# SE06/3267/F

# POLYTUNNEL DEVELOPMENT AT PENNOXSTONE COURT, KING'S CAPLE. DRAINAGE APPRAISAL

for

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King's Caple
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by

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# PENNOXSTONE COURT DRAINAGE APPRAISAL NON TECHNICAL SUMMARY

A planning application for polytunnel (Spanish Tunnel) development at Pennoxstone Court, King's Caple has been submitted on behalf of Mr N. Cockburn by consultants Antony Aspbury Associates. A drainage appraisal has been undertaken to support the application. The principal objective of the appraisal is to establish the effect of the polytunnels on the runoff characteristics of the fields on which they are located.

This report has been prepared by JDIH (Water & Environment) Ltd [JDIH], a specialist independent water resources and water management consultancy.

The report sets out in detail the calculations that were undertaken to compare predicted rates of runoff from the development area, with and without polytunnels and for different land uses. This comparison is based on the whole polytunnel growing area. It includes consideration of areas covered and not covered in polytunnels; drainage channels through the system; and storage in the form of ponds before the runoff exits downslope at the farm catchment boundary or into the River Wye.

The emphasis is that the polytunnel drainage at Pennoxstone Court is an agricultural drainage issue and not an urban drainage issue. Therefore, the analysis is based on the assumption that the alternative to using polytunnels, is using the land for row crops.

The key technical issue that has been considered is whether the presence of polytunnels increases runoff rates following rainfall. A quantitative assessment has been undertaken which compares calculated runoff at Pennoxstone Court with and without polytunnels. This then gives us a measure of the effects of the polytunnels.

The calculations were based on a well established technique known as the Rational Method, which is appropriate for small catchments such as these.

The analysis shows that if the drainage of the polytunnel area is actively managed, that the peak runoff rate associated with the polytunnel development is similar to that of open meadow, and is less than that for of open row cropping, which is the alternative if polytunnels are not used.

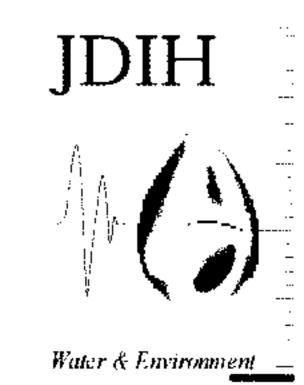
The analysis does not take account of the polytunnels only being erected between February and November. In addition, it is estimated that only 60% of the polytunnels are erected at any one time. This makes the analysis conservative.

The analysis shows that there will be no impact on ponds which reportedly contain Great Crested Newts.

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## PENNOXSTONE COURT DRAINAGE APPRAISAL

#### 1 INTRODUCTION

A planning application for polytunnel (Spanish Tunnel) development at Pennoxstone Court, King's Caple has been submitted on behalf of Mr N. Cockburn by consultants Antony Aspbury Associates. This drainage appraisal has been prepared to support the submission. The principal objective of the appraisal is to establish the effect of the polytunnels on the runoff characteristics of the fields on which they are located.

The drainage appraisal includes:

- Surface water flow calculations for each parcel of land and modelling of storm events for a 1 in 100 year storm event plus a 20% increase to accommodate climate change;
- Topographic data showing surface water flow routes from polytunnels to receiving watercourses;
- 3. Details of how runoff is collected and stored.

This report has been prepared by JDIH (Water & Environment) Ltd [JDIH], a specialist water resources and water management company. The lead consultant was James Dodds, the Managing Director of JDIH, who has some 20 years experience in water management consulting.

#### 2 SITE DESCRIPTION

#### 2.1 Site location

Pennoxstone Court is located at King's Caple, approximately 6km to the northwest of the town of Ross-on-Wye. The farm is centred at grid reference SO 555 286 and elevations across the farm site vary between 36 and 65mAOD.

Based on Ordnance Survey mapping at a scale of 1:10000, the topography of the farm site consists of several small drainage catchments and natural drainage courses that have gradients ranging from 0.4% to 11%. The main farm area is located on the western slopes of a spur that projects into the Wye Valley with the natural farm drainage courses eventually flowing into the River Wye at the farm boundary (Figure 1).

The geology of the site has been taken from British Geological Survey (BGS) sheet 215 (Ross-on-Wye) and comprises the sandstones of the Brownstones Formation of the Lower Old Red Sandstone Group of Silurian age. According to the Soil Survey of England and Wales map and classification, the Brownstones Formation are overlain by well drained, reddish or coarse loamy soils (Category 541c) and deep stone less permeable silty soils (Category 561b) on flat lying land adjacent to the River Wye.

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# 2.2 Hydrological characterisation of the site

Based upon a combination of Ordnance Survey topographic mapping and a detailed walkover survey of the site undertaken by JDIH on 14 August 2006, the polytunnel area has been subdivided into seven sub-catchment areas, which are shown in Figure 1. These areas (Areas A to G) form the basis of the quantitative assessment of runoff from the site.

The spatial characteristics of each of the sub catchment areas are described in Table 1 and illustrated in Figures 1, 2 and 3.

Table 1 Characteristics of sub catchment areas A and G

Location	Hedgerow & Headland (m²)	Thick Grass & Woodland or Grass & Orchard (m <sup>2</sup> )	Small Grain Crop (m²)	Hard standing (m²)	Połytunnels (m²)	Meadow (m²)	Row Crop (m²)	Track (m²)	Total area (m²)
Area A	840	0	2,000	0	6,700	0	0	460	10,000
Area B	2,250	0	57,000	0	52,950	0	0	800	113,000
Area C	17,700	70,300	9,000	0	90,760	89,940	0	8,300	286,000
Area D	3,330	22,710	83,000	0	44,000	0	0	2,960	156,000
Area E	6,300	0	182,000	0	71,000	0	53,000	3,700	316,000
Area F	720	0	0	0	6,800	0	0	480	8,000
Area G	3,600	8,000	0	0	59,100	0	0	3,300	74,000
Catchment Total	34,740	101,010	333,000	0	331,310	89,940	53,000	20,000	963,000

Figure 1 shows the analysis areas and provides detailed land use information for each one. Areas C, D and E have been combined for the following reasons:

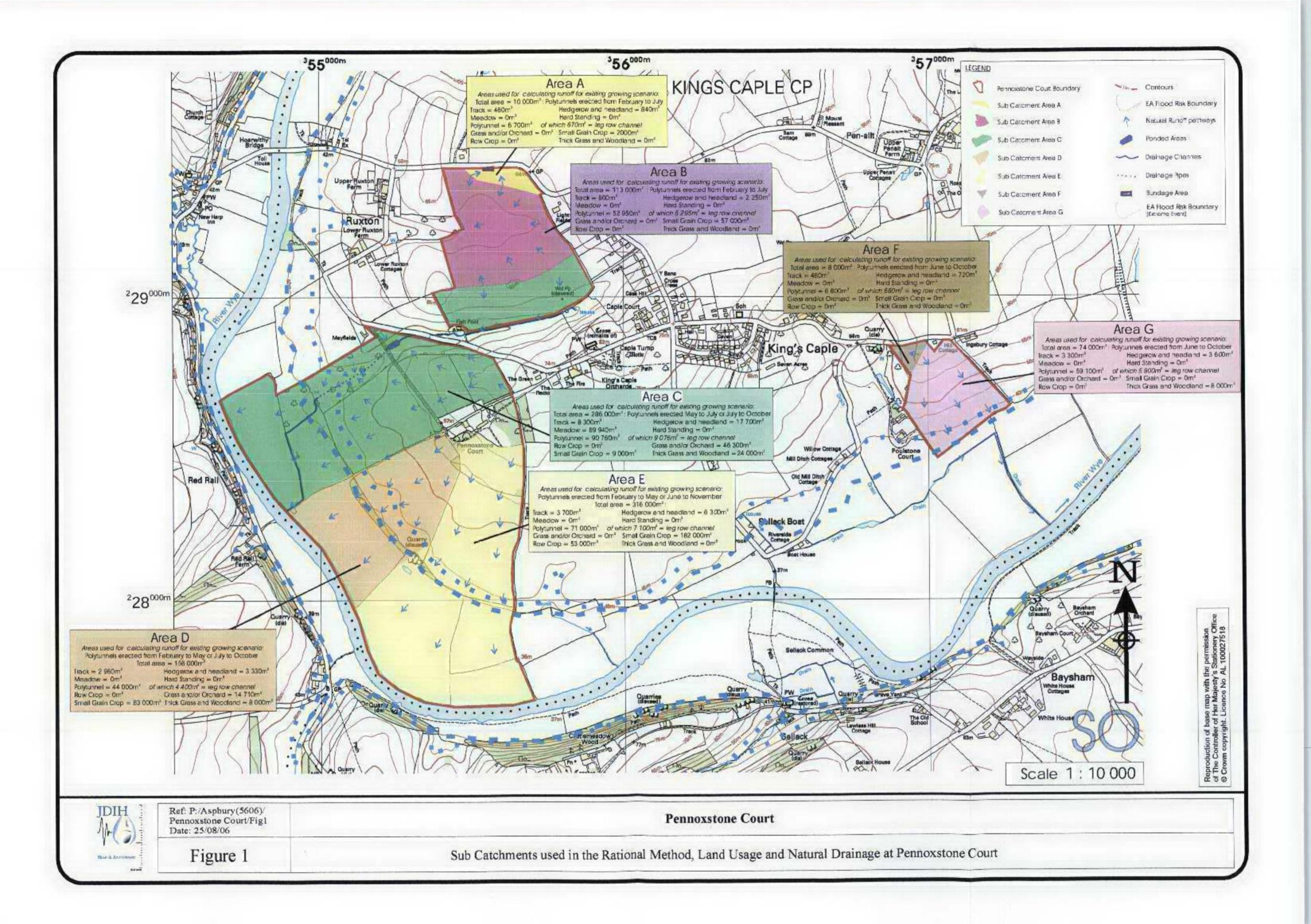
- Each of the sub-catchment areas runs to the same reach of the River Wye
- Each of the sub-catchments drains across the flood plain with runoff largely controlled by overland flow
- To reduce the total number of sub-catchment areas in the analysis

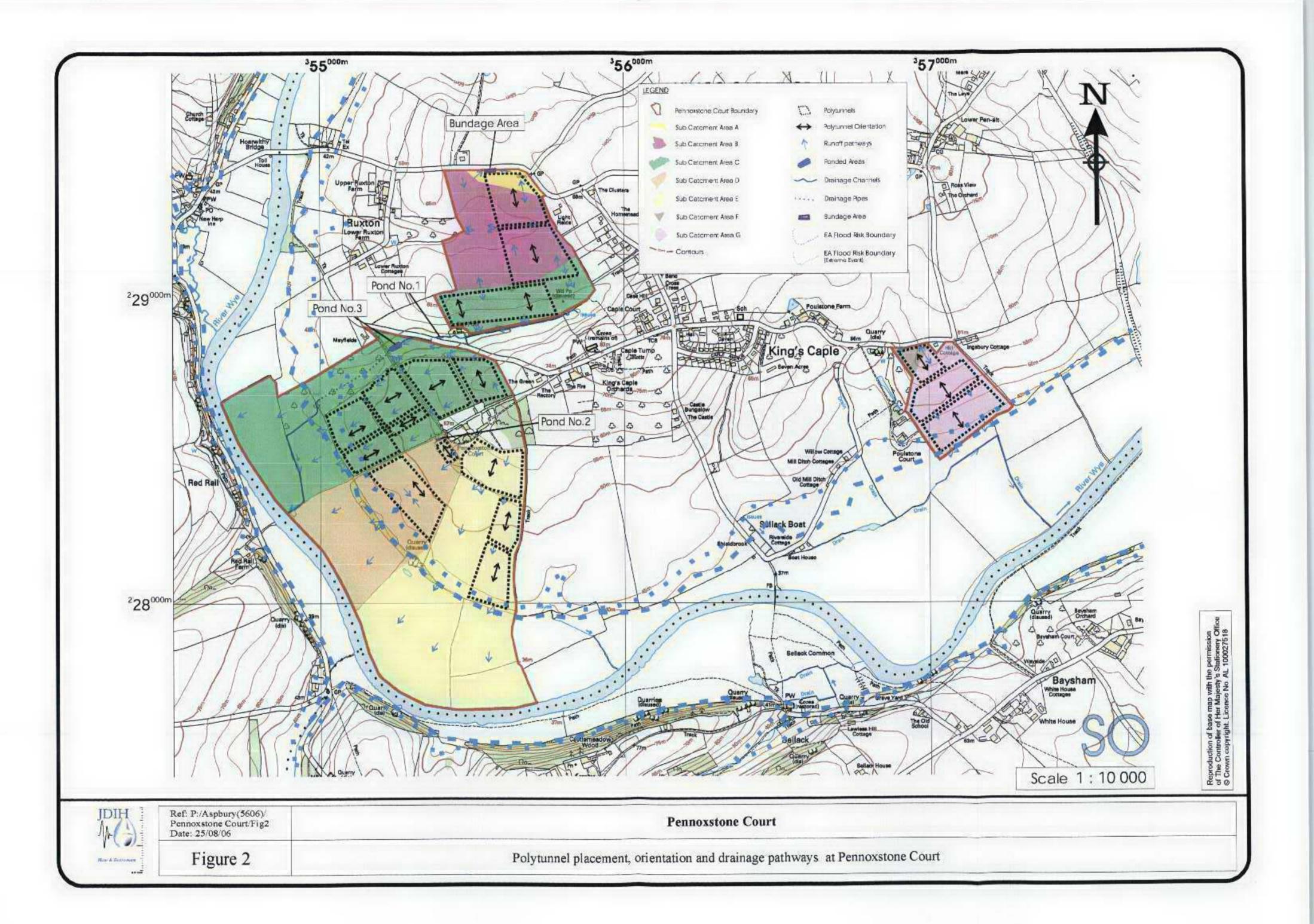
It is considered that combining the sub-catchments into a single analysis area, will not materially effect the conclusions drawn from the assessment.

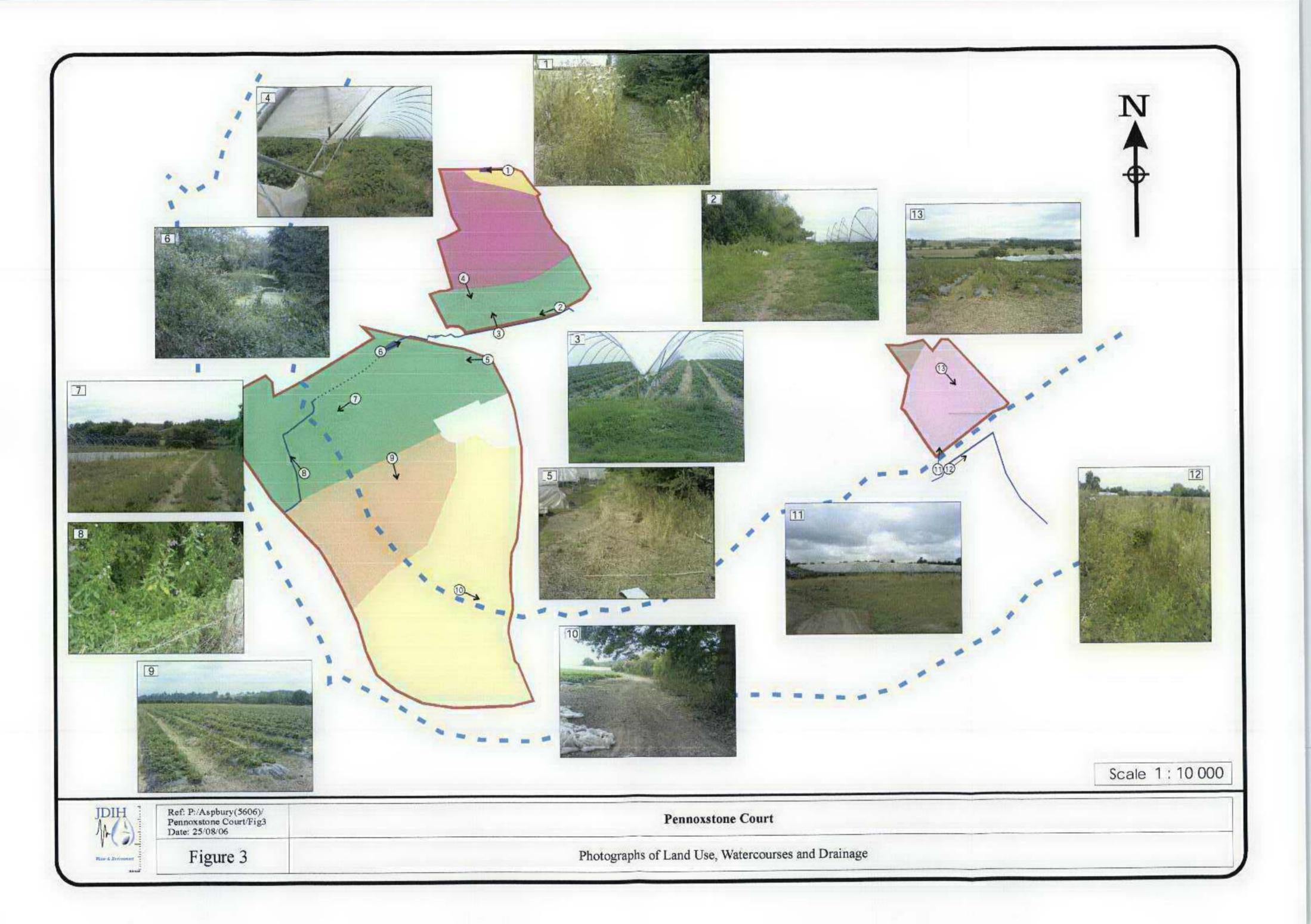
Figure 2 complements Figure 1 and shows the areas of polytunnel development, together with the direction of overland runoff.

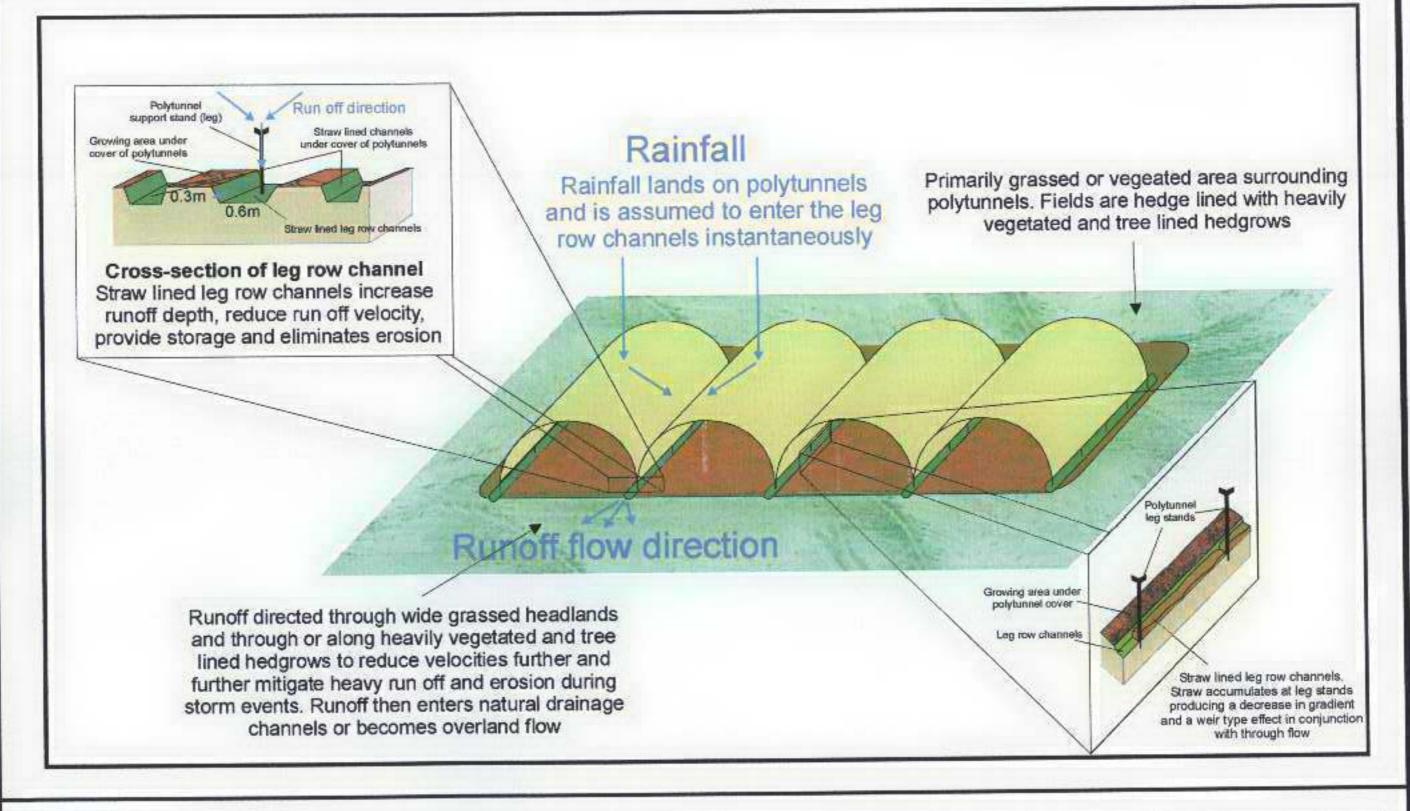
Pennoxstone Court uses polytunnels to grow soft fruits in the ground. Drainage from the polytunnels is achieved by a series of straw lined channels that run along the line of the polytunnel leg stands, as illustrated in Figures 3 and 4. These lines will be called "leg row channels" for the purpose of this report. The straw accumulates in the leg row channels producing a weir effect, thereby reducing the effective gradient, increasing the resistance to flow and therefore reducing flow velocities. In addition to straw, some leg row channels also have vegetation growing within them, which further reduces the channel velocity. The net result of straw and vegetated leg row channels is to reduce the flow velocities and runoff rate of the polytunnels and channels.

This conceptualisation is important. The polytunnel drainage is an agricultural drainage system and not an urban drainage system. In essence, the objective of the system is to











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Figure 4

Schematic Diagram of Polytunnel Runoff and Drainage

reduce runoff rates and hence peak flows. It is therefore important that the analysis approach and technique reflects this.

The polytunnel development represents one land use type. If polytunnels were not used, the land would still be farmed as profitably as possible. Therefore the alternative land would be row crops, such as potatoes, sugar beet or similar crops, and these types of crops would cover the full cropping areas rather than just the polytunnel areas.

Runoff and drainage from the farm eventually finds its way to the River Wye. The River Wye has a wide flood plain, as shown in Figure 1, in which the flood risk as categorised by the EA is "Significant". The floodplain is used for small grain crops or grazing and no polytunnels are located within the Significant flood zone. Within the main farm catchment, at the edge of the floodplain there is a levee that rises up to between 1 and 3 metres in height to meet the steeper slopes at the farm. The EA "Extreme" flood risk zone rises above this levee. Figure 2 illustrates that at certain locations, the lower edges of the polytunnels at the base of the slope infringe on this extreme flooding zone.

# 2.3 Polytunnel layout

Figures 2 and 3 show the location and layout of the polytunnels on the farm, based on the results of the JDIH site walk-over survey and site plans provided by Mr N. Cockburn.

The catchment area within which the polytunnels are located extends to some 96ha. This is the sum of areas A to G (Figure 1). Of this, approximately 33ha (Table 1) is covered in plastic, for some of the year. It is estimated that at any one time, only 60% of the polytunnel growing areas have polytunnels erected.

During the course of a year there will be periods when the polytunnels are not covered, particularly in the winter and when strong winds are forecast. This assessment assumes that the polytunnels are covered and therefore represents a worst case scenario.

### 2.4 Polytunnel orientation and drainage

The polytunnel orientations at Pennoxstone Court are illustrated in Figure 2. Drainage from the polytunnels is in two stages. Initially, rainfall hits the polytunnels and instantaneously runs off to the ground surface before accumulating in each of the leg row channels. Once channel storage, comprising storage within the straw, has been overcome, flow will be initiated parallel to the tunnel orientation. At the open end of each polytunnel block, the runoff from each leg row channel is dispersed by a wide vegetated headland. This is shown graphically in Figure 4.

Flow is then either through or along thick heavily vegetated and tree lined hedgerows in the form of overland flow. In the majority of cases, drainage flows onto the River Wye floodplain area as overland flow or alternatively finds its way into natural drainage channels; ponds and field drainage pipes before entering the River Wye.

Where the polytunnels are oriented across the principal slope direction there is a reduction in the velocity of the runoff and hence reduced potential for high rates of rainfall accumulation and erosion (Quinton and Catt, 2004). However, across-slope cultivation is generally avoided in the UK to minimise machinery slips or overturns (Chambers *et al.*, 2000).

For Area A, the runoff accumulates at the low point of the area by a bund. A resulting overflow of this bund in an extreme event would cause the overspill to pond within the area.

For Area B, runoff from polytunnels reaches the low point of the farm catchment and finds its way through a thick heavily vegetated hedgerow. There is no evidence of drainage channels or eroded channels beyond this point, although runoff will eventually find its way to the River Wye via the small hamlet of Ruxton.

For Area C, runoff from polytunnels generally accumulates in natural drainage channels and ponds before entering the River Wye.

For Areas D, E and F, runoff from the polytunnels is dispersed into overland flow and enters the floodplain of the River Wye.

For Area F, runoff runs away from the River Wye to the low point of the sub-catchment at the farm catchment boundary. From here, it follows the path of least resistance to a ponded area at Poulstone Court before draining to the River Wye floodplain.

## 2.5 Sediment erosion and mobilisation

The use of straw in the leg row channels, together with the grassed headlands and heavily vegetated hedgerows around the polytunnels, has a significant positive effect on the reduction of soil erosion and sediment mobilisation.

Overland flow velocities >1cm/s have the potential to start mobilising soil particles and therefore initiate erosion; and velocities >10cm/s will almost certainly transport soil particles and initiate erosion, if the water is flowing over bare soil (Reading, 1986).

By utilising the straw, leg row channel velocities are reduced. By dispersing the flow over the heavily vegetated areas overland flow velocities are reduced. As a result, soil stability is greatly increased. Soil stability is increased further by the binding effects of the roots.

#### 3 DATA ANALYSIS

# 3.1 Approach

The technical approach undertaken for this investigation comprised the following elements:

- A walk-over survey by JDIH to define catchment areas and drainage routes across the site;
- The use of the Rational Method to calculate peak runoff rates for critical storm events;
- A comparison of peak runoff rates for the current polytunnel scenario versus open grassed meadow versus open row crop.

The analysis used analytical models for calculating storm event intensities; rainfall runoff; surface discharges; and channel discharges. These are simplifications but are generally accepted equations that perform well, if realistic estimates of parameters are used. The emphasis is that the polytunnel drainage at Pennoxstone Court is an agricultural drainage issue and not an urban drainage issue.

The peak discharge rates produced by various rainfall events for the all sub-catchment areas of Pennoxstone Court was assessed by using a well established technique for small catchments called the Rational Method. The key parameters in the Rational method are: Time of Concentration, rainfall intensity, and runoff coefficient. The derivation of these parameters is discussed in the sections that follow.

#### 3.1.1 Rainfall

Rainfall intensities for this catchment area were determined using the Flood Estimation Handbook (CEH Institute of Hydrology, 1999)

This report considers the 1 in 10 year and 1 in 100 year critical storm events. In addition, a 20% increase in the 1 in 100 year event has been included for the assessment of the effects of climate change.

#### 3.1.2 Runoff Coefficient

Generic runoff coefficients have been derived from the Department of Agricultural and Biological Engineering at Purdue University, USA, and are given in Table 2.

The full details of runoff coefficient data can be seen on the following website:

http://pasture.ecn.purdue.edu/~engelb/abe526/Runoff/C\_table.html & http://pasture.ecn.purdue.edu/%7Eengelb/abe526/Runoff/

**Table 2** Runoff coefficients used in the Rational Method

Track	0.55
Row Crop	0.5 – 0.65
Meadow	0.35 – 0.5
Polytunnels	0.79 – 0.85 (Weighted Runoff Coefficient)
Hard Standing	0.9
Small Grain Crop	0.3
Thick Grass and Woodland	0.15
Grass and/or Orchard	0.4
Hedgerow and Headland	0,25

The analysis is particularly sensitive to the value used for the runoff coefficient. For this reason, a range has been used for the main land use types within the catchments being considered. The runoff coefficients have been applied to the different land uses and an average weighted value for the full catchment developed based on the area of each land use type. The weighting is described in detail in Appendix A.

The weighted runoff coefficient will vary between the different runoff scenarios that have been assessed. For instance, the weighted runoff coefficient for the polytunnel scenario is less than that for row crops, despite the runoff coefficient for polytunnels being higher. This is due to the row crop scenario assuming the full catchment is farmed as row crop, while in the polytunnel scenario, the catchment will include polytunnels and meadow.

#### 3.1.3 Time of Concentration

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The time of concentration is the time taken for water falling at the furthest point of the catchment to leave the catchment. The principal components are therefore, the time to generate flow (this will be called the runoff generation time for the remainder of this report) and the overland flow velocity and travel distance. Calculated overland flow velocities are given in Table 3 and a breakdown of the time of concentration pathways for the farm sub-catchments are given in Appendix B.

The runoff generation time is an important aspect of the time of concentration. While the runoff from the polytunnel surface is considered to be instantaneous, it takes time for the leg row channels to wet up and for flow to start. The generation time is controlled by the antecedent moisture content of the soil, the field gradient, roughness and depression storage of the channel and storage within the vegetation and straw within the channel. It is therefore impossible to calculate the generation time due to the complex interaction, but field observation and experience suggests that a period of 10 minutes is reasonable.

Peak runoff rates are calculated based on a storm event for a time period equal to that of the time of concentration.

Table 3 Overland flow velocities

	Velocity (m/s) for slope of 0.6%	Velocity (m/s) for slope of 2.5%
Paved Area Sheet Flow	0.48	1
Bare Land	0.25	0.47
Short Grass	0.18	0.32
Small Grain & Row Crop	0.11	0.28
Meadow & Woodland	0.08	0.12

Source: Hydraulic Design Manual (Texas Department of Transportation – Design Division, 2004. <a href="http://www.dot.state.tx.us/services/general\_services/manuals.htm">http://www.dot.state.tx.us/services/general\_services/manuals.htm</a>)

## 3.2 Rainfall events and associated peak runoff rates

The peak runoff rates for the three scenarios (existing polytunnel; open meadow; row crop) are presented in the tables below to provide direct comparison. The runoff rates are given in litres per second per hectare for the areas of A to G to the farm boundary of each sub-catchment. The main farm area (Areas C, D and E) all discharge into the same section of the River Wye via the same floodplain and therefore, have been grouped into one farm catchment area.

The comparison is based on the whole polytunnel growing area within the sub-catchments, including areas covered and not covered in polytunnels; drainage channels through the system; and storage in the form of ponds before the runoff exits downstream at the farm boundary.

Table 4 shows the comparison of critical storm rainfall intensities (in mm per hour) calculated for the time of concentration for each storm event and scenario. Table 5 shows the comparison for the range of peak runoff rates (in litres per second per hectare) produced for the critical rainfall intensities using ranges of runoff coefficients for each given scenario.

A full set of results tables including the times of concentration and the various runoff coefficients (ROC's) used to provide the weighted runoff coefficient can be found in Appendix C.

Table 4. Comparison of critical rainfall intensities for each storm event and scenario

		FEH Storm Event		
		1 in 10 year	1 in 100 year	1 in 100 year +20%
	Meadow Scenario	11	22	27
Area	Row Crop Scenario	13	24	29
₹	Existing Polytunnel Scenario	10	19	23
<b>A</b>	Meadow Scenario	11	20	25
ea	Row Crop Scenario	13	26	31
A I	Existing Polytunnel Scenario	13	25	30
<u>ე</u> ⊟	Meadow Scenario	10	18	22
rea ( and	Row Crop Scenario	10	19	23
Ar Da	Existing Polytunnel Scenario	10	18	22
<b>[x</b> <sub>1</sub>	Meadow Scenario	13	28	34
5	Row Crop Scenario	13	28	33
₹	Existing Polytunnel Scenario	13	28	34
	Meadow Scenario	13	27	34
5	Row Crop Scenario	14	29	34
rea	Existing Polytunnel Scenario	14	29	34
•	50% reduction in Polytunnels	14	29	34
<del></del>			mm/hr	

Table 5. Comparison of ranges of peak runoff rates for the critical storm intensities for various storm events and scenarios

<del>-</del>		FEH Storm Event		
		1 in 10 year	l in 100 year	1 in 100 year +20%
<	Meadow Scenario	11 - 16	21 - 30	26 - 36
Area	Row Crop Scenario	17 - 22	33 - 43	40 - 51
<b>4</b>	Existing Polytunnel Scenario	18 - 19	34 - 37	41 - 44
<u>m</u>	Meadow Scenario	10 - 15	20 - 28	24 - 34
rea	Row Crop Scenario	18 - 24	36 - 47	43 - 56
₹	Existing Polytunnel Scenario	19 - 20	37 - 39	44 - 47
C <sub>E</sub> C	Meadow Scenario	9 - 13	18 - 25	21 - 30
rea ( and	Row Crop Scenario	14 - 18	26 - 34	31 - 40
Ar D :	Existing Polytunnel Scenario	12 - 14	24 - 26	28 - 31
<b>F</b>	Meadow Scenario	13 - 18	27 - 39	33 - 47
Area	Row Crop Scenario	17 - 22	37 - 48	45 - 58
₹	Existing Polytunnel Scenario	27 - 29	57 - 61	69 - 74
,,	Meadow Scenario	13 - 18	27 - 38	32 - 45
a G	Row Crop Scenario	19 - 24	39 - 51	47 - 61
Area	Existing Polytunnel Scenario	26 - 28	54 - 58	65 - 70
	50% reduction in Polytunnels	19 - 20	39 - 41	46 - 49
			litres/second/hectare	

The results show that the open meadow scenario produces the lowest peak runoff rates for the critical storm events. The low return period 1 in 10 year storm gives a peak runoff of between 9 and 18l/s/ha. This can be considered as the "Greenfield Runoff". The equivalent for a 1 in 100 year storm is 18 to 39l/s/ha.

With the exception of Areas F and G, the existing polytunnel scenario yields moderately higher runoff rates to that of an open meadow land use producing peak runoff rates between 24 and 39l/s/ha for the 1 in 100 year critical storm event.

Again with the exception of Areas F and G, the open row crop scenario produces the highest peak runoff rates for critical storm events, ranging from 26 to 47l/s/ha for the 1 in 100 year critical storm.

In contrast, the existing polytunnel scenario produces the highest runoff rates for Areas F and G. However, calculations for Area G have shown if the existing polytunnels were reduced by 50% and replaced by small grain crops, then peak runoff rates can again be reduced to values less than that of row crops.

#### 4 QUALITATIVE ASSESSMENT

The conclusion that the peak runoff rate when areas of land are covered by polytunnels is only moderately higher to that of open meadow and is reduced in comparison to row crop land use, may initially seem unlikely.

This conclusion is brought about by the fact that the drainage from the polytunnels is actively managed to reduce flow velocities in the leg row channels and is discharged over meadow areas, which reduces velocities to less than that in the situation where the fields are farmed for row crops. The reduction in velocities is translated in the analysis to lower times of concentration and therefore critical storms.

It is important to consider that a no polytunnel scenario does not mean that the land would be meadow. This is very different to urban development, where it is reasonable to compare the developed land (usually hard surface and high runoff) with a "Greenfield runoff" rate. In the case of polytunnel development, the alternative to the polytunnels would be row crops, as grassland is unlikely to be economically viable. The analysis shows that peak runoff rates from row crops are generally higher than the polytunnel scenario, for the reasons given above.

The successful management of drainage from the polytunnels is therefore dependent on the pro-active management of drainage through the leg row channels and the dispersal of drainage across meadows. This is different from urban drainage systems where the provision of hard standing and drains, increases flow velocities and results in the need for storage to attenuate peak discharges. In the case of Pennoxstone Court the reduction in flood peaks is achieved by increasing the resistance to flow in the leg row channels and overland flow across grassland.

# **5 FURTHER CONSIDERATIONS**

In addition to this drainage appraisal, an ecological survey has been carried out at Pennoxstone Court by Davies Light Associates entitled "Pennoxstone Farm, Kings Caple. – Herpetological Research and Consultancy – Report No; Ref: 1154/eco/report01/June06". The report highlighted the presence of Great Crested Newts at Pond No.2 (Figure 2). Pond 2 has good terrestrial links to terrestrial habitats for foraging and hibernation of Great Crested Newts.

The drainage appraisal and active management proposals ensure that this pond receives a water supply that keeps the pond wet from April to September and therefore, the pond has the potential for a long term viable Great Crested Newt breeding population. Therefore, the drainage of polytunnels at Pennoxstone Court help maintain this pond for the Great Crested Newt population by not interfering with the ponds water supply.

The placement of polytunnels and the active management of drainage to reduce flow velocities will also reduce the risk of soil erosion. Thus the management regime will improve the conditions for Great Crested Newts when compared to row crops, where bare fields in the spring and winter can result in significant soil erosion.

Therefore it is concluded that the placement of polytunnels will not interfere with this pond and thus will not impact on the Great Crested Newts.

Davies Light Associates have also compiled an accompanying landscape and visual report entitled "Enforcement against Polytunnels at Pennoxstone Court, Kings Caple. Landscape and Visual Appraisal - Report No: Ref; 1154/rpt/lva/01 26/7/06". The landscape planting proposals shown on drawing DLA/1154/07 within the report, will also assist in reducing peak flow rates further and assist with soil conservation.

During the drainage analysis, it was noted that the discharge from Pond No.3 (Figure 2 and picture 6 on Figure 3) is from a 300mm pipe that has an estimated maximum discharge velocity of 3.3m/s. This equates to a flow rate off approximately 845m³/hr. During the 1 in 100 year plus 20% critical storm event, it was calculated that this would hold back a surplus of 300m³. Based on approximations of the pond dimensions, this would raise the level of the pond by 15 to 25cm above the pipe outlet. This rise in water level is containable within the pond dimensions without causing flooding to off-site areas.

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### CONCLUSIONS

This assessment has demonstrated that the polytunnel development at Pennoxstone Court will not have a detrimental impact on drainage when compared to the alternative land use, which would be row crops.

It is important that the drainage system is actively managed, as is currently the case, to reduce flow velocities in the leg row channels and to distribute drainage over grassed areas.

There will be no impact on Pond No. 2 which reportedly contains Great Crested Newts.

James Dodds MSc CGeol FGS Director

Lee Clarke MSc FGS

Peer review by:

Dr R Drayton, Independent Hydrological Consultant

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# Appendix A

Methodology for Rational Method

# Methodology for Rational Method

- The polytunnel catchment area has been sub-divided into five sub-catchments (Areas A, B, C-E, F and G). These sub-catchments are sub-divided further depending on the land use to provide a composite analysis of the polytunnel catchment areas. Areas are calculated for the polytunnel catchment area and the sub-divided areas.
- ▶ Each land use has been given runoff coefficient values to best represent Pennoxstone Court. In addition, a range of runoff coefficients (ROC's) for meadow (0.35 to 0.6); for polytunnels (0.79 to 0.85) and for row crops (0.5 − 0.65) have been used to represent the dominant land types for the comparative scenarios and to represent the variability of runoff coefficients based on data from the Purdue University website (Table A1). The polytunnel runoff coefficient takes into account both the area covered by polythene (high ROC's) area combined with the area along the leg row channels (moderate ROC's) to provide a weighted runoff coefficient. These runoff coefficients are then combined with the runoff coefficients for other land uses to provide a weighted runoff coefficient for the sub-catchments. In turn, combining sub-catchments where relevant gives a weighted runoff coefficient for the polytunnel catchment area for various comparative scenarios.

Table A1 Generic runoff coefficients

	Hydrologic Soil Group				
Land Use, Crop, and Management	A	В	С	D	
CULTIVATED, with crop rotations					
Row Crops, poor management	0.55	0.65	0.7	0.75	
Row Crops, conservation mgmt	0.5	0.55	0.65	0.7	
Small Grains, poor management	0.35	0.4	0.45	0.5	
Small Grains, conservation mgmt	0.2	0.22	0.25	0.3	
MEADOW	0.3	0.35	0.4	0.45	
PASTURE, permanent w/moderate grazing	0.1	0.2	0.25	0.3	

#### **Hydrologic Soil Group Descriptions:**

- A -- Well-drained sand and gravel; high permeability.
- B -- Moderate to well-drained; moderately fine to moderately coarse texture; moderate permeability
- C -- Poor to moderately well-drained; moderately fine to fine texture; slow permeability
- **D** -- Poorly drained, clay soils with high swelling potential, permanent high water table, claypan, or shallow soils over nearly impervious layer(s).

Source: Purdue University, West Lafayette, Indiana, USA. Department of Agricultural and Biological Engineering website:

http://pasture.ecn.purdue.edu/~engelb/abe526/Runoff/C\_table.html & http://pasture.ecn.purdue.edu/%7Eengelb/abe526/Runoff/

- Storm event data has been calculated and tabulated for a 1 in 10 year and a 1 in 100 year
  event at Pennoxstone Court from the FEH CD-ROM (CEH Institute of Hydrology). A further 20
  percent of rainfall was added to the 1 in 100 year event to anticipate potential future climate
  changes. This storm event data was then used in the Rational Method.
- Flow velocities for the natural drainage channels, leg row channels and field drains have been calculated based on dimensions and shape factors observed and measured in the field: a range of gradients (a mean slope of 0.4% to a maximum slope of 11%) representing those found at Pennoxstone Court; a Manning's coefficient of 0.06 to 0.08 for straw lined or vegetated channels; the Manning's Formula dependent on shape of channel; a Newton-Raphson iteration process; and the Colebrook-White equation for pipe velocities. All pipe velocities used assume full pipes. These were calculated for the relevant critical storms, to be placed into the time of concentration (Tc) calculations. This, in itself, is iterative so that the flow velocity best fits the time of concentration for the appropriate runoff area and runoff coefficient

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of the scenario in question. The velocities used in the time of concentration for drainage channels and field drains are illustrated in Appendix B.

- The time taken for runoff to flow through storage areas has been added to the time of concentration. The value is the time taken to reach the maximum overspill discharge from the storage area. Calculations have been based on the storage volume to the top of the outfall pipe or maximum overspill point; the critical rainfall intensity for the 1 in 100 year event; and a runoff area and runoff coefficient appropriate for the contributing catchment area and scenario. Again, this process is iterative so that the critical storm best fits the time of concentration.
- The time of concentration was calculated for the pathway of sub-catchment areas A, B, F and G and the combined sub-catchments area C, D and E to their respective outfall point at the farm boundary illustrated in Figure 1. These lengths are displayed in the scenarios presented in Appendix B. When the peak runoff rates are calculated for combined sub-catchments, it is the longest time of concentration that is used to determine the critical storm intensity.
- The overland flow velocities for meadow were calculated using the same range of gradients as used for the field drains and drainage channels and data from the Hydraulic Design Manual (Texas Department of Transportation Design Division, 2004. <a href="http://manuals.dot.state.tx.us">http://manuals.dot.state.tx.us</a>). These values were utilised in the time of concentration calculation. Appendix B contains the velocities used along with a brief description of the time of concentration pathway for each sub-catchment
- Runoff generation times for the time of concentration have been estimated based on the land
  use in the given scenario. This time qualitatively considers the infiltration rate; time taken for
  the ground to become wetted; time taken for overland flow velocities to reach upper limits; and
  the critical storm intensity for a 1 in 100 year storm.
- The rainfall depths for the relevant times of concentration (critical storm) have been calculated using the FEH storm event data. For example:

	Time of concentration	1 in 100 year storm rainfall depth for time of concentration (mm)	Critical storm rainfall intensity (mm/hr)
Area A	68.67 minutes	25.38	22.18

- The rainfall depths were then divided by the time of concentration and in turn, multiplied by 60
  to give a rainfall intensity in mm per hour.
- The rainfall intensities were then input into the Rational Method along with the calculated areas and the runoff coefficients given for the land use in each sub-catchment. This gave peak runoff rates for the sub-catchment areas A, B, F and G and the combined subcatchments areas C, D and E.
- The process has been repeated several times to account for variations in runoff coefficients and storm events for all the scenarios modelled.
- The results have been compressed and presented in tabulated form showing the meadow, row crop and polytunnel scenarios for each catchment considered versus the return period of the storm event. The results have been displayed as litres/second/hectare.
- The main results tables have been presented in tabulated form in Appendix C showing weighted runoff coefficients for the designated area versus the return period of the storm event. These results include the time of concentration, the critical storm intensities, the runoff coefficients, and the land use areas used in the calculation. The results have also been displayed as litres/second/hectare.

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# Appendix B

Detailed Analysis Criteria

Brief description of the pathways for the time of concentration for sub-catchment area A for the meadow, row crop and existing polytunnel scenario.

	Meadow Scenario.	Starts at 64.5mAQD. F	Kainfall falls onto	meadow area.			
	·. ·			. ·			
The overland flow vel	ed instantaneously. Runoi locities also require time t	f will occur once infilt o reach maximum vek	ration rates are ex	ceeded and the gr	round has been wetted.	Runoff generation time =	720s
however, usin	g the 1 in 100 year storm	event a runoff generati	ion time is estimat	ed that is conside	red reasonable.	Kunant Reneration (une –	7203
however, usin	g the I in 100 year storm	event a runoff generati	ion time is estimat Om over grassland	ed that is conside	red reasonable.	Hydraulic Gradient ≃	0.0059 m/m 0.05 m/s 3400 s

	Row Crop Scenario. Starts at 64.5mAOD. Rainfall falls onto row crop area	
The overland flow veloc	instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted cities also require time to reach maximum velocities. These factors are dependent on the storm intensity, the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable.	Runoff generation time = 600 s
From 64.5mAOD to	o 64mAOD runoff travels a mean distance of 80m along row crop orientation to the field boundary.	Hydraulic Gradient = 0.0063 m/m  Overland flow velocity = 0.11 m/s  Time over pathway = 727 s
From 64mAOD to 63.5m	nAOD runoff travels a mean distance of 100m along field boundary to accumulate and pond at low point of field.	Hydraulic Gradient = 0.0050 m/m  Overland flow velocity = 0.05 m/s  Time over pathway = 2000 s
		Time of concentration for area = 55.45 minutes

Existing Polytunnel Scenario, Starts at 64.5mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface.  Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels	
Runoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity; however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable. The focussed channelling of rainfall into polytumnel leg channels decreases runoff generation time, however, this is offset by straw filled polytumnel leg channels.	Runoff generation time = 570 s
From 64.5m AOD to 64m AOD runoff travels a mean distance of 80m along polytumnel leg row channels (trapezoid shaped with 600mm bed base) to the field boundary. Straw in the channels naturally accumulate at each polytumnel leg stand producing a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient = 0.0039 m/m  Leg Channel flow velocity = 0.09 m/s*  Time over pathway = 842 s
eg channel flow is dispersed by vegetation and wide headland at polytumel ends. From 64mAOD to 63.5mAOD runoff travels a mean distance of 100m over and along headland at field boundary to the bunded area.	Hydraulic Gradient = 0.0050 m/m  Overland flow velocity = 0.05 m/s  Time over pathway = 2000 s
Sundage area storage capacity = 75m <sup>3</sup> . When overspills will accumulate and pond on low point of field. Time to overspill based on upper limit of runoff at 40 litres/sec/hectare.	Time to overspill ≃ 1875 s
leg channel velocity calculation is based on a 1 in 100 year storm event for the critical infall intensity, a singular polytunnel runoff area and a reduction in gradient due to coumulation of straw at leg stands.	Time of concentration for area = 88.62 minutes

Brief description of the pathways for the time of concentration for sub-catchment area B for the meadow, row crop and existing polytunnel scenario.

Meadow Scenario. Starts at 64.5mAOD. Rainfall falls onto meadow area.			
moff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity, however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable.	Runoff generation time =	720	s
From 64.5mAOD to 59mAOD runoff travels a mean distance of 200m over grassland to point where gradient decreases	Hydraulic Gradient =  Overland flow velocity =  Time over pathway =	0.0275 0.1 2000	m/m m/s s
From 59mAOD to 56mAOD runoff travels a mean distance of 190m over grassland to field boundary where it leaves farm catchment area	Hydraulic Gradient = Overland flow velocity = Time over pathway =	0.0158 0.09 2111	m/m m/s
Tim	e of concentration for area =	80.52	minute

Row Crop Scenario. Starts at 64.5m AOD. Ramfall falls onto row crop area			
Runoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity, however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable.	Runoff generation time =	600	\$
Emm 64 5m 40D to 60 5m 40D ====655===============================	Hydraulic Gradient =	0.0267	m/m
From 64.5mAOD to 60.5mAOD runoff travels a mean distance of 150m along row crop orientation to point where gradient decreases.	Overland flow velocity =	0.22	m/s
	Time over pathway =	682	
	<del></del>		
imm 60 5m 40D to 56m 40D man 6 to man district to 2000 to 1 t	Hydraulic Gradient =	0.0161	m/m
From 60.5mAOD to 56mAOD runoff travels a mean distance of 280m along path of least resistance to headland and field boundary where it leaves the farm catchment area.		0.0161	m/m m/s
rom 60.5mAOD to 56mAOD runoff travels a mean distance of 280m along path of least resistance to headland and field boundary where it leaves the farm catchment area.	Hydraulic Gradient =		

Existing Polytunnel Scenario. Starts at 64.5mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface.  Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels			
Runoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity, however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable. The focussed channelling of rainfall into polytumnel leg channels decreases runoff generation time, however, this is offset by straw filled polytumnel leg channels.	Runoff generation time =	570	8
From 64.5mAOD to 60.5mAOD runoff travels a mean distance of 150m along polynumel leg row channels (trapezoid shaped with 600mm bed base). Straw in the channels naturally accumulate at each polynumel leg stand producing a reduced runoff slope angle	Hydraulic Gradient =  Leg Channel flow velocity =	0.0067	m/m m/s*
and a weir effect thereby reducing velocities.	Time over pathway =	1000	S
Leg channel flow is dispersed to overland flow at polytunnel ends. From 60.5mAOD to 58mAOD runoff travels a mean distance of 170m as overland flow following path of least resistance.	Hydraulic Gradient = Overland flow velocity =	0.0147	m/m m/s
	Time over pathway =	944	S
From S8mAOD to 56mAOD runoff travels a mean distance of 110m as overland flow through small grain crop to headland and field boundary consisting of a wide swath of heavily vegetated hedgerow.	Hydraulic Gradient = Overland flow velocity =	0.0182	m/m m/s
	Time over pathway =	550	S
leg channel velocity calculation is based on a 1 in 100 year storm event for the critical sinfall intensity, a singular polytunnel runoff area and a reduction in gradient due to Compulation of straw at leg stands.	ime of concentration for area =	51.57	minu

Brief description of the pathways for the time of concentration for sub-catchment areas C, D and E for the meadow, row crop and existing polytunnel scenario.

	Time of concentration for area =	100.45	minute
	Time over pathway =	1119	· <b>5</b>
From 41mAOD to 39mAOD runoff travels a mean distance of 470m through a heavily vegetated trapezoid shaped channel (1000mm wide bed base with 1m/m channel sides) before entering the River Wye.	Channel flow velocity =	0.42	m/s
	Time over pathway =  Hydraulic Gradient =	0,0043	s m/m
rom 47mAOD to 41mAOD, in the event of an overspill, flow becomes overland flow and channel flow over 280m. Channel would develop with trapezoid shape as flow follows path of least resistance (~1,2m bed base and 0.2m/m side slopes).	Hydraulic Gradient =  Channel flow velocity =	0.0214	m/m m/s
	Time over pathway =	248	s
lowing to small heavily vegetated trapezoid shaped channel (1000mm wide bed base with 1m/m channel sides). Maximum pe flow = 72m <sup>3</sup> /hr or 11/s/hectare for farm catchment. Once pipe flow is exceeded and the overspill at the pipe entrance is also exceeded, flow resorts to overland flow that eventually forms a channel to the pipe outlet.		1.13	m/s
From 45mAOD to 41mAOD flow enters 150mm smooth edge ceramic drainage pipe and travels a mean distance of 280m,	Hydraulic Gradient =	0.0143	m/m
ow enters a 150mm smooth edge pipe at 45mAOD. Maximum pipe flow = 860m³/hr or 20t/s/hectare for farm catchment area.	Time over pathway =	6	s
At 47mAOD, flow leaves pond through a 300mm smooth edged pipe that has half the pipe submerged in pond. This extends approximately three metres. The flow then leaves pipe and falls approximately 1m vertically into a guttering system. This guttering also comprises a 300mm smooth edge pipe that turns and runs horizontally under the pond embankment for proximately 20m and outfalls into small overflow storage area (capacity ~ 3m <sup>3</sup> ) on opposite side of embankment. From here	Hydraulic Gradient =  Max pipe flow velocity =	0.0500	m/m m/s
	i.e. capacity/(area*ROC*critsto	rmintensity/	secinhr)
pipe submerged in pond. Overflow storage capacity to top of pipe = 50m x 20m x 0.15m (Note: Actual overflow storage capacity of pond is much greater than to the top of pipe if pipe maximum discharge is exceeded)	Pond recession time =	643	s
At 47mAOD, the channel enters a large pond (rectangular to oval in plan view) that is surrounded by woods and heavy regetation. Pond is approximately 20m wide where channel enters. Flow leaves pond through a 300mm pipe that has half the	Storage capacity =	150	m3
	Time over pathway =	212	S
trapezoid shaped channel (600mm wide bed base with 1m/m channel sides) to a large ponded area (Pond No.3).	Channel flow velocity =	0.52	m/s
From 48mAOD to 47mAOD flow leaves drainage pipe and travels a mean distance of 110m along small heavily vegetated	Hydraulic Gradient =	0.0091	m/m
	Time over pathway =	2	<b>5</b> .
pezoid shaped channel (400mm wide bed base with 1m/m channel sides). Maximum pipe flow = 1000m <sup>3</sup> /hr or 431/s/hectare for farm catchment	Max pipe flow velocity =	3.90	m/s
om 48.5mAOD to 48mAOD flow enters drainage pipe and travels a mean distance of 7m, flowing to small heavily vegetated	Hydraulic Gradient =	0.0714	m/m
	Time over pathway =	59	S
rom 49mAOD to 48.5mAOD runoff leaves ponded area and travels a mean distance of 30m through small heavily vegetated apezoid shaped channel (400mm wide bed base with 1m/m channel sides) to a dramage pipe (300mm flat sided ceramic pipe) that runs under public highway.	Hydraulic Gradient = Channel flow velocity =	0.0167 0.51	m/m m/s
	i.e. capacity/(area*ROC*critste	ormintensity	/secinhr)
At 49mAOD, the channel enters a small marshy/ponded area (triangular in plan view) that is wooded and heavily vegetated causing the channel to disperse overland. Storage capacity = 20m x 10m x 0.3m	Pond recession time =	603	S
	Time over pathway =  Storage capacity =	1103	m3
rom 55mAOD to 49mAOD runoff travels a mean distance of 430m through small heavily vegetated trapezoid shaped channel (400mm wide bed base with 0.2m/m channel sides) to a heavily vegetated and wooded ponded area (Pond No.1).	Channel flow velocity =	0.0140	m/m m/s
	Time over pathway =		· s
From 64.5mAOD to 55mAOD runoff travels a mean distance of 170m over grassland to field boundary and small vegetated trapezoid shaped channel on opposing side of hedgerow.	Hydraulic Gradient = Overland flow velocity =	0.0559	m/m m/s
unoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted, he overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity however, using the 1 m 100 year storm event a runoff generation time is estimated that is considered reasonable.		720	·s
Meadew Scenario, Starts at 64.5mAOD. Rainfall falls onto meadow area.			

Row Crop Scenario. Starts at 64.5mAOD. Rainfall falls onto row crop area			
Now Crop Scenario. States & V4. Just C12. Regulate this Otto Tow Grop mea			
Runoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity, however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable.	Runoff generation time =	600	s
From 64.5mAOD to 57.5mAOD runoff travels a mean distance of 1.70m along row crop orientation to field boundary and a heavily vegetated and wooded area.	Ity draulic Gradient =  Overland flow velocity =  Time over pathway =	0.0412 0.28 607	m/m m/s
From 57.5mAOD to 55mAOD runoff travels a mean distance of 70m through heavily vegetated wooded area before entering small heavily vegetated trapezoid shaped channel.	Hydraulic Gradient = Overland flow velocity =	0.0357 0.14	m/m m/s
From 55mAOD to 49mAOD runoff travels a mean distance of 430m through small heavily vegetated trapezoid shaped channel (400mm wide bed base with 0.2m/m channel sides) to a heavily vegetated and wooded pended area (Pond No.1).	Time over pathway =  Hydraelic Gradient =  Channel flow velocity =	0.0140 0.42	m/m m/s
At 49mAOD, the channel enters a small marshy/ponded area (triangular in plan view) that is wooded and heavily vegetated causing the channel to disperse overland. Storage capacity = 20m x 10m x 0.3m.	Time over pathway =  Storage capacity =  Pond recession time =	1024 60 307	m3 3
From 49mAOD to 48.5mAOD runoff leaves ponded area and travels a mean distance of 30m through small heavily vegetated rapezoid shaped channel (400mm wide bed base with 1m/m channel sides) to a drainage pipe (300mm flat sided ceramic pipe) that runs under public highway.	i.e. capacity/(area*ROC*crits  Hydraulic Gradient =  Channel flow velocity =	0.0167 0.58	m/m m/s
From 48.5mAOD to 48mAOD flow enters drainage pipe and travels a mean distance of 7m, flowing to small heavily vegetated apezoid shaped channel (400mm wide bed base with 1m/m channel aides). Maximum pipe flow = 1000m³/hr or 43l/s/hectare for farm catchment	Time over pathway =  Hydraulic Gradient =  Max pipe flow velocity =  Time over pathway =	0.0714 3.90	m/m m/s
From 48mAOD to 47mAOD flow leaves drainage pipe and travels a mean distance of 110m along small heavily vegetated trapezoid shaped channel (600mm wide bed base with 1m/m channel sides) to a large ponded area (Pond No.3).	Hydraulic Gradient =  Channel flow velocity =	0.0091	no/m m/s
at 47mAOD, the channel enters a large pond (rectangular to oval in plan view) that is surrounded by woods and heavy vegetation.	Time over pathway =  Storage capacity =	193 150	ъ т3
ond is approximately 20m wide where channel enters. Flow leaves pond through a 300mm pipe that has half the pipe submerged in pond. Overflow storage capacity to top of pipe = 50m x 20m x 0.15m (Note: Actual overflow storage capacity of pond is much greater than to the top of pipe if pipe maximum discharge is exceeded)	Pond recession time =	409	8
At 47mAOD, flow leaves pond through a 300mm smooth edged pipe that has half the pipe submerged in pond. This extends proximately three metres. The flow then leaves pipe and falls approximately 1m vertically into a guttering system. This guttering to comprises a 300mm smooth edge pipe that turns and runs horizontally under the pond embankment for approximately 20m and	i.e. capacity/(area*ROC*crits Hydraulic Gradient =	tormintensit 0.0500	ty/secin m/m
outfalls into small overflow storage area (capacity ~ 3m³) on opposite side of embankment. From here flow enters a 150mm smooth edge pipe at 45mAOD. Maximum pipe flow = 860m³/hr or 20l/s/hectare for farm catchment area.	Max pipe flow velocity =  Tune over pathway =	3.32 6	m/s s
om 45mAOD to 41mAOD flow enters 150mm smooth edge ceramic dramage pipe and travels a mean distance of 280m, flowing of small heavily vegetated trapezoid shaped channel (1000mm wide bed base with 1m/m channel sides). Maximum pipe flow = m³/hr or 11/s/hectare for farm catchment. Once pipe flow is exceeded and the overspill at the pipe entrance is also exceeded, flow resorts to overland flow that eventually forms a channel to the pipe outlet.	Hydrautic Gradient =  Max pipe flow velocity =  Time over pathway =	0.0143 1.13 248	m/m m/s s
From 47mAOD to 41mAOD, in the event of an overspill, flow becomes overland flow and V channel following row crop orientation.	Hydraulic Gradient = Overland flow velocity =	0.0214	m/m m/s
From 41mAOD to 39mAOD runoff travels a mean distance of 470m through a heavily vegetated trapezoid shaped channel (1000mm wide bed base with 1m/m channel sides) before entering the River Wye.	Time over pathway =  Hydraulic Gradient =  Channel flow velocity =	0.0043 0.62	m/m m/s
	Tame over pathway = of concentration for area =	758 91.06	s minut

Existing Polytunnel Scenario. Starts at 64.5mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface.  Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels			· · . · .
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unoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The		<u> </u>	: · .
overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity.			
however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable. The focussed channelling of rainfall into polytumed leg channels decreases runoff generation time, however, this is offset by straw filled	Runoff generation time =	570	.8
polytumnel leg channels.		٠.	· · · · · ·
From 64.5mAOD to 57.5mAOD runoff travels a mean distance of 170m polytunnel leg row channels (trapezoid shaped with	Hydraulic Gradient =	0.0165	m/n
600mm bed base) and is dispersed at end of channel before reaching field boundary and a heavily vegetated and wooded area.  Straw in the channels naturally accumulate at each polytunnel leg stand producing a reduced runoff slope angle and a weir effect	Leg Channel flow velocity =	0.17	m/s
thereby reducing velocities.	Time over pathway =	944	
mm 57 5m 40D to 55m 40D minoff travals a man distance of 70m distance is 5 minor to 10 min	Hydraulic Gradient =	0.0357	пуп
rom 57.5mAOD to 55mAOD runoff travels a mean distance of 70m through heavily vegetated wooded area before entering small heavily vegetated trapezoid shaped channel.	Overland flow velocity =	0.14	m/s
	Time over pathway =	1214	s
T E5 4 OT 4 O	Hydraulic Gradient =	0.0140	m/n
From 55mAOD to 49mAOD nanoff travels a mean distance of 430m through small heavily vegetated trapezoid shaped channel (400mm wide bed base with 0.2m/m channel sides) to a heavily vegetated and wooded ponded area (Pond No.1).	Changel flow velocity =	0.42	m/s
	Tune over pathway =	1024	
49mAOD, the channel enters a small marshy/ponded area (triangular in plan view) that is wooded and heavily vegetated causing the channel to disperse overland. Storage capacity = 20m x 10m x 0.3m	Storage capacity =  Pond recession time =	60 307	. —-
A TOM		307	
	i.e. capacity/(area*ROC*critst	ormintensi	ry/secir
From 49mAOD to 48.5mAOD runoff leaves ponded area and travels a mean distance of 30m through small heavily vegetated pezoid shaped channel (400mm wide bed base with 1m/m channel sides) to a drainage pipe (300mm flat sided ceramic pipe) that	Hydraulic Gradient =	0.0167	m/n
runs under public highway	Channel flow velocity =	0.58	m/s
	Time over pathway =	52	S
From 48.5mAOD to 48mAOD flow enters drainage pipe and travels a mean distance of 7m, flowing to small heavily vegetated	Hydraulic Gradient =	0.0714	m/n
pezoid shaped channel (400mm wide bed base with 1m/m channel sides). Maximum pipe flow = 1000m³/hr or 43l/s/hectare for farm catchment	Max pipe flow velocity =	3.90	m/s
	Time over pathway =	2	s .
	Hydraulic Gradient =	0.0091	m/n
From 48mAOD to 47mAOD flow leaves drainage pipe and travels a mean distance of 110m along small heavily vegetated		0.0091	iTN
trapezoid shaped channel (600mm wide bed base with 1m/m channel sides) to a large ponded area (Pond No3).	Channel flow velocity =	0.57	m/s
	Time over pathway =	193	s
			·
47mAOD, the channel enters a large pond (rectangular to oval in plan view) that is surrounded by woods and heavy vegetation.	Storage capacity =	150	m3
and is approximately 20m wide where channel enters. Flow leaves pond through a 300mm pipe that has half the pipe submerged pond. Overflow storage capacity to top of pipe = 50m x 20m x 0.15m (Note: Actual overflow storage capacity of pond is much			
greater than to the top of pipe if pipe maximum discharge is exceeded)	Pond recession time =	409	s
	i.e. capacity/(area*ROC*critsto	omintensit	v/sacin
At 47mAOD, flow leaves pond through a 300mm smooth edged pipe that has half the pipe submerged in pond. This extends			
proxumately three metres. The flow then leaves pipe and falls approximately I'm vertically into a guttering system. This guttering	Hydraulic Gradient =	0.0500	m/m
aso comprises a 300mm smooth edge pape that turns and runs horizontally under the pond embankment for approximately 20m and outfalls into small overflow storage area (capacity ~ 3m²) on opposite side of embankment. From here flow enters a 150mm			
smooth edge pipe at 45mAOD. Maximum pipe flow = 860m³/hr or 20l/s/hectare for farm catchment area	Max pipe flow velocity =	3.32	m/s
m 45mAOD to 41mAOD flow enters 150mm smooth edge ceramic drainage pipe and travels a mean distance of 280m, flowing	Time over pathway =	6	
small heavily vegetated trapezoid shaped channel (1000mm wide bed base with 1m/m channel sides). Maximum one flow =	Hydraulic Gradient =	0.0143	m/m
n3/hr or 11/s/hectare for farm catchment. Once pipe flow is exceeded and the overspill at the pipe entrance is also exceeded, flow resorts to overland flow that eventually forms a channel to the pipe outlet.	Max pipe flow velocity =	1.13	m/s
	Time over pathway =	248	s
om 47mAOD to 41mAOD, in the event of an overspill, flow becomes overland flow and channel flow over 280m. Channel is a	Hydraulic Gradient =	0.0214	m/m
short grassed, ephemeral V channel with 0.7m/m side slopes.	Overland flow velocity =	0.74	m/s
	Time over pathway =	378	\$
From 41mAOD to 39mAOD runoff travels a mean distance of 470m through a heavily vegetated trapezoid shaped channel	Hydraulic Gradient =	0.0043	m/m
(1000mm wide bed base with 1m/m channel sides) before entering the River Wye.	Channel flow velocity =	0.62	m/s
channel velocity calculation is based on a 1 in 100 year storm event for the critical rainfall	Time over pathway =	758	\$
	· · · · · · · · · · · · · · · · · · ·	<del></del>	

Brief description of the pathways for the time of concentration for sub-catchment area F for the meadow, row crop and existing polytunnel scenario.

				· · · · · · · · · · · · · · · · · · ·					
	Meadew Scenario.	Starts at 64,5m.	AOD Rainfall	falls onto mead	low area.				
•			·						
			· .						
overland flow veloci	instantaneously. Runoff ities also require time to the 1 in 100 year storm	reach maximus	n velocities. The	ese factors are	dependent on the	storm intensity,	Runoff generation time =	720	s
overland flow veloci however, using	ties also require time to the 1 in 100 year storm	reach maximum event a runoff;	n velocities. The generation time	ese factors are is estimated th	dependent on the at is considered a	storm intensity, easonable	Runoff generation time =  Hydraulic Gradient =	720 0.1100	s m/m
overland flow veloci however, using	ities also require time to	reach maximum event a runoff; an distance of 1	n velocities. The generation time	ese factors are is estimated th	dependent on the at is considered a	storm intensity, easonable		·	s m/m m/s
overland flow veloci however, using	ties also require time to the 1 in 100 year storm	reach maximum event a runoff; an distance of 1	n velocities. The generation time 00m over grass	ese factors are is estimated th	dependent on the at is considered a	storm intensity, easonable	Hydraulic Gradient =	0.1100	

Row Crop Scenario. Starts at 64.5m AOD. Rainfall falls onto row crop area			
Runoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity, however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable.	Runoff generation time ==	600	S
	Hydraulic Gradient =	0.0400	m/m
rom 61mAOD to 59mAOD runoff travels a mean distance of 50m along row crop orientation to the headland and field boundary.	Overland flow velocity =	0.29	m/s
	Time over pathway =	172	 5
	Hydraulic Gradient =	0.1143	m/m
From 59mAOD to 51mAOD runoff travels a mean distance of 70m along the headland to the low point of the hedgerow field boundary and beyond the farm catchment.	Overland flow velocity =	0.45	πı∕s
	Time over pathway =	156	s
	ime of concentration for area =	15.47	minutes

Existing Polytunnel Scenario. Starts at 64.5mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface.  Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels			
Runoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity, however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable. The focussed channelling of rainfall into polytunnel leg channels decreases runoff generation time, however, this is offset by straw filled polytunnel leg channels.	Runoff generation time =	570	<b>.</b>
From 61mAOD to 59mAOD runoff travels a mean distance of 50m along polytennel leg row channels (trapezoid shaped with 600mm bed base) to the wide vegetated headland and heavily vegetated and tree lined field boundary. Straw in the channels naturally accumulate at each polytennel leg stand producing a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient =  Leg Channel flow velocity =  Time over pathway =	0,0160 0,13 343	m/s*
Leg channel flow is dispersed by vegetation and wide headland at polytumnel ends. From 59mAOD to 51mAOD mnoff travels a mean distance of 70m along the headland and vegetated and tree lined hedgerow to the low point of the hedgerow field boundary and beyond the farm catchment.	Hydraulic Gradient =  Overland flow velocity =  Time over pathway =	0.1143 0.45 156	m/m m/s s
*leg channel velocity calculation is based on a 1 in 100 year storm event for the critical rainfall intensity, a singular polytunnel runoff area and a reduction in gradient due to accumulation of straw at leg stands.	Time of concentration for area =	18.31	minutes

Brief description of the pathways for the time of concentration for sub-catchment area G for the meadow, row crop, existing polytunnel scenario, and 50% reduction in existing polytunnel scenario.

M	eadow Scenario. S	tarts at 64.5mAOD. Rainfal	l falls onto meadow area.				
tunoff is not generated instants overland flow velocities als	so require time to n	each maximum velocities. T	hese factors are depender	it on the storm intensity,	The Runoff generation time =	720	
moworet, using the 1	in touyear storm e	vent a funoff generation tim	e is estimated that is cons	sidered reasonable.		720	Þ
From 61mAOD to 39mAOD	· · · · · · · · · · · · · · · · · · ·				Hydraulic Gradient =	0.0759 0.21 1381	m/m m/s

								<i>:</i>
noff is not generate	ed instantaneously. Rur	moff will occur on	ce infiltration rates are o	exceeded and the grou	und has been wetted.			
	VICTIAC BIGA MONITOR THAT	RD 30 FEEDIN WISVIEN	ing the contract of the second					
however, us	locities also require time sing the 1 in 100 year sk	ne to reach maxim	im velocities. These lac	imated that is conside	red reasonable	Runoff generation time =	600	. <u>s</u>
however, us	ing the 1 in 100 year st	ne to reach maxim	im velocities. These tak	imated that is conside	red reasonable	Runoff generation time =  Hydraulic Gradient =		s m/n
however, us	sing the 1 in 100 year sk	itorm event a runoi	f generation time is esti	imated that is conside	red reasonable.	Hydraulic Gradient =	0.0759	m/n m/s

Existing Polytunnel Scenario. Starts at 64.5mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface.  Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels			· · · ·
Runoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity, however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable. The focussed channelling of rainfall into polytunnel leg channels decreases runoff generation time, however, this is offset by straw filled polytunnel leg channels.	Runoff generation time =	570	s
From 61mAOD to 39mAOD runoff travels a mean distance of 290m along polytunnel leg row channels (trapezoid shaped with 600mm bed base) with three tracks intersected along the runoff path until runoff reaches a the wide vegetated headland and heavily vegetated field boundary. Straw in the channels naturally accumulate at each polytunnel leg stand producing a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient =  Leg Channel flow velocity =  Time over pathway =	0.0169 0.27 1036	m/m m/s*
*leg channel velocity calculation is based on a 1 in 100 year storm event for the critical rainfall intensity, a singular polytunnel runoff area and a reduction in gradient due to accumulation of straw at leg stands.	Time of concentration for area =	27.26	minutes

Existing Polytunnel Scenario with 50% reduction in polytunnels. Starts at 64.5mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface. Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels			
Runoff is not generated instantaneously. Runoff will occur once infiltration rates are exceeded and the ground has been wetted. The overland flow velocities also require time to reach maximum velocities. These factors are dependent on the storm intensity, however, using the 1 in 100 year storm event a runoff generation time is estimated that is considered reasonable. The focussed channelling of ramfall into polyturnel leg channels decreases runoff generation time, however, this is offset by straw filled polyturnel leg channels.	Runoff generation time =	570	<u> </u>
From 61mAOD to 54mAOD runoff travels a mean distance of 100m along polytunnel leg row channels (trapezoid shaped with 600mm bed base) and is dispersed at end of channels by meadow or small grain crop. Straw in the channels naturally accumulate at each polytunnel leg stand producing a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient =  Leg Channel flow velocity =  Time over pathway =	0.0156 0.22 435	m/m m/s*
From 54mAOD to 44mAOD runoff travels a mean distance of 90m as overland flow over meadow or small grain crop area to polytunnel area on lower slope.	Hydraulic Gradient = Overland flow velocity = Time over pathway =	0.1111 0.45 200	m/m m/s
From 44mAOD to 39mAOD runoff travels a mean distance of 100m along polytunnel leg row channels (trapezoid shaped with 600mm bed base) runoff reaches the wide vegetated headland and heavily vegetated field boundary. Straw in the channels naturally accumulate at each polytunnel leg stand producing a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient =  Leg Channel flow velocity =  Time over pathway =	0.0167 0.24 417	m/m m/s*
*leg channel velocity calculation is based on a 1 in 100 year storm event for the critical rainfall intensity, a singular polytunnel runoff area and a reduction in gradient due to accumulation of straw at leg stands.	ime of concentration for area =	27.52	minute

# Appendix C

**Tabulated Results** 

Tabulated results for sub-catchment area A for the meadow, row crop and existing polytunnel scenario including critical rainfall intensities, times of concentration and runoff coefficients used to compile results for each scenario.

Row Crop Scenar	io. Critical Storm Peak discharge (i time of couce	n <i>litres/second/kectare</i> ) for Area A using longest atration		Time of concentration =	55,45	minutes
		Weighted ROC's  0.486 0.533 0.580 0.628	Critical Storm Rainfall Intensity (mm/hr)	Hedgerow and headland =  Row Crop =	ROC 0.25 0.5 - 0.65	Area (m²) 560 9440
FEH Storm Event	l in 10 year l in 100 year l in 100 year + 20%	17 19 20 27 33 36 39 43 40 43 47 51 htres/second/hectare	13 24 29			

Meadow Scenari	io. Critical Storm Peak discharge ( time of conc		d/hectare) for	r Area A usi	ng longest		Time of concentration =	68.67	minutes
			Weighte	ed ROC's		Critical Storm Rainfall Intensity	Hedgerow =	ROC 0.25	Area (m²) 280
		0.347	0.396	0.444	0.493	(mm/br)	Meadow=	0.35 - 0.5	9 720
E to	l in 10 year	11	13	14	16	11			
FEH Storm Event	1 in 100 year	21	24	27	30	22			
<u>F</u>	1 in 100 year + 20%	26	29	33	36	27			
			litres seco	nd hectare			:		

Existing Polymercel Sector to Critical Storm Freit using hought that t	(	*****	Auctors) la	Ama A		Time of concessors	### ####	Inimales
		Weighte	i ROC's		Catocal Stocas	Dondage /	74.00	***
					Ramfell Lateraute (menetate)		RCC	Alex (az²)
1 in 10 year	18	0.649 18	1 <del>8</del> 0.663	0.676	10	Hedgerow and head Polymenel weig		840 6 700
1 in 100 year	34	33 	<b>36</b>	37	<b>19</b>		mole* 55.55	2.600
i in 100 year + 20%	41	42 Kires/seco	43 idhemore	- 44	23	Small Gram (	10p+ 0.36	460

Tabulated results for sub-catchment area B for the meadow, row crop and existing polytunnel scenario including critical rainfall intensities, times of concentration and runoff coefficients used to compile results for each scenario.

Row Crop Scena	rio. Critical Storm Peak discharge (in time of concent	litres/second/hecture) for Area B using langest ration		Time of concentration =	45.93	minutes
		Weighted ROC's  0.497 0.546 0,595 0.645	Critical Storm Ramfall Intensity (mm/hr)	Hedgerow and headland= Row Crop =	ROC 0.25 0.5 - 0.65	Area (m²) 1 500 111 500
FEH Storm Event	1 in 10 year 1 in 100 year 1 in 100 year + 20%	18     20     22     24       36     40     43     47       43     48     52     56       https://second/hectare	13 26 31			

Meadow Scenario	o. Critical Storm Peak discharge (in time of conce		hectare) for	Area B usin	g longest		Time of concentration =	80.52	minutes
			Weighte	ed ROC's		Critical Storm Rainfall Intensity	Hedgerow =	ROC 0.25	Area (m²)
		0.349	0.399	0.449	0.498	(mm/hr)	Meadow=	0.35 - 0.5	112 250
E +	1 in 10 year	10	12	13	15	11			
FEH Storm Event	l in 100 year	20	23	26	28	20			
щ	1 in 100 year + 20%	24	27	31	34	25			
			litres/seco	nd hectare					

Existing Polyment Scenario, Critical Signal Principal Signal Principal Signal S	ak discharge (in <i>Noverhe</i> cond/hesters) for A e of equentishin	rea B	Time of openeration +	St 37 minutes
	Weighted ROC's	Craicat Securi Raminal	Helpson and leadand=	ROC Ansa (m²)
€ 1.ab 1€ year	0510 0.540 0.549 19 19 20	0.550 (manufact)	Polytamel wedgined** Track**	6 79-985 \$2-950 0.55 \$00
1.00 (0 year)	27 38 38 44 45 46	JF 25	Smull Geom Crop-	o.30 \$7 600
	** Errorsecond heatare			

Tabulated results for sub-catchment areas C, D and E for the meadow, row crop and existing polytunnel scenario including critical rainfall intensities, times of concentration and runoff coefficients used to compile results for each scenario.

Row Crop Scenario.	. Critical Storm Peak discharge using longest time o			for Area C,	D and E		Time of concentration #	91.06	minutes
		0.489	Weighte	od ROC's 0.584	0.632	Critical Storm Rainfall Intensity (mm/hr)	Hedgerow and headland= Row Crop=	ROC 0.25 0.5 - 0.65	Area (m²) 18 220 724 280
E 52	l in 10 year	14	15	16	18	16	Thick grass and woodland=	0.15	12 000
FEH Sto Eveni	l in 100 year	26	29	31	34	19			
<b>Þ</b> i	1 in 100 year + 20%	31	34	37	40	23			
	·		litres/seco	nd/hectare	•				

Mes	adow Scenario	o. Critical Storm Peak discharge using longest time o		-	or Area C, I	D and E		Time of concentration =	100.45	minutes
				Weighte	ed ROC's		Critical Storm Rainfall Intensity	Hedgerow=	ROC 0.25	Area (m²) 9 1 10
<u> </u>			0.347	0.395	0.443	0,492	(mm/br)	Meadow=	0.35 - 0.5	733 390
	form nt	I in 10 year	9	10	12	13	10	Thick grass and woodland=	0.15	12 000
	FEH Storm Event	1 in 100 year	18	20	22	25	18			
'	-	1 in 100 year + 20%	21	24	27	30	22			
				litres/seco.	nd hectare					

Weighted ROC's State Reviews Review	
Thick grow and woodland* 0.5 -0.65 32  Weighted RGC's Storm Rew Crop * 0.5 -0.65 35  Rew Crop *	
Weighted ROCs States Reference 0.5 - 0.65 59 Reference and Anadisade 0.25 25	
Routest Performe and Annalised 025 27	.000
	330
	760
1 of 10 year. 72 Y3 13 14 (h) Track= 035 14	966
	666
https://www.llectare	940

Tabulated results for sub-catchment area F for the meadow, row crop and existing polytunnel scenario including critical rainfall intensities, times of concentration and runoff coefficients used to compile results for each scenario.

Row Crop Scenario.	Critical Storm Peak discharge (in time of concents	itres/second/hecture) for Area F using longest ration.		Time of concentration =	15.47	minutes
		Weighted ROC's  0.485 0.532 0.579 0.626	Critical Storm Rainfall Intensity (mm/hr)	Hedgerow and headland≃ Row Crop =	ROC 0.25 0.5 - 0.65	Area (m²) 480 7 520
FEH Storm Event	l in 10 year l in 100 year l in 100 year + 20%	17 19 21 22 37 41 44 48 45 49 53 58 litres/second/hectare	13 28 33			

Meadow Scenario	. Critical Storm Peak discharge (in time of concen		hectare) for	Area F using	g longest		Time of concentration =	18.67	minutes
			Weighte	d ROC's		Critical Storm Rainfall Intensity	Hedgerow=	ROC 0.25	Area (m²)
		0.347	0.396	0.444	0.493	(mm/br)	Meadow=	0.35 - 0,5	7 760
E +	l in 10 year	13	15	16	18	13			
FEH Storm Event	1 in 100 year	27	31	35	39	28			
<u> </u>	1 in 100 year + 20%	33	37	42	47	34			
			litres seco.	nd hectare					

Existing Polytomed Scenario. Critical Stores Peak dis- taking Joograf Sizes of t	PROBER DESCRIPTION RECORD FROM A CONTRACTOR OF THE PROBERT OF A CONTRACTOR OF THE PROBERT OF THE PROBERT OF THE		Time of quarentation	r 18.5) gardes
	Weighted ROC's	Conces Section		ROC Ame.(m²)
	0.727 0.744 0.761 0.778	Laufell Avening (norther)	Polymenel waspited Track	
1 in House	27 28 28 29	9	Haripeove and headland	- 025 720
1 in 100 year 1 in 100 year + 20%	57 59 60 61 69 70 71 74	34 34		
	hires/second/hectors			

Tabulated results for sub-catchment area G for the meadow, row crop and existing polytunnel scenario with the addition of the existing polytunnel scenario with a 50% reduction in polytunnels. Results also including critical rainfall intensities, times of concentration and runoff coefficients used to compile results for each scenario.

Row Crop Scenari	io. Critical Storm Peak discharge (in i time of concents		/hectare) for	Area G using	g longest		Time of concentration =	22.08	minutes
		0.492	Weighte	d ROC's 0.589	0,637	Critical Storm Rainfall Intensity (mm/hr)	Hedgerow and headland= Row Crop =	ROC 0.25 0.5 - 0.65	Area (m²) 2 400 71 600
orm	l in 10 year	19	20	22	24	14			
FEH Storr Event	1 in 100 year	39	43	47	51	29			
E.	1 m 100 year + 20%	47	52	36	61	34			
•		· · · · · · · · · · · · · · · · · · ·	htres/seco	nd/hectare					

Meadow Scenario	Meadow Scenario. Critical Storm Peak discharge (in litres/second/hectare) for Area G using longest time of concentration						Time of concentration =	35.02	minutes
			Weighte	d ROC's		Critical Storm Rainfall Intensity	Hedgerow=	ROC 0.25	Area (m²)
		0.348	0.398	0.447	0.496	(mm/hr)	Meadow=	0.35 - 0.5	72 800
it orm	1 in 10 year	13	15	17	18	13			
FEH Storm Event	I in 100 year	27	30	34	38	27			
<b>14</b>	1 in 100 year + 20%	32	36	41	45	33			
			litres seco	nd/hectare					

Leiting Polysumed Soc	naria. Cristed Steve Peak di Wring Joseph Stee of c	NO CONTRACTO DE LA CONTRACTORIO D	racand/hactery) Str	Ares G		Tereofic	ecentratos =	27.26 n	unites
		1	Veighted ROCs		Critical Storen Reenfeli	Polyton	ad weighted*	BOC /	sess (m²)
			700 0.716	0.732	(minds)		Tester	4.55	3 300
The State of the S	l in (flayser		27 27 38 27	2# 9#	14 29	The greet of	nd heedigede d'encellande	0:35 0:15	3-690
	1 in 100 year + 20%		67 68 es/second/hectara		34				

Existing Putyment Streets with 50% reducti Critical Sterm Peak discharge in the research		and a finite of the contract of an artists of	Contract of the Contract of th	and the control of th		Thus of concentration :	27.52 spenites
					Critical		
		Weights	dROCs		Storm Ramfall Intensity	Polytence senglited	0.79-0.85 29.550
	0.489	0.497	0.505	0.512	(madu)	Tracks	0.55 9.300
1 in 10 year 100 year 1 in 100 year	19	19	19	20	14	findgen wand bendland	
1 in 100 year + 20%	19 46	39 47	柳	H H	29 34	Small Gram Coops  Takk grant and secondards	
		litres/seco	nd/heciare				