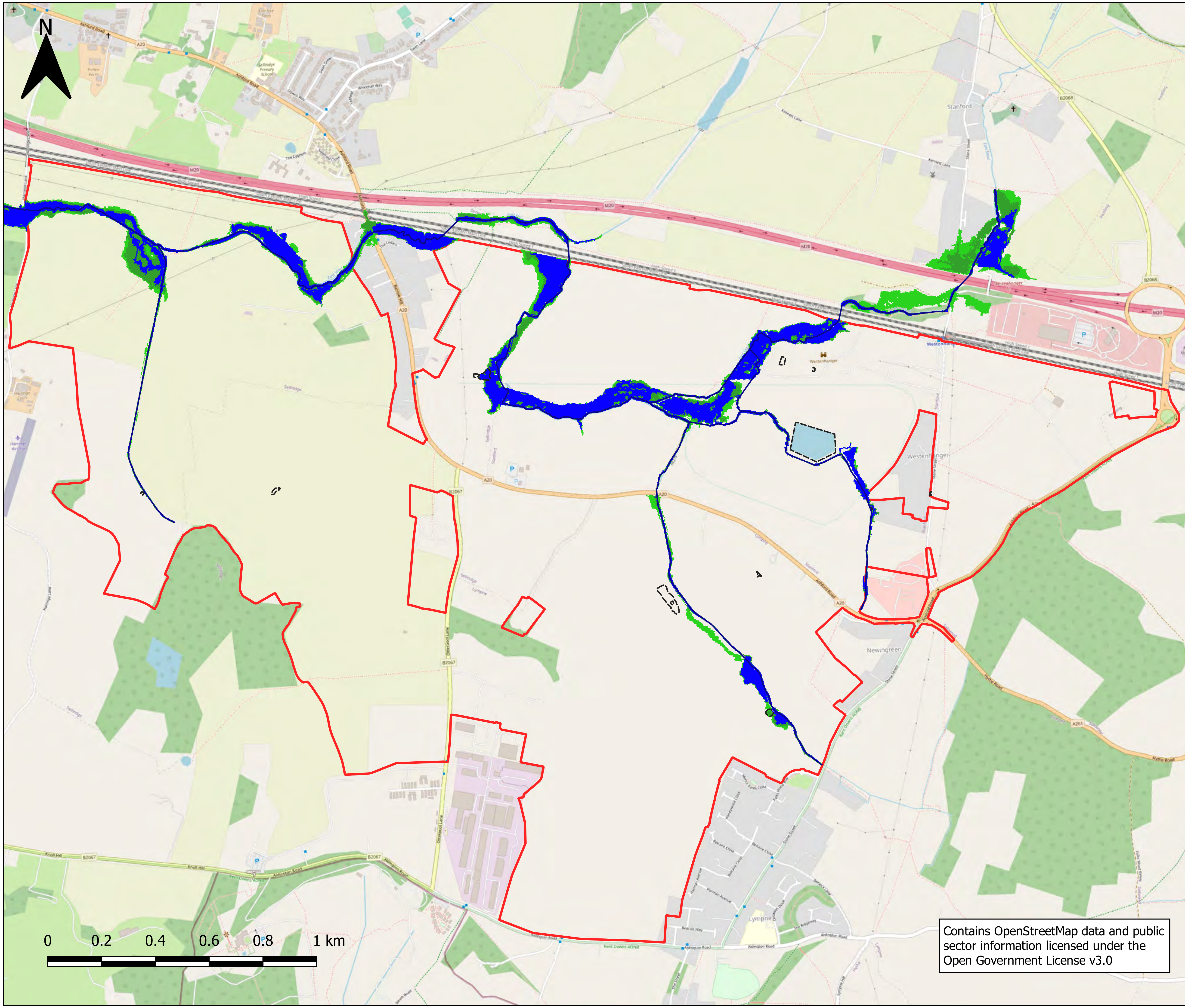
ARCADIS

80Fen
80 Fenchurch Street
London
EC3M 4BY

OTTERPOOL PARK
COUNTRYSIDE • CONNECTED • CREATIVE

Otterpool Park - Baseline Flood Extents
10029956-AUK-XX-XX-DR-CW-0018-P5

scale	original size	datum	grid
1:12,500	A3	mAOD	OSGB 27700



Contains OpenStreetMap data and public sector information licensed under the Open Government License v3.0

Legend

- Modelled Watercourses
- Existing Ponds/ Lakes
- Baseline 1% AEP Flood Extent
- Baseline 1% AEP +38% CC Flood Extent
- Baseline 1% AEP +101% CC Flood Extent
- OPA Site Boundary

Note:

1. The baseline model build methodology is fully described in Flood Modelling Report 10029956-AUK-XX-XX-RP-CW-0021-P2

2. The latest hydrology is described in the Baseline Hydrology Update 10029956-AUK-XX-XX-FN-CW-0045-P3

Version	Date	Status	Author	Checker	Approver
P5	15/03/2022	FINAL	MG	CG	RG

ARCADIS

80Fen
80 Fenchurch Street
London
EC3M 4BY

OTTERPOOL PARK
COUNTRYSIDE • CONNECTED • CREATIVE

Otterpool Park - Baseline 1% AEP Flood Extents with Climate Change
10029956-AUK-XX-XX-DR-CW-0019-P5

scale	original size	datum	grid
1:12,500	A3	mAOD	OSGB 27700

APPENDIX J

Proposed Scheme Modelling

MEMO

ARCADIS Design & Consultancy for natural and built assets

SUBJECT
Otterpool Park: Proposed Development Modelling

DATE
15 March 2022

DEPARTMENT
Arcadis - Water Management and Resilience

COPIES TO
Claire Gibson (Arcadis)
Hywel Roberts (Arcadis)
Renuka Gunasekara (Arcadis)

TO
Andy Jarrett, Julia Wallace – Otterpool Park LLP

OUR REF
10029956-AUK-XX-XX-RP-CW-0033-P3

PROJECT NUMBER
10023060

FROM
Michael Grogan (Arcadis)
T +44(0)1483 803061
E Michael.Grogan@Arcadis.com

1. Introduction

A Flood Risk Assessment (FRA) and Surface Water Drainage Strategy Report (10029956-AUK-XX-XX-RP-CW-0010-P3) has been prepared to support the revised Tier 1 Outline Planning Application for the proposed Development (also known as Otterpool Park) in accordance with the National Planning Policy Framework (NPPF) and the associated Flood Risk & Coastal Change planning practice guidance (PPG) as well as local guidance. The River East Stour, which flows through the proposed Development, has had Flood Zones 2 and 3 mapped by the Environment Agency (EA) using a broad-scale national mapping study (JFLOW). The information available was not suitable for informing site-specific Flood Risk Assessments (FRA) and, therefore, a detailed flood model has been constructed using Flood Modeller Pro (FMP) and TUFLOW to inform the revised FRA.

A bespoke hydraulic model of the River East Stour and three of its tributaries (the Harringe Brook, North Lympne Drain and the Racecourse Drain) has been constructed by Arcadis. The detailed baseline flood model, including the results of the baseline modelling that are detailed in the Flood Modelling Report (10029956-AUK-XX-XX-RP-CW-0021-P2), have been reviewed by the Environment Agency (EA). The EA accepted the findings of the baseline modelling and therefore this model has been taken forward for the modelling of the proposed changes to the watercourses and floodplain, resulting from the proposed Development.

Following the baseline modelling, sensitivity testing was undertaken by Arcadis on the effects of antecedent conditions on flows in the catchment. This showed that the catchment was very sensitive to the choice of antecedent conditions and the design event flows were revised based on the outcome of this testing. The testing undertaken and outcomes are detailed in the Baseline Hydrology Update technical note (10029956-AUK-XX-XX-FN-CW-0045-P3).

This document details the modelling works undertaken to model the features of the proposed Development. The design model was developed from the EA approved baseline model and run for the same five events assessed for the baseline modelling: 5%, 1% and 0.1% Annual Exceedance Probability (AEP) events and the 1% AEP + 38% Central Climate Change (CC) and 101% Upper Limit CC events.

2. Model Build

This section describes the changes which have been made to the baseline hydraulic model to represent the following proposed key features which are part of the proposed Development.

2.1 Wetlands

It is proposed that extensive wetland areas will be created as part of the Sustainable Drainage System (SuDS) and nutrient mitigation measures. The wetlands have been designed using Autodesk InfraWorks and exported as ground elevation grids which are read directly into the model. Three separate grids have been produced, referred to as Area 1, Area 2 and Area 3.

Figure 2-1 to Figure 2-3 below show the extents of the individual wetlands (prefixed with 'W') within these areas. These wetlands have not been designed to specifically provide stormwater flood attenuation storage as part of the SuDS scheme, as their main purpose will be for water treatment and amenity. Note that the SuDS scheme separately provides the required 1% AEP + 40%[1] climate change stormwater attenuation storage for the new paved and roof areas within the proposed Development. The water treatment and amenity wetlands are located at the downstream end of the SuDS scheme, and they are therefore available to provide additional floodplain storage in extreme events for fluvial flows, potentially reducing the flood peak and attenuating flows. Discussion on the interaction between floodwater and water quality is provided in the Water Cycle Strategy.

Incorporated within the wetlands are open water features, comprising a mixture of shallow pools and deeper ponds with permanent water, to enable water treatment and wider benefits in line with the EA's Guidance Manual for Constructed Wetlands – R&D Technical Report, P2-159/TR2 (2003). Therefore, the model assumes that they are full by applying initial water levels set at 50mm below the ground levels in the wetland. This level has been chosen for stability purposes and to ensure that water does not spill onto or out of the wetlands at the start of the run.

Figure 2-1 Locations of proposed wetlands – Area 1
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

[1] Note that the climate change allowance for rainfall intensity differs from the climate change allowance applied to peak river flows, in line with EA guidance.

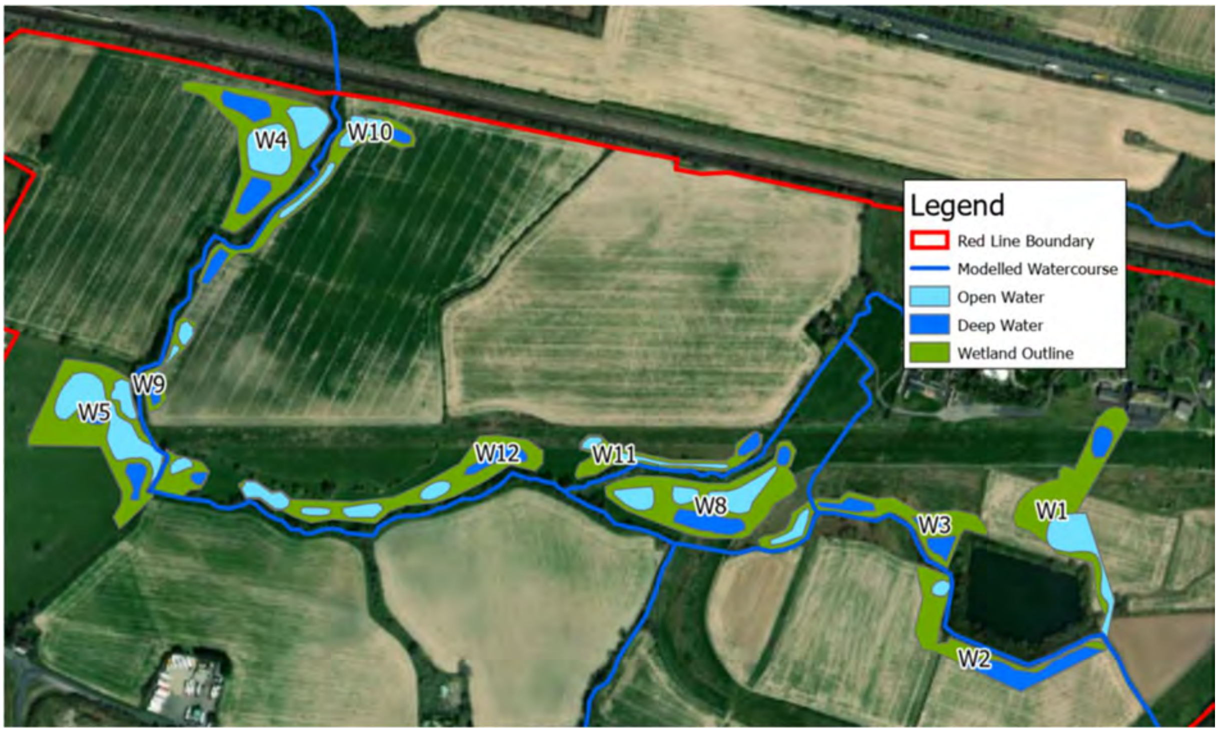


Figure 2-2 Locations of proposed wetlands – Area 2
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2-3 Locations of proposed wetlands – Area 3
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Some flow from the Harringe Brook is diverted into wetland W7 in Area 1 whereas some flow from the Racecourse Drain is diverted into wetland W8 in Area 2 through offtake channels, which will enhance base flows within these two wetlands. However, the larger flood flows will continue flowing over 700mm high check weir structures (or flumes), which will be located on the existing watercourses immediately downstream of the offtake channel. The other wetlands are fed only by the stormwater from the SuDS scheme, overland runoff and groundwater seepage; these mechanisms are not modelled in this fluvial flood model.

Flow can enter wetlands W7 and W8 from the existing watercourses via 450mm diameter pipes which have been modelled as flapped orifice units within FMP and connected to the wetlands in the 2D domain. Flapped orifices have been used to prevent backflow into the watercourse from these two wetlands. A single 225mm diameter orifice has been modelled, which is integrated within the 700mm high check weir structures, to control flow passing down the watercourse and help divert baseflow into the wetlands.

Only the drainage features of those wetlands affected by fluvial flooding have been modelled. These are located at the downstream ends of the six wetlands (W7, W4, W10, W5, W12 and W8). Drainage features exist for other wetlands, however they do not interact with the modelled watercourses and therefore have not been included. Flapped outfall orifices have been added to the model at the downstream end of these six wetlands, which will allow them to drain down following flood events.

These flapped outfalls have been added to the model as 100mm diameter orifices, with invert levels set to the base level of the wetlands and connected to the appropriate River East Stour channel cross section in FMP. The orifices have been linked to the 2D TUFLOW domain at their upstream faces and have been modelled as flapped outfalls to prevent water flowing into the wetlands from the River East Stour at all times.

The outfall connections between wetlands W12 and W5 and wetlands W9 and W10 have been modelled as 100mm diameter ESTRY conduits. This is to allow continuous flow through the wetlands so that the water features do not dry out under normal flow conditions.

2.2 Culvert Removal

Five existing culverts under the racecourse track will be removed as part of the proposals; opening the watercourses will reduce flooding and provide ecological benefits. The culverts removed are located on the River East Stour (FMP model nodes ESTO01_17959 and ESTO01_16971) and on the Racecourse Drain (FMP model nodes RCD010930 and RCD010088 and ESTRY model node RCD02_0144). In all locations the levels and dimensions in the new sections of open channel created by the removal of the culverts have been interpolated between the levels at the upstream and downstream faces of the culverts to maintain existing channel capacity. Figure 2-4 shows the locations of the culverts which will be removed.

Figure 2-4 Proposed culvert removals
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

2.3 New bridges

Three new bridges crossing the River East Stour will be created as part of the proposed Development to provide access within the development between the left and right banks of the River East Stour. The bridges are located at the FMP model nodes ESTO01_17618BU, ESTO01_17135BU and ESTO01_16731BU. Figure 2-5 shows the locations of the proposed bridges, Figure 2-6 to Figure 2-8 show the proposed cross sections of the bridges. All cross sections are looking downstream.

The bridges have been designed to be clear spanning resulting in only a minor impediment to floodplain flow. At the location of the first bridge (ESTO01_17618BU), channel realignment is required on both the River East Stour and the North Lympne Drain. The floodplain volume compensation is discussed in Section 2.3.1 below.

The EA have requested that the bridges be expanded to allow for mammal ledges to be created under each bridge. The bridge openings have been extended by 2m on each bank with a two-stage mammal ledge added in the additional chainage. The mammal ledges consist of a 600mm wide section rising from ground level in a 1:2 slope, followed by a flat 500mm wide section with a second 1:1 slope 300mm wide and the final 600mm wide flat section. A mammal ledge has not been added to the left bank of ESTO01_16731BU because this bank is high enough that it is not required.

Figure 2-5 Proposed bridge locations
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

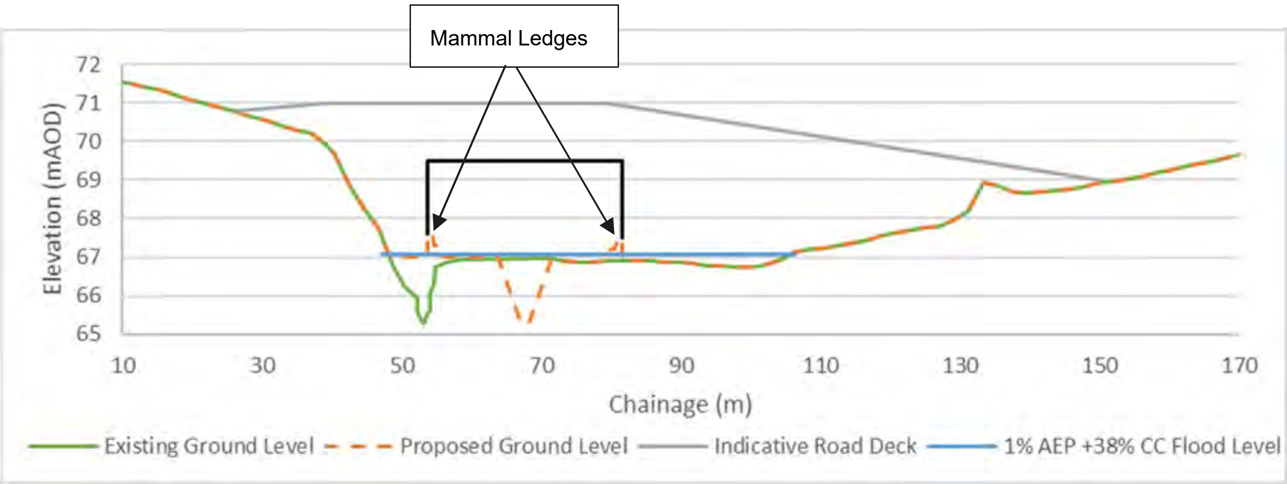


Figure 2-6 Proposed bridge at ESTO01_17618BU

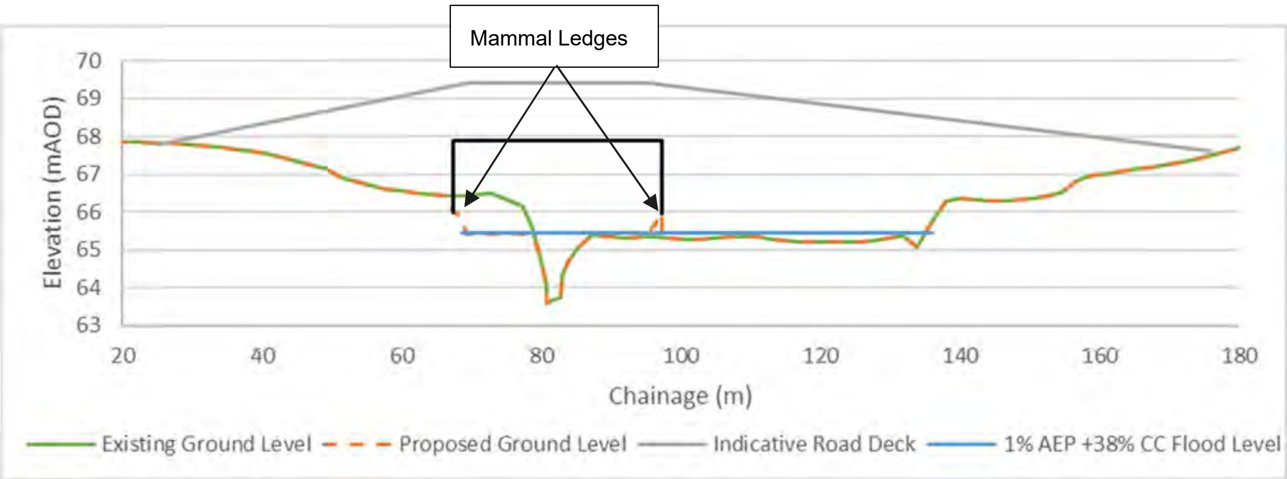


Figure 2-7 Proposed bridge at ESTO01_17135BU

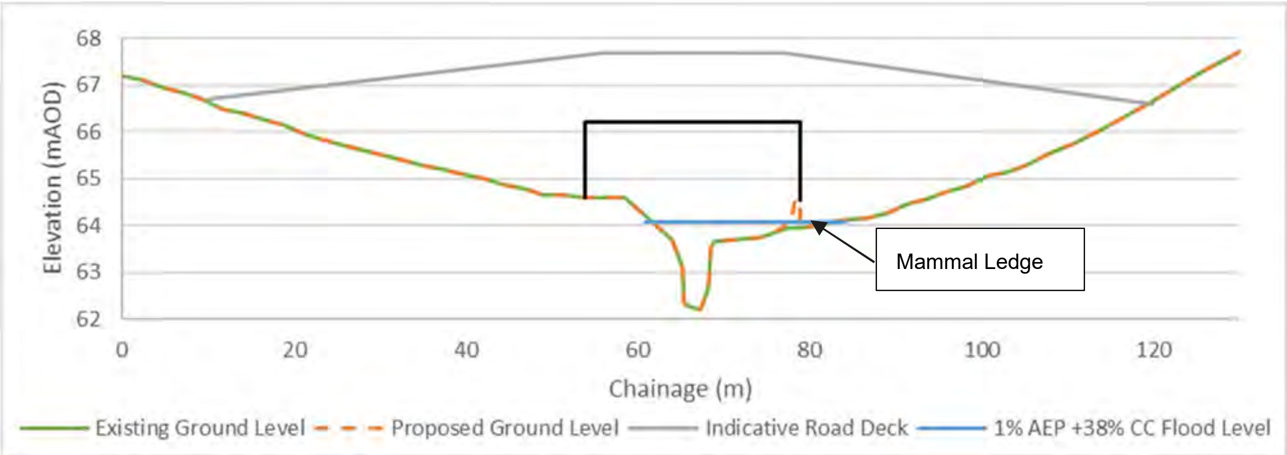


Figure 2-8 Proposed bridge at ESTO01_16731BU

2.3.1 Floodplain Volume Compensation

The embankments associated with the proposed bridges reduce the available floodplain storage in the vicinity. In line with the EA requirements, level for level volume compensation is required. As the proposed wetlands are not being used for SuDS attenuation storage, there is an opportunity to use them for the level for level volume compensation. Compensation requirements have been calculated up to the modelled level of the 1% AEP +38% CC. The volume of storage removed by the road embankments has been calculated in 0.1m slices to determine the volume of compensation storage required. Figure 2-5 shows the locations of the proposed compensation areas and Table 2-1 details the lost floodplain volume and available volume within these compensation areas.

Table 2-1 Floodplain volume compensation requirements and volume availability

Bridge	Lowest Baseline Flood Elevation (mAOD)	1% AEP +38% CC Flood Level (mAOD)	Elevation of slice (mAOD)	Volume Required (m^3)	Volume Available (m^3)	Wetland used for volume compensation
ESTO01_17618BU	66.70	67.08	66.70 – 66.80	56.0	311.1	W8, W11 and W12
			66.80 – 66.90	77.3	1233.9	
			66.90 – 67.00	35.8	1466.5	
			67.00 – 67.10	1.9	1607.5	
ESTO01_17135BU	65.00	65.44	65.00 – 65.10	0.0	547.5	W5, W9 and W12
			65.10 – 65.20	1.1	344.0	
			65.20 – 65.30	42.8	206.5	
			65.30 – 65.40	93.0	140.8	
			65.40 – 65.50	55.1	100.0	
ESTO01_16731BU	63.90	64.08	63.60 – 63.70	0.0	125.5	W9 and W10
			63.70 – 63.80	0.0	101.2	
			63.80 – 63.90	1.2	24.4	
			63.90 – 64.00	1.7	8.8	
			64.10 – 64.20	3.6	12.7	

2.4 New Pond

A new pond has been created along the Racecourse Drain. This is an inline attenuation feature which will be used for both fluvial and surface water (SuDS) storage as well as providing a valuable local amenity. Due to the steep channel gradient (1:41) of the existing watercourse at this location, three weirs will be installed across the pond to ensure that water is retained in the pond. These weirs will be 300mm above the upstream channel bed with a 1m wide notch in the centre located 100mm above the upstream bed level to allow water to flow continuously through the pond, as requested by the EA. They have been modelled using FMP spill units. In addition, some minor reprofiling of the channel bed will be carried out to further manage water levels within the pond.

A plan view of the pond and weirs is shown in Figure 2-9. A long section showing the proposed bed and weir crest levels is shown in Figure 2-10.

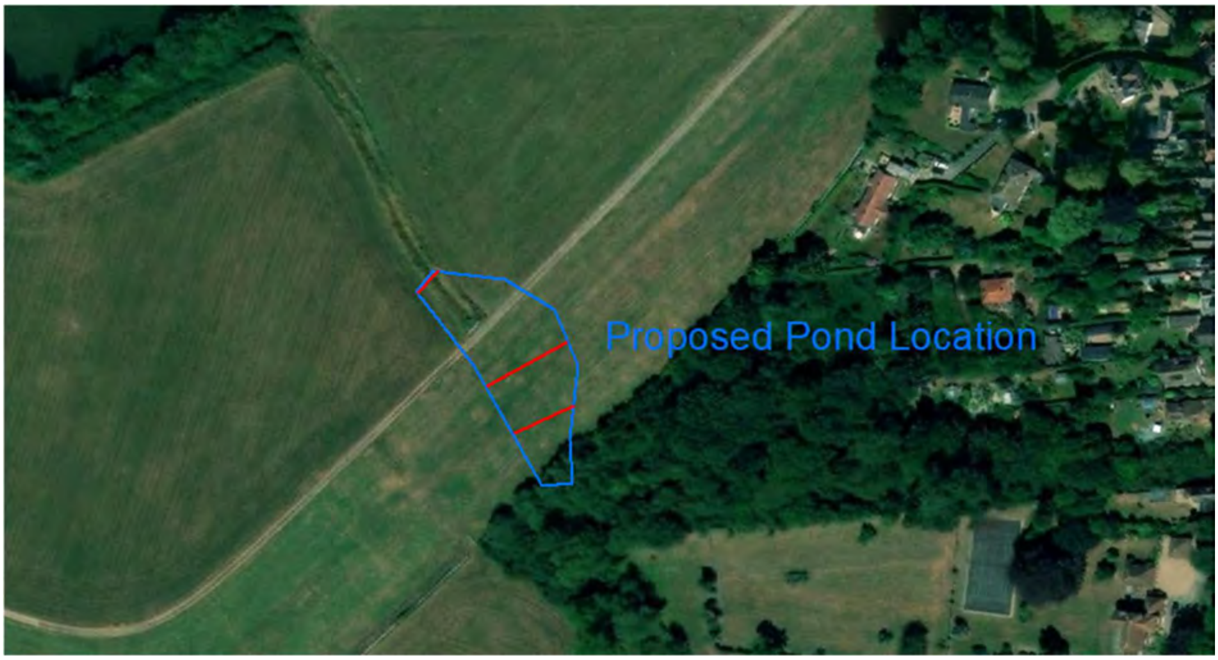


Figure 2-9 Proposed location of pond and weirs (in red)
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

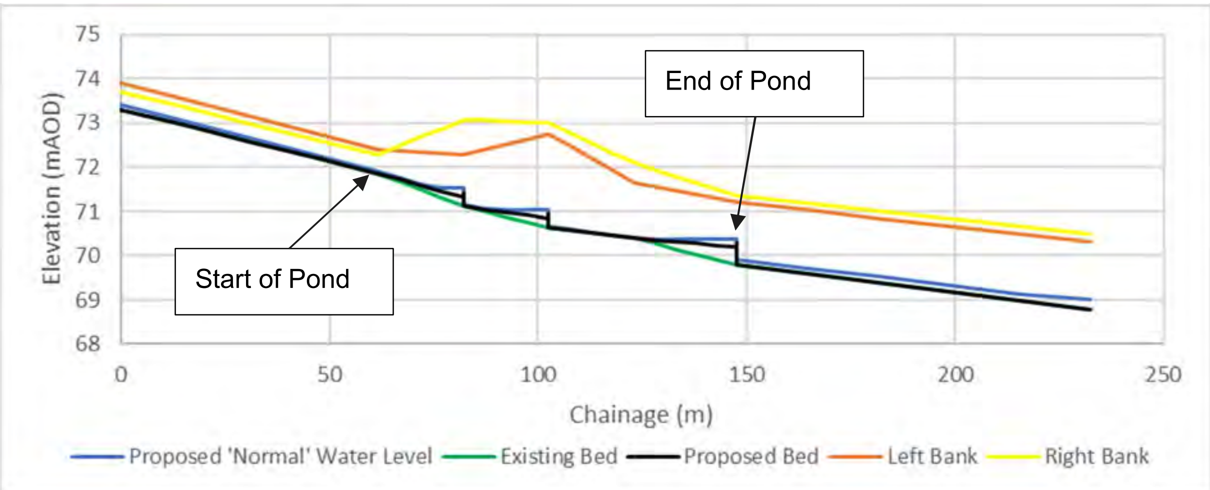


Figure 2-10 Proposed long section through the pond

3. Model Results

The model has been run for the same five events as the baseline model: the 5%, 1% and 0.1% AEP events and the 1% AEP + 38% CC and 101% CC events. The results of the proposed model runs have been compared against the baseline model runs to confirm that the proposed changes to the model do not result in any detrimental impacts on the site or to third parties.

3.1 Downstream Flood Conditions and Third Party Flooding

Comparing the flow at the downstream end of the site shows a slight decrease in peak flow, due to the attenuation effects of the wetlands, between the baseline and the proposed scenarios, potentially offering a slight betterment downstream of the site. Figure 3-1 shows the comparison of the flow hydrographs for the 5% AEP and 1% AEP +38%CC events (these events have been chosen to show a range of flow conditions).

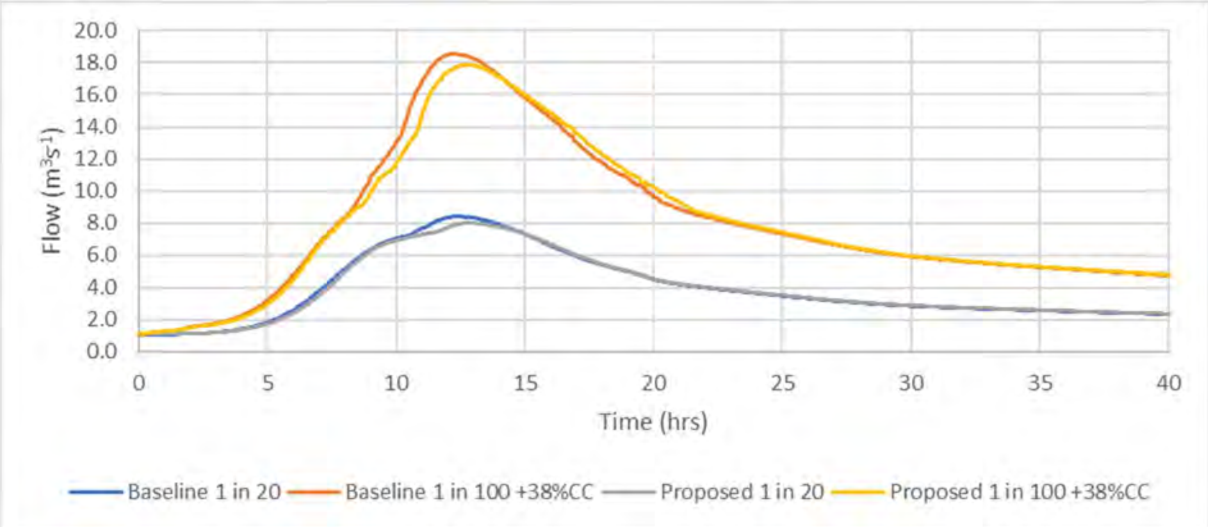


Figure 3-1 Comparison of flows at Harringe Lane bridge for the 5% AEP and 1% AEP +38% CC events

The hydrograph shows only minor differences for the 5% AEP event with the peak of the proposed scenario being 0.40m^{3}s^{-1} below that of the baseline and the shape of the hydrograph unchanged.

For the 1% AEP +38% CC event, the hydrograph shows that the peak flow has been reduced by 0.65m^{3}s^{-1} and that the occurrence of the peak flow has been delayed by 30mins. The attenuation is due to water being stored in the wetlands and being released slowly into the River East Stour as the flood peak passes.

The two events show that the proposed works associated with the Otterpool Park development will not have a detrimental impact on flood risk associated with the River East Stour and, in larger events, a slight betterment for third parties downstream of the site is predicted.

A rating curve has been extracted at the downstream extent of the model (Figure 3-2) to demonstrate that the proposed scenario will not alter the operation of the Aldington FSA, located 1.5km downstream of Otterpool Park. The relationship between flow and stage remains virtually unchanged, confirming that any control structures associated with the FSA should operate as they do at present.

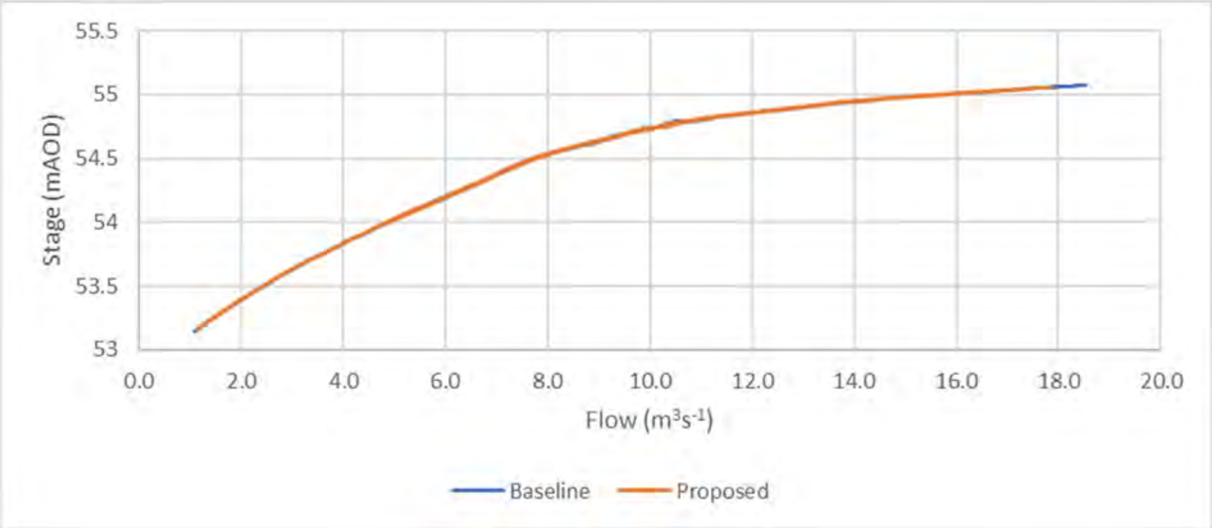


Figure 3-2 Comparison of rating curve at downstream end of model

3.2 On Site Flood Extents and Depths

When comparing the flood extents, the effects of the proposed wetlands and bridge embankments can be seen. Aside from those areas which have been designed to flood, the impacts are retained within the existing flood envelope. Figure 3-3 to Figure 3-6 illustrate the difference between the 1% AEP +38% CC event flood extents for the baseline and proposed scenarios only at locations where the flood extents have changed. The full flood extents for all modelled events are shown in drawings “10029956-AUK-XX-XX-DR-CW-0018-P5-Baseline Flood Extents” and “10029956-AUK-XX-XX-DR-CW-0019-P5-Baseline Flood Extents with Climate Change” for the baseline scenario and “10029956-AUK-XX-XX-DR-CW-0031-P3-Proposed Flood Extents” and “10029956-AUK-XX-XX-DR-CW-0032-P3-Proposed Flood Extents with Climate Change” for the proposed scenario.

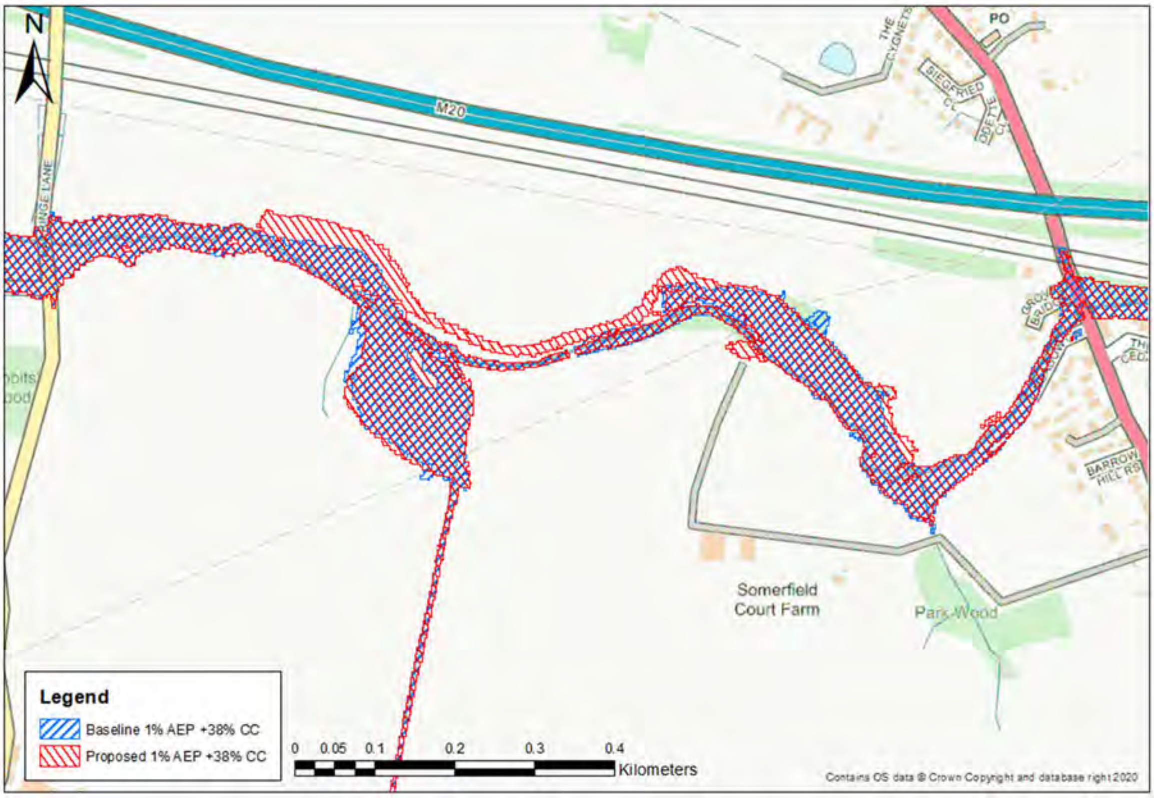


Figure 3-3 Comparison of baseline and proposed flood extents for the 1% AEP +38% CC at the confluence of the River East Stour and Harringe Brook

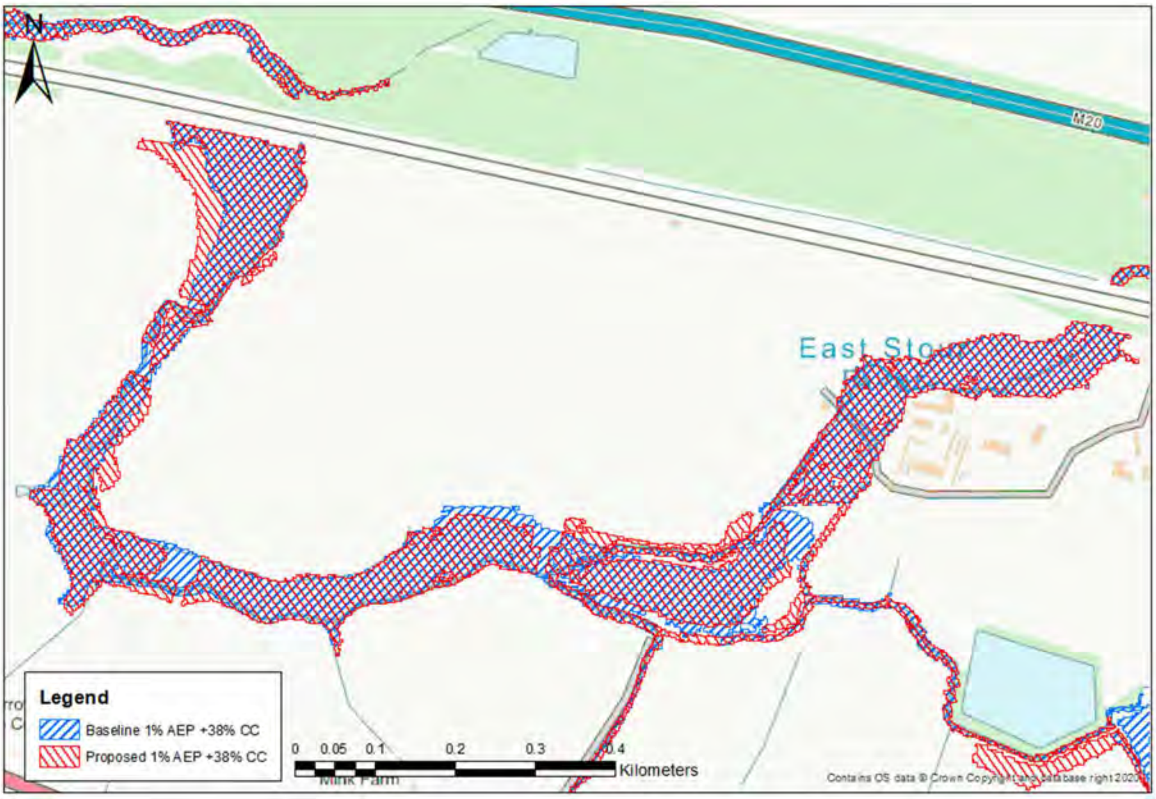


Figure 3-4 Comparison of baseline and proposed flood extents for the 1% AEP +38% CC at the confluence of the

River East Stour with the North Lympne Drain and Racecourse Drain

Figure 3-5 Comparison of baseline and proposed flood extents for the 1% AEP +38% CC on the upper reaches of the Racecourse Drain

Figure 3-6 Comparison of baseline and proposed flood extents for the 1% AEP +38% CC at the upstream end of North Lympne Drain

The figures show that outside of the areas where the wetlands have been created, the flood extents generally remain unchanged. In the areas where wetlands have been created the flood extents follow the outline of the wetlands indicating that they are operating as flood storage as intended. This has resulted in a reduction in flood extents at some locations and an increase in those where the wetlands have reprofiled the floodplain. This is acceptable as the wetlands are designed to accommodate this water.

The embankments associated with the proposed bridges have a minimal impact on the flood extents as they are mitigated for by the additional storage within the proposed wetlands.

The culvert removals have also had a minimal impact on flood extents, the only exception being the removal of a culvert (node RCD010930) on the Racecourse Drain. The removal of this culvert has removed the baseline flooding associated with its limited capacity (Figure 3-5). The creation of an inline pond at this location also has no significant impact on flood extents in the area.

With the exception of the water compatible wetlands and the proposed bridges the development of the site will not be situated in the floodplain and there will be no impact from fluvial flooding on the proposed development.

4. Conclusions and Recommendations

4.1 Conclusions

The design (with proposed Development) model has been developed from the previously approved baseline model. The proposed wetlands and ponds have been added to the model along with three bridges spanning the River East Stour and its floodplain. Five existing culverts under the former racecourse have been removed and an inline pond has been added to the Racecourse Drain.

The addition of the bridges and the ponds have a minimal impact on floodplain flows and extents. The culvert removals also have a minimal impact except for a culvert (node RCD010930) on the Racecourse Drain which has removed a constriction from the watercourse, alleviating previously predicted flooding in the area.

The addition of the wetlands has slightly reduced and delayed the peak of the flood for larger events as water is stored in the wetlands before being slowly released back into the River East Stour as the flood peak passes.

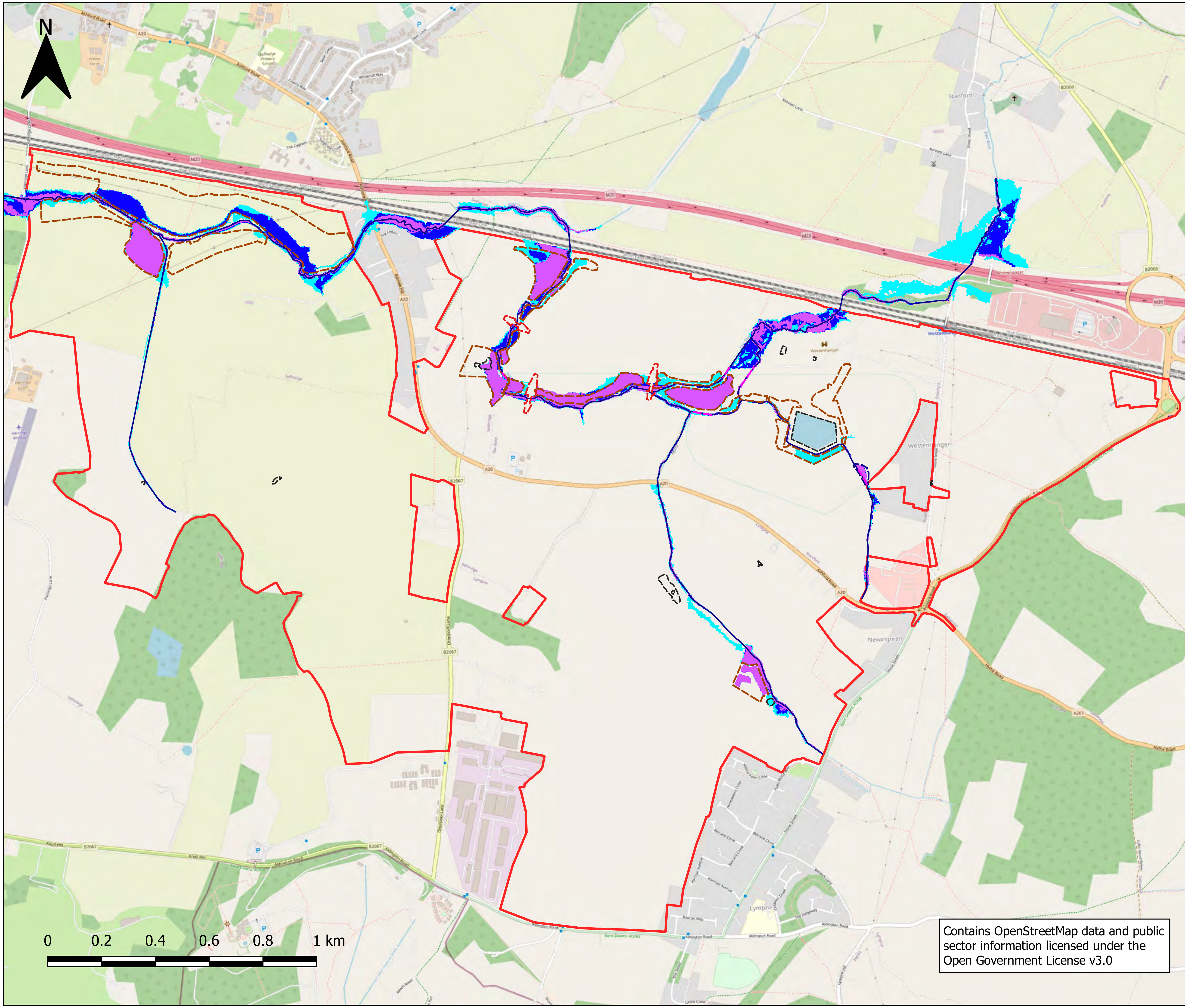
With the exception of the water compatible wetlands and the proposed bridges, the development of the site will not be situated in the floodplain.

The modelling of the proposed Development scenario has shown that through the site the impacts of the proposed changes are confined to the existing floodplain area and that they have no detrimental impact on third parties downstream or upstream.

4.2 Recommendations

Recommendations in relation to the management and assessment of flood risk are covered in the FRA Report (10029956-AUK-XX-XX-RP-CW-0010-P3) written to support the Otterpool Park revised Tier 1 outline planning application.

With regard to the proposed scheme modelling, it is recommended that the proposed scenario is remodelled following any major updates to the proposed design as it progresses through the detailed design stages, to ensure that the future updates do not have an adverse impact on flood risk to the site or third parties.



Legend

- Footprint of Proposed Bridge and Embankments
- Existing Culverts to be Removed
- Proposed Online Pond
- Proposed Wetlands
- Modelled Watercourses
- Existing Ponds/ Lakes
- Proposed 5% AEP Flood Extent
- Proposed 1% AEP Flood Extent
- Proposed 0.1% AEP Flood Extent
- OPA Site Boundary

Note:

1. Flood outlines are for present-day scenario and do not include an allowance for climate change. Allowance for climate change for the proposed development scheme is mapped in a seperate drawing (10029956-AUK-XX-XX-DR-CW-0032-P3).

2. The modelling methodology of the proposed bridges/ wetlands/ponds and the removal of existing culverts are fully described in Proposed Scheme Modelling technical note (10029956-AUK-XX-XX-RP-CW-0033-P3)

3. Only fluvial flood extents directly linked with the modelled watercourses are shown on this drawing. Note that the proposed wetlands and SuDS features will also have additional designated storage areas, which can hold stormwater as permanently wet or temporarily wet features (i.e. under flood conditions).

4. The latest hydrology is described in the Baseline Hydrology Update 10029956-AUK-XX-XX-FNCW-0045-P3

Version	Date	Status	Author	Checker	Approver
P3	13/03/2022	FINAL	MG	CG	RG

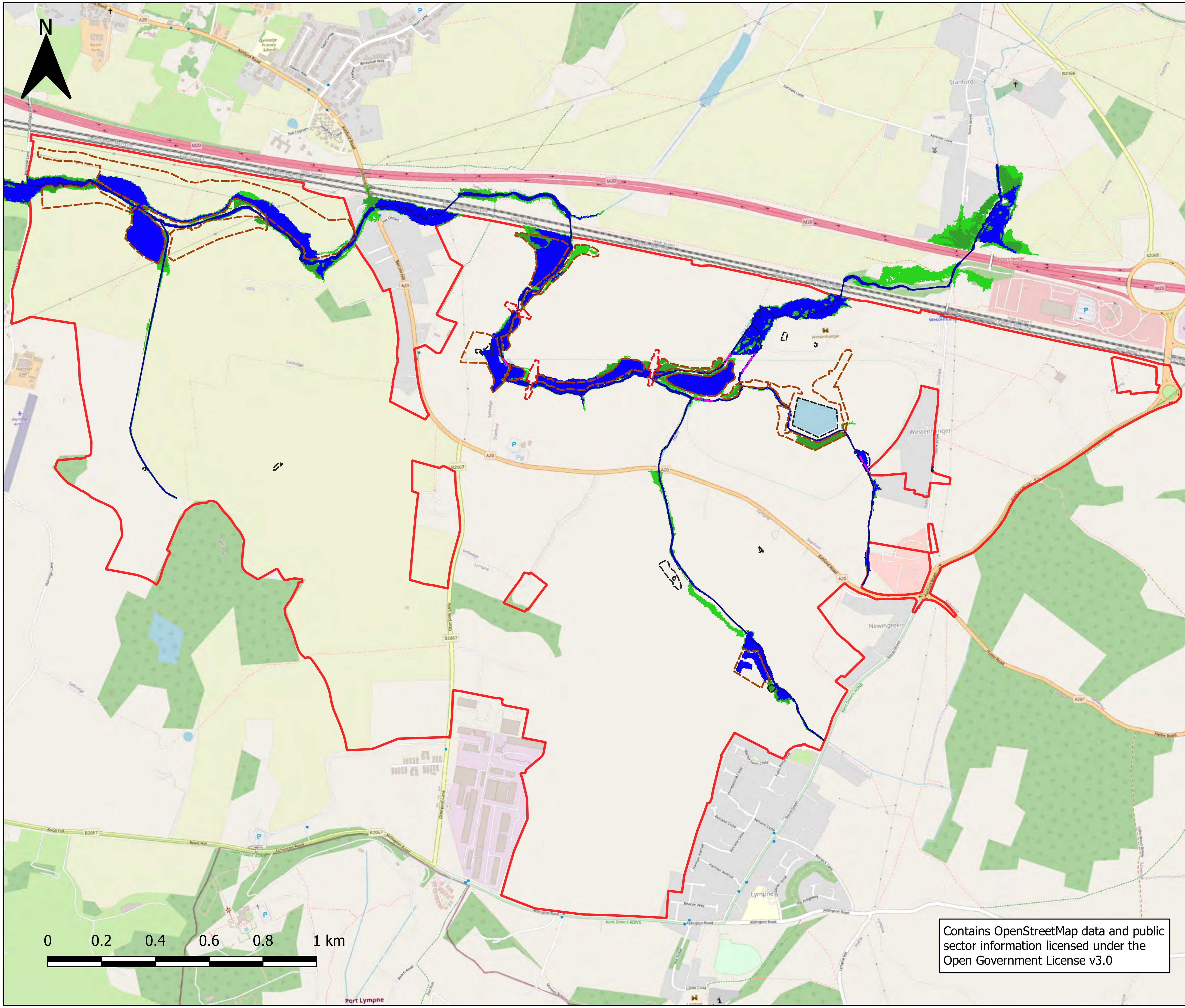
ARCADIS

80Fen
80 Fenchurch Street
London
EC3M 4BY

OTTERPOOL PARK
COUNTRYSIDE • CONNECTED • CREATIVE

Otterpool Park - Proposed Flood Extents
10029956-AUK-XX-XX-DR-CW-0031-P3

scale	original size	datum	grid
1:12,500	A3	mAOD	OSGB 27700



Legend

- Footprint of Proposed Bridge and Embankments
- Existing Culverts to be Removed
- Proposed Online Pond
- Proposed Wetlands
- Modelled Watercourses
- Existing Ponds/ Lakes
- Proposed 1% AEP Flood Extent
- Proposed 1% AEP +38% CC Flood Extent
- Proposed 1% AEP +101% CC Flood Extent
- OPA Site Boundary

Note:

1. The modelling methodology of the proposed bridges/wetlands/ponds and the removal of existing culverts are fully described in design model build technical note (10029956-AUK-XX-XX-RP-CW-0033-P3)

2. Only fluvial flood extents directly linked with the modelled watercourses are shown on this drawing. Note that the proposed wetlands and SuDS features will also have additional designated storage areas, which can hold stormwater as permanently wet or temporarily wet features (i.e. under flood conditions).

3. The latest hydrology is described in the Baseline Hydrology Update 10029956-AUK-XX-XX-FNCW-0045-P3

Version	Date	Status	Author	Checker	Approver
P3	13/03/2022	FINAL	MG	CG	RG

ARCADIS

80Fen
80 Fenchurch Street
London
EC3M 4BY

OTTERPOOL PARK
COUNTRYSIDE • CONNECTED • CREATIVE

Otterpool Park - Proposed 1% AEP Flood Extents with Climate Change
10029956-AUK-XX-XX-DR-CW-0032-P3

scale	original size	datum	grid
1:12,500	A3	mAOD	OSGB 27700

APPENDIX K

Groundwater modelling

SUBJECT
Hydrogeological assessment and estimate of groundwater mounding for proposed SUDS drainage basins at the Otterpool Park development

DATE
9TH MARCH 2021

DEPARTMENT
Hydrogeology

COPIES TO
Paul Goff, Stephen Smith

TO
Renuka Gunasekara

OUR REF
10029956-AUK--XX-XX-RP-CW-0044-P1-SuDs Groundwater Mounding Summary

PROJECT NUMBER
10029956

FROM
LYNDON STOTESBURY
T 07867169838 E LYNDON.STOTESBURY@ARCADIS.COM

1 Introduction

Shepway District Council plans on developing Otterpool Park as a new garden town at a location southeast of Ashford. The development includes a sustainable urban drainage management system (SUDS). An assessment of the potential for groundwater flooding caused by SUDS to confirm hydrogeological risks has therefore been requested by the Arcadis Water Management Team.

The Otterpool Park development is centred on NGR TR115366. As shown in Figure 1 there are several phasing zones to the development which include individual SUDS drainage areas. The location and allocated infiltration rates of the SUDS areas has been provided by Arcadis Water Management Team (Arcadis, 2020a) (Arcadis, 2020b) (Arcadis, 2020c).

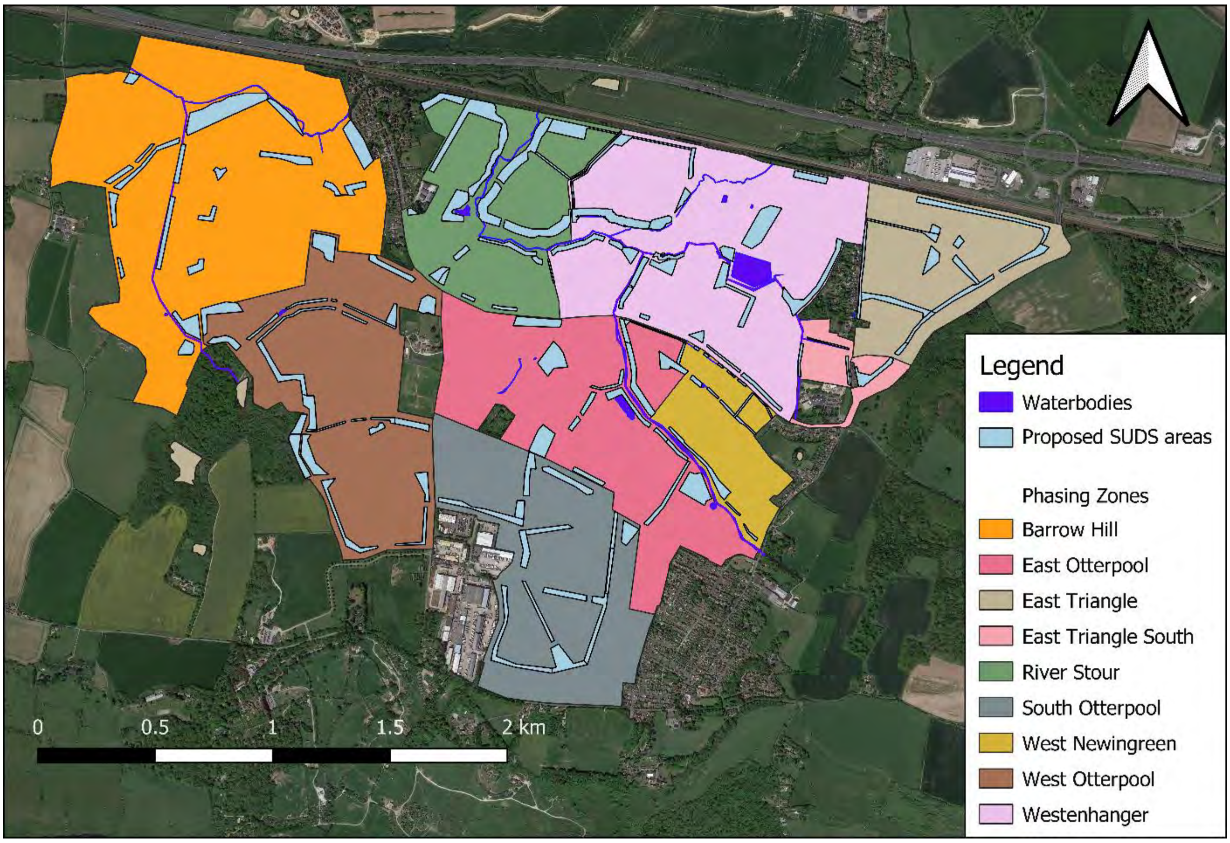


Figure 1 Otterpool Park Development and proposed SUDS areas

Section 2 of this memo briefly describes our conceptual model of the hydrogeology of the site and a summary of the method used to calculate groundwater mounding. The results are presented in section 3. Our conclusions and recommendations are listed in section 4.

2 Assessment method

2.1 Introduction

Our method of assessment has been to develop a conceptual understanding of the hydrogeology of the site, followed by analytical calculations to estimate groundwater mounding beneath each of the SUDS drainage areas. These calculations will be performed using infiltration rates representative of 1 in 100-year rainfall event. Therefore, mounding caused by less intense rainfall will result in lower values than being calculated.

2.2 Conceptual model

Our conceptual model of the site is based on the following sources of information:

- BGS GeoIndex mapping reference tool (British Geological Survey, 2020)
- PBA report (Peter Brett Associates, 2008)
- Arcadis Factual GI report Otterpool Park (Arcadis, 2017)
- Hydrogeological assessment report (Arcadis, 2018)

Figure 2 shows the OS 1:25000 scale map of the proposed Otterpool Park area and surrounds. The topography varies significantly across the site from elevations of 175.5 m aOD to 13.2 m aOD at the East River Stour. The site includes a spring in the central southeast area of the site (adjacent to Newingreen Farm), and two smaller streams which flow north to join the East River Stour. The spring indicates that groundwater levels are likely to be close to ground level in the Newingreen Farm area, which is within the East Otterpool phasing zone of the site.

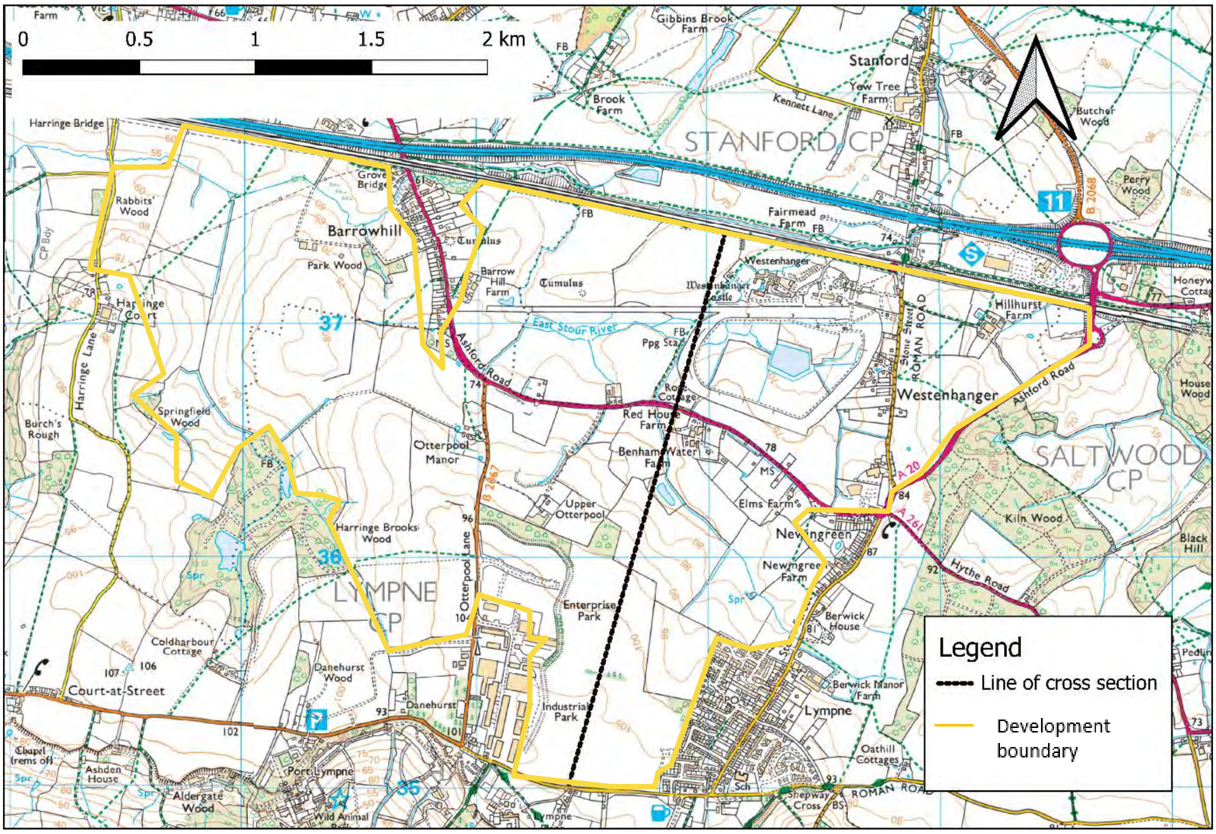


Figure 2 OS map extract showing the line of cross section across Otterpool development site

Borehole logs and trial pits from a ground investigation (Arcadis, 2017) and LIDAR data at a resolution of 1 m (Environment Agency, 2020) were used to produce a geological cross-section across the centre of the development site from north to south (Figure 3 and as per line of section shown in Figure 2). The position of the line of cross section was chosen in accordance with ground investigation borehole locations and to best capture the full range of the site for conceptualisation. The cross section goes through the centre of the site from south to north (Figure 3), cutting through two smaller streams and the East Stour River.

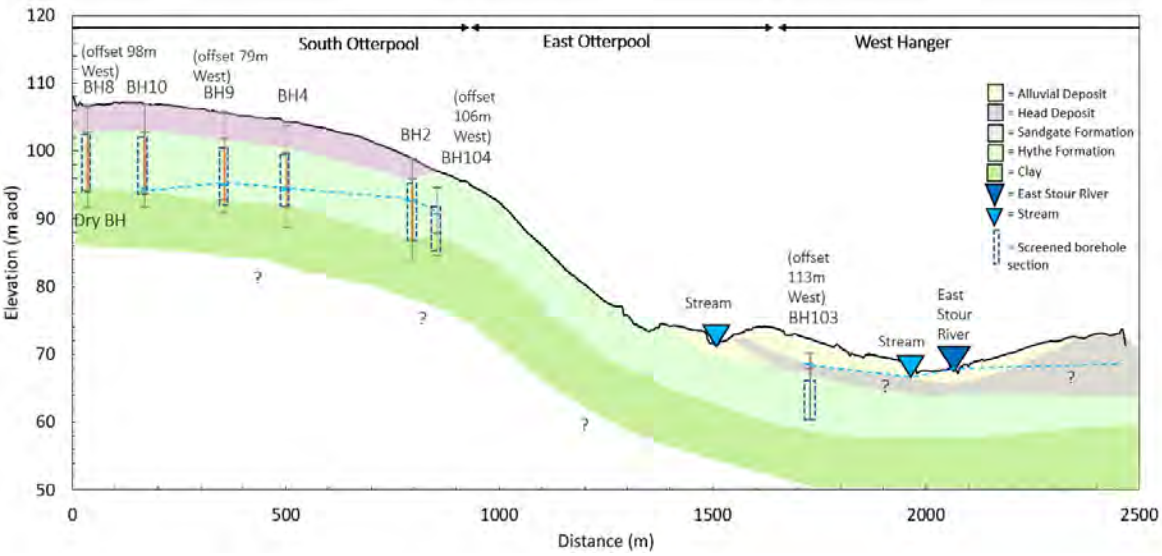


Figure 3 Cross section (borehole offset from line of section as indicated). Question marks provided as depth of Clay is unknown, and the groundwater level in proximity to the East Stour River is also unknown.

In general, the geological sequence comprises of superficial deposits (head and alluvial), overlying the Sandgate Formation, the Hythe Formation and the Atherfield Clay Formation. The head deposits are mapped and identified in boreholes within South Otterpool at the top of the hill. These deposits are typically described as sandy to very sandy clay with occassional coarse flint gravel. The alluvial deposits in the valley and in close proximity to the streams and East Stour River are characterised as slightly gravelly sandy Clay, where gravel is angular fine to coarse sandstone and limestone. The Folkestone Formation comprises medium and coarse-grained, well-sorted cross-bedded sands and weakly cemeted sandstones. The Sandgate Formation is only present beneath the lower level of the site and beneath the East Stour River, and is described as a gravelly sandy siltstone. The Hythe Formation shows heterogenity, in the upper layers it is identified as a fractured micritic limestone, whilst at greater depths it is delineated as a gravelly clayey completely weathered sandstone.

Groundwater levels are typically more than 5 m below ground level (bgl) on the top of the hill (South Otterpool). Shallow (near ground surface) groundwater levels are observed in the vicinity of the East River Stour. Groundwater flow is expected to be north towards the lower site elevations and the river.

Details of the specific geological sequence and groundwater levels encountered within each Phasing Zone are provided in Appendix A.

2.3 Analytical calculations

Groundwater mounding estimates beneath proposed SUDS areas were calculated using the USGS spreadsheet-based solution of the Hantush equation for mounding beneath infiltration basins (United States Geological Society, 2015). The Hantush method proposes a solution describing the growth and decay of groundwater mounds in response to uniform percolation and are widely implemented to estimate water table mounds beneath infiltration basins and other infiltration structures. Using this method, the iterative calculation considers specific yield, horizontal hydraulic conductivity, basin dimensions, water table, thickness of the saturated zone, and the infiltration period. The calculation provides an estimate of water table mounding at a specified time.

The Hantush method assumes a water-table aquifer of infinite extent and finite thickness with a horizontal, impermeable base; featuring the simplifying assumption that all flow is horizontal (Hantush, 1967). The solution also assumes a negligible change of transmissivity with a change in head, providing results that correspond well with similar analytical solutions and some field measurements (Carleton, 2010).

Input parameters for the groundwater mounding calculation were derived as follows:

- Infiltration rate – provided by Arcadis Water Management Team
- SUDS basin dimensions – two calculations were performed, one using the combined (total) area of SUDS basins within each Phasing Zone; to provide an estimate of groundwater mounding for the total volume of water infiltrated within that Zone. A second calculation used the dimensions of an individual SUDS basin (polygon measured using GIS) within the Drainage Zone that had the highest infiltration rate; to provide a maximum estimate of groundwater mounding.
- Duration of infiltration – provided by Arcadis Water Management Team
- Specific yield and permeability values were collated from several sources as listed in Table 1.

Table 1 Aquifer hydraulic properties used in the calculation of groundwater mounding

Parameter	Middle mounding estimate	High mounding estimate	Source
Head deposits			
Specific yield (m3/m3)	0.07	0.03	Values for sandy clay (USGS, 1992)
Permeability (m/d)	0.01	0.001	Estimate based on typical values for mixed silts, sand, clay (Barnes, 2016)
Sandgate Formation			
Specific yield (m3/m3)	0.035	0.01	Estimate based on typical values for fine sands, silts
Permeability (m/d)	0.1	0.01	Estimate based on typical values for fine sands, silts
Hythe Formation			
Specific yield (m3/m3)	0.1	0.035	Values of 0.08 to 0.15 (Rushton & Carter, 2012) Calibrated model value of 0.035 (Mott MacDonald, 1993)
Permeability (m/d)	5	1.2	Value of 10 m/d used (Mott MacDonald, 1993) 1.2 m/d is geometric mean of in-situ permeability tests from site (Arcadis, 2017)

Note that lower specific yield values predict greater values of groundwater mounding, so the high mounding estimate is given by the lowest specific yield value. Higher permeability values predict lower groundwater mounding, so the high mounding estimate is given by the lowest permeability value. Whilst the middle mounding estimate is defined using average specific yield and permeability values.

3 Results

3.1 Groundwater mounding

Table 2 summarises the results from the groundwater mounding calculations. Appendix A shows the results compared to the estimated depth to groundwater level within each Phasing Zone. This indicates that groundwater mounding is less than the estimated depth to groundwater level and therefore the risk of groundwater flooding due to SUDS infiltration is low in most areas.

The spring located within the East Otterpool Phasing Zone indicates that groundwater levels are likely to be close to ground level in this area. We recommend that an observational approach is taken during construction and/or additional ground investigation be carried out in this area to better assess the risk. By observational approach we mean that if groundwater seepage is noted during construction of the SUDS basins in this area, they should be relocated to different part of the site. It would be prudent however to investigate this area prior to any construction being undertaken.

The calculation for the South Otterpool Zone is based on groundwater mounding in the Hythe Formation because ground investigation data indicates groundwater level is within this formation and there is no evidence of perched groundwater. However, there is risk of SUDS basin infiltration failure in South Otterpool due to the presence of clay head deposits. Soakaway tests in this area indicate highly variable infiltration rates, from no infiltration to extremely fast infiltration (Arcadis, 2017).

The radius (distance) of influence of groundwater mounding is within the range 5 m to 20 m. Therefore, it is unlikely there will be any significant superposition of groundwater mounding between individual SUDS basins. This is due to individual SUDS features being typically >20m apart within the development plan. In addition, groundwater mounding decreases exponentially with distance so superposition will likely be insignificant when combined with mounding from other SUDS basins.

Table 2 Results of groundwater mounding calculations

Drainage catchment		Infiltration rate (m/d)	Duration of infiltration period (days)	Groundwater mounding (m)	Distance of influence (m)
Westhanger	No infiltration				
East Otterpool	Combined SUDS; middle estimate	0.074	0.608	0.45	20
	Combined SUDS; higher estimate	0.074	0.608	1.3	20
	Polygon DR-EO1; middle estimate	0.183	0.396	0.7	5
	Polygon DR-EO1; higher estimate	0.183	0.396	2.1	5
West Newingreen	No infiltration				
East Triangle	Combined SUDS; middle estimate	0.002	1.718	0.1	5
	Combined SUDS; higher estimate	0.002	1.718	0.34	5
	Polygon DR-ET2; middle estimate	0.002	1.679	0.1	5
	Polygon DR-ET2; higher estimate	0.002	1.679	0.34	5
East Triangle South	Combined SUDS; middle estimate	0.002	2.188	0.1	5
	Combined SUDS; higher estimate	0.002	2.188	0.1	5
South Otterpool	Combined SUDS; middle estimate	0.183	0.328	0.6	15
	Combined SUDS; higher estimate	0.183	0.328	1.7	15

Drainage catchment		Infiltration rate (m/d)	Duration of infiltration period (days)	Groundwater mounding (m)	Distance of influence (m)
	Polygon DR-SO2; middle estimate	0.183	0.308	0.5	15
	Polygon DR-SO2; higher estimate	0.183	0.308	1.6	15
West Otterpool	Combined SUDS; middle estimate	0.018	1.602	0.3	6
	Combined SUDS; higher estimate	0.018	1.602	0.8	11
	Polygon DR-WO1; middle estimate	0.018	1.492	0.2	5
	Polygon DR-WO1; higher estimate	0.018	1.492	0.7	10
Barrow Hill	Combined SUDS; middle estimate	0.373	0.248	0.9	6
	Combined SUDS; higher estimate	0.373	0.248	2.6	6
	Polygon DR-BH3; middle estimate	0.373	0.246	0.9	7
	Polygon DR-BH3; higher estimate	0.373	0.246	2.6	7
River Stour	No infiltration				

4 Conclusions and recommendations

4.1 Conclusions

The adoption of SUDs will invariably lead to an intermittent rise in groundwater levels beneath individual drainage basins that could lead to groundwater flooding and/or failure of the SUDs basin. Groundwater mounding extent has therefore been calculated across the Otterpool Park development site for each of the SUDS basin zones, where higher and middle estimates were estimated to represent the range of uncertainty in calculation input parameters.

Calculations were performed for the combined SUDS areas within each Phasing Zone as well as for individual SUDS basins with the greatest risk of groundwater mounding given the conceptual understanding of the site. The results indicate that groundwater mounding is less than the estimated depth to groundwater level associated with the majority of individual basins assessed and therefore the risk of groundwater flooding and/or basin failure due to SUDS infiltration is low in most areas. In addition, calculations were performed using infiltration values representative of a 1 in 100-year event, where mounding caused by less intense rainfall would be lower than calculated.

However, the spring located within the East Otterpool Phasing Zone indicates that groundwater levels are likely to be close to ground level in this area. Adoption of SUDs in this area may therefore lead to groundwater flooding and/or basin failure. Furthermore, there is risk of basin failure in South Otterpool and due to clay head deposits. Soakaway tests in this area indicate highly variable infiltration rates, from no infiltration to extremely fast infiltration (Arcadis, 2017).

4.2 Recommendations

We recommend that an observational approach is taken during construction and/or additional ground investigation be carried out in the East Otterpool and South Otterpool Phasing Zones to better assess the risk. By observational approach we mean that if clay layers or groundwater seepage is noted during construction of the SUDS basins, they may not be appropriate for that part of the site.

References

Arcadis, 2017. *Otterpool Park Ground Investigation Factual Report,* London: Arcadis Consulting (UK) Ltd.

Arcadis, 2018. *High level hydrogeological assessment of the feasibility of a proposed infiltration basin at the Otterpool Park development,* London: Arcadis Consulting (UK) Ltd.

Arcadis, 2020a. *Otterpool: SuDS Strategy flows and volumes. Ref. 10029956-AUK-XX-XX-CA-CW-0042-P1,* London: Arcadis Consulting (UK) Ltd..

Arcadis, 2020b. *Otterpool: SuDS Groundwater Mounding. Ref. 10029956-AUK-XX-XX-CA-CW-0043-P1,* London: Arcadis Consulting (UK) Ltd..

Arcadis, 2020c. *Otterpool: SuDS Groundwater Mounding Summary. Ref. 10029956-AUK-XX-XX-FN-CW-0044-P1,* London: Arcadis Consulting (UK) Ltd..

Barnes, 2016. *Soil Mechanics: Principles and Practice.* Fouth Edition ed. London: MacMillan Education UK.

British Geological Society, 2018 (a). *BGS.* [Online] Available at: http://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=HY [Accessed 06 02 2018].

British Geological Survey, 1990. *Sheets 305 and 306. Folkestone and Dover A.* Southampton: British Geological Survey.

British Geological Survey, 2018 (b). *http://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=AC.* [Online] Available at: http://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=AC [Accessed 06 02 2018].

British Geological Survey, 2018 (c). *http://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=WC.* [Online] Available at: http://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=WC [Accessed 06 02 2018].

British Geological Survey, 2020. *GeoIndex mapping reference tool,* London: British Geological Society.

Carleton, G., 2010. Simulation of groundwater mounding beneath hypothetical stormwater infiltration basins. *U.S. Geological Survey Scientific Investigations Report,* p. 64.

Environment Agency, 2020. *National LIDAR Programme Survey Download,* London: Department for Enviornment Food & Rural Affairs.

Hantush, M., 1967. Growth and decay of groundwater mounds in response to uniform percolation. *Water Resources Research,* pp. 227-234.

Jones, H. et al., 2000. The physical properties of minor aquifers in England and Wales. *British Geological Survey,* p. 234.

Mott MacDonald, 1993. *Darent Catchment Investigation. CWP/8709. Catchment Model Calibration Report prepared for National Rivers Authority. Ref. 70223B01/GDC/2/B/DCI/WP.,* London: Mott MacDonald.

Peter Brett Associates, 2008. *Report on Hydrogeological Assessment,* Kent: Peter Brett Associates.

Rushton, K. & Carter, R., 2012. Groundwater resources of aquifers with extensive confined regions illustrated by the Woburn Sands, Bedfordshire, UK. *Journal of Engineering Geology and Hydrogeology,* Volume 45, pp. 31-44.

United States Geological Society, 2015. *Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Basings. Scientific Investigations Report 2010-5102,* Virginia: U.S.G.S.

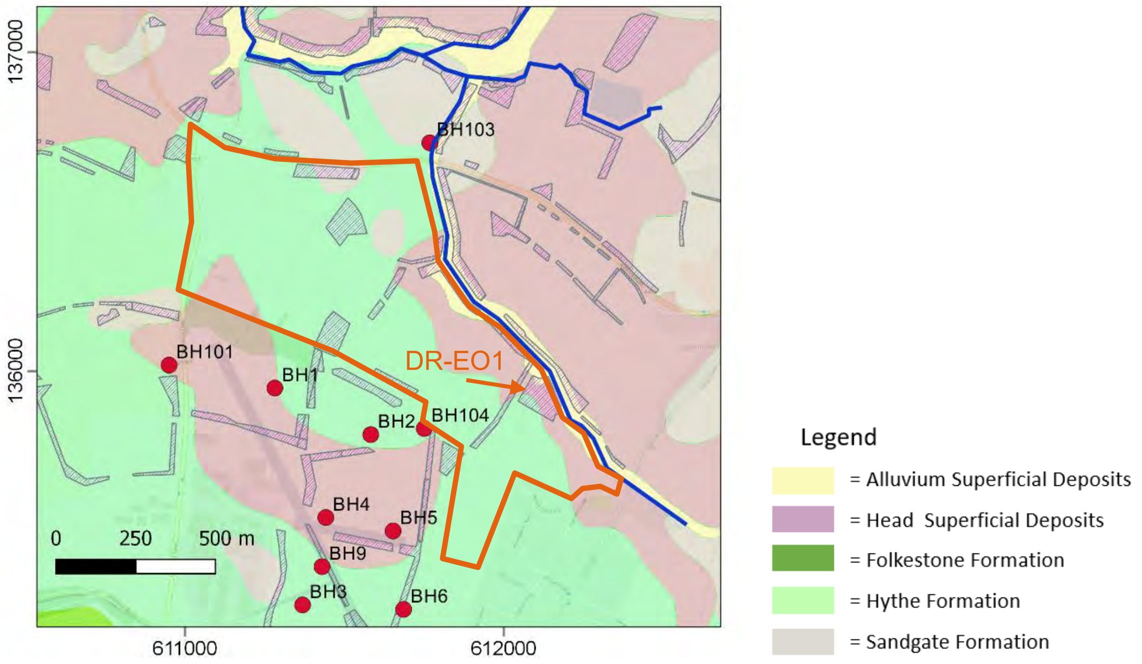
USGS, 1992. *Specific Yield - Compilation of Specific Tields for Various Materials. Water Supply Paper 1662-D,* Washington, D.C: U.S. Government Printing Office.

Washington State Government, 2018. *http://www.wsdot.wa.gov.* [Online] Available at: http://www.wsdot.wa.gov/publications/fulltext/Hydraulics/StormSHED/InfiltrationCalc.Spreadsheet.xls [Accessed 25 01 2018].

APPENDIX A

Groundwater mounding calculations

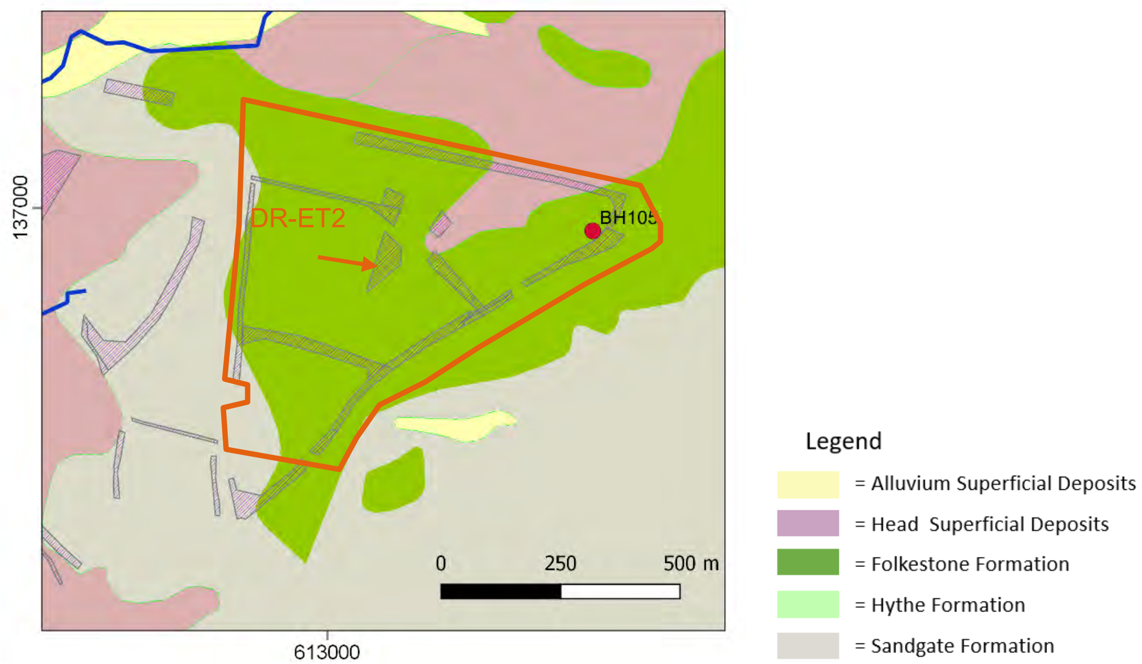
East Otterpool



East Otterpool		
Nearest borehole	BH104	
Superficial deposits	None in BH104. BGS map shows head deposits and alluvium adjacent to stream	
Bedrock and depth to base	Hythe Formation to 6.8 m bgl	
Average GWL (m bgl)	3.58	
Saturated zone thickness (m)	3.22	
	Middle estimate	High estimate
Specific yield (m^3/m^3)	0.1	0.035
Permeability (m/d)	5	1.2

Predicted groundwater mounding for 1 in 100-year storm	Middle estimate (m)	High estimate (m)
Combined SUDS area	0.5	1.3
Polygon DR-EO1	0.7	2.1
Assessment comments	OS mapping indicates a spring, located along the stream bank just upstream of DR-EO1 polygon. Groundwater levels may be locally <2 m below ground level, adjacent to the stream.	

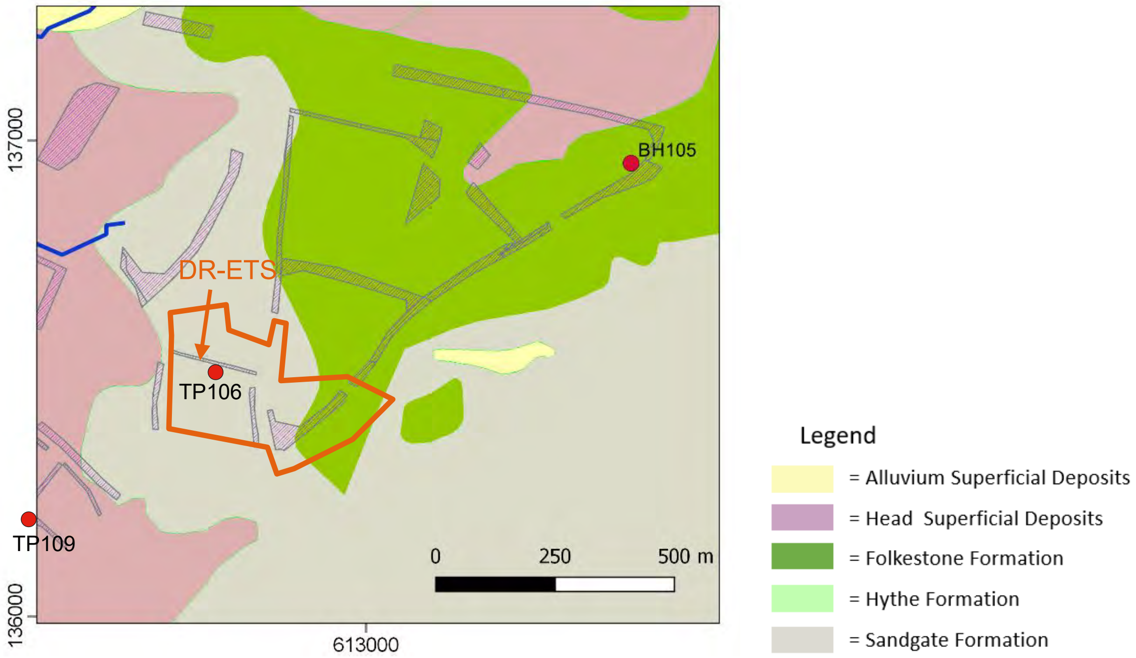
East Triangle



East Triangle		
Nearest borehole	BH105	
Superficial deposits	Patch of head deposits	
Bedrock and depth to base	Mapped as Folkestone Formation but BH105 indicates Sandgate Formation to at least 10 m bgl	
Average GWL (m bgl)	3.57	
Saturated zone thickness (m)	Minimum 6 m	
	Middle estimate	High estimate
Specific yield (m^3/m^3)	0.035	0.01
Permeability (m/d)	0.1	0.01

Predicted groundwater mounding for 1 in 100-year storm	Middle estimate (m)	High estimate (m)
Combined SUDS area	0.1	0.3
Polygon DR-EO1	0.1	0.3
Assessment comments	BH105 indicates head deposits to a depth of 3.5 m bgl, so they may be more widespread than mapped. The borehole log describes head deposits as sand, therefore likely to have high specific yield and groundwater mounding is expected to be minimal.	

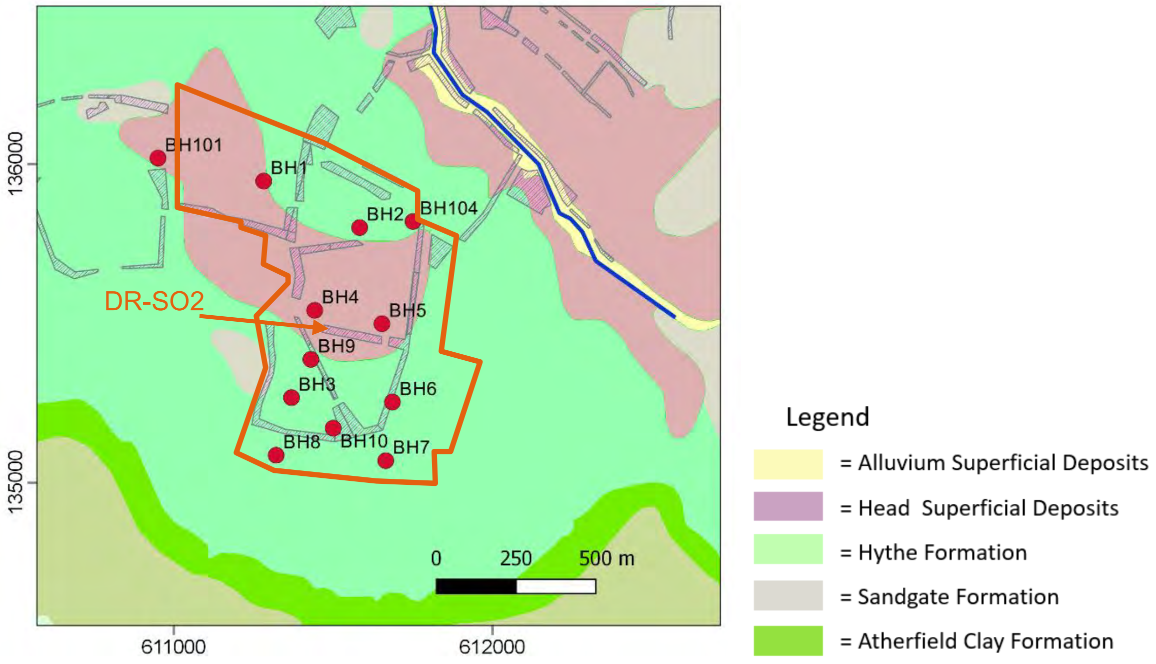
East Triangle South



East Triangle South		
Nearest borehole	TP106	
Superficial deposits	Head deposits described as sandy Clay to a depth of at least 2.5m	
Bedrock and depth to base	Not proven. Mapped as Sandgate Formation in the western part and Folkestone Formation in the east.	
Average GWL (m bgl)	Groundwater not encountered	
Saturated zone thickness (m)	Unknown, estimate 2 m.	
	Middle estimate	High estimate
Specific yield (m^3/m^3)	0.07	3
Permeability (m/d)	0.01	0.001

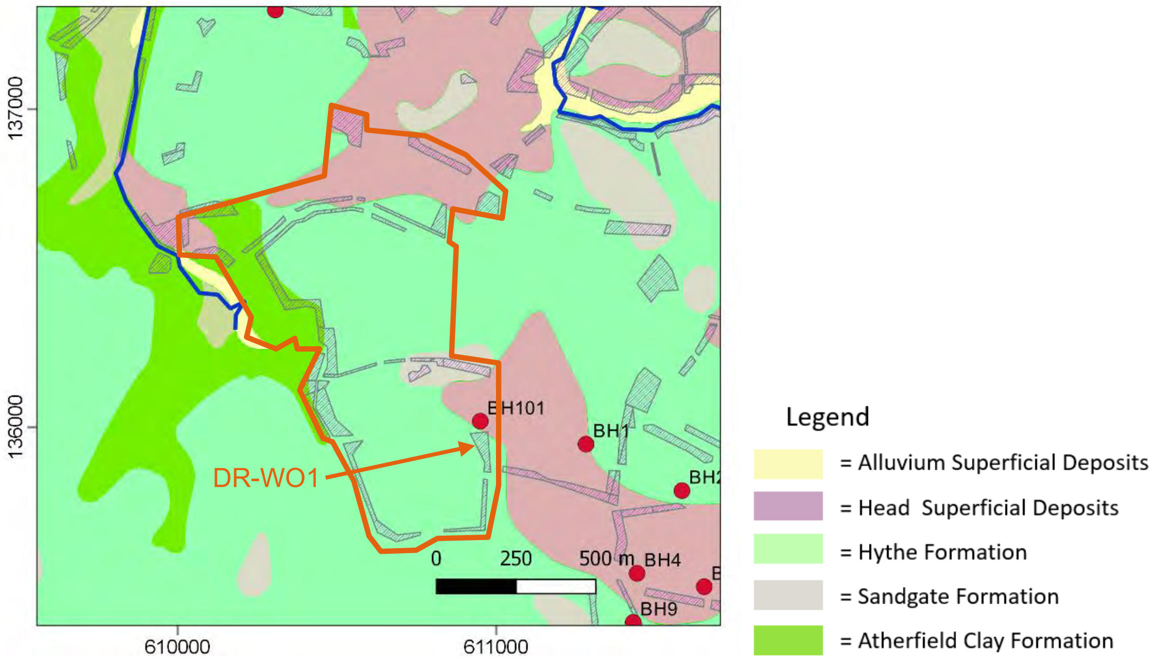
Predicted groundwater mounding for 1 in 100-year storm	Middle estimate (m)	High estimate (m)
Combined SUDS area	0.1	0.1
Polygon DR-EO1	0.1	0.1
Assessment comments	Soakaway tests at the two nearest exploratory holes, TP106 and TP109, failed because the time taken to drain was longer than 240 minutes. Infiltration rates are likely to be very low.	

South Otterpool



South Otterpool		
Nearest borehole	BH5	
Superficial deposits	Head deposits described as sandy CLAY to 4.0 m bgl, recorded in all boreholes within South Otterpool Zone	
Bedrock and depth to base	Hythe Formation to 12.5 m bgl	
Average GWL (m bgl)	9.06	
Saturated zone thickness (m)	3.44	
	Middle estimate	High estimate
Specific yield (m^3/m^3)	0.1	0.035
Permeability (m/d)	5	1.2
Predicted groundwater mounding for 1 in 100-year storm	Middle estimate (m)	High estimate (m)
Combined SUDS area	0.6	1.7
Polygon DR-EO1	0.5	1.6
Assessment comments	Soakaway tests in this area indicate highly variable infiltration rates, from no infiltration to extremely fast infiltration.	

West Otterpool

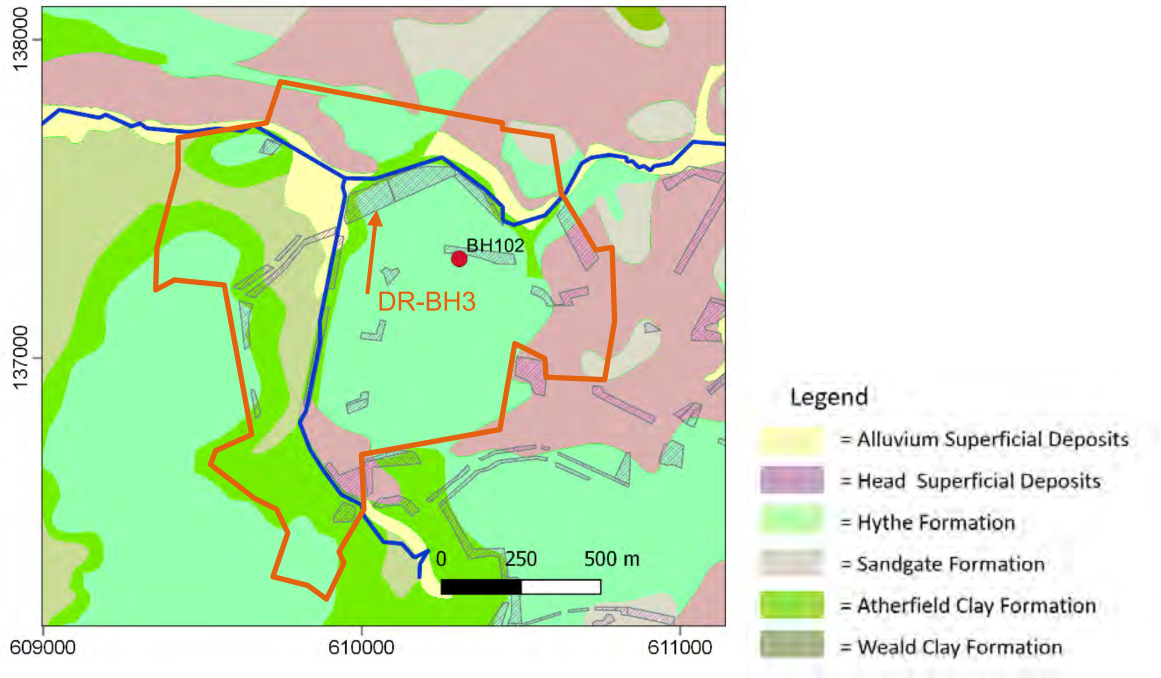


West Otterpool		
Nearest borehole	BH101	
Superficial deposits	Head deposits to a depth of 4.0 m bgl in BH101, described as clayey fine to coarse SAND. None mapped across most of the zone.	
Bedrock and depth to base	Sandgate Formation to between 4 m and 6 m bgl, described as slightly silty slightly gravelly fine to coarse SAND. Hythe Formation to at least 10 m bgl.	
Average GWL (m bgl)	9.89	
Saturated zone thickness (m)	1	
	Middle estimate	High estimate
Specific yield (m^3/m^3)	0.1	0.035
Permeability (m/d)	5	1.2

Predicted groundwater mounding for 1 in 100-year storm	Middle estimate (m)	High estimate (m)
Combined SUDS area	0.3	0.8
Polygon DR-EO1	0.2	0.7

West Otterpool	
Assessment comments	BH101 has sandy head deposits and sandy Sandgate Fm, no groundwater encountered. Therefore, it is assumed SUDS infiltration would percolate down to the Hythe Fm.

Barrow Hill



Barrow Hill		
Nearest borehole	BH102	
Superficial deposits	In BH102, Head deposits to a depth of 3.0 m bgl, described as sandy CLAY and silty fine to medium SAND. None mapped across most of the zone.	
Bedrock and depth to base	The Sandgate Formation comprises slightly silty fine to coarse SAND from 3.0 to 4.5 m bgl, underlain by very stiff brown slightly sandy gravelly CLAY.	
Average GWL (m bgl)	Groundwater not encountered	
Saturated zone thickness (m)	0.1	
	Middle estimate	High estimate
Specific yield (m^3/m^3)	0.1	0.035
Permeability (m/d)	5	1.2

Predicted groundwater mounding for 1 in 100-year storm	Middle estimate (m)	High estimate (m)
Combined SUDS area	0.9	2.6
Polygon DR-EO1	0.9	2.6
Assessment comments	BH102 indicates the presence of head deposits that are not mapped. BH102 being dry indicates low groundwater levels with low risk of mounding	

APPENDIX L

Racecourse Lake Survey

Control Used
Type: E60733148 | Description: TR 1187 3691 | Level: 68.884

Notes:
Grid and levels relate to OS GPS Active Network.
Sheet is North orientated unless stated.

Maltby Surveys Ltd
2 QUEENS ROAD
HAYWARDS HEATH
WEST SUSSEX
RH16 1EB
Tel: 01444 416246
Fax: 01444 417697
E-Mail: MLS@maltbysurveys.com
WebSite: http://www.maltbysurveys.com

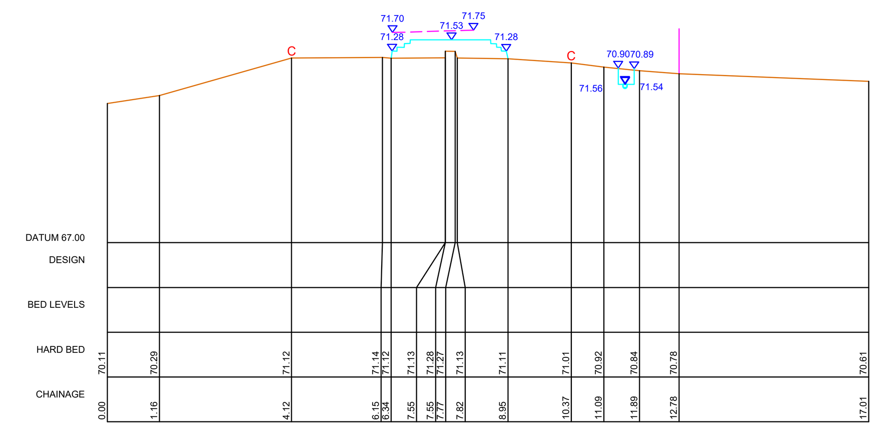
SURVEYED	DHB	ARCADIS
DRAWN	DHB	
CHECKED	ITS	
	SCALE	1:300

OTTERPOOL PARK GARDEN TOWN

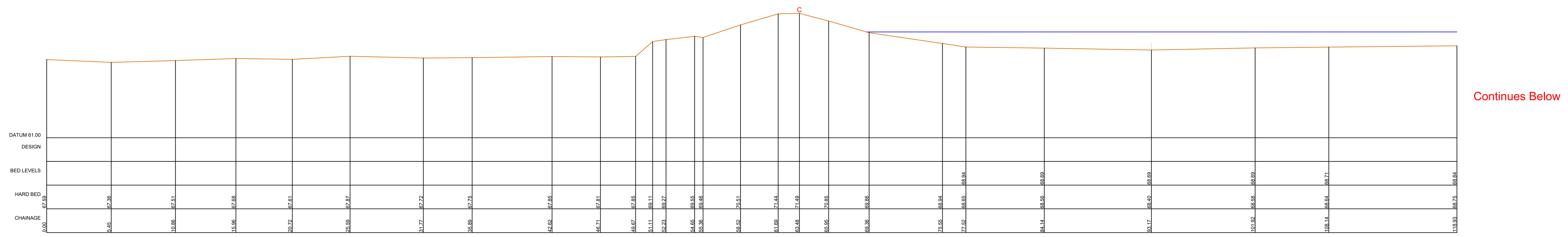
RACECOURSE POND
ADDITIONAL TOPOGRAPHIC SURVEY

Job No	Rev	Drawing Number
21_303		T-21-303-01

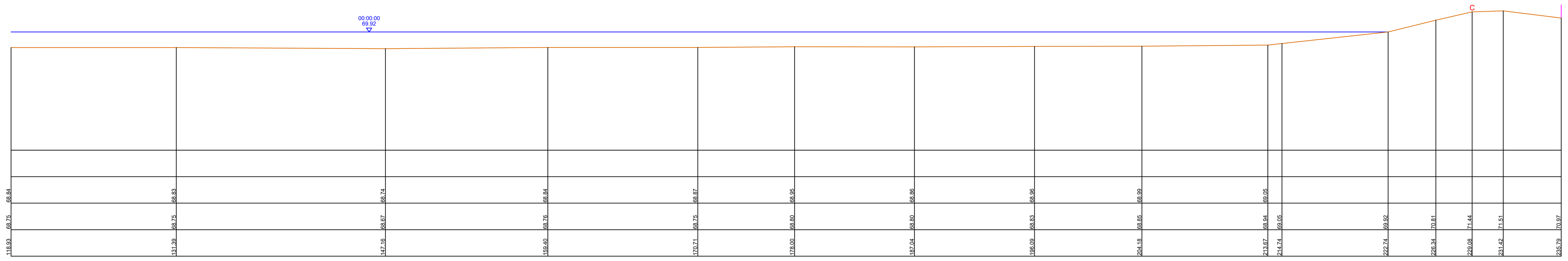
Date : OCT 2021

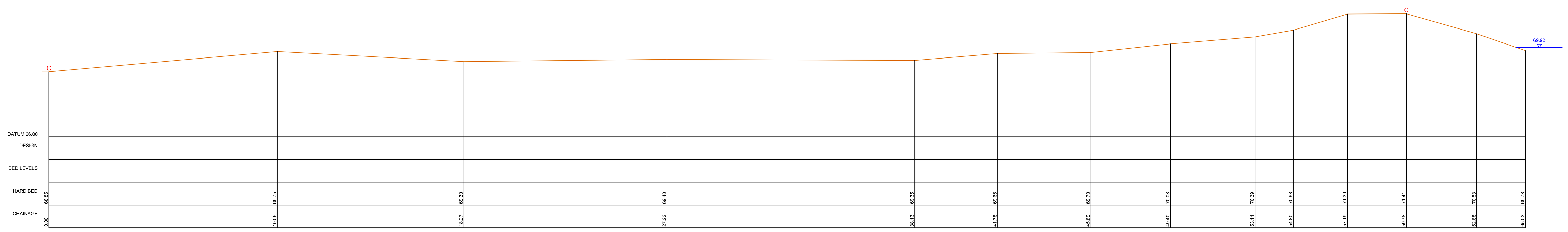


1.001 - 1:100
612351.93mE 136900.59mN Brg 18
Open Channel

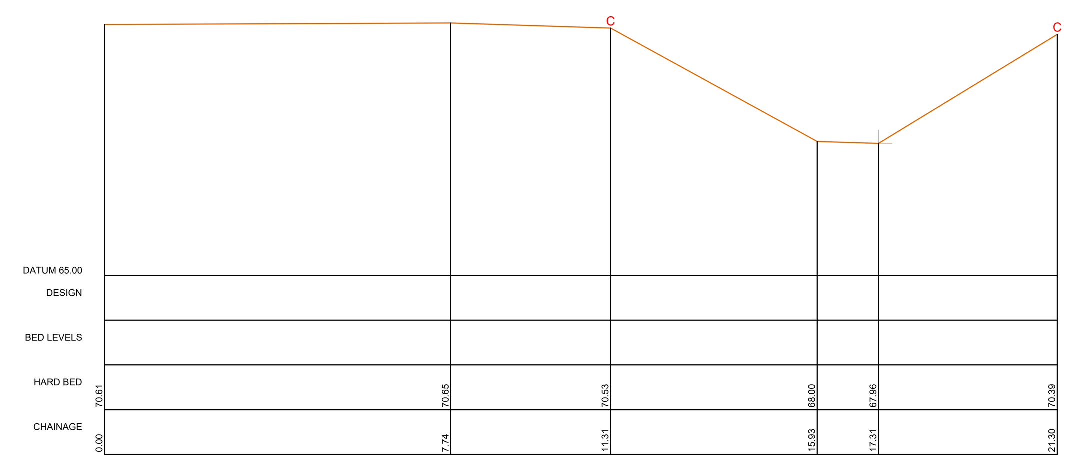


1.002
612216.62mE 136899.26mN Brg 104
Open Channel

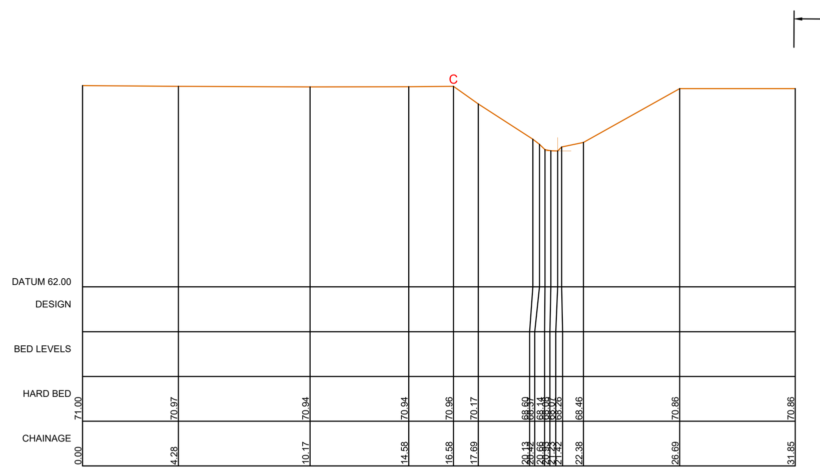




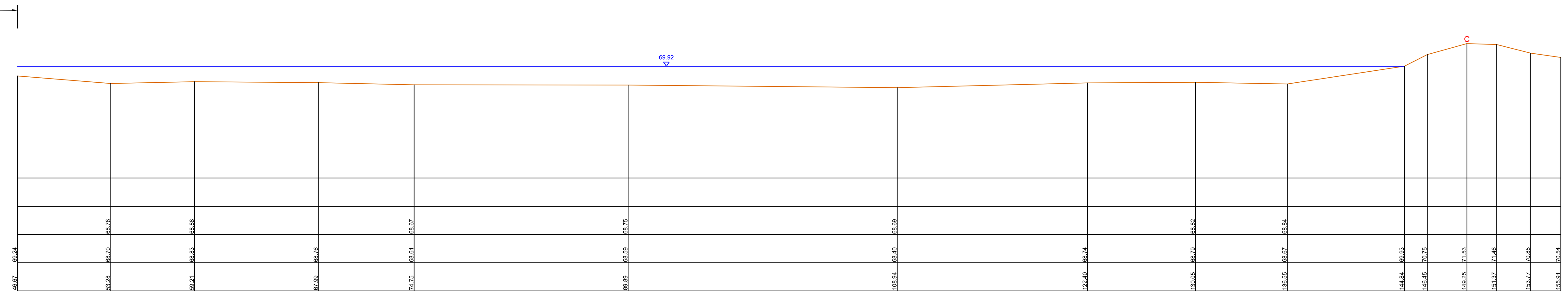
1.003 - 1:100
612223.67mE 136914.44mN Brg 92
Open Channel



1.004 - 1:100
612239.91mE 136847.67mN Brg 91
Open Channel



1.005 - 1:200
612271.64mE 136774.52mN Brg 19
Open Channel

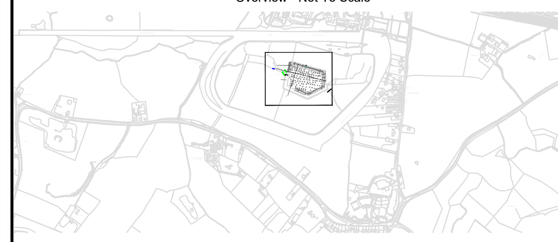


Lake Profile

Key:

- Fence
- Top Of Bank
- Bottom Of Bank
- WL Water Level
- Spot Level
- Silt Level

Overview - Not To Scale



LOCATION PLAN ORIENTATION

N

LEGEND

BANKING — WALL

BUSHES & HEDGES — BUILDING

TREES — OPEN SIDED BUILDING

MT / 3T / 0.2 / 6
Multiple Trunks / No of Trunks / Dia of Bole / Height of Tree

NOTE:- SPREADS AND HEIGHTS ARE INDICATIVE ONLY

GLASS ROOFED

GATES (Single, Double) — CONTOURS (25.50)

ABBREVIATIONS (WHERE APPLICABLE)

ARCH HEAD HEIGHT	AHH	MARKER	MKR
ARCH HEAD LEVEL	AHL	MONITORING WELL	MW
ARCH SPRINGER HEIGHT	ASH	NOTICE BOARD	NB
ARCH SPRINGER LEVEL	ASL	NAME PLATE	NP
AIR VALVE	AV	OVERHEAD WIRES	OHW
BED LEVEL	BL	PARKING METER	PM
BELISHA BEACON	BB	RIDGE LEVEL	RID
BOLLARD	B	ROOF LEVEL	RL
BRITISH TELECOM BOX	BTB	ROAD SIGN	RS
BRITISH TELECOM MANHOLE	BTMH	RODDING EYE	RE
BRICKWORK	BKWK	RETAINING WALL	RTW
BUS STOP	BS	RAIN WATER PIPE	RWP
CABLE TV	CATV	SLUICE VALVE	SV
COVER LEVEL	CL	STOP COCK	SC
CABLE MARKER	CM	SOFFIT LEVEL	SOF
COLUMN	Col	STRUCTURAL SLAB LEVEL	SSL
CONCRETE POST	CP	TREE STUMP	ST
EAVES LEVEL	EAV	SOIL AND VENT PIPE	SVP
ELECTRICAL COVER	ELEC	THRESHOLD LEVEL	THL
ELECTRICITY CONTROL BOX	ECB	TELEGRAPH POLE	TP
ELECTRICITY POLE	EP	TELEPHONE CALL BOX	TCB
EARTH ROD	ER	TOP OF KERB	TK
FLOWER BED	FB	TURNSTILE	TS
FINISHED FLOOR LEVEL	FFL	TRAFFIC LIGHT	TL
FIRE HYDRANT	FH	TOP OF WALL	TW
FLOOR LEVEL	FL	UNABLE TO LIFT	UTL
FLAG STAFF	FS	UNABLE TO SURVEY	UTS
GAS PIPE	GP	VENT PIPE	VP
GAS VALVE	GV	WATER METER	WM
GULLY	G	WATER LEVEL	WL
GATE STOP	GS	WASH OUT	WO
INSPECTION COVER	IC	WASTE PIPE	WP
INVERT LEVEL	IL	WATER TANK	WT
LAMP POST	LP	WATER VALVE	WV

FENCES

BARBED WIRE FENCE	BWF	LARCH LAP FENCE	LLF
CORRUGATED IRON FENCE	CIF	METAL RAILING FENCE	MRF
CLOSE BOARD FENCE	CBF	POST AND CHAIN FENCE	PCF
CHAIN LINK FENCE	CLF	PICKET FENCE	PIF
CHESTNUT PALING FENCE	CPF	POST AND RAIL FENCE	PRF
FENCE POST	FPO	POST AND WIRE FENCE	PWF
INTERWOVEN FENCE	IWF	STEEL PALISADE SECURITY FENCE	SPSF
IRON RAILING FENCE	IRF	TUBULAR STEEL RAIL FENCE	TSRF

REV.	NOTES	DWN	DATE

QMS ISO 9001 REGISTERED — A MEMBER OF THE THE SURVEY ASSOCIATION — QMS ISO 14001 REGISTERED

Control Used

Type	Description	Level
E60733148	TR 1187 3691	68.884

Notes:

Grid and levels relate to OS GPS Active Network.
Sheet is North orientated unless stated.

Maltby Surveys Ltd
2 QUEENS ROAD
HAYWARDS HEATH
WEST SUSSEX
RH16 1EB
Tel: 01444 416246
Fax: 01444 417697
E-Mail: MLS@maltbysurveys.com
WebSite: http://www.maltbysurveys.com

SURVEYED	DHB	ARCADIS
DRAWN	DHB	
CHECKED	ITS	
RICS		SCALE: AS SHOWN

OTTERPOOL PARK GARDEN TOWN

RACECOURSE POND
TOPOGRAPHIC SURVEY
CROSS SECTIONS 1.001 - 1.005

Job No	Rev	Drawing Number
21_303		T-21-303-02

Date : OCT 2021

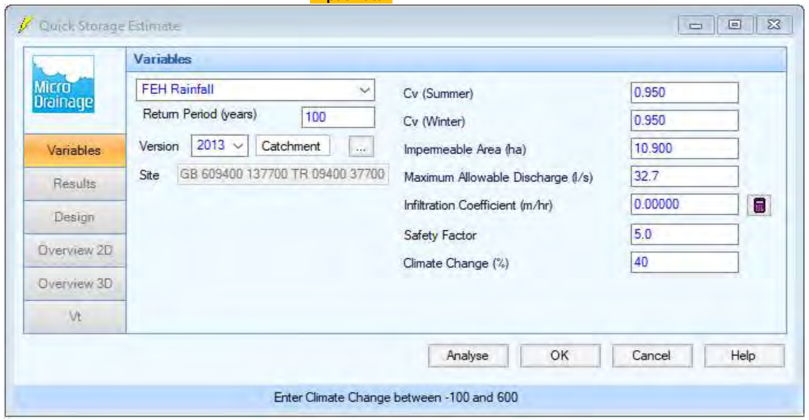
APPENDIX M

MicroDrainage Quick Storage Calculation Printouts

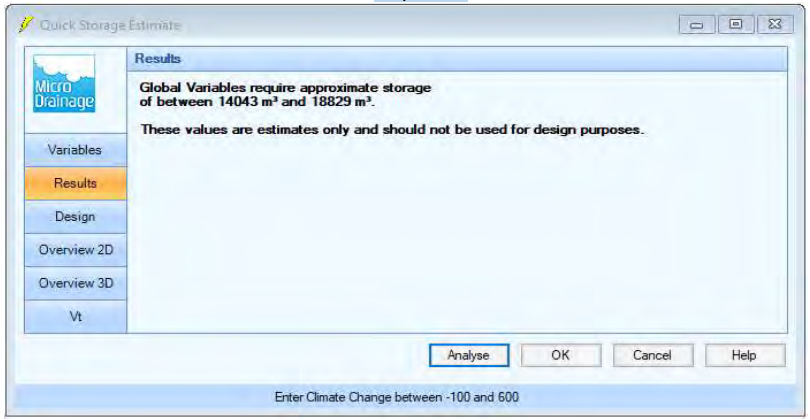
Drainage Zone: Westenhanger
Drainage Sub-Zone: DR-WH1

Storm Event: 1 in 100 Annual Chance

Input Data

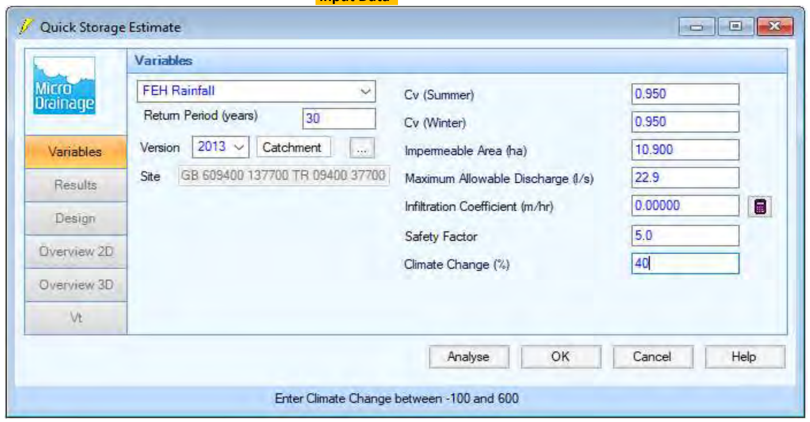


Output Data

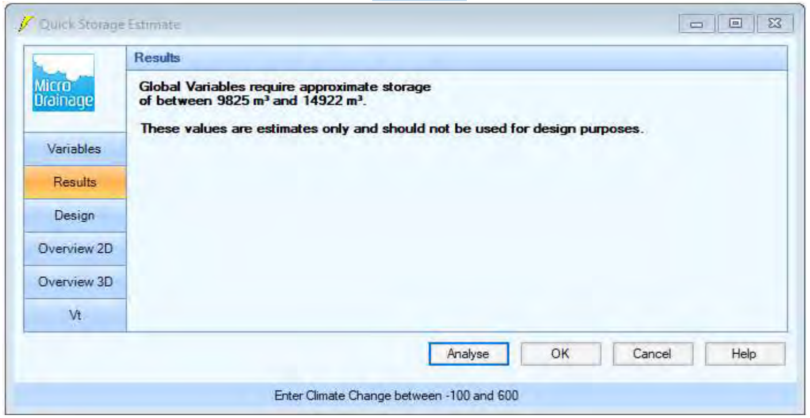


Storm Event: 1 in 30 Annual Chance

Input Data



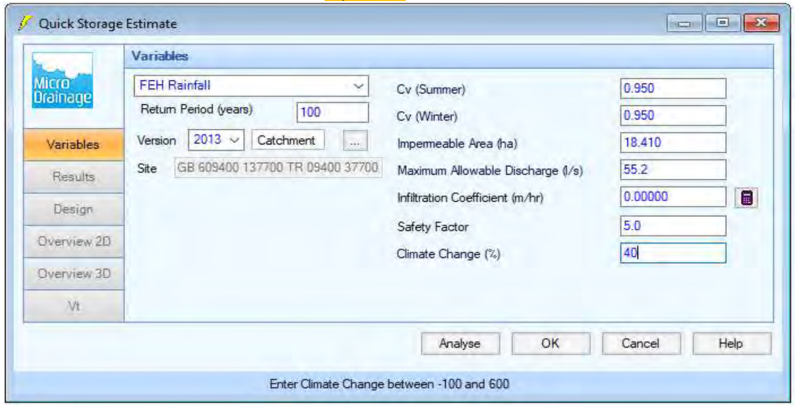
Output Data



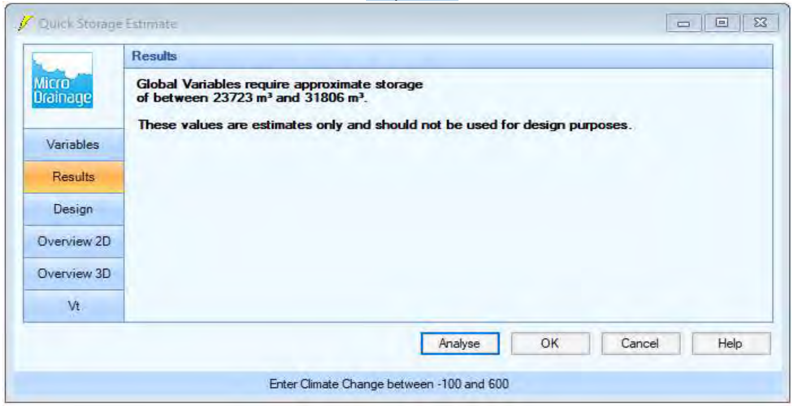
Drainage Zone: Westenhanger
Drainage Sub-Zone: DR-WH2

Storm Event: 1 in 100 Annual Chance

Input Data

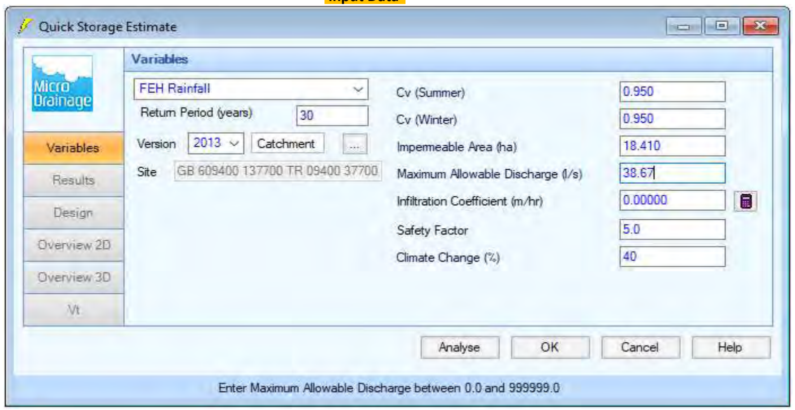


Output Data

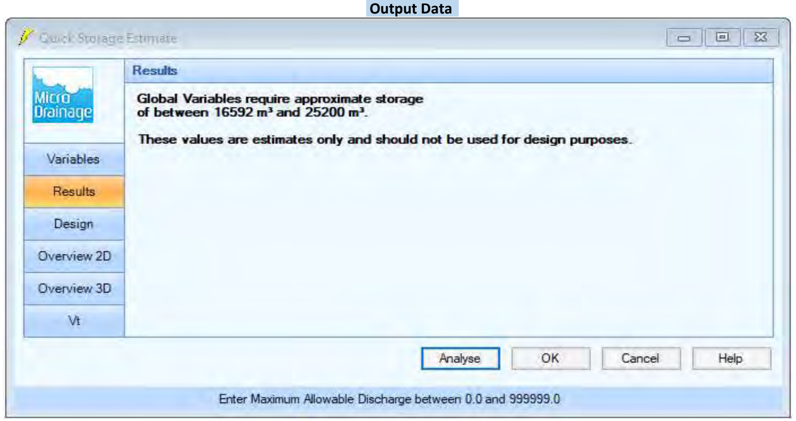


Storm Event: 1 in 30 Annual Chance

Input Data



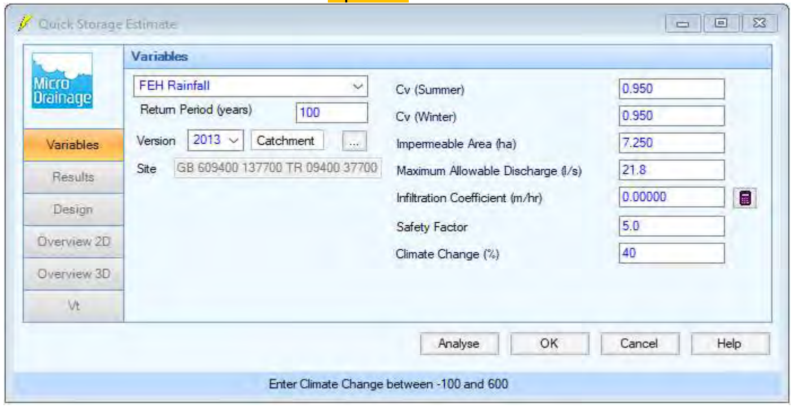
Output Data



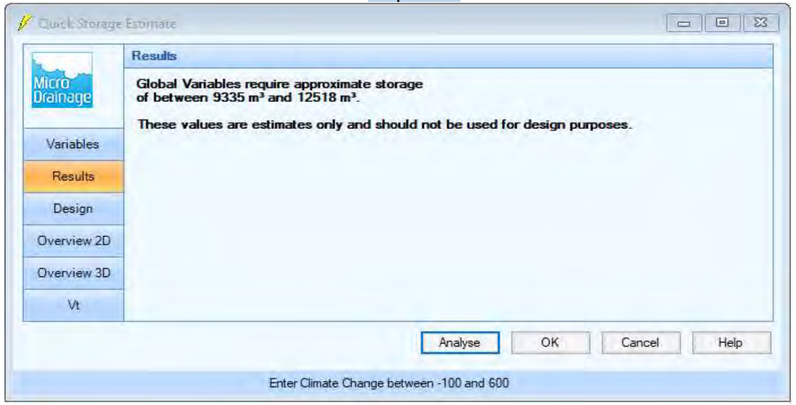
Drainage Zone: Westenhanger
Drainage Sub-Zone: DR-WH3

Storm Event: 1 in 100 Annual Chance

Input Data

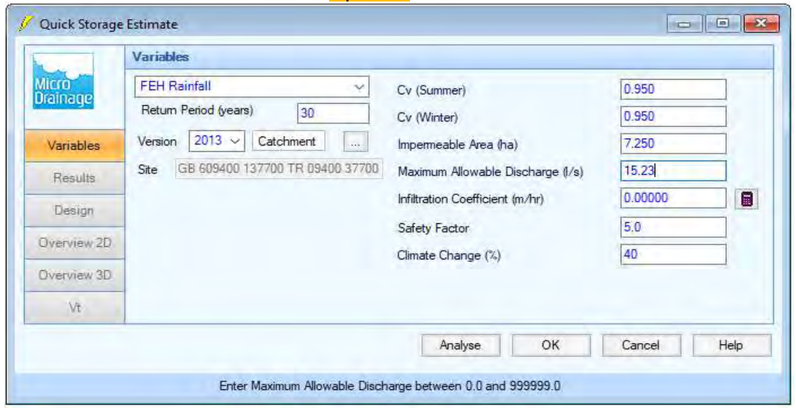


Output Data

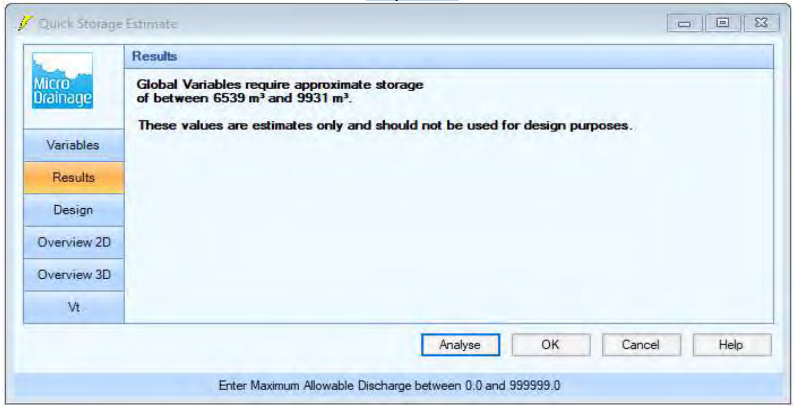


Storm Event: 1 in 30 Annual Chance

Input Data



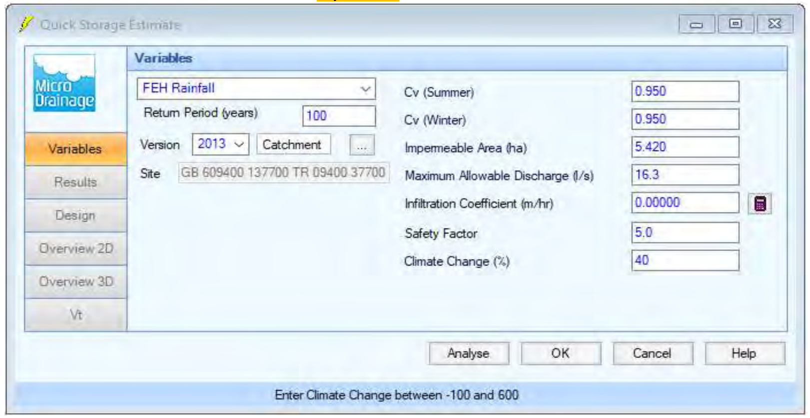
Output Data



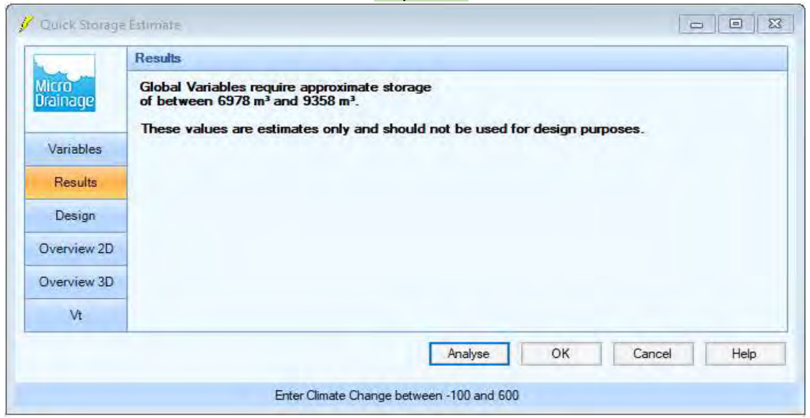
Drainage Zone: Westenhanger
Drainage Sub-Zone: DR-WH4

Storm Event: 1 in 100 Annual Chance

Input Data

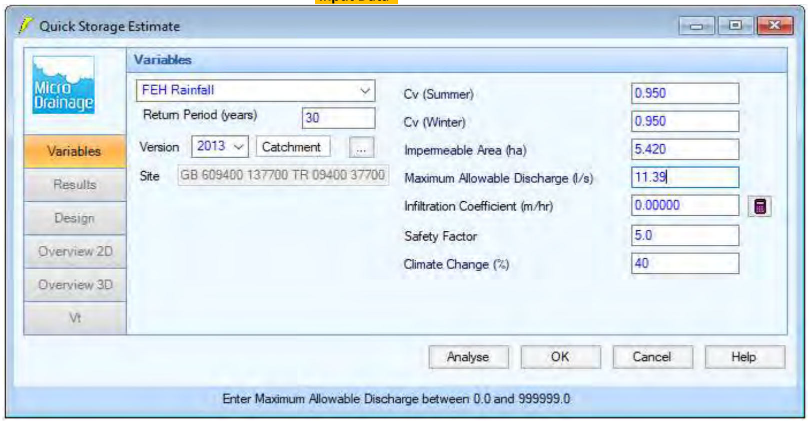


Output Data

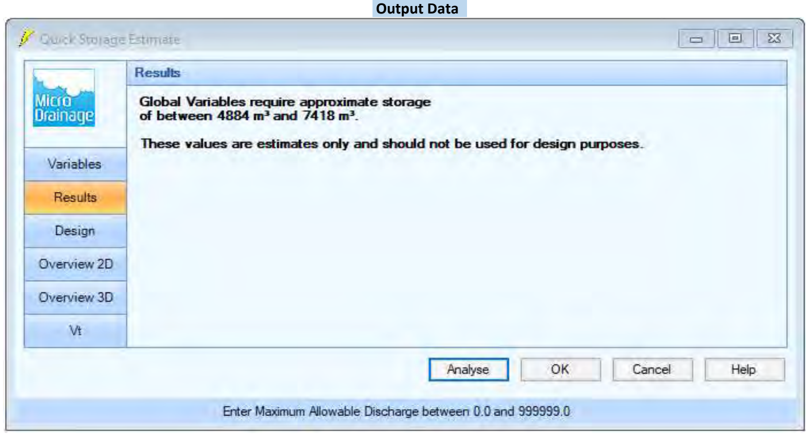


Storm Event: 1 in 30 Annual Chance

Input Data



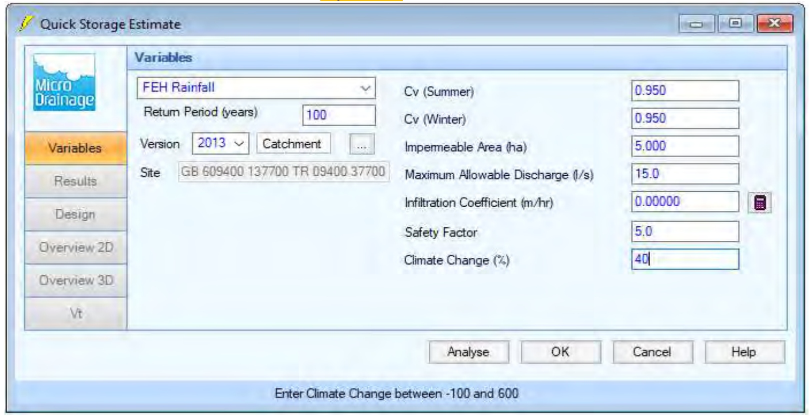
Output Data



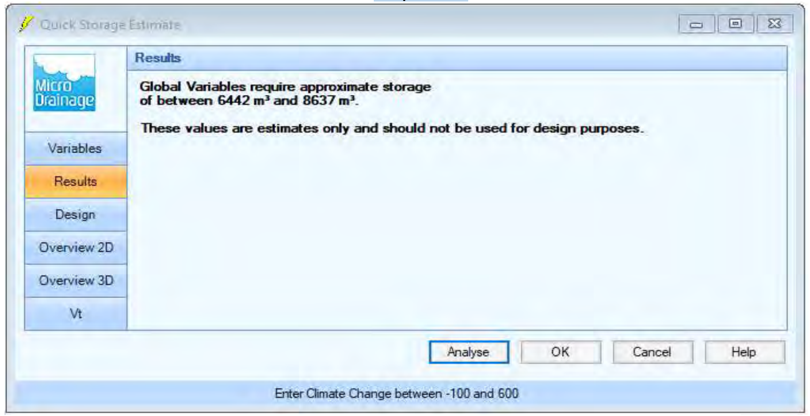
Drainage Zone: Westenhanger
Drainage Sub-Zone: DR-WH5

Storm Event: 1 in 100 Annual Chance

Input Data

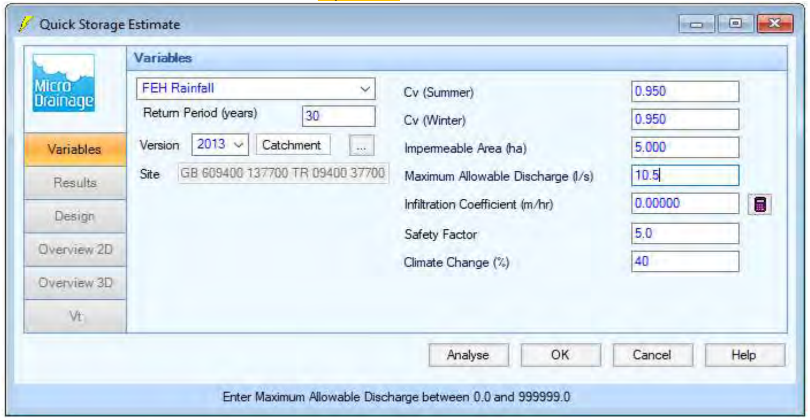


Output Data

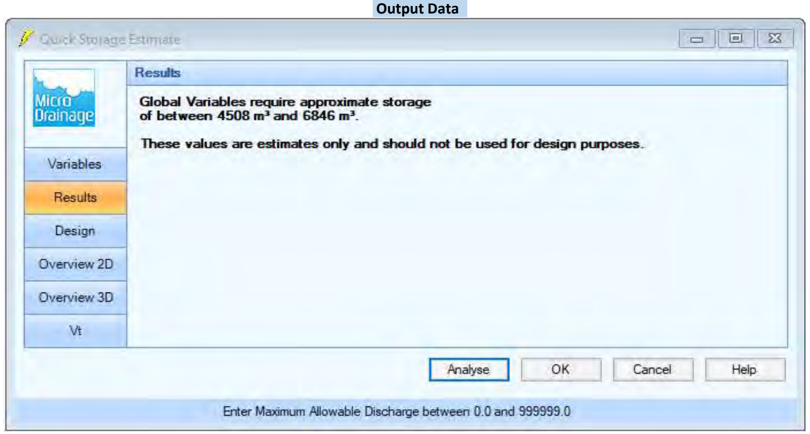


Storm Event: 1 in 30 Annual Chance

Input Data



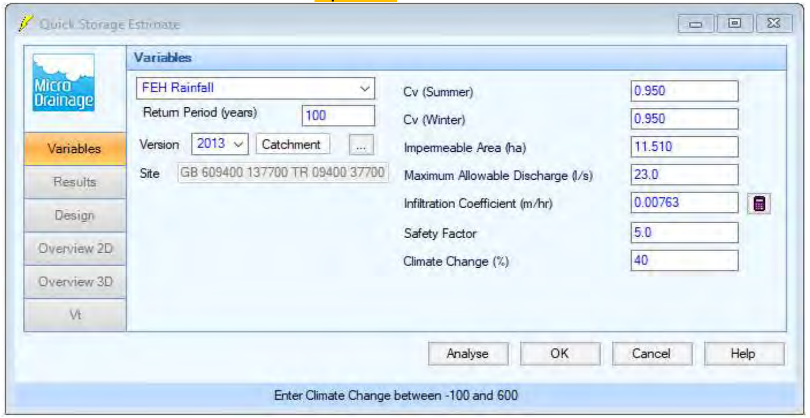
Output Data



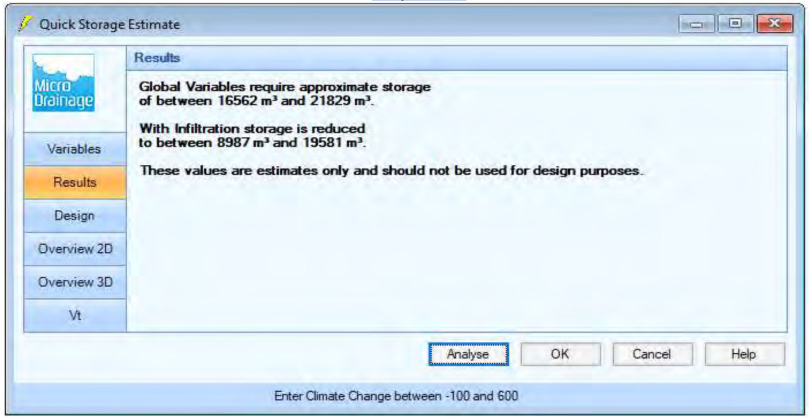
Drainage Zone: East Otterpool
Drainage Sub-Zone: DR-EO1

Storm Event: 1 in 100 Annual Chance

Input Data

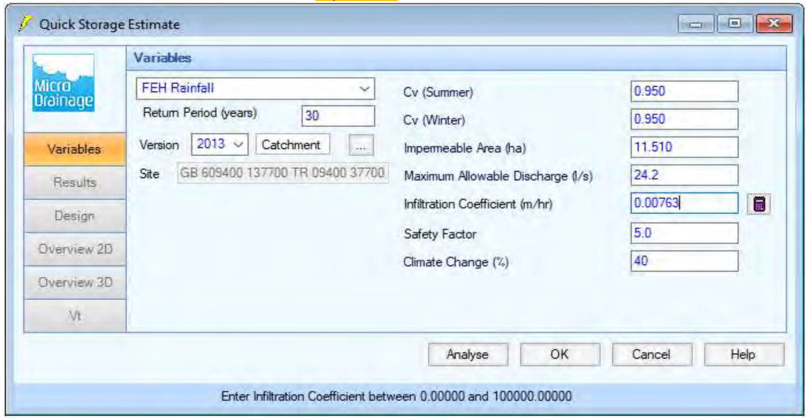


Output Data

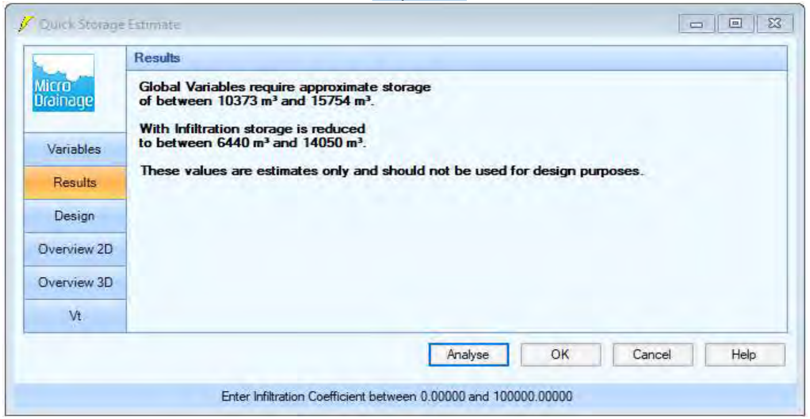


Storm Event: 1 in 30 Annual Chance

Input Data



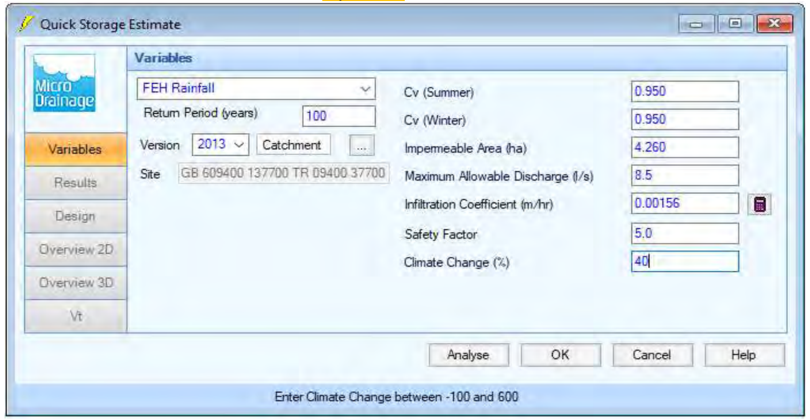
Output Data



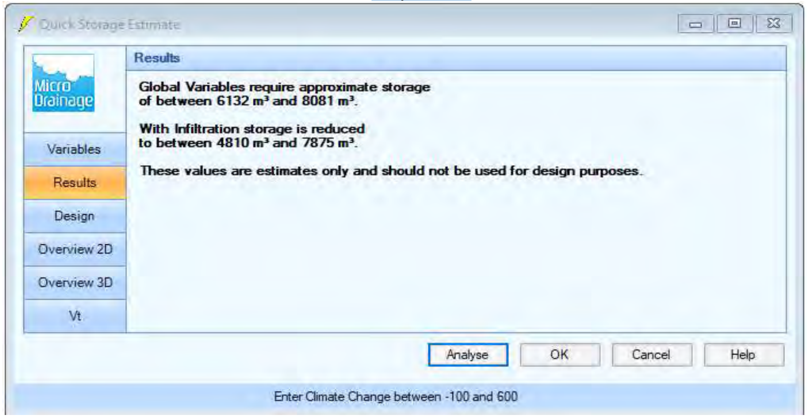
Drainage Zone: East Otterpool
Drainage Sub-Zone: DR-EO2

Storm Event: 1 in 100 Annual Chance

Input Data

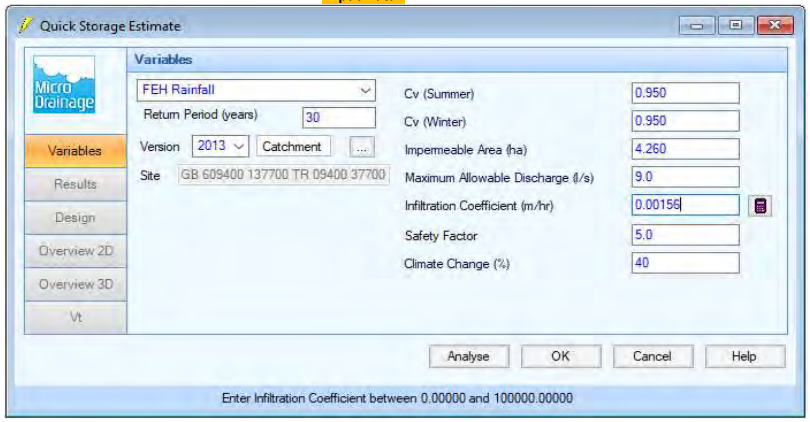


Output Data

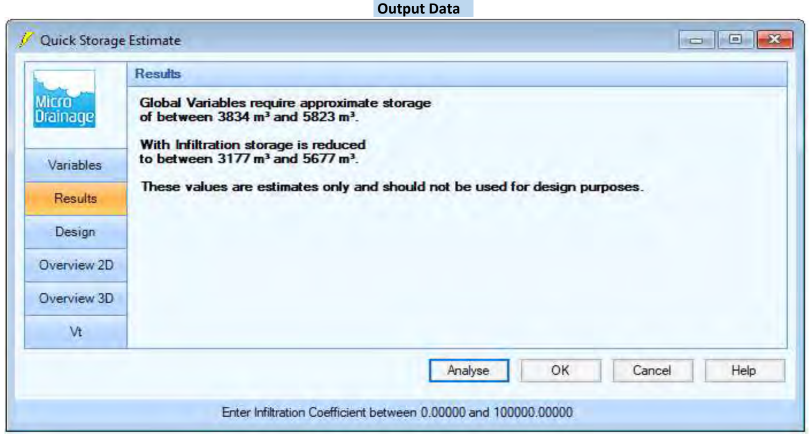


Storm Event: 1 in 30 Annual Chance

Input Data



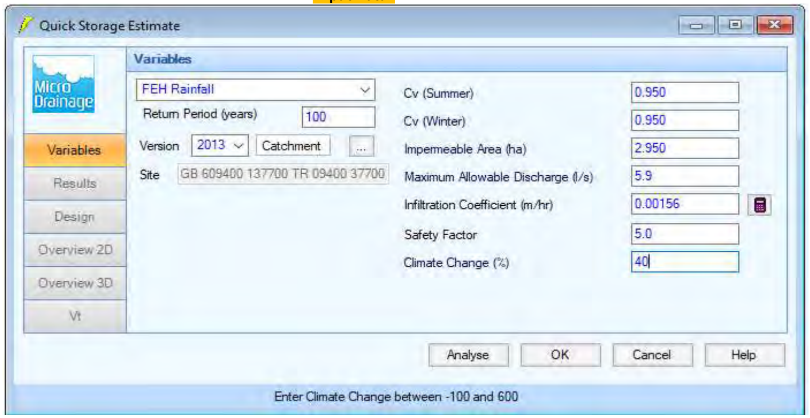
Output Data



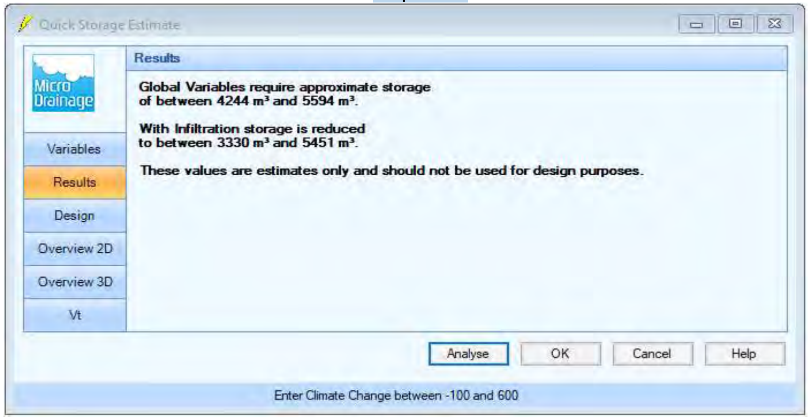
Drainage Zone: East Otterpool
Drainage Sub-Zone: DR-EO3

Storm Event: 1 in 100 Annual Chance

Input Data

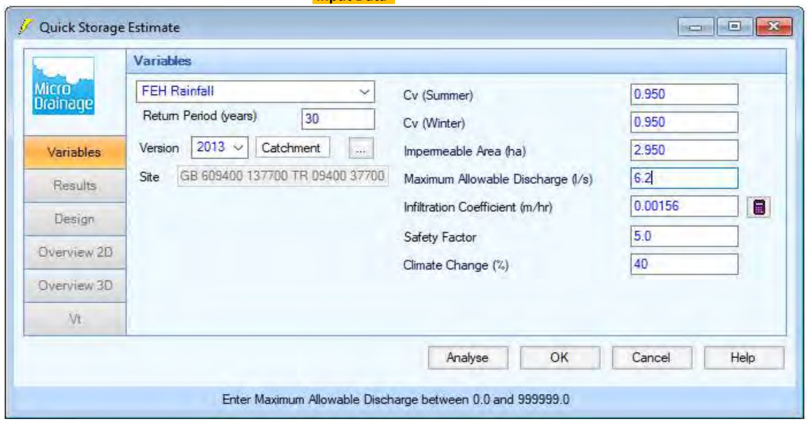


Output Data

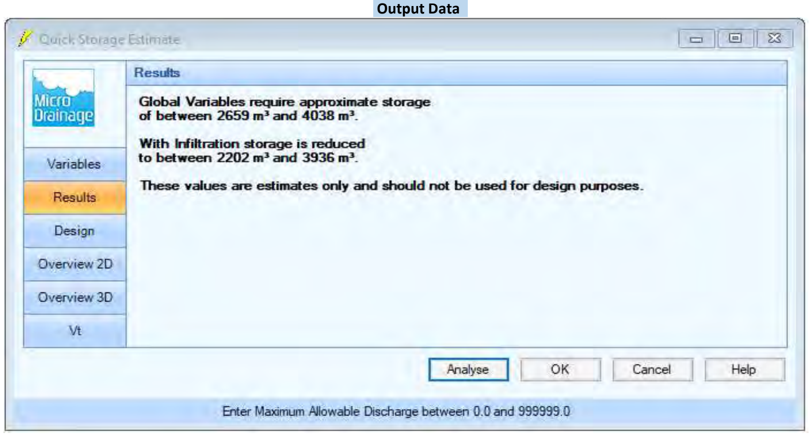


Storm Event: 1 in 30 Annual Chance

Input Data



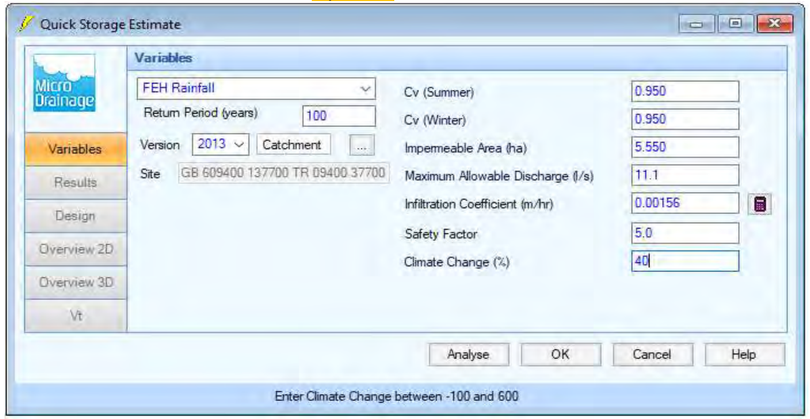
Output Data



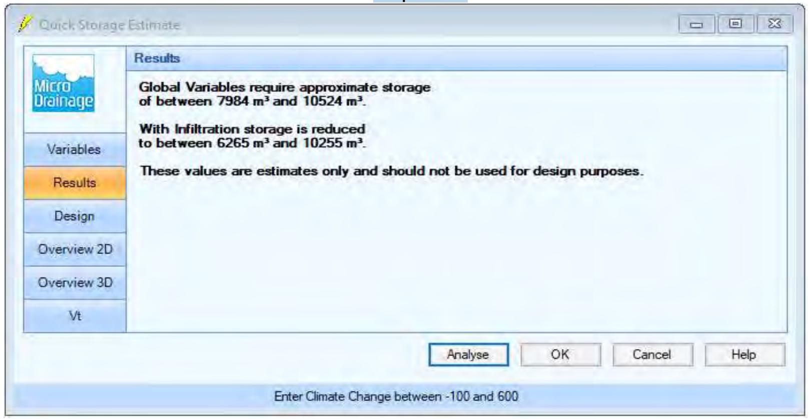
Drainage Zone: East Otterpool
Drainage Sub-Zone: DR-EO4

Storm Event: 1 in 100 Annual Chance

Input Data

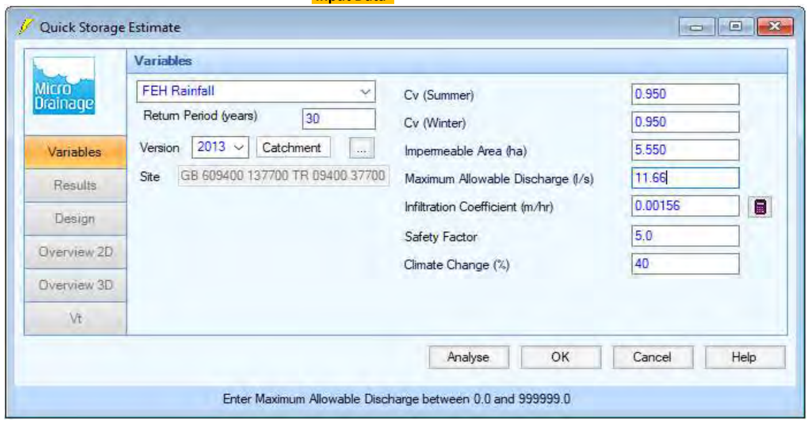


Output Data

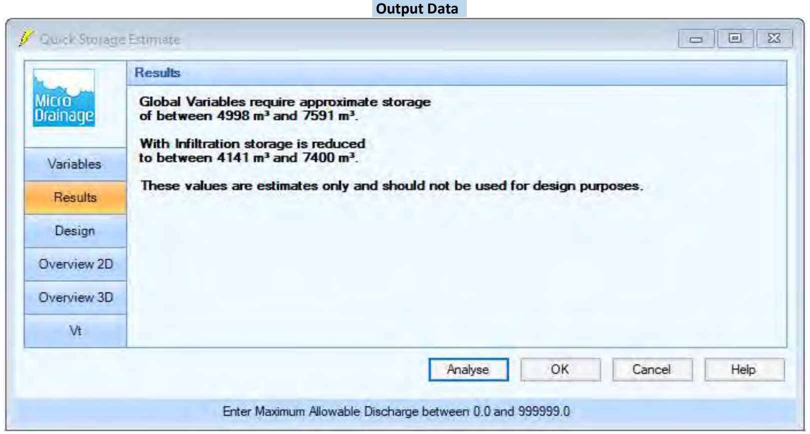


Storm Event: 1 in 30 Annual Chance

Input Data



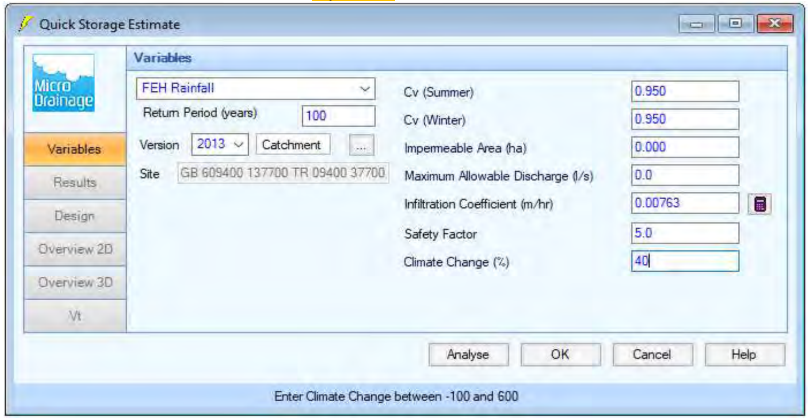
Output Data



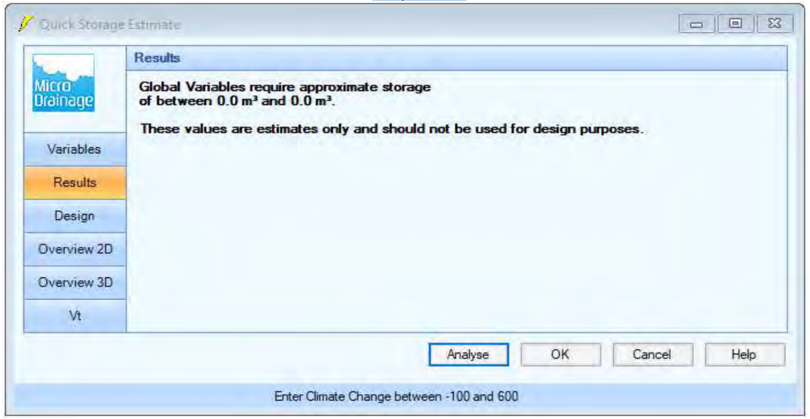
Drainage Zone: East Otterpool
Drainage Sub-Zone: DR-EO5

Storm Event: 1 in 100 Annual Chance

Input Data

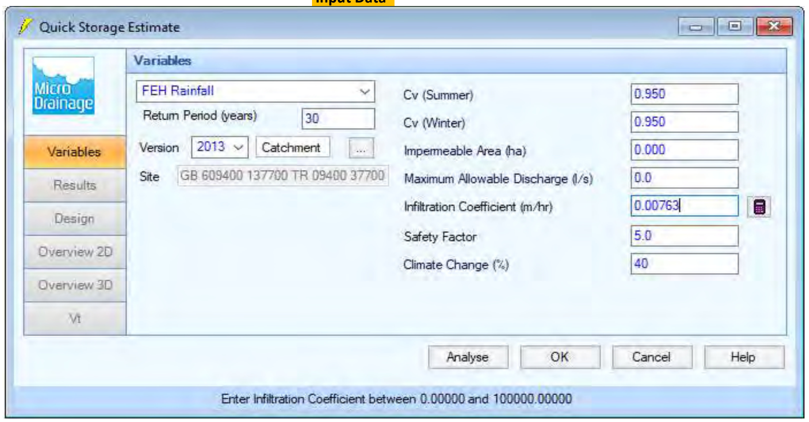


Output Data

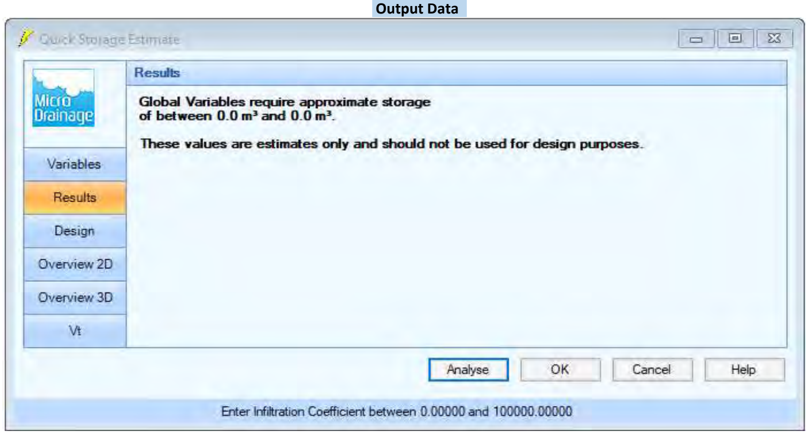


Storm Event: 1 in 30 Annual Chance

Input Data



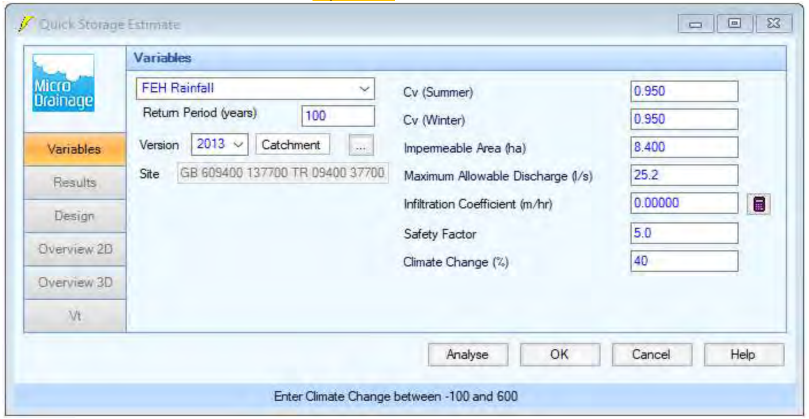
Output Data



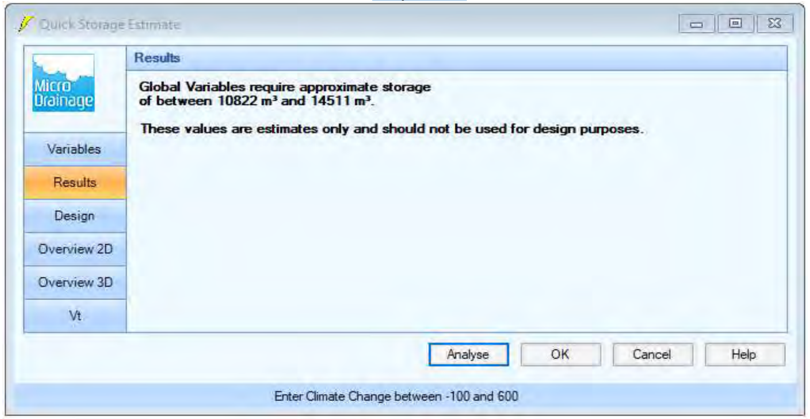
Drainage Zone: West Newingreen
Drainage Sub-Zone: DR-WN1

Storm Event: 1 in 100 Annual Chance

Input Data

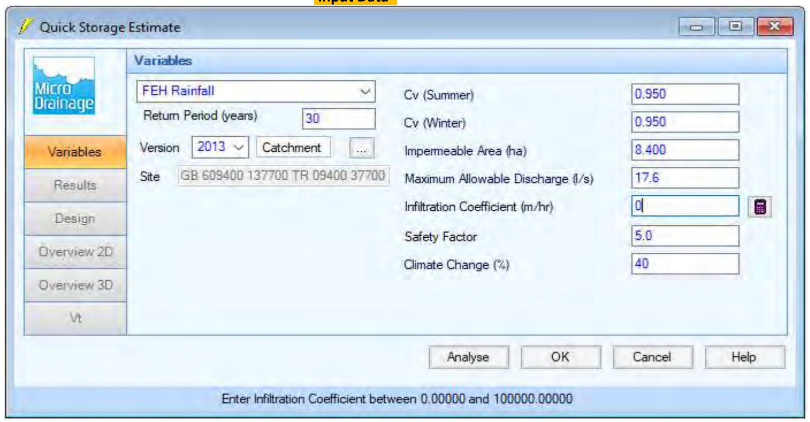


Output Data

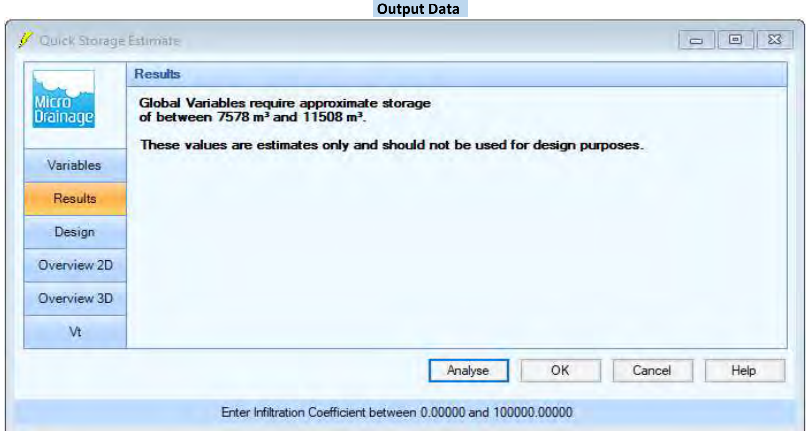


Storm Event: 1 in 30 Annual Chance

Input Data



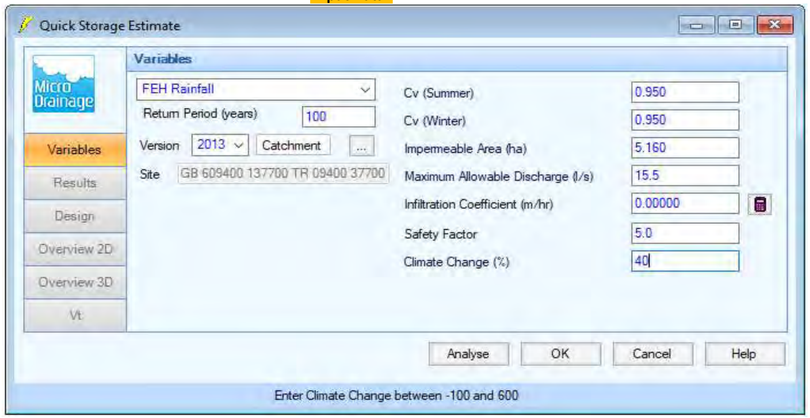
Output Data



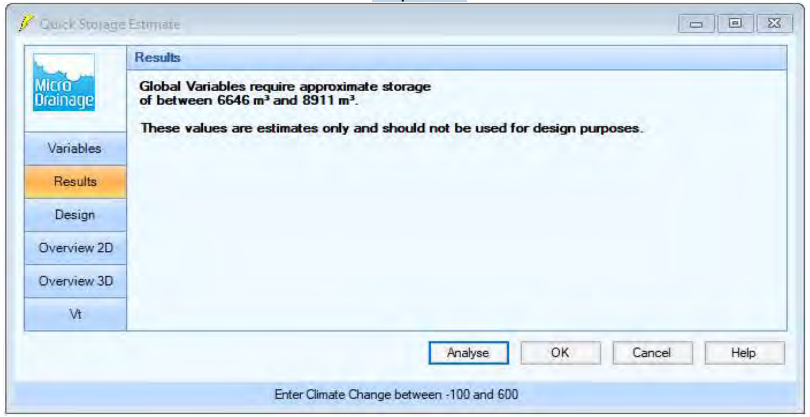
Drainage Zone: West Newingreen
Drainage Sub-Zone: DR-WN2

Storm Event: 1 in 100 Annual Chance

Input Data

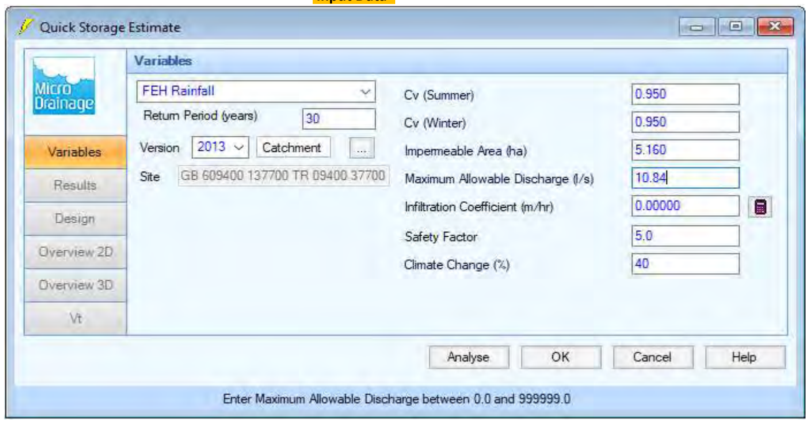


Output Data

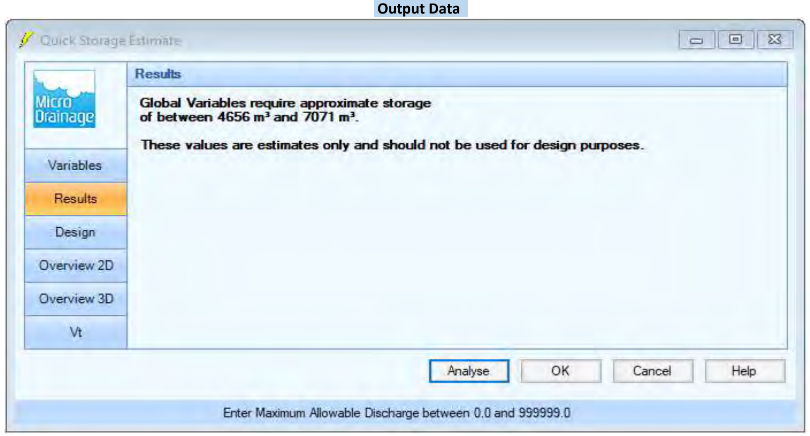


Storm Event: 1 in 30 Annual Chance

Input Data



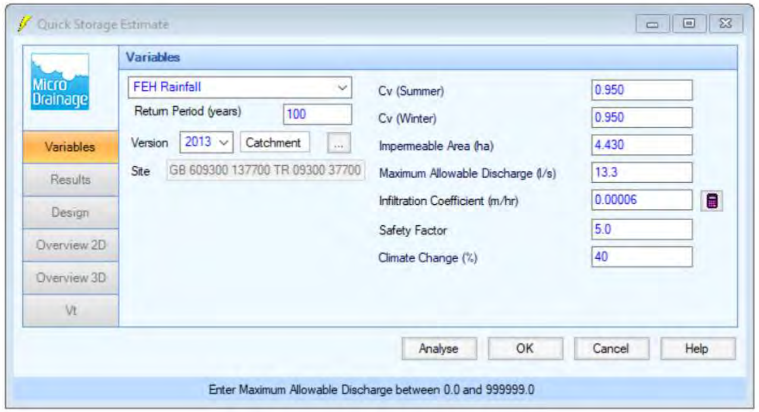
Output Data



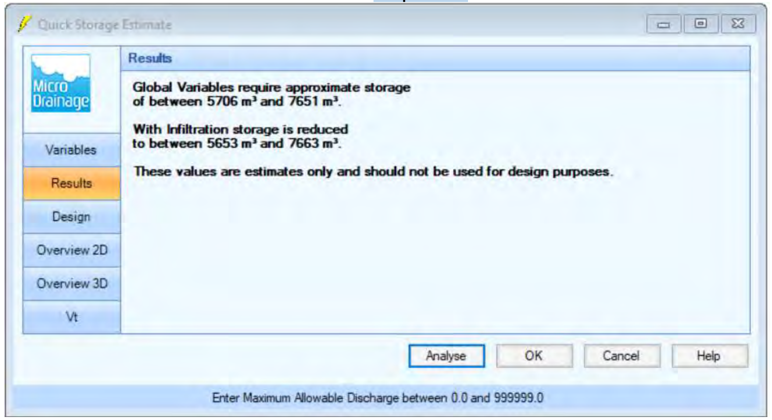
Drainage Zone: **East Triangle**
Drainage Sub-Zone: **DR-ET1**

Storm Event: 1 in 100 Annual Chance

Input Data

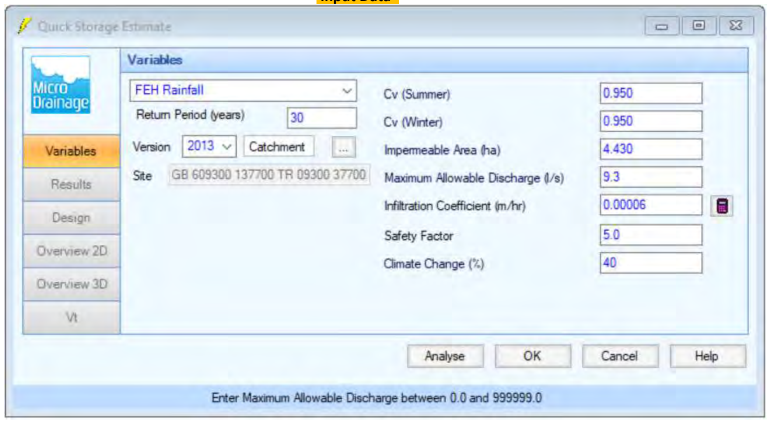


Output Data

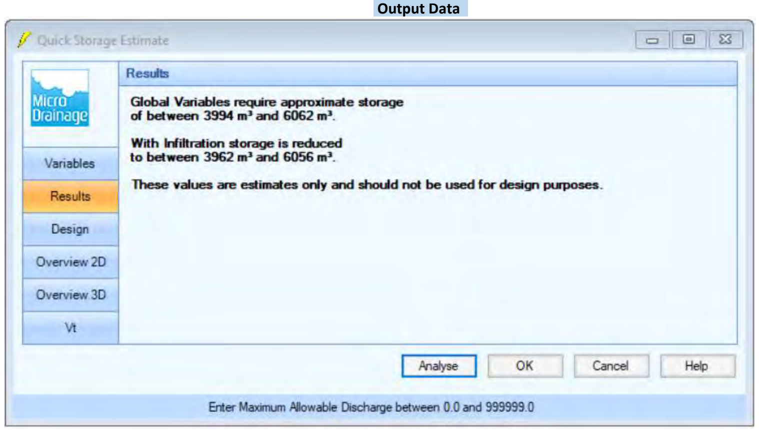


Storm Event: 1 in 30 Annual Chance

Input Data



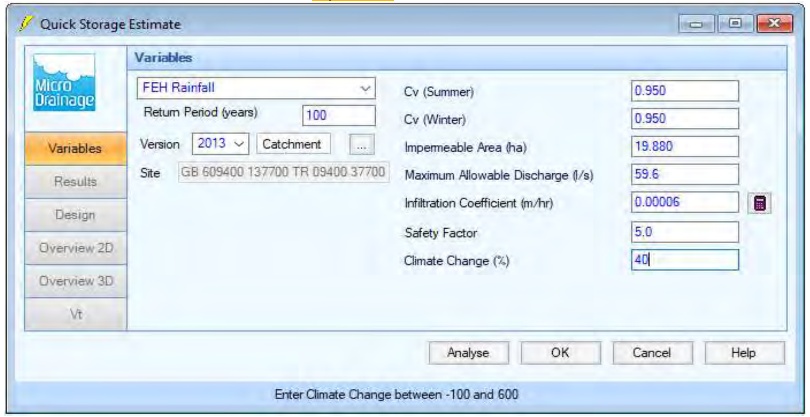
Output Data



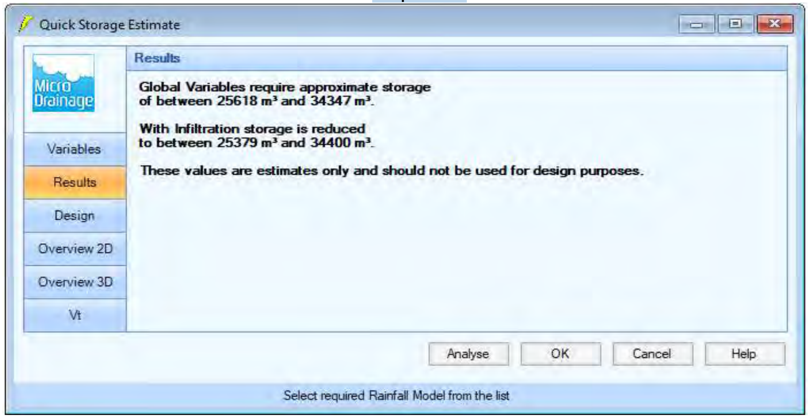
Drainage Zone: East Triangle
Drainage Sub-Zone: DR-ET2

Storm Event: 1 in 100 Annual Chance

Input Data

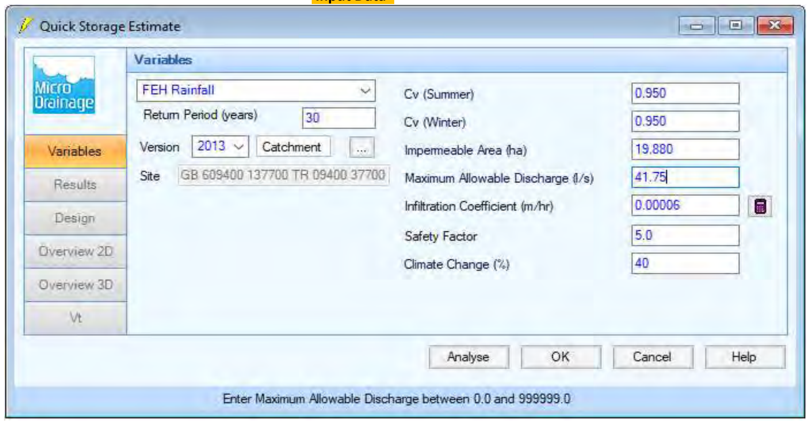


Output Data

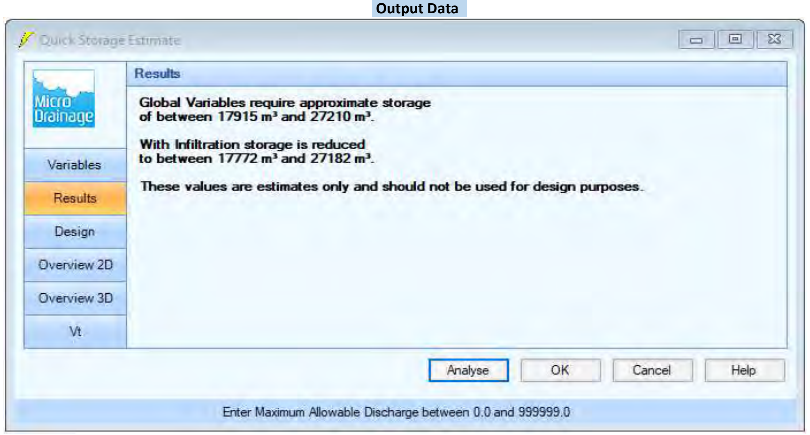


Storm Event: 1 in 30 Annual Chance

Input Data



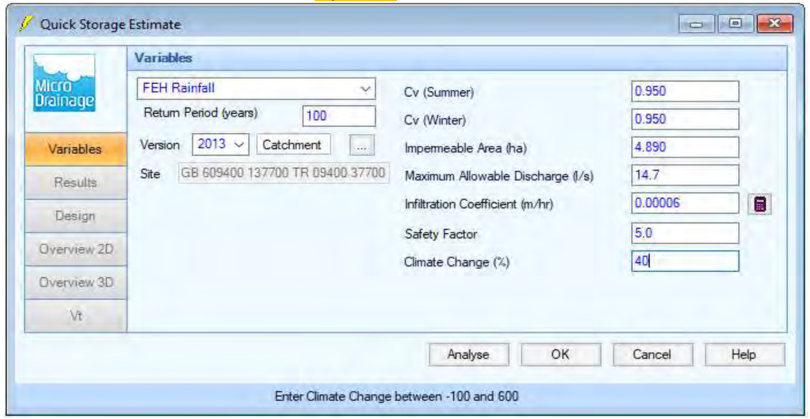
Output Data



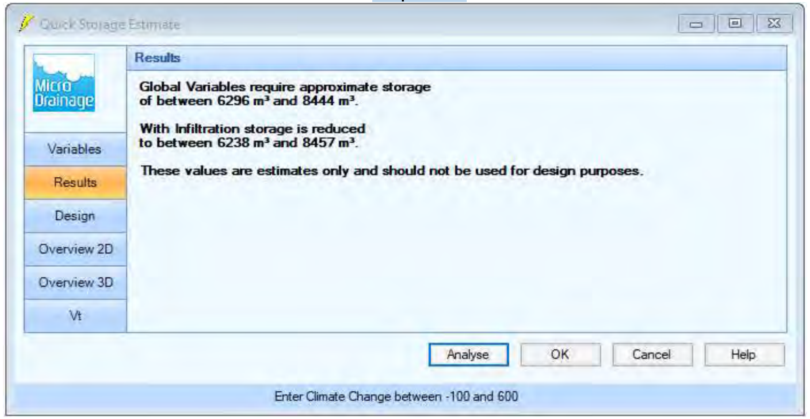
Drainage Zone: East Triangle South
Drainage Sub-Zone: DR-ETS

Storm Event: 1 in 100 Annual Chance

Input Data

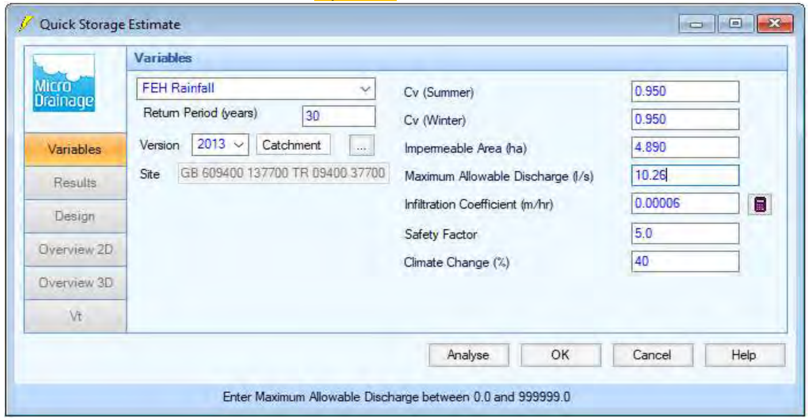


Output Data

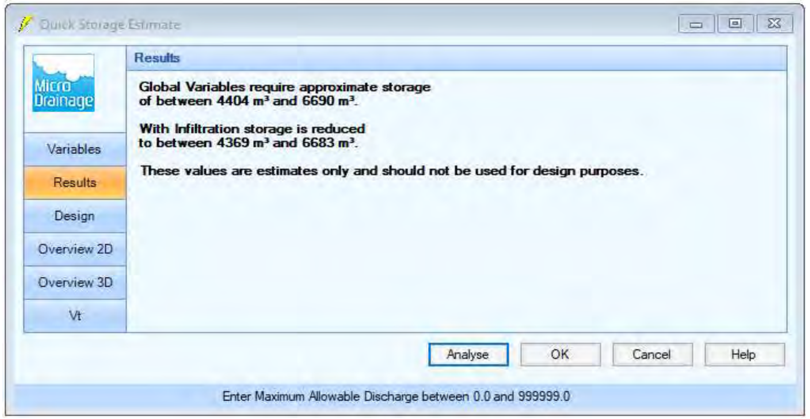


Storm Event: 1 in 30 Annual Chance

Input Data



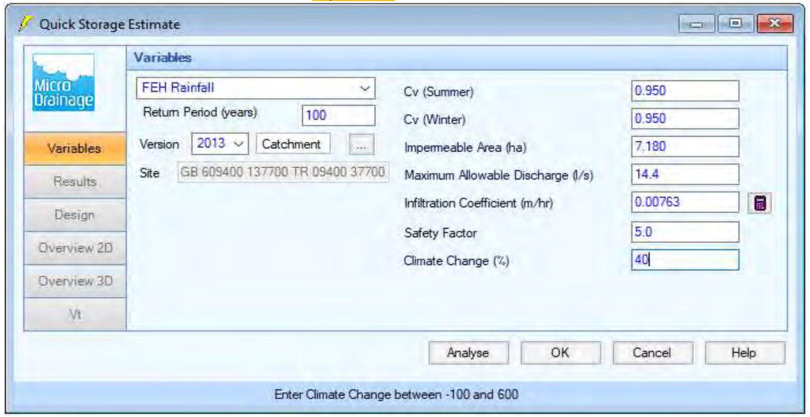
Output Data



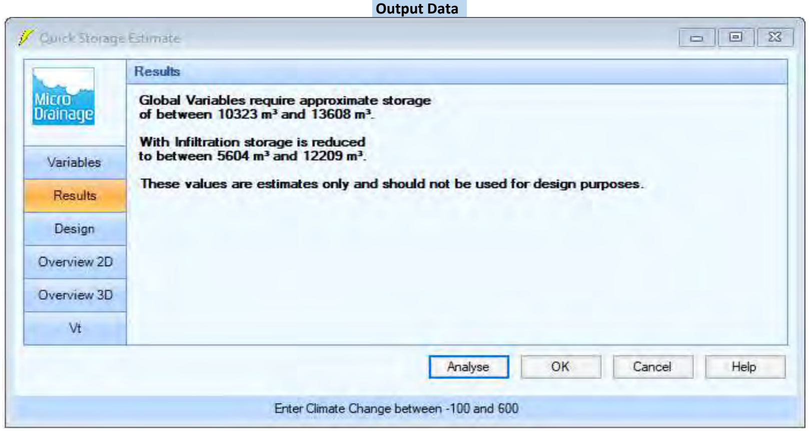
Drainage Zone: **South Otterpool**
Drainage Sub-Zone: **DR-SO1**

Storm Event: 1 in 100 Annual Chance

Input Data

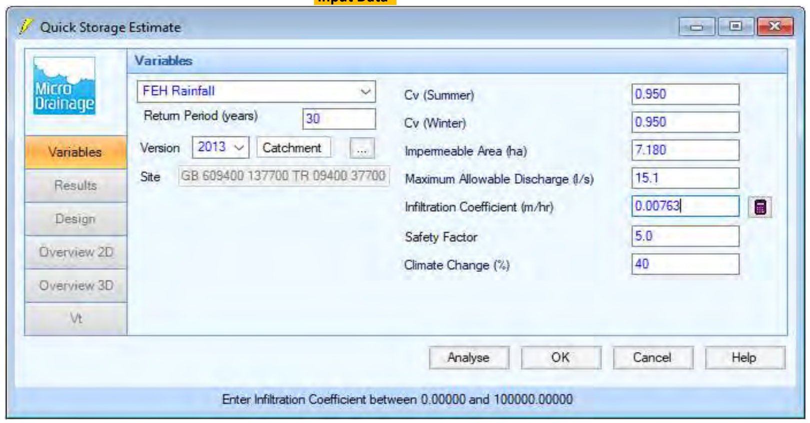


Output Data

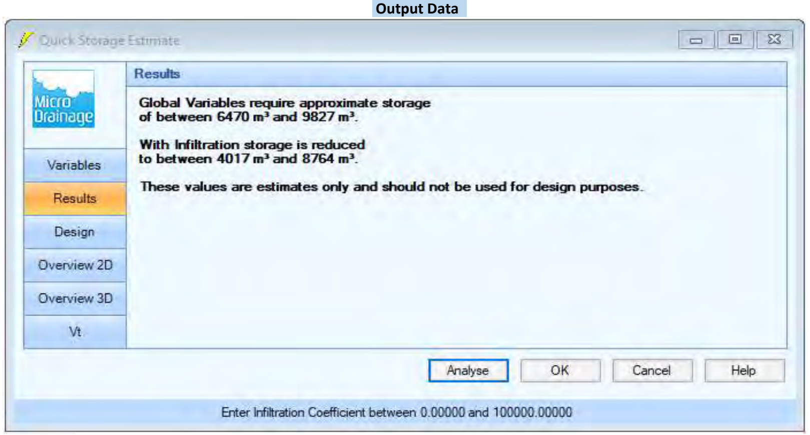


Storm Event: 1 in 30 Annual Chance

Input Data



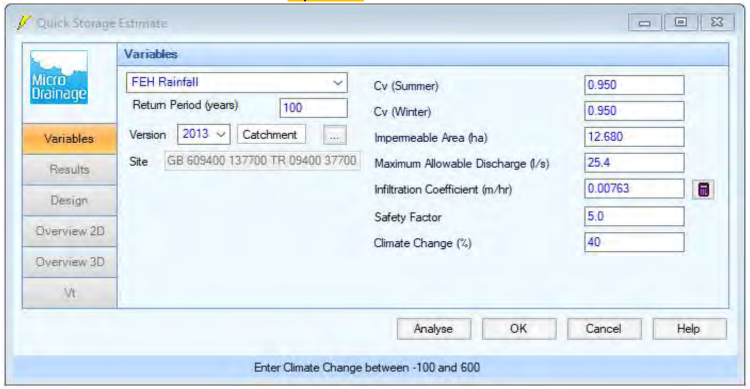
Output Data



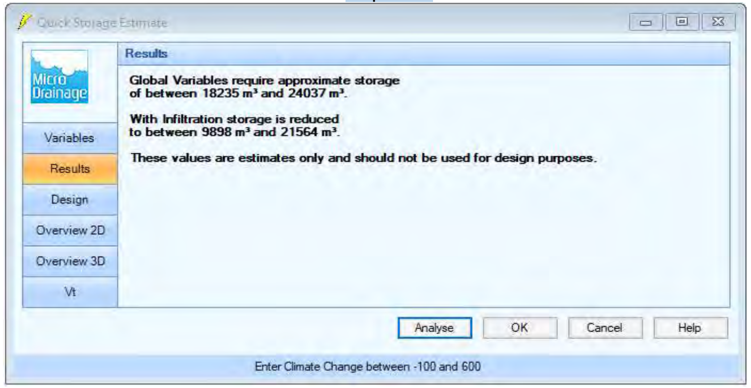
Drainage Zone: South Otterpool
Drainage Sub-Zone: DR-SO2

Storm Event: 1 in 100 Annual Chance

Input Data

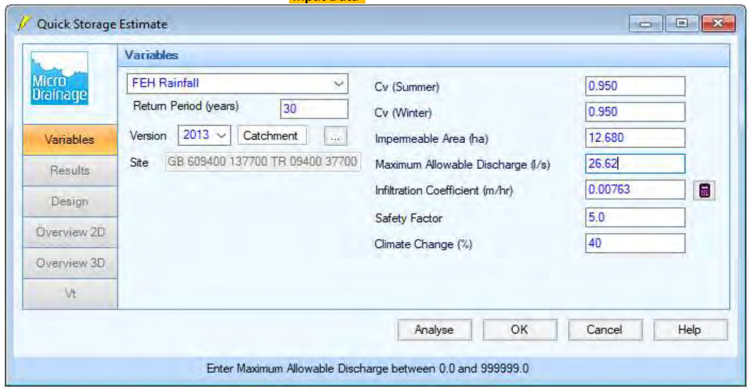


Output Data

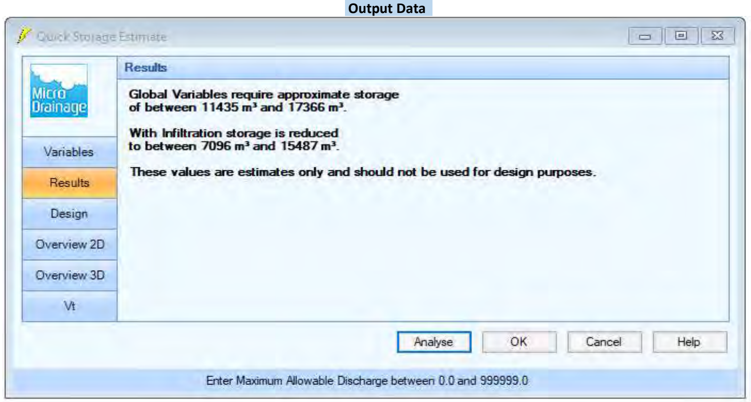


Storm Event: 1 in 30 Annual Chance

Input Data



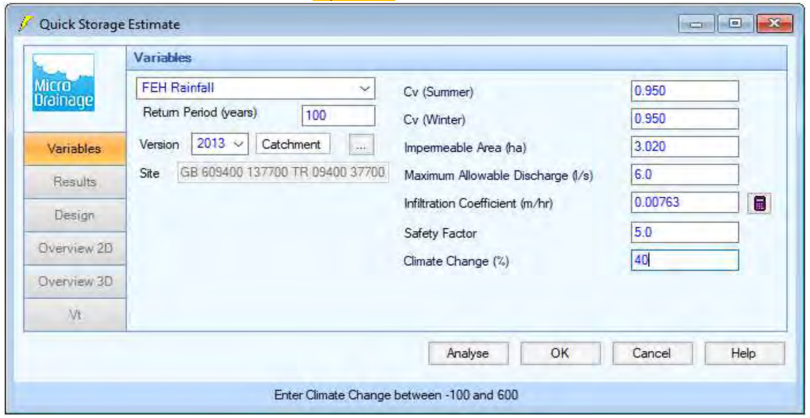
Output Data



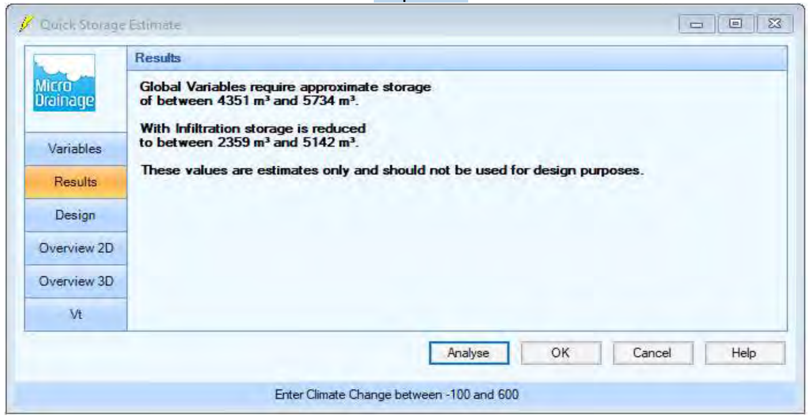
Drainage Zone: South Otterpool
Drainage Sub-Zone: DR-SO3

Storm Event: 1 in 100 Annual Chance

Input Data

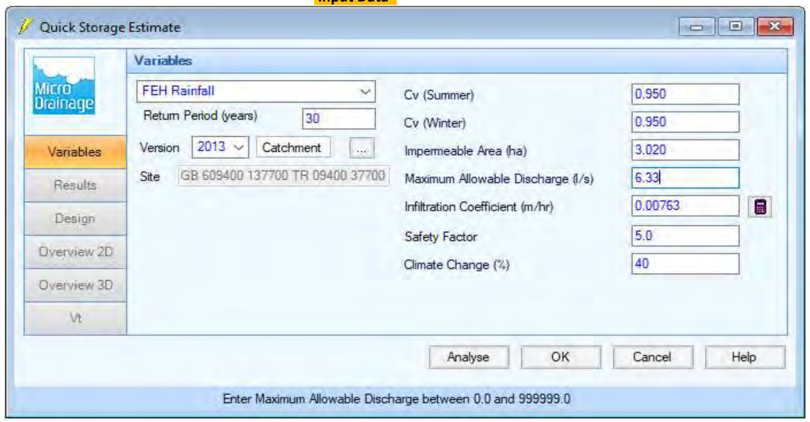


Output Data

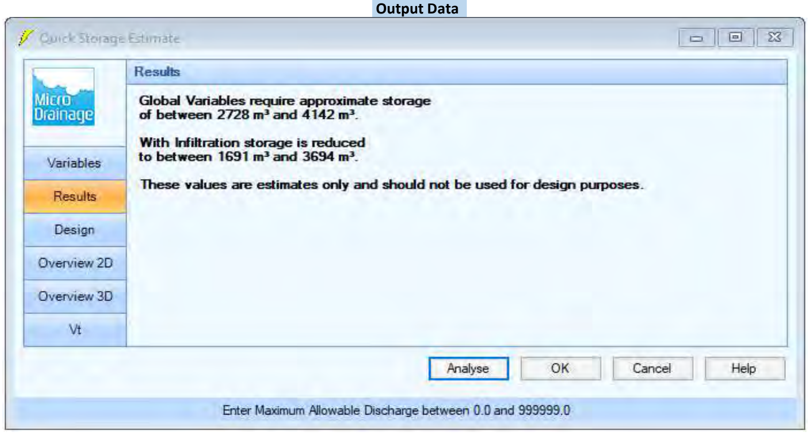


Storm Event: 1 in 30 Annual Chance

Input Data



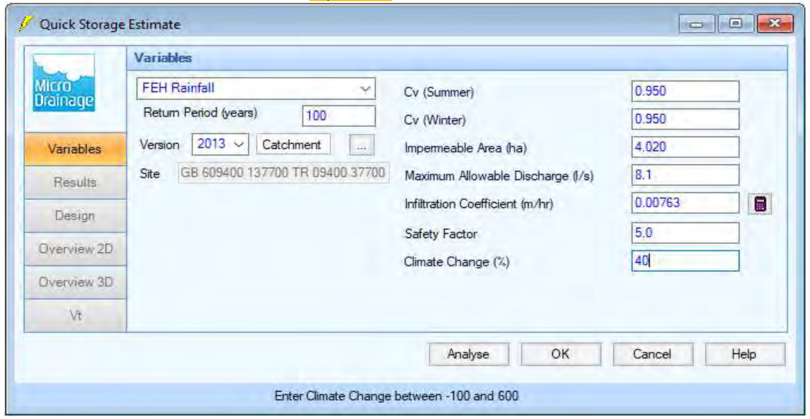
Output Data



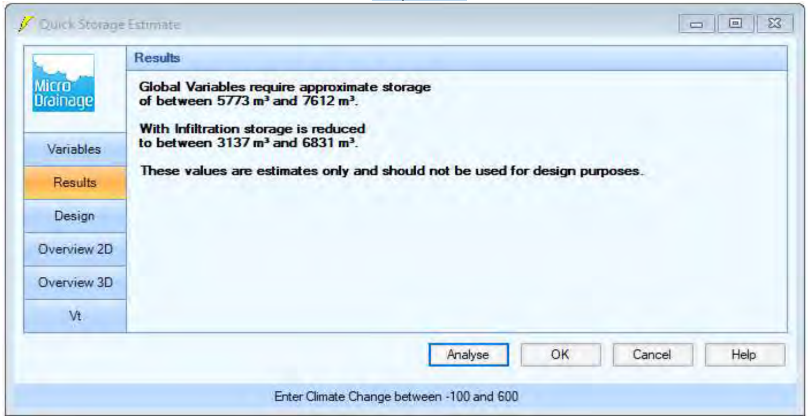
Drainage Zone: South Otterpool
Drainage Sub-Zone: DR-SO4

Storm Event: 1 in 100 Annual Chance

Input Data

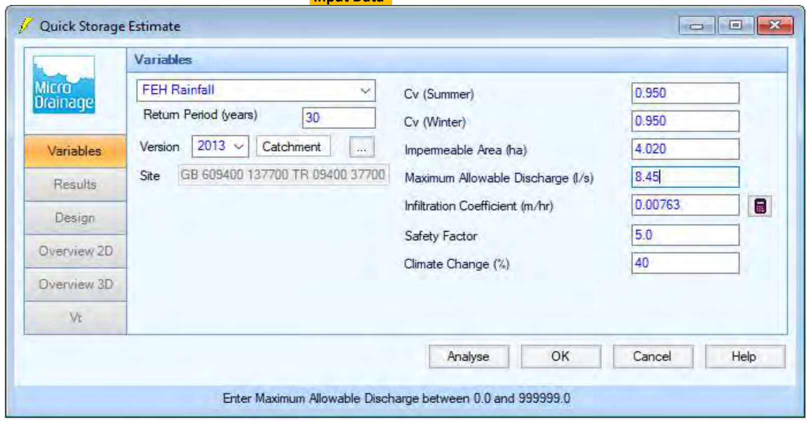


Output Data

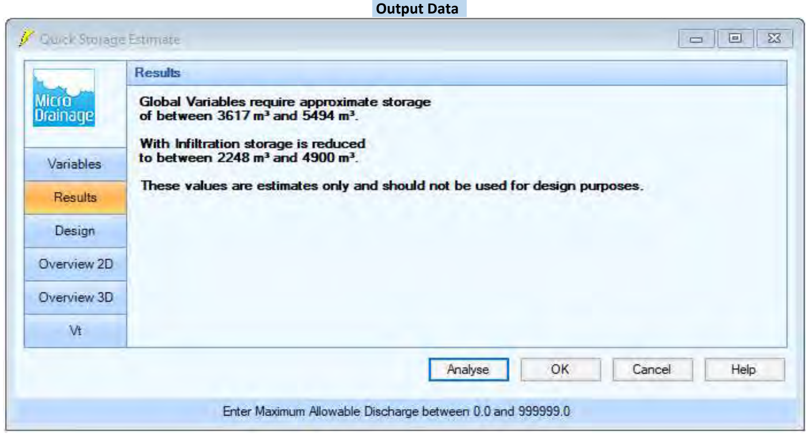


Storm Event: 1 in 30 Annual Chance

Input Data



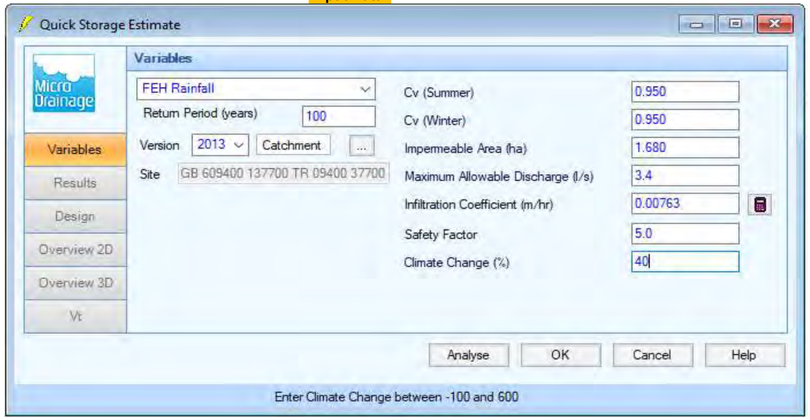
Output Data



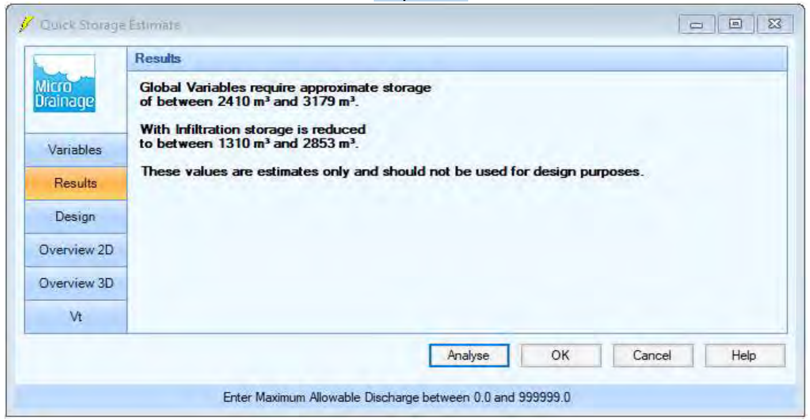
Drainage Zone: South Otterpool
Drainage Sub-Zone: DR-SO5

Storm Event: 1 in 100 Annual Chance

Input Data

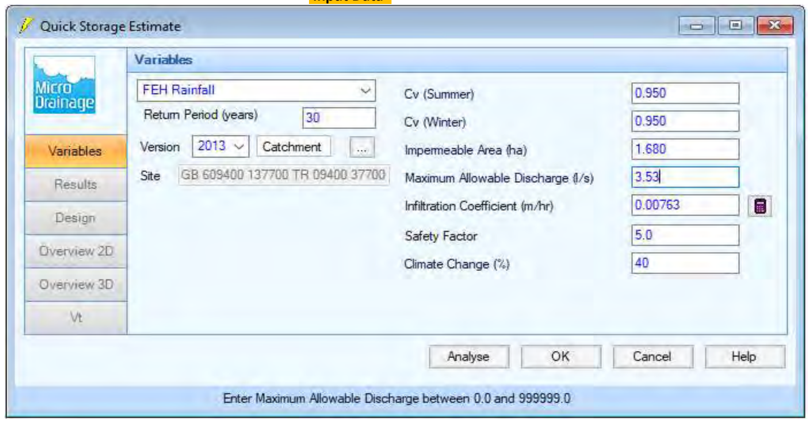


Output Data

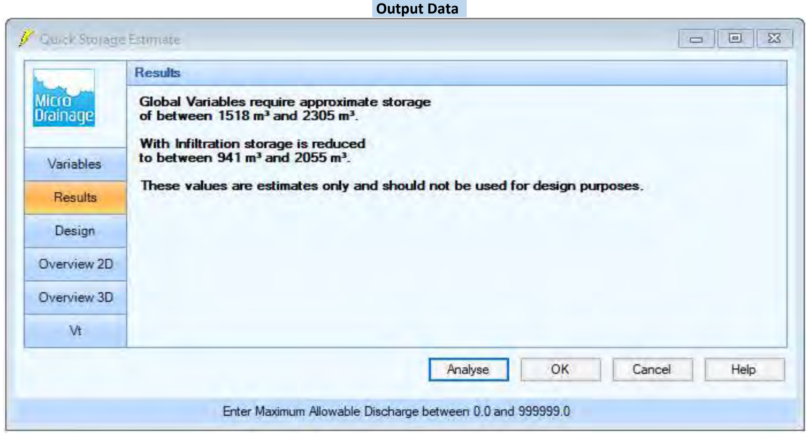


Storm Event: 1 in 30 Annual Chance

Input Data



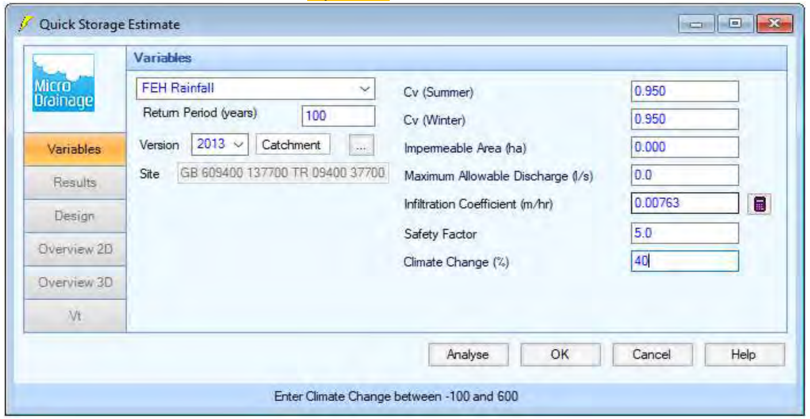
Output Data



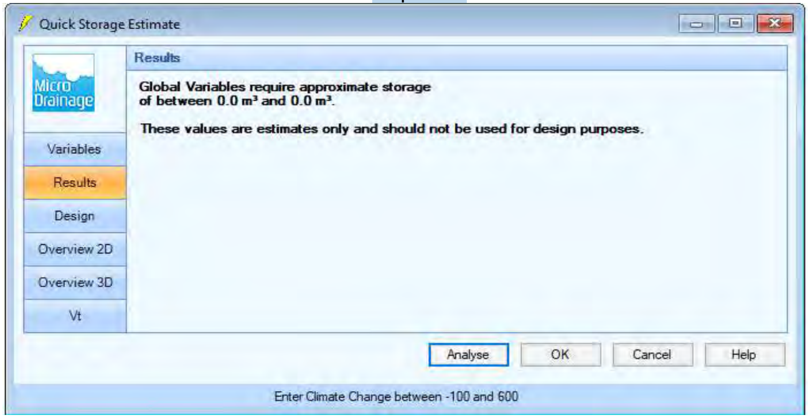
Drainage Zone: South Otterpool
Drainage Sub-Zone: DR-SO6

Storm Event: 1 in 100 Annual Chance

Input Data

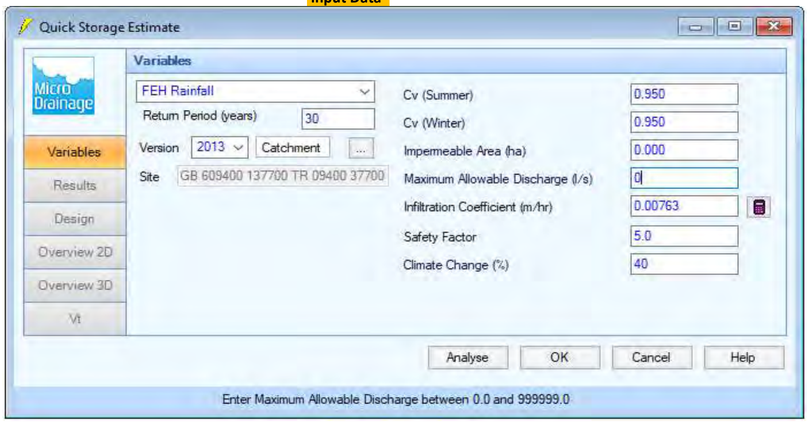


Output Data

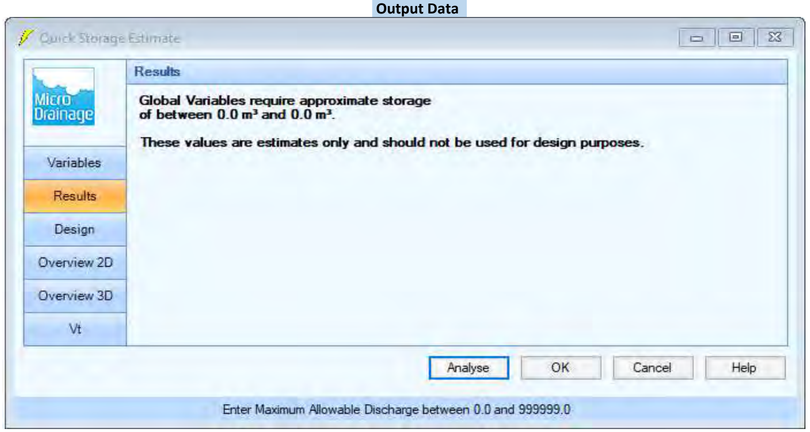


Storm Event: 1 in 30 Annual Chance

Input Data



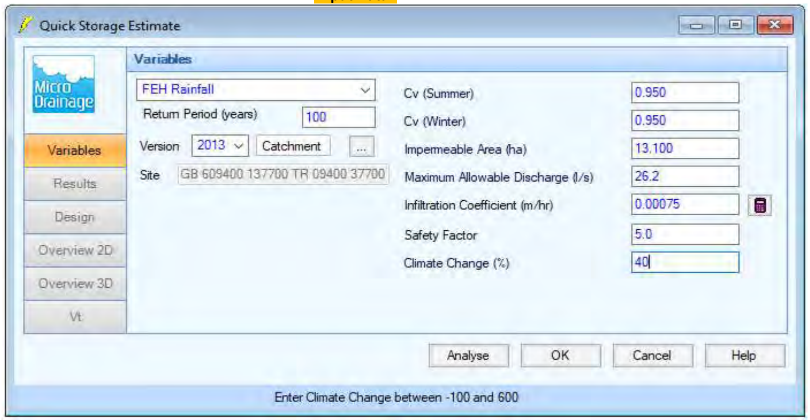
Output Data



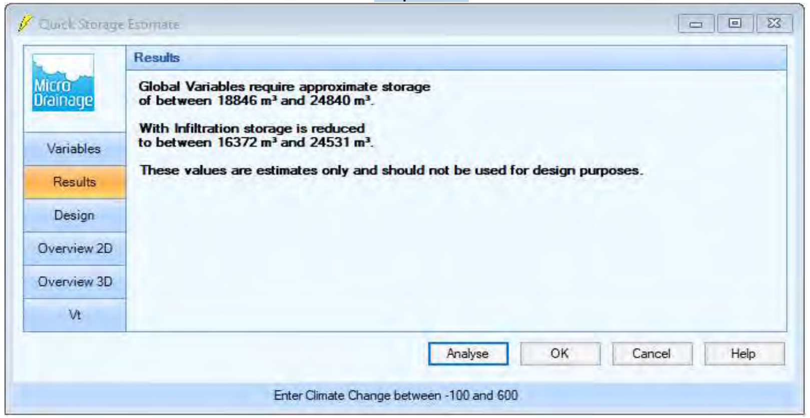
Drainage Zone: West Otterpool
Drainage Sub-Zone: DR-WO1

Storm Event: 1 in 100 Annual Chance

Input Data

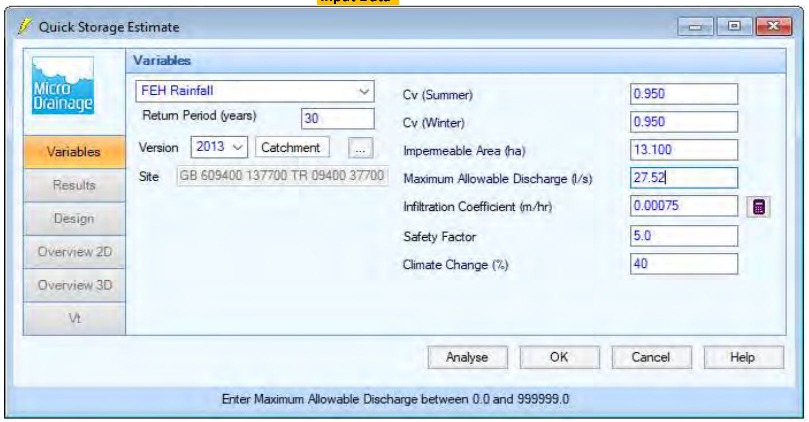


Output Data

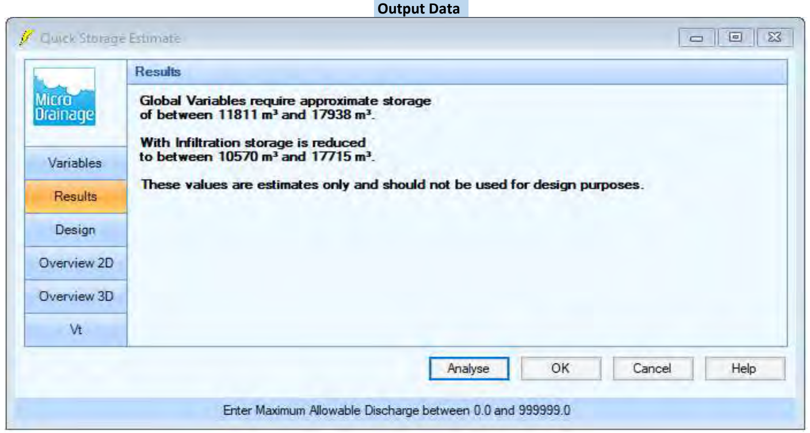


Storm Event: 1 in 30 Annual Chance

Input Data



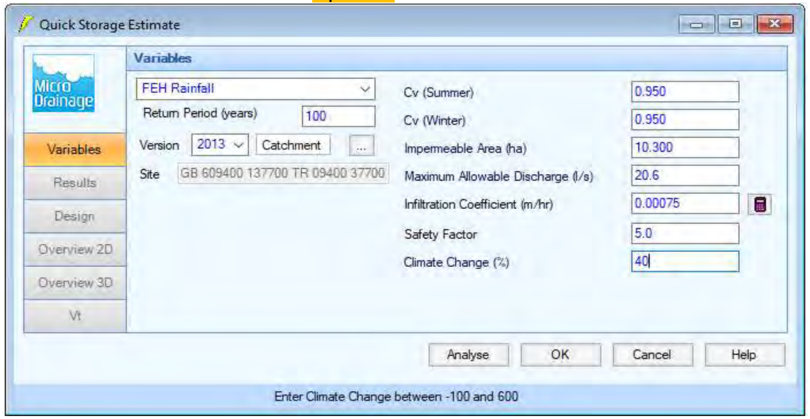
Output Data



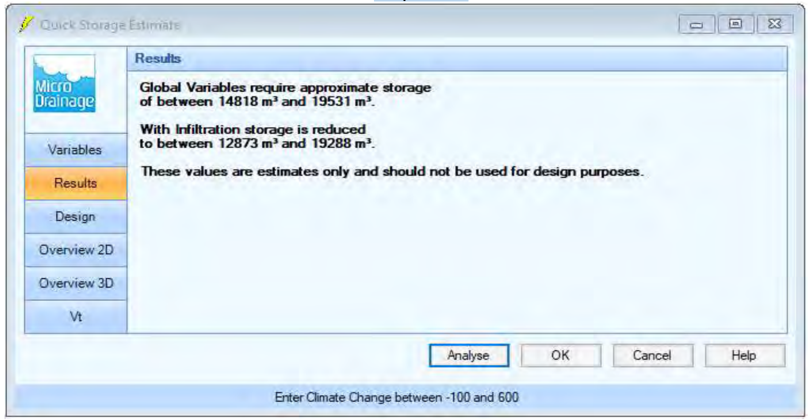
Drainage Zone: West Otterpool
Drainage Sub-Zone: DR-WO2

Storm Event: 1 in 100 Annual Chance

Input Data

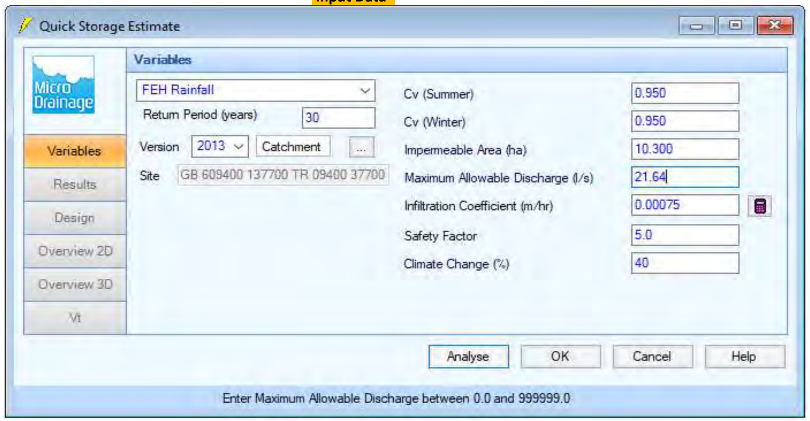


Output Data

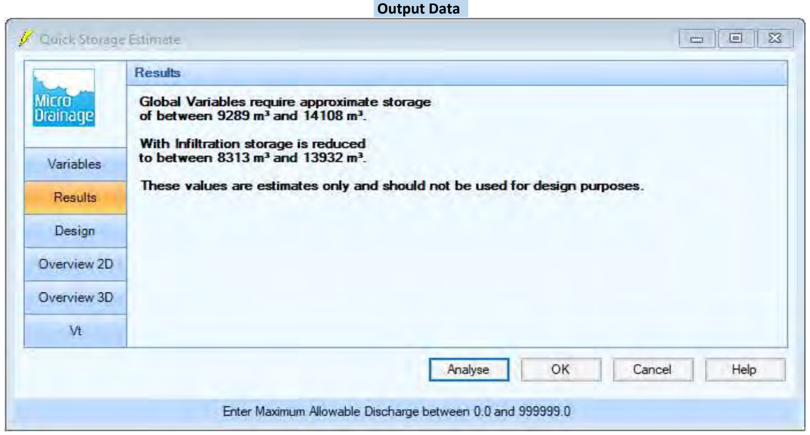


Storm Event: 1 in 30 Annual Chance

Input Data



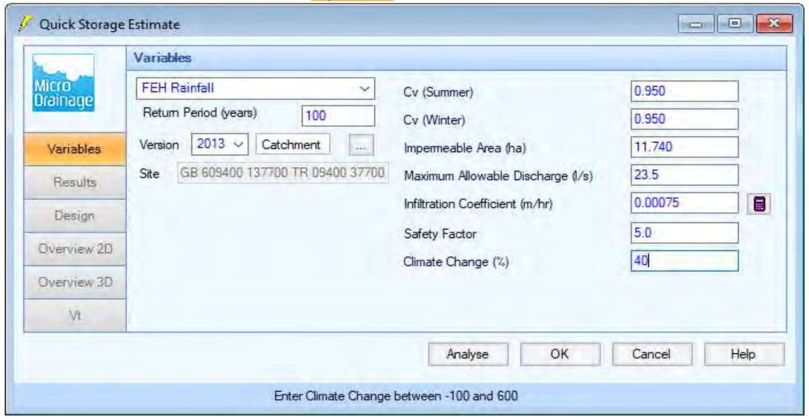
Output Data



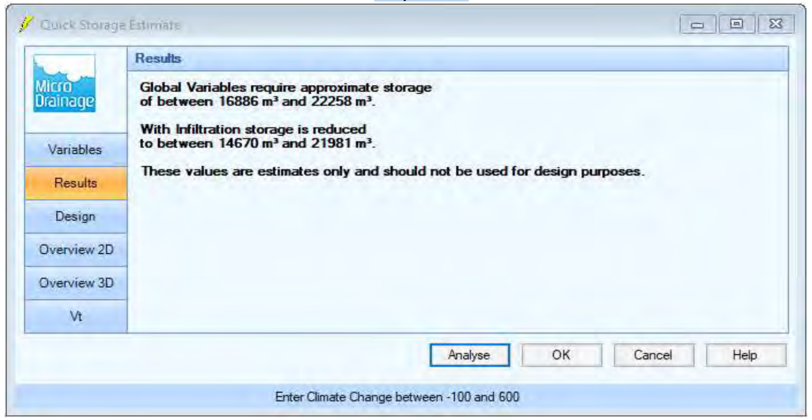
Drainage Zone: **West Otterpool**
Drainage Sub-Zone: **DR-WO3**

Storm Event: 1 in 100 Annual Chance

Input Data

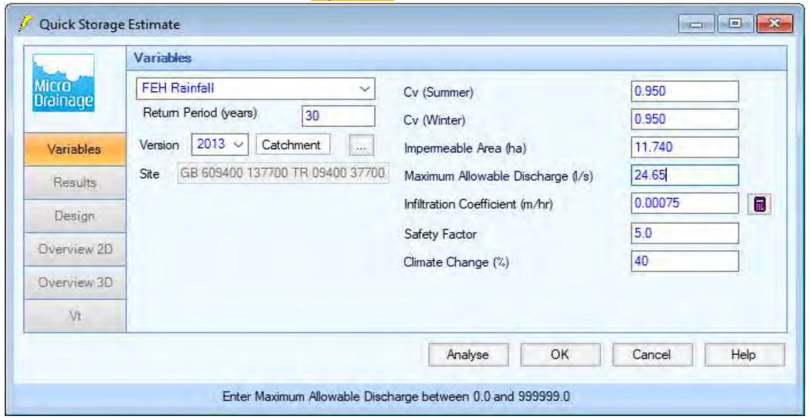


Output Data

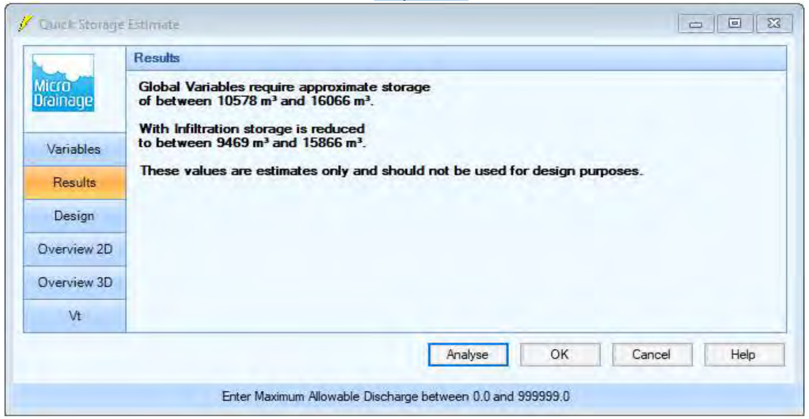


Storm Event: 1 in 30 Annual Chance

Input Data



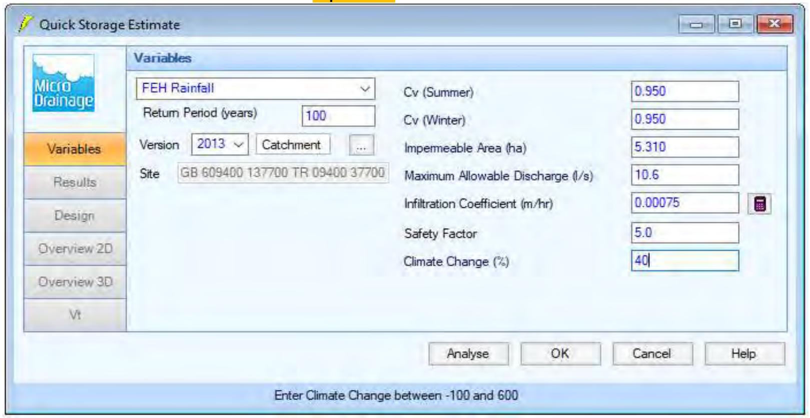
Output Data



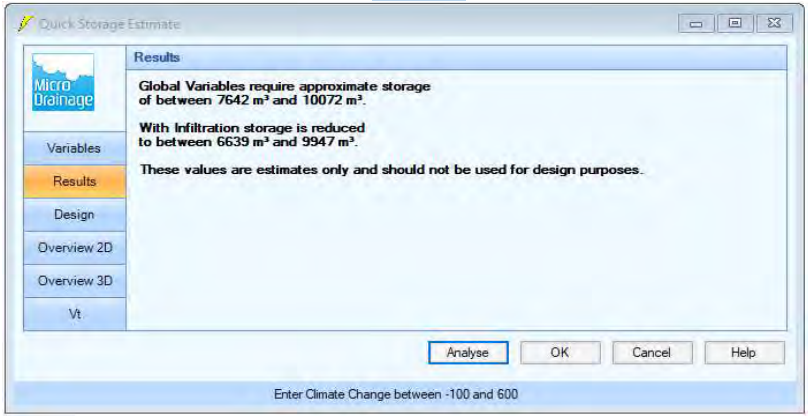
Drainage Zone: West Otterpool
Drainage Sub-Zone: DR-WO4

Storm Event: 1 in 100 Annual Chance

Input Data

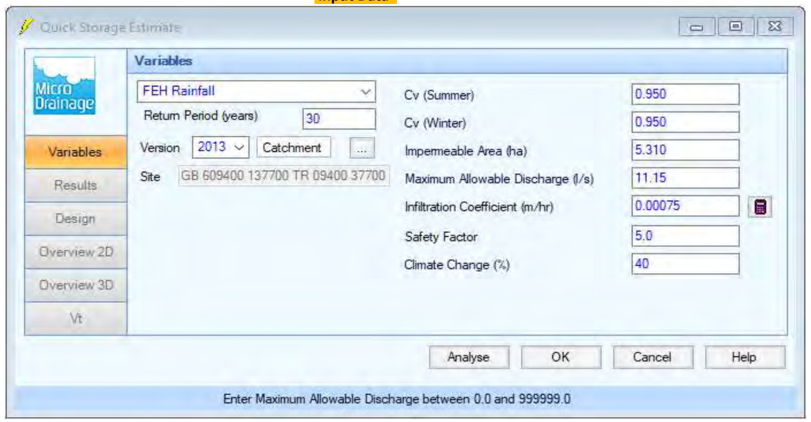


Output Data

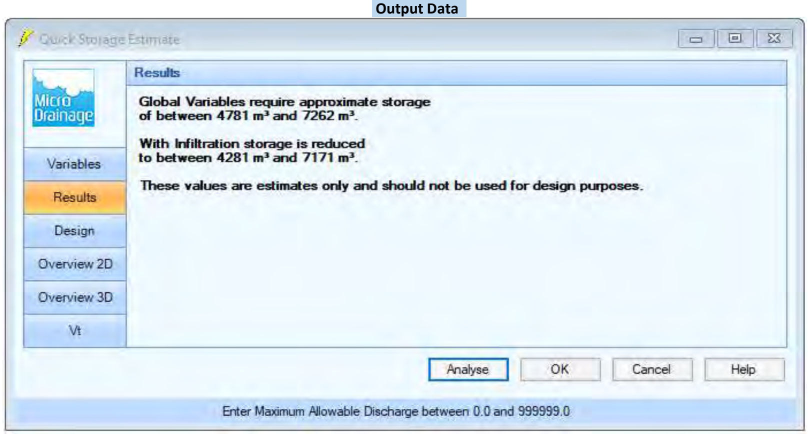


Storm Event: 1 in 30 Annual Chance

Input Data



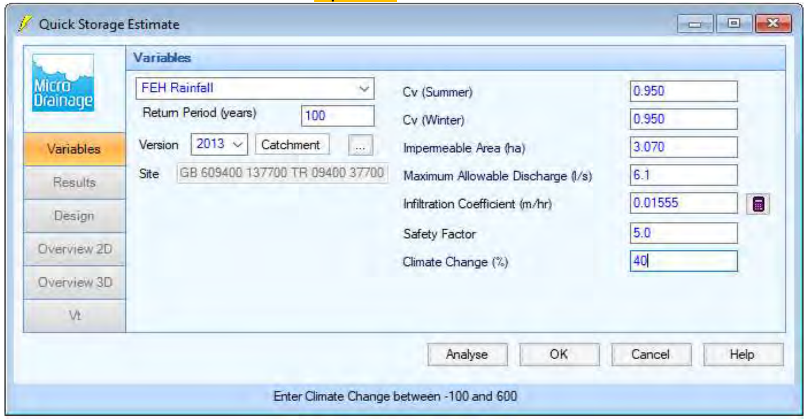
Output Data



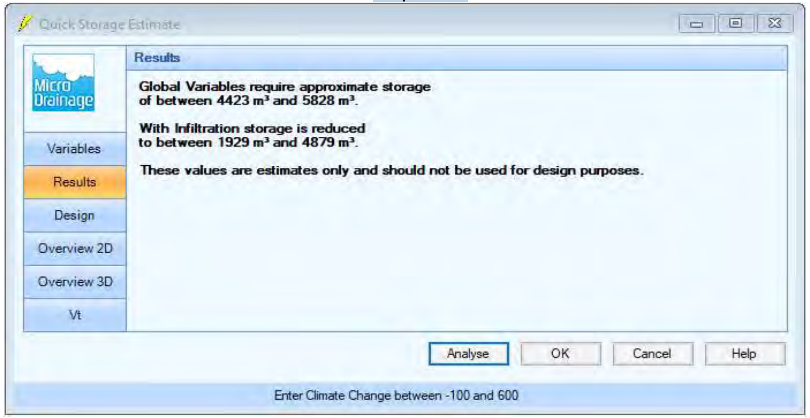
Drainage Zone: Barrow Hill
Drainage Sub-Zone: DR-BH1

Storm Event: 1 in 100 Annual Chance

Input Data

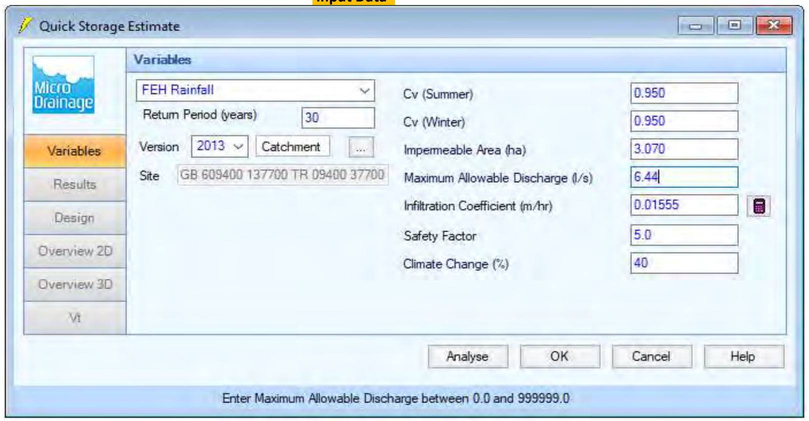


Output Data

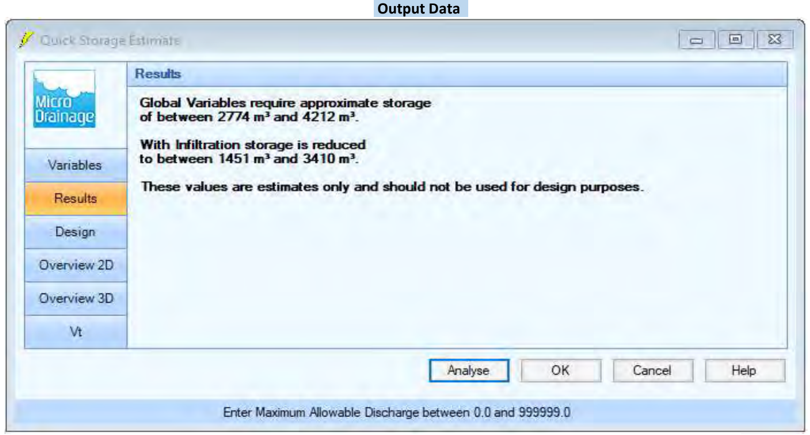


Storm Event: 1 in 30 Annual Chance

Input Data



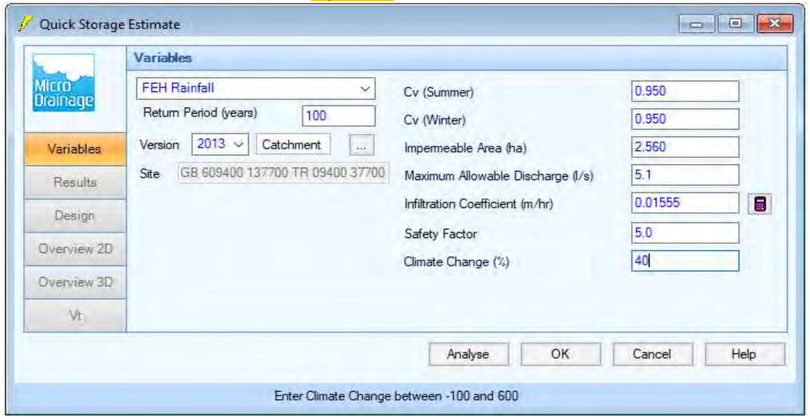
Output Data



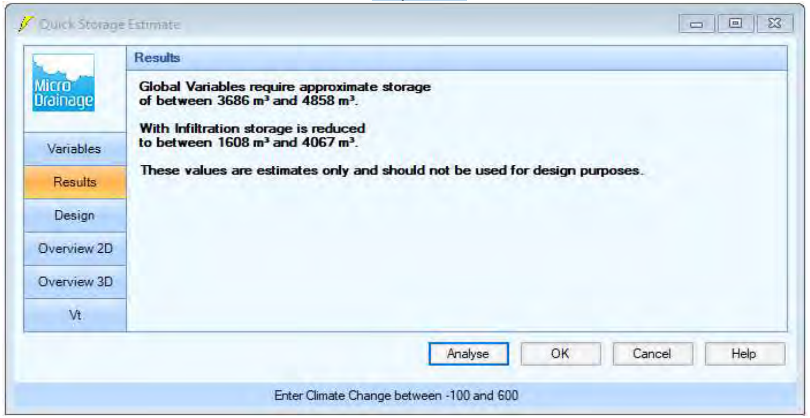
Drainage Zone: Barrow Hill
Drainage Sub-Zone: **DR-BH2**

Storm Event: 1 in 100 Annual Chance

Input Data

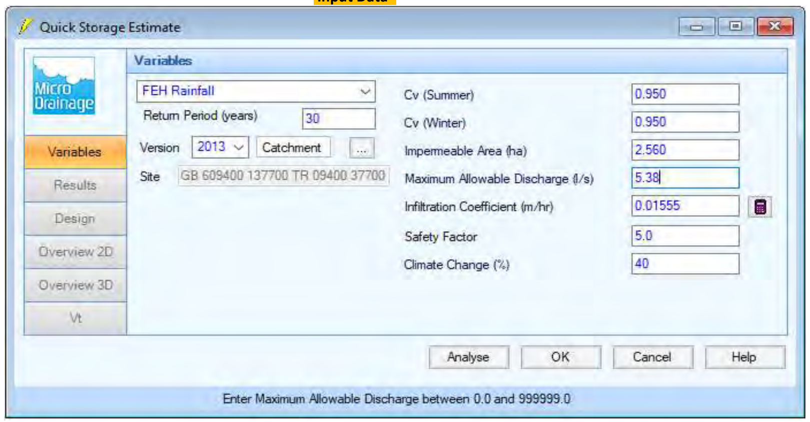


Output Data

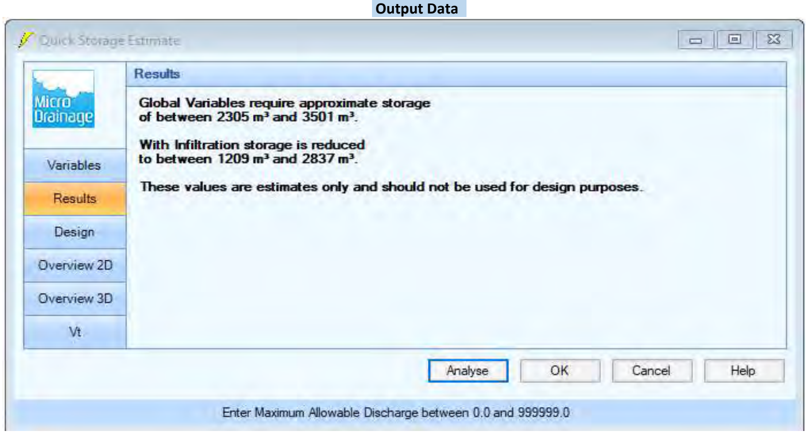


Storm Event: 1 in 30 Annual Chance

Input Data



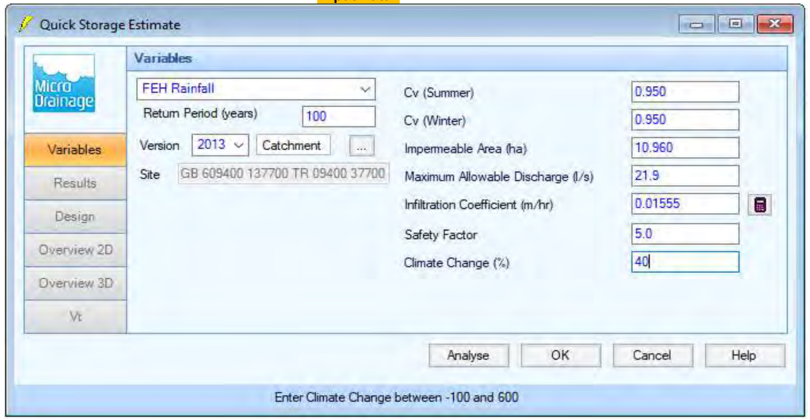
Output Data



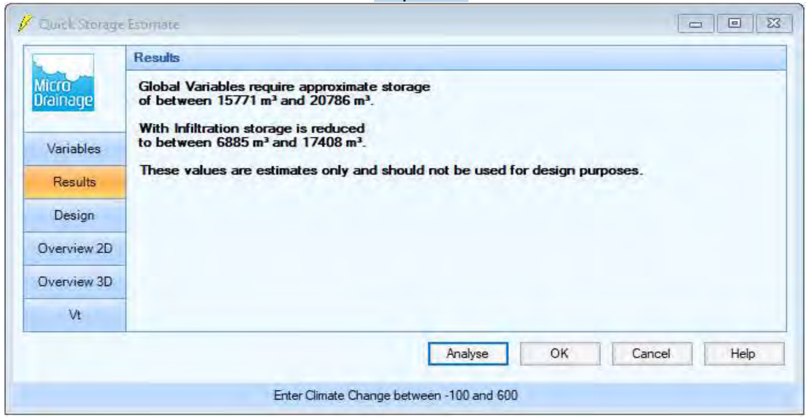
Drainage Zone: Barrow Hill
Drainage Sub-Zone: DR-BH3

Storm Event: 1 in 100 Annual Chance

Input Data

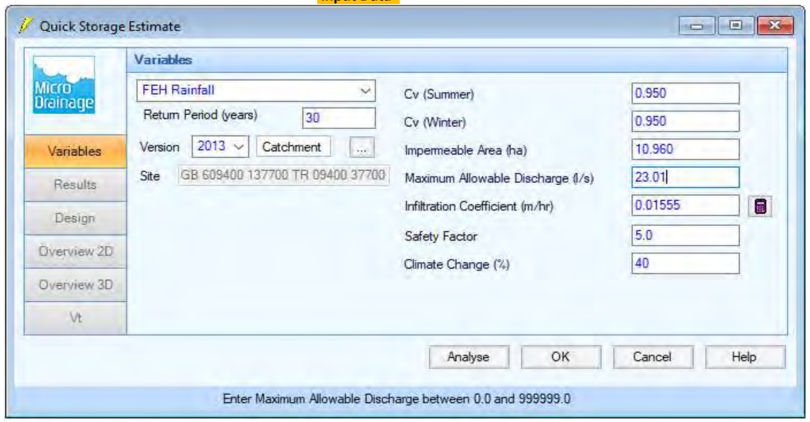


Output Data

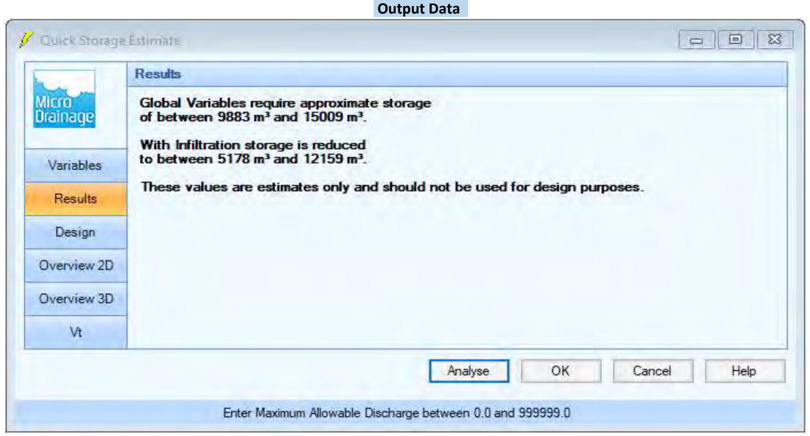


Storm Event: 1 in 30 Annual Chance

Input Data



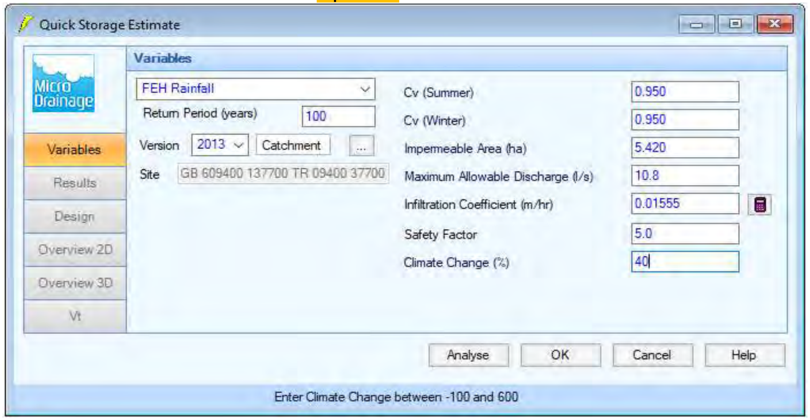
Output Data



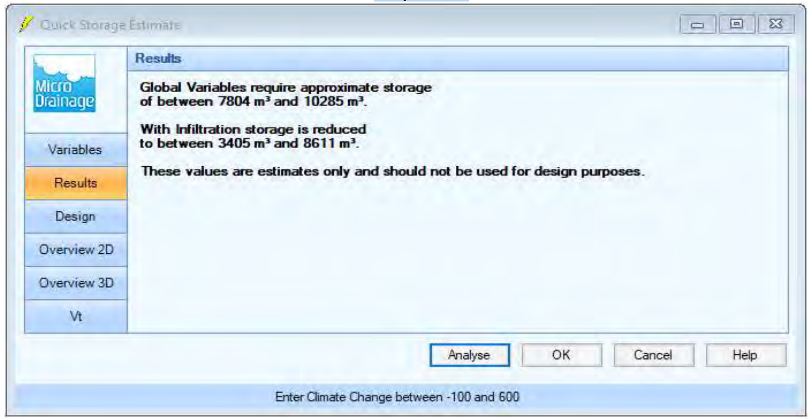
Drainage Zone: Barrow Hill
Drainage Sub-Zone: DR-BH4

Storm Event: 1 in 100 Annual Chance

Input Data

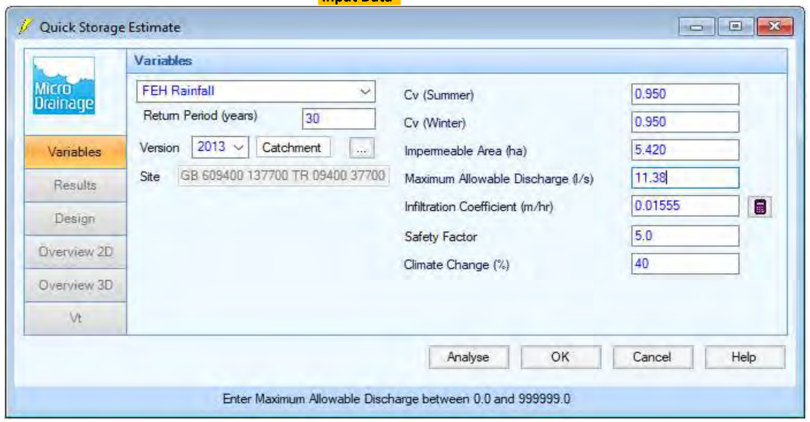


Output Data

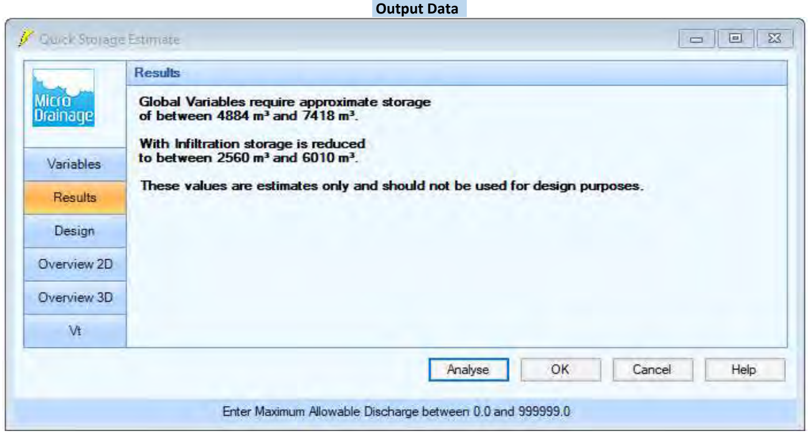


Storm Event: 1 in 30 Annual Chance

Input Data



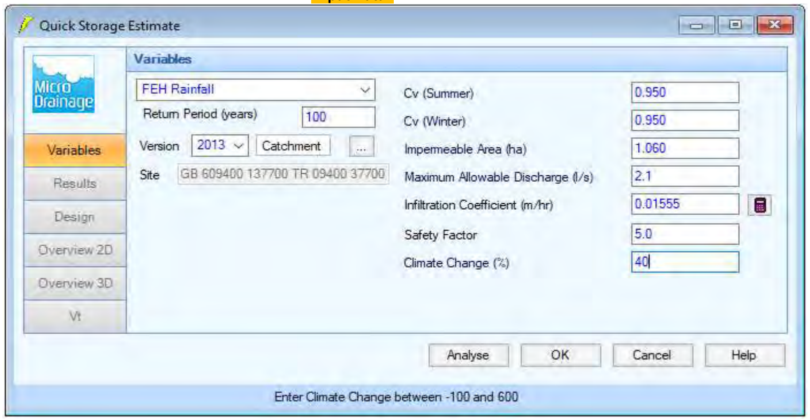
Output Data



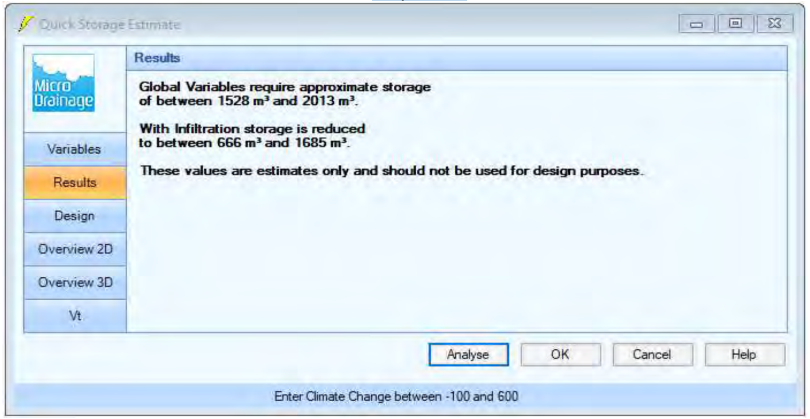
Drainage Zone: Barrow Hill
Drainage Sub-Zone: DR-BH5

Storm Event: 1 in 100 Annual Chance

Input Data

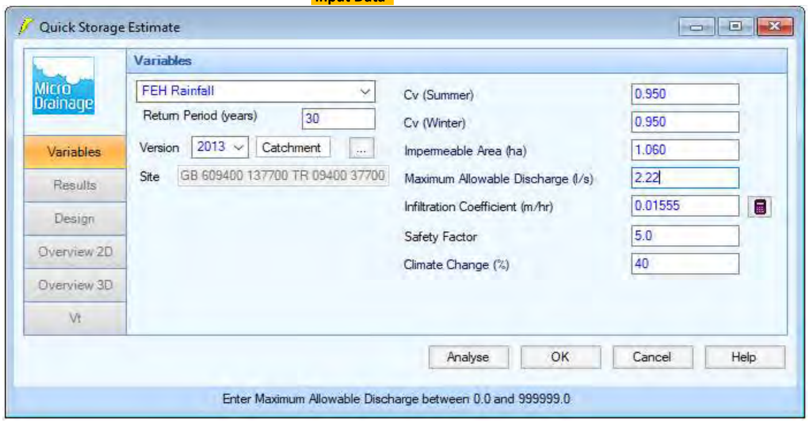


Output Data

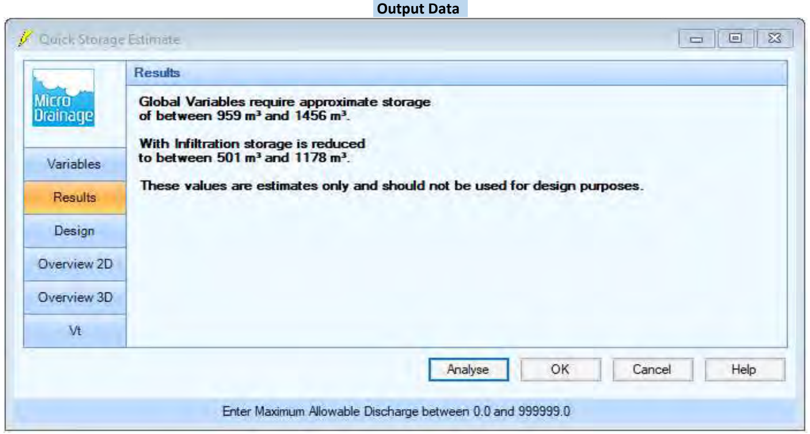


Storm Event: 1 in 30 Annual Chance

Input Data



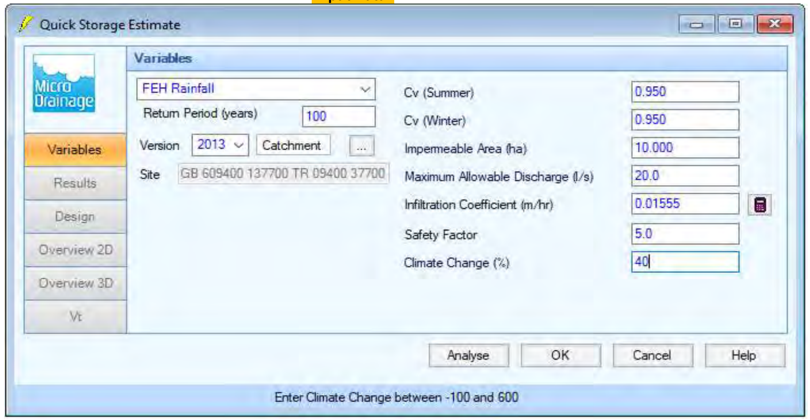
Output Data



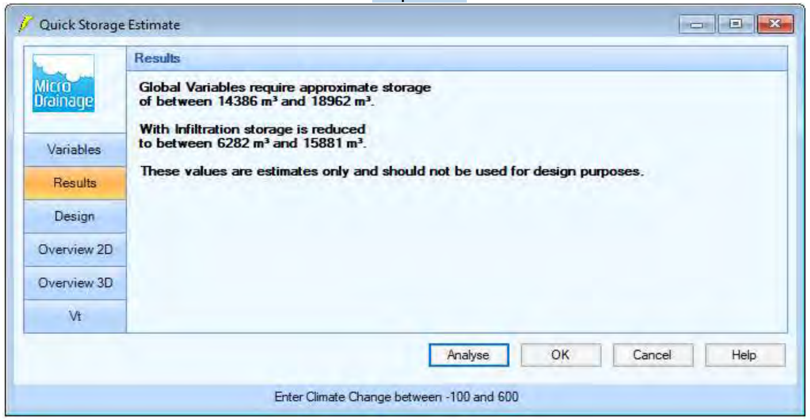
Drainage Zone: Barrow Hill
Drainage Sub-Zone: DR-BH6

Storm Event: 1 in 100 Annual Chance

Input Data

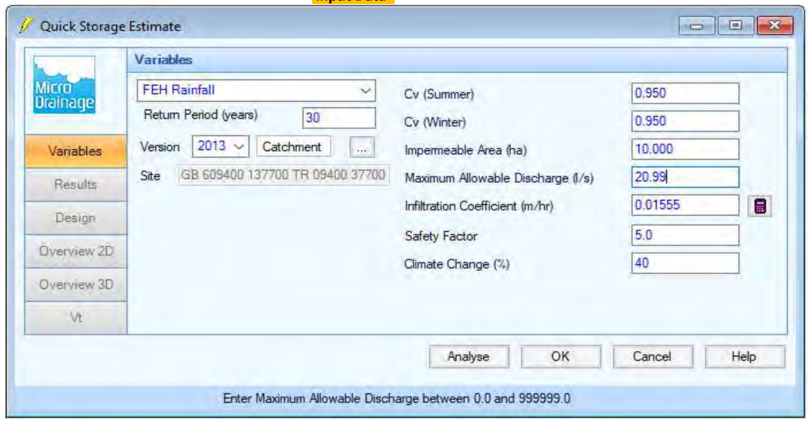


Output Data

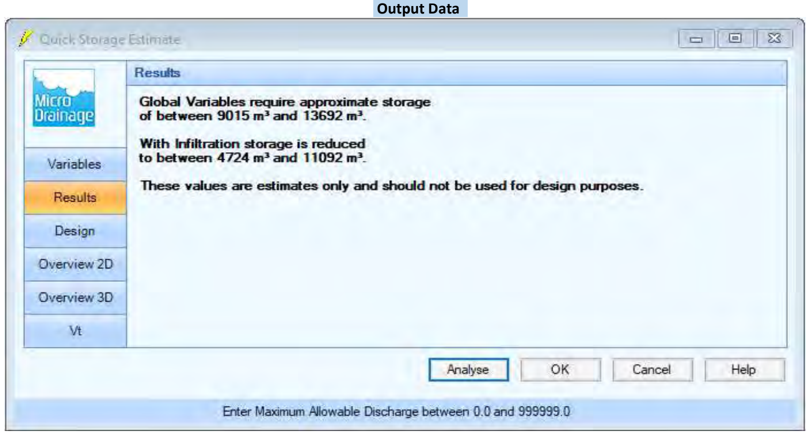


Storm Event: 1 in 30 Annual Chance

Input Data



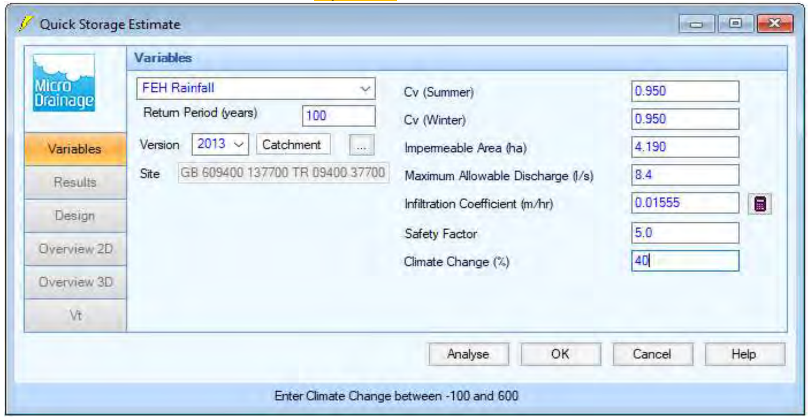
Output Data



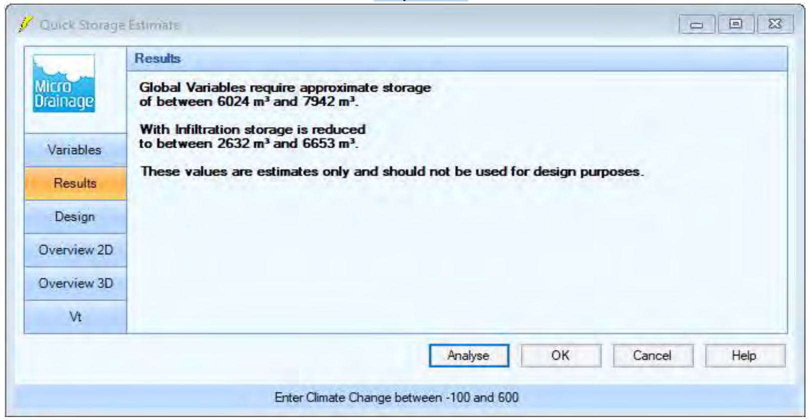
Drainage Zone: Barrow Hill
Drainage Sub-Zone: DR-BH7

Storm Event: 1 in 100 Annual Chance

Input Data

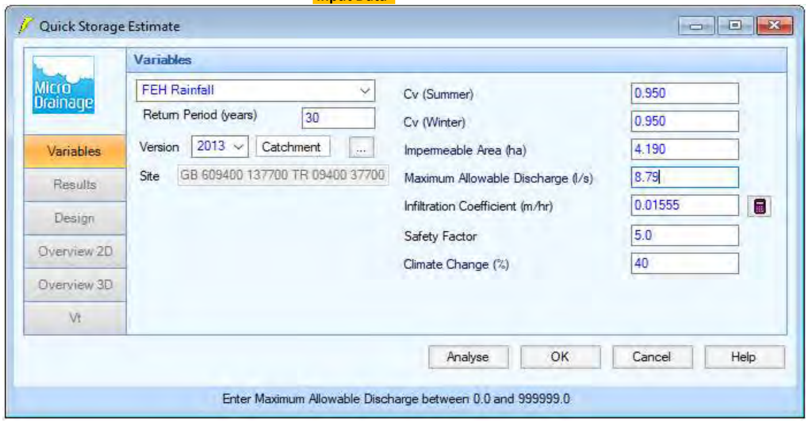


Output Data

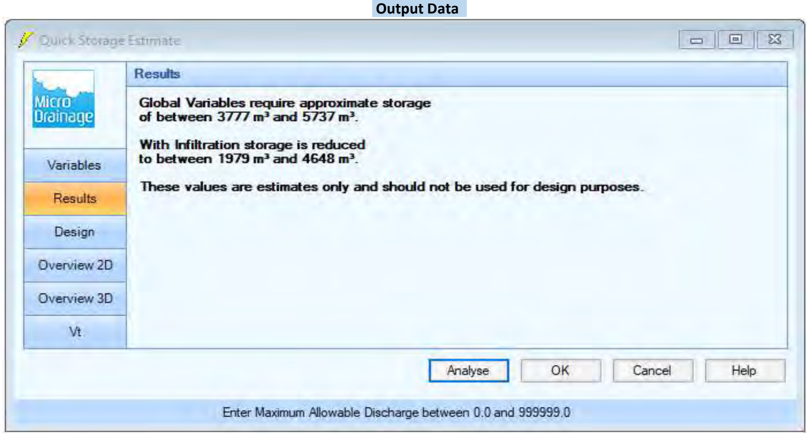


Storm Event: 1 in 30 Annual Chance

Input Data



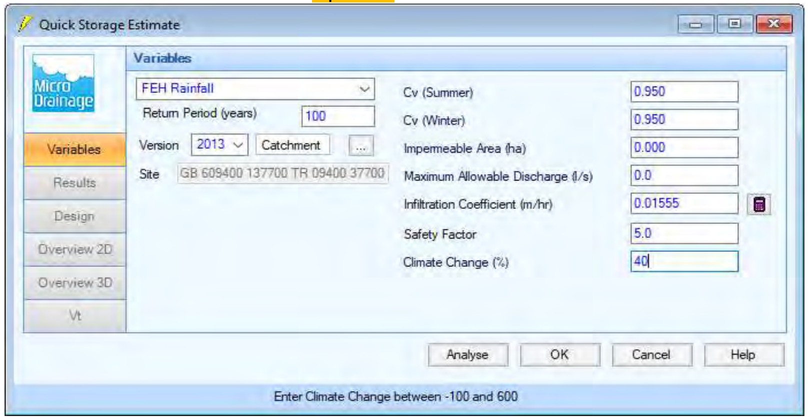
Output Data



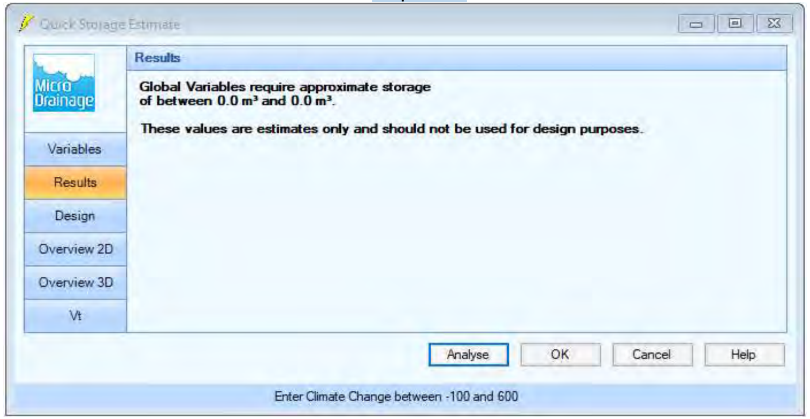
Drainage Zone: Barrow Hill
Drainage Sub-Zone: DR-BH8

Storm Event: 1 in 100 Annual Chance

Input Data

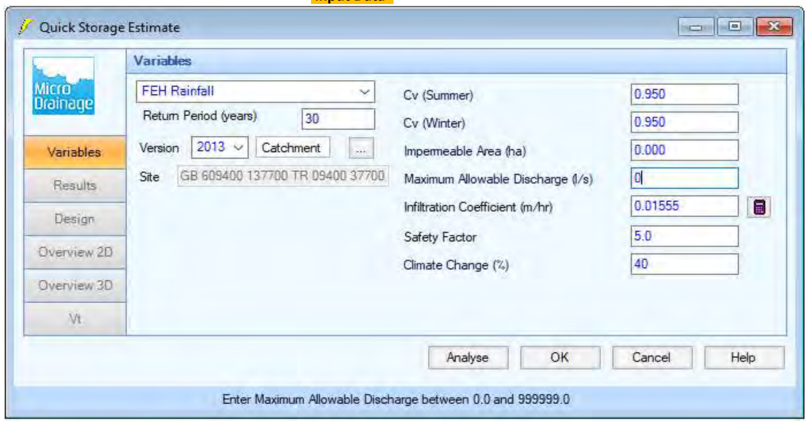


Output Data

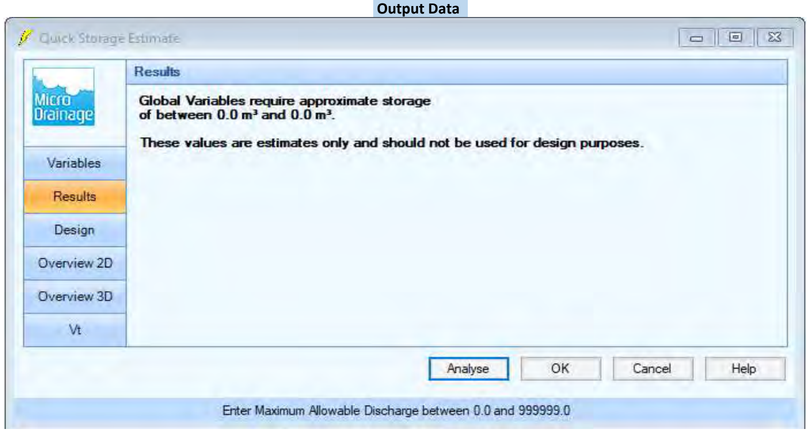


Storm Event: 1 in 30 Annual Chance

Input Data



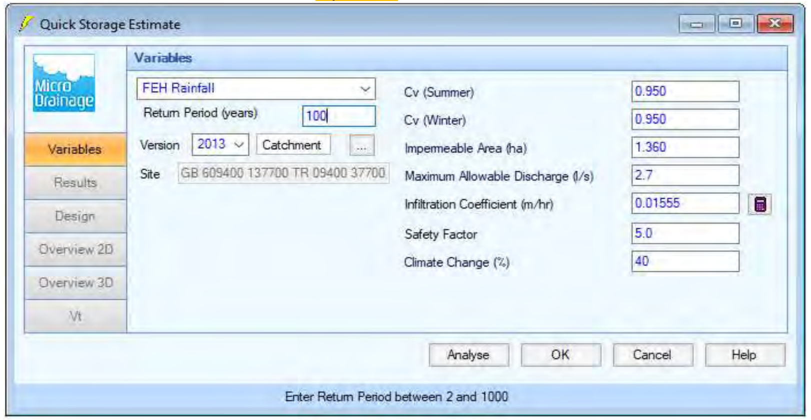
Output Data



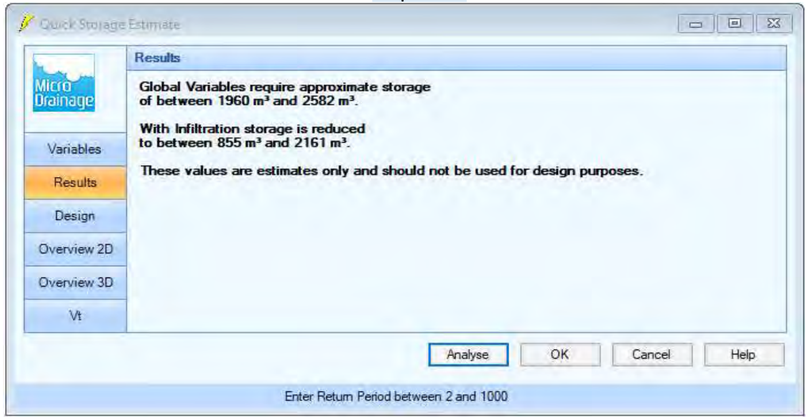
Drainage Zone: Barrow Hill
Drainage Sub-Zone: DR-BH9

Storm Event: 1 in 100 Annual Chance

Input Data

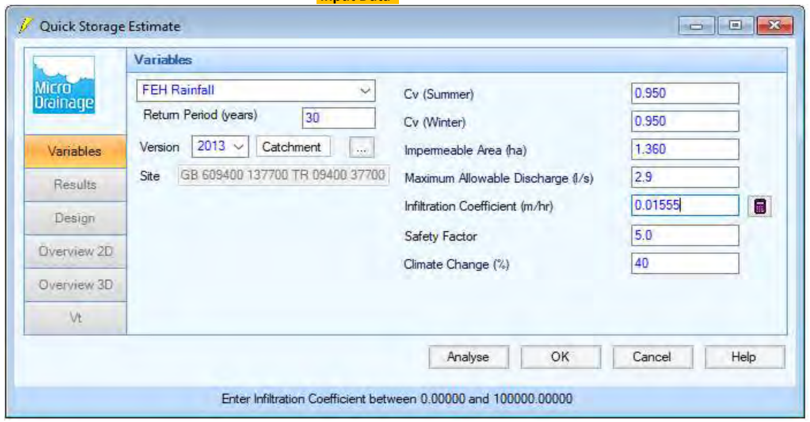


Output Data

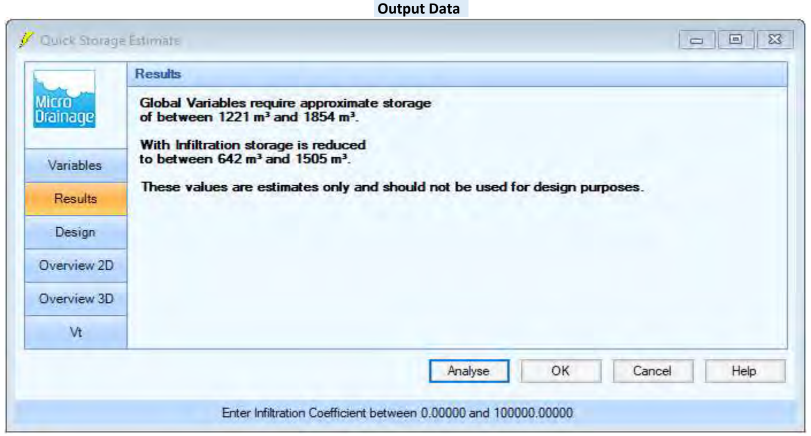


Storm Event: 1 in 30 Annual Chance

Input Data



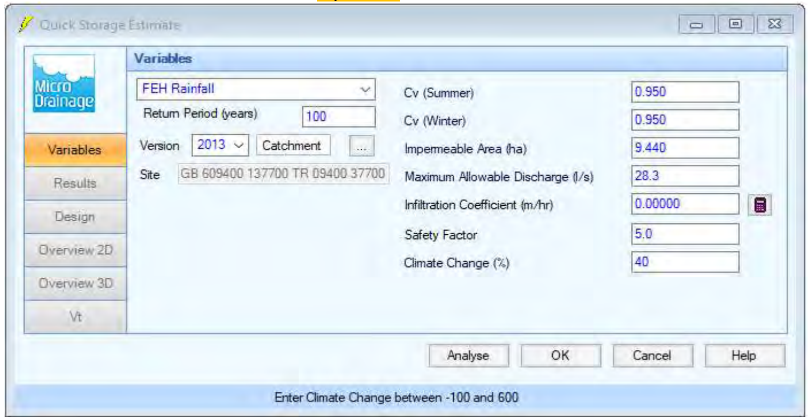
Output Data



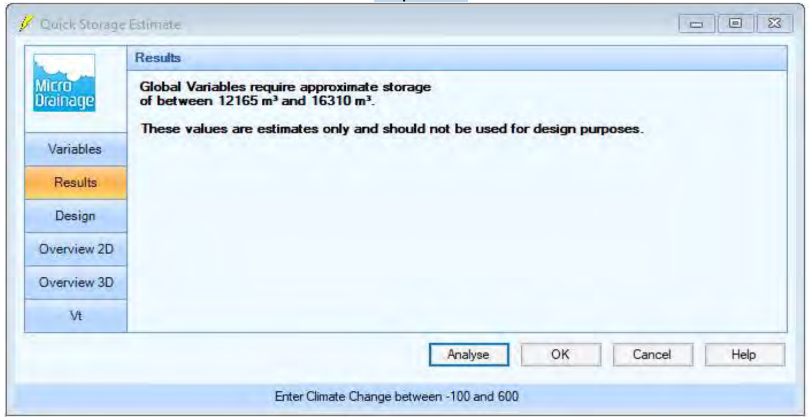
Drainage Zone: River Stour
Drainage Sub-Zone: DR-RS1

Storm Event: 1 in 100 Annual Chance

Input Data

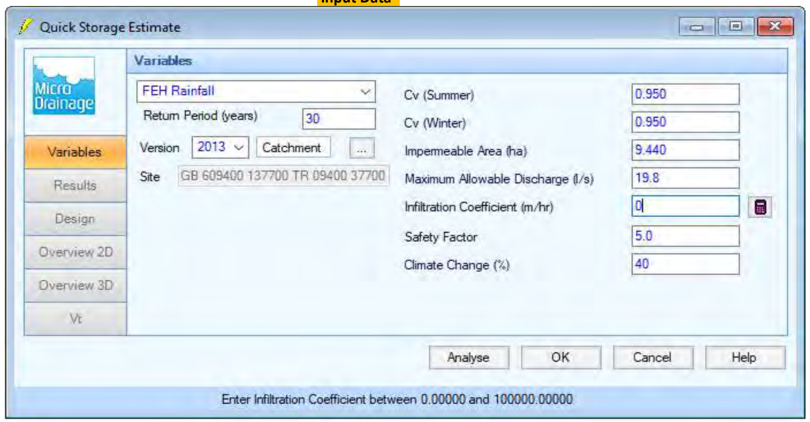


Output Data

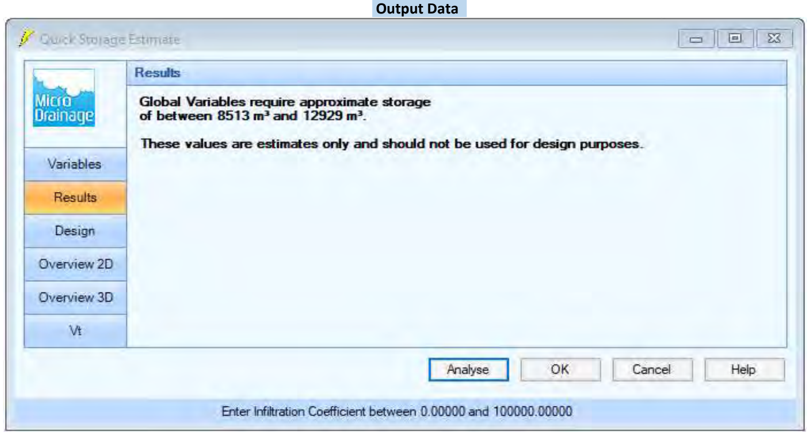


Storm Event: 1 in 30 Annual Chance

Input Data



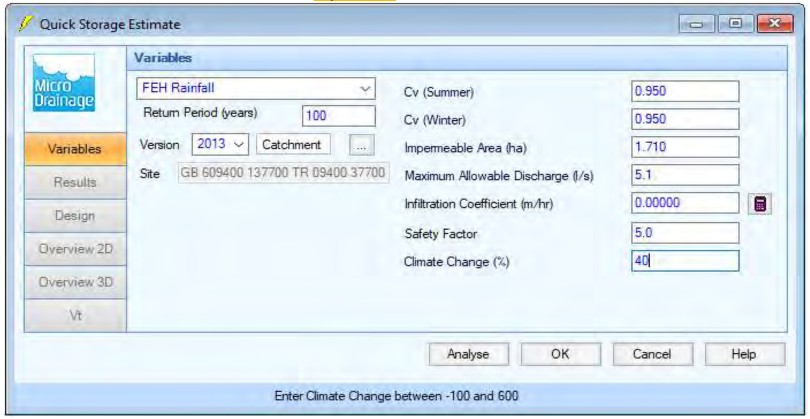
Output Data



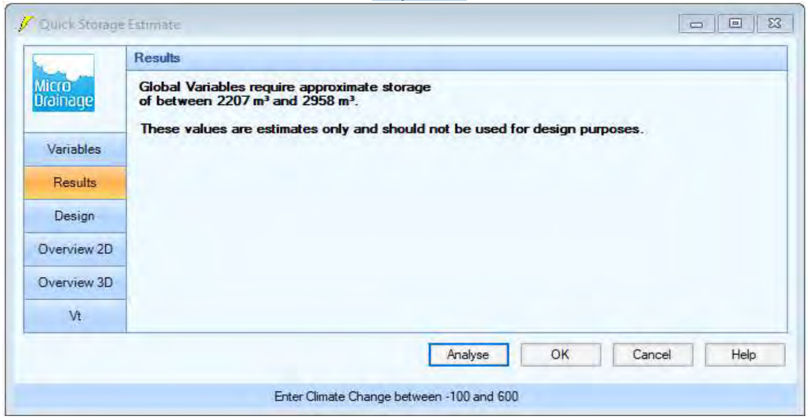
Drainage Zone: River Stour
Drainage Sub-Zone: DR-RS2

Storm Event: 1 in 100 Annual Chance

Input Data

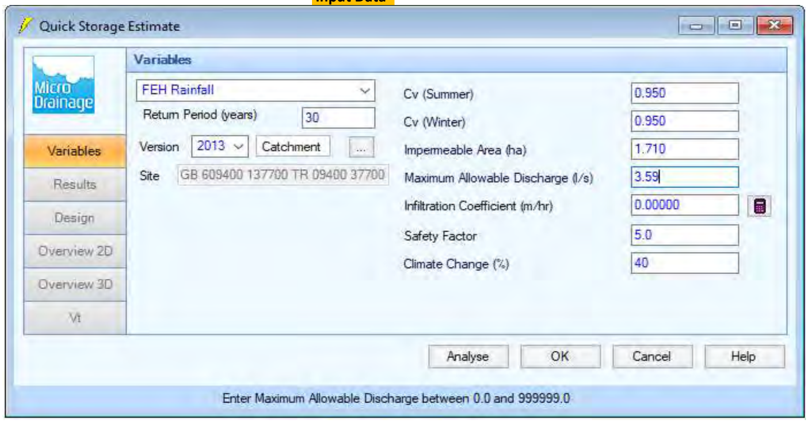


Output Data

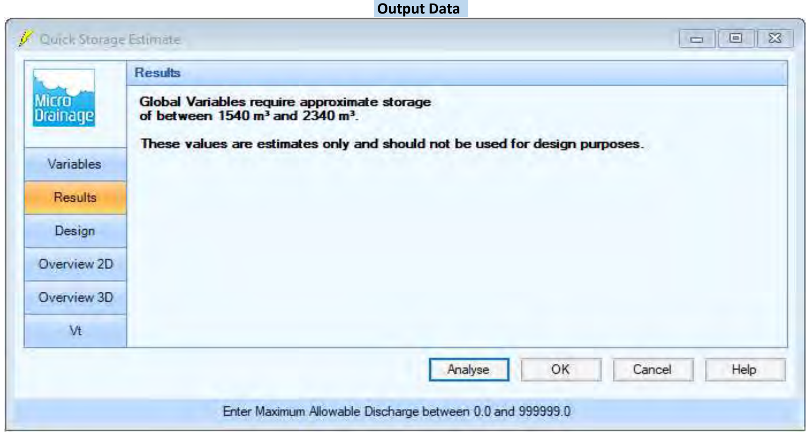


Storm Event: 1 in 30 Annual Chance

Input Data



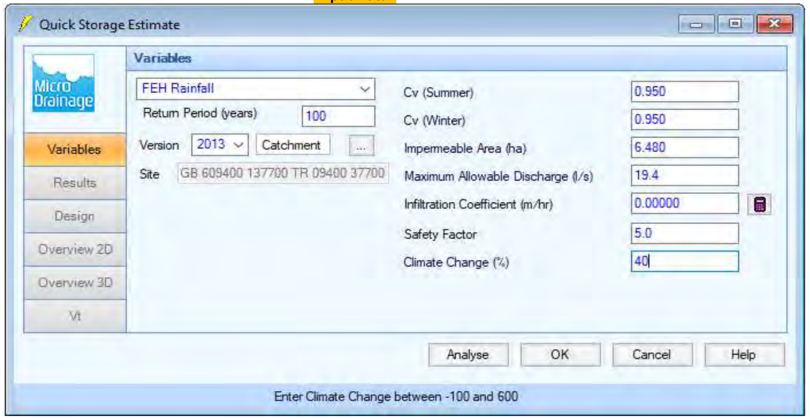
Output Data



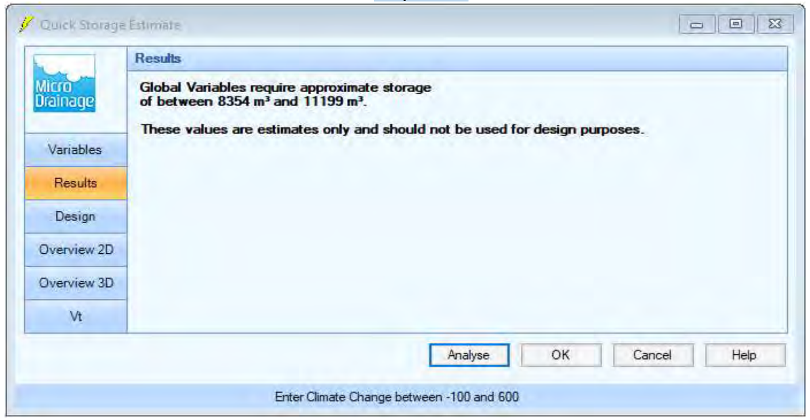
Drainage Zone: River Stour
Drainage Sub-Zone: DR-RS3

Storm Event: 1 in 100 Annual Chance

Input Data

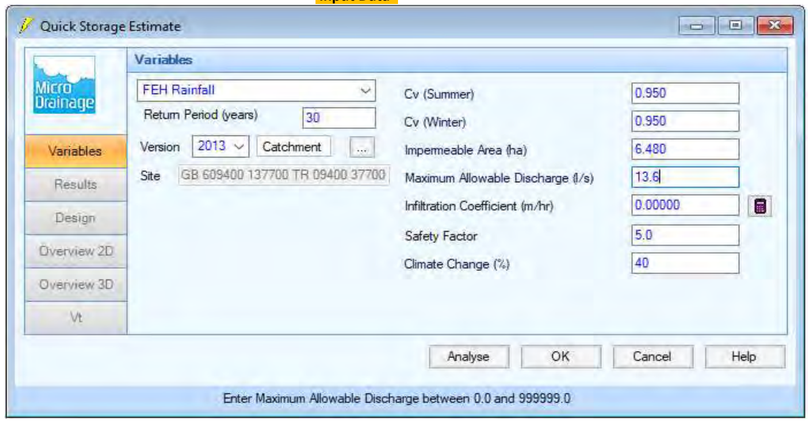


Output Data

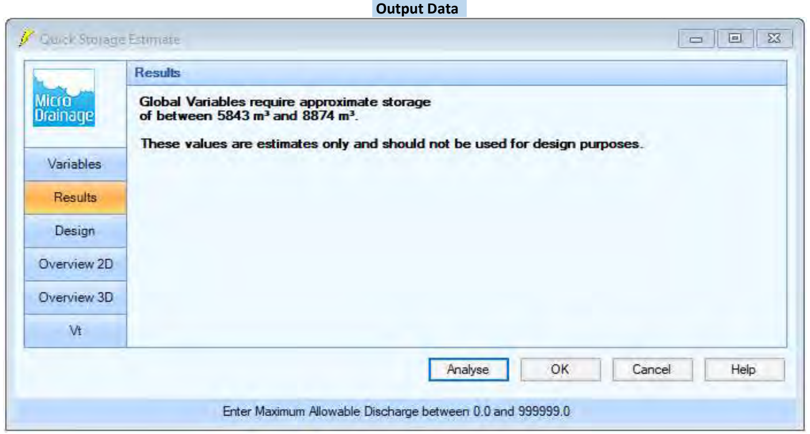


Storm Event: 1 in 30 Annual Chance

Input Data



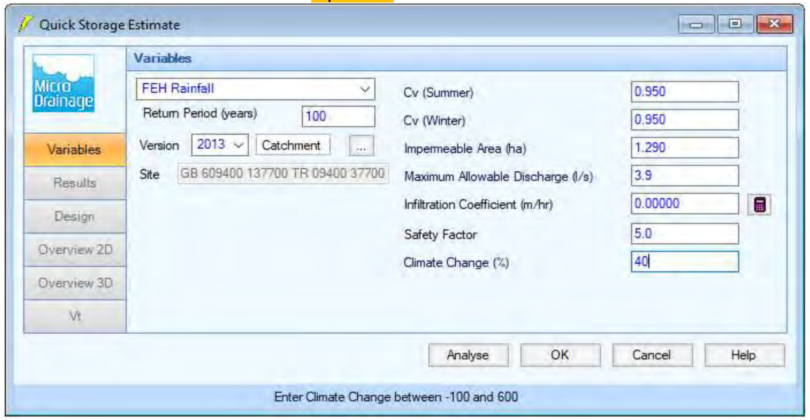
Output Data



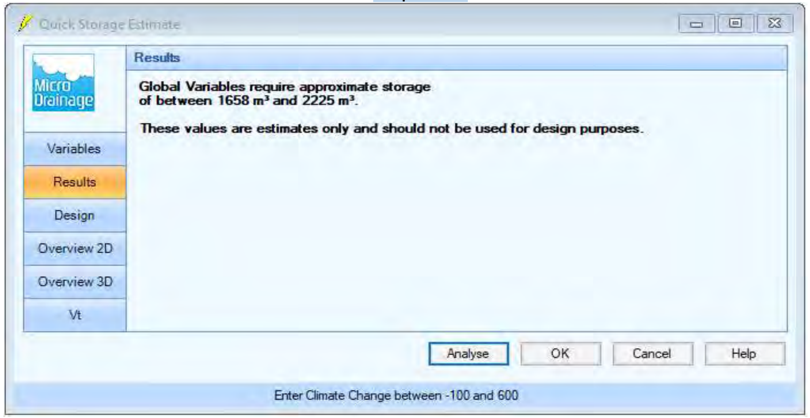
Drainage Zone: River Stour
Drainage Sub-Zone: DR-RS4

Storm Event: 1 in 100 Annual Chance

Input Data

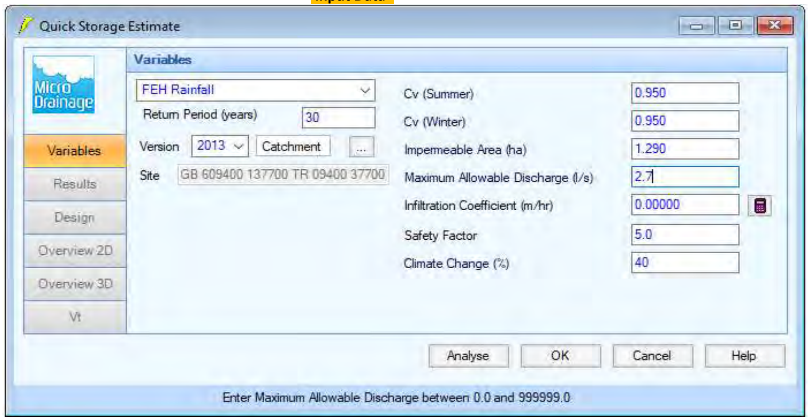


Output Data

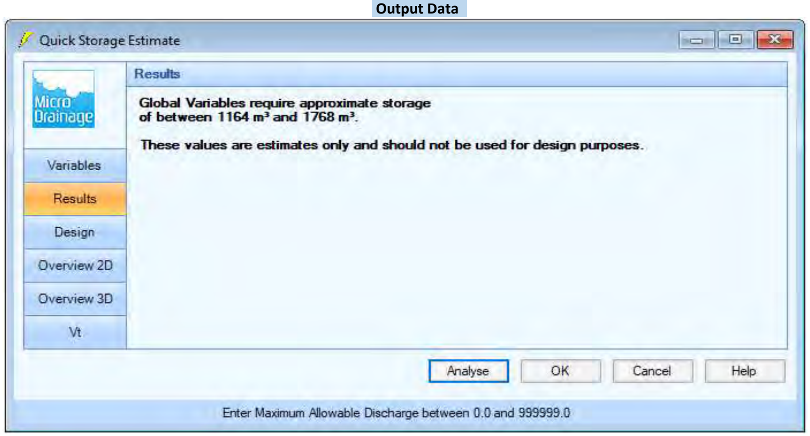


Storm Event: 1 in 30 Annual Chance

Input Data



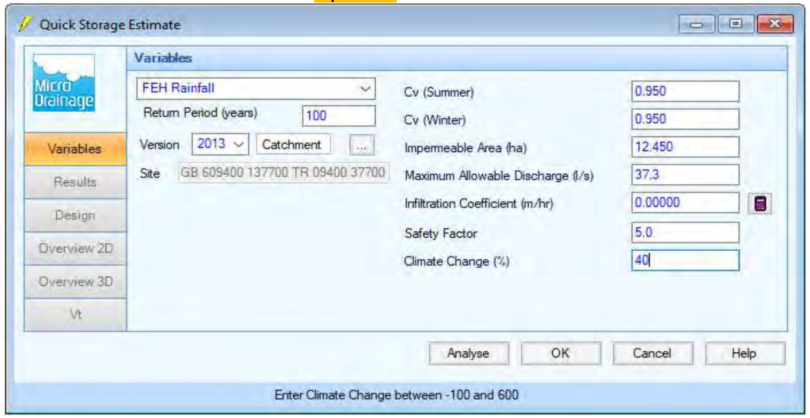
Output Data



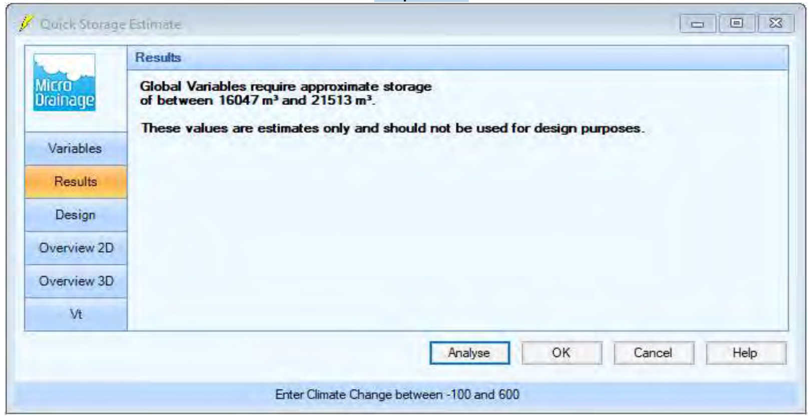
Drainage Zone: River Stour
Drainage Sub-Zone: DR-RS5

Storm Event: 1 in 100 Annual Chance

Input Data

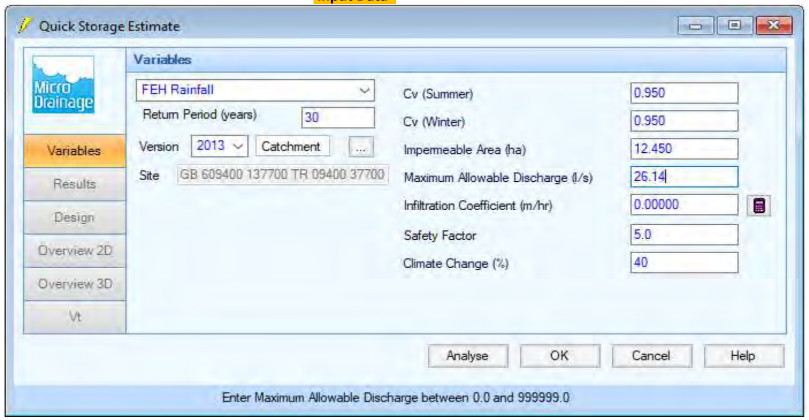


Output Data

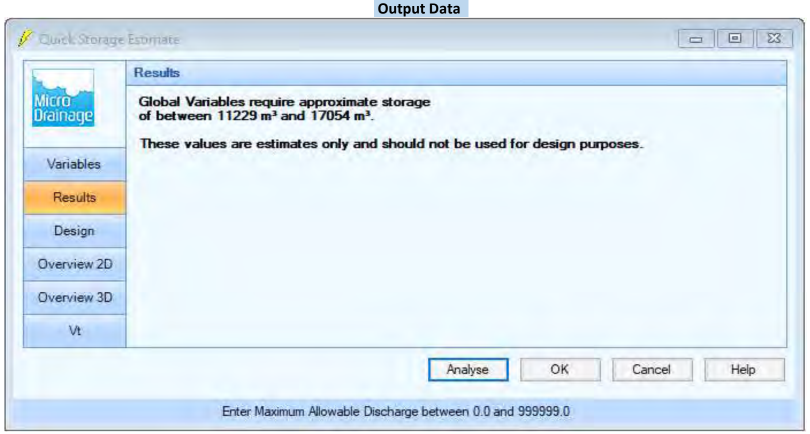


Storm Event: 1 in 30 Annual Chance

Input Data



Output Data



Arcadis Consulting (UK) Limited

80Fen
80 Fenchurch Street
London
T: +44 (0) 20 7812 2000

arcadis.com