APPENDIX 7 – HYDROLOGY

WATER RESOURCES EVALUATION RELATING TO THE RETENTION OF EXISTING POLYTUNNEL DEVELOPMENT AT PENNOXSTONE COURT, KING'S CAPLE

for

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by

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WATER RESOURCES EVALUATION IN SUPPORT OF IN SUPPORT OF PROPOSED RETENTION OF EXISTING POLYTUNNELS IN ASSOCIATION WITH RAISED BED STRAWBERRY PRODUCTION AT PENNOXSTONE COURT, KING'S CAPLE, HEREFORDSHIRE, HR1 4TX

1 INTRODUCTION

This report forms part of the supporting information for a new planning application for the proposed retention of existing polytunnels in association with raised bed strawberry production at Pennoxstone Court, King's Caple, Herefordshire.

2 BACKGROUND

The Cockburn family has farmed at Pennoxstone Court since the middle of the 19th Century. Mr. Neil Cockburn, the Applicant, has used Spanish Polytunnels for growing soft fruit at Pennoxstone Court (the holding name encompassing the whole of the current Application Site) since the early 1990s, but after 2001 polytunnel coverage expanded significantly as demand for home-grown soft fruit increased (see below).

An Application for planning permission to regularise the tunnels then erected on part of the current Application Site was submitted in October 2006 (Your Ref. DCSE2006/3267/F and withdrawn in December 2006. The Council served an Enforcement Notice on 26 February 2007 in relation to the polytunnels then erected on the Site. An Appeal was lodged against this Notice (PINS Ref.: APP/W1850/C/07/2041603) and heard by public local inquiry in November 2007.

The terms of the Appeal decision left Mr. Cockburn in a position where he did not have enough land upon which he could erect polytunnels over a sufficiently long period to permit him to continue to operate a viable business (a situation he still faces [see below]), it was therefore necessary to formulate new proposals.

Revised proposals were the subject of two concurrent planning applications (Your Refs.: DCSE2008/3036/F and DCSE/3040/F), dated 19 December 2008, which were refused, under delegated powers, by decision notices dated 17 September 2009. These decisions left the Applicant in a precarious position, with commercial commitments in terms of the purchase of plants, product supply and staff contracts for the 2010 season already made, with the imminent prospect of the 2-year planning permissions granted by the Inspector lapsing in January 2010 and with inadequate lawful tunnel areas to sustain a viable business.

At a meeting between the Applicant and the Council on 12 October 2009, revised proposals and a fresh planning application were discussed between the parties and these were set out fully in a letter to Herefordshire Council dated 6 November 2009. Submission of a new application was disrupted by a requirement for the submission of an Environmental Impact Assessment in support of any Application at Pennoxstone Court.

A new planning application is now being submitted of which this report forms part of the supporting documentation.

3 REGULATION

Water has been abstracted from the River Wye for trickle irrigation at Pennoxstone Court since 1987. The crop type and therefore growing method has altered as the business has grown over time, but the abstraction (project) has been ongoing.

Under current legislation the abstraction for trickle irrigation is exempt from abstraction licensing; however upon full implementation of the Water Act 2003 abstraction for trickle irrigation will become a licensable activity. The current estimate is that the relevant parts of the act will not be implemented before April 2009 and it is possible that further delays will be experienced. It is expected that abstraction licence applications will have to be submitted before the end of 2010 and that the Agency will determine the application before 2012 or 2013. It is also expected that abstractions legally operating before the introduction of the new regulations will be allowed to continue until the licence application is determined.

On 1 March 2003 the Water Resources Environmental Impact Assessment (EIA) Regulations were introduced to ensure that new abstraction projects that were not covered by either planning or other water resources legislation could be assessed in terms of the need for an Environmental Impact Assessment (EIA). The Water Resources EIA Regulations apply to 'abstraction projects' started after their introduction. As the Pennoxstone Court abstraction commenced prior to the introduction of the regulations, the abstraction falls outside these regulations.

Therefore, as far as we are aware, while the trickle irrigation abstraction at Pennoxstone Court is unregulated, it complies with the current legal framework.

Because trickle irrigation is currently unregulated there is no requirement for irrigators to submit abstraction data to the Agency. Data covering the 2004, 2005 and 2006 irrigation seasons has been provided and is included in this report as Table 2. This information will aid the Agency in improving water resources planning for the next round of the River Wye Catchment Abstraction Management Strategy (CAMS) and aid in the assessment of impact of abstractions as part of the Review of Consents process, being undertaken under the Habitats Directive; and in planning for the introduction of trickle irrigation licensing. In submitting this data, Mr Cockburn is demonstrating the historic and ongoing need for the water, while supporting the Agency's desire for information and data.

The Review of Consents process mentioned above is an assessment being undertaken by the Agency to determine the in-combination effects of all licensed abstractions on the River Wye SAC. The Agency is also trying to include information on trickle irrigation abstraction to improve the overall level of assessment and inform the next CAMS.

The upcoming changes in the regulatory control of trickle irrigation, together with the review of consents and the CAMS process means that the trickle irrigation abstraction at Pennoxstone Court will be reviewed in detail between 2008 and 2012 when an abstraction licence application will have to be made and determined, within the context of a much more detailed water resources management strategy and policy framework, than can be established at present. The application process may result in new conditions being placed on the abstraction.

4 IRRIGATION SYSTEM

Water for trickle irrigation is abstracted from the River Wye using two bank mounted pumps located at SO 5506 2814 and SO 5722 2816 (Figure 1). Water is abstracted from the river and pumped directly to where it is used for irrigation, or to one small storage tank with a capacity of $50m^3$ (SO 5538 2854). Water is mixed (in-line) with fertilizer at 3 locations SO 5538 2854, SO 5546 2888 and SO 5703 2847 and these mixing points are fitted with non-return valves to ensure fertilizer cannot be discharged back into the river.

Irrigation at Pennoxstone Court is very carefully controlled using an Enviroscan system, which monitors soil moisture deficit (SMD) at pre-determined depths in the strawberry beds using Frequency Domain Reflectometry. There are 20 monitoring locations in representative areas of the cropping area. The

SMD recorded is immediate, rather than retrospective which is usual with some neutron probe systems. Readings are taken on a weekly basis by an agronomist advisor from KG Growers, the marketing group that Pennoxstone Court grow for, who is based on site. This "real time" SMD data is used to plan the irrigation application for the coming week. Cropping at Pennoxstone Court currently consists of strawberries, raspberries and blueberries, grown in raised beds.

The growing method and irrigation system described above has been operating at Pennoxstone Court for several years and the same system will operate in the future. The planning application in question **will not increase** the annual abstraction volume or abstraction rates from the River Wye over that which is currently undertaken.

5 ABSTRACTION AND IMPACT ON RIVER FLOWS

The River Wye from which the abstraction takes place, is designated as both a Site of Special Scientific Interest (SSSI) and a Special Area of Conservation (SAC). The Agency is concerned that the Pennoxstone Court abstraction, along with other abstractions from the Wye and its tributaries may have an adverse effect upon SAC features through flow depletion and resultant loss of marginal habitat. Due to the nature of irrigation the Pennoxstone Court abstraction will usually coincide with summer low flow periods. However, it must be stressed that the abstraction is not new and is well established within the Wye system.

5.1 River Flow Calculations

Flows in the River Wye are gauged by the Agency at Belmont (SO 485 388, station number 55002) and Redbrook (SO 528 110, station number 55023). The Pennoxstone Court abstraction point is located approximately 30km downstream of the Belmont gauge and approximately 50km upstream of the Redbrook gauge (Figure 2). The abstraction point drains a catchment area of 3127.5km^2 which represents approximately 78% of the size of the catchment at the Redbrook gauge. Summary information for the Wye at the Belmont and Redbrook gauging stations and estimated figures for the abstraction point are given in Table 1 below. The data for the abstraction point have been estimated using an areal reduction of the Redbrook data using the ratio of catchment areas.

Table 1 Summary data for gauging stations and abstraction point

	Belmont Gauging Station**	**Abstraction point (*estimation*)**	**Redbrook Gauging Station****
Station number	55002	-	55023
Catchment Area (km2)	1895.9	3127.5*	4010
Station elevation (mOD)	46.3	-	9.2
Q95 flow (m3/s)	6.1	8.89	11.40
Mean flow (m3/s)	47.4	57.6	73.9
Q10 flow (m3/s)	113.3	135.7	174.0
Average Annual rainfall (61-90) (mm)	1231	-	1011

* Reference 1 (Flood Estimation Handbook)
** Reference 2 (National River Flow Archive)

The gauged flows from the Redbrook gauging station include the effect of all the abstraction upstream from the gauge, including the Pennoxstone Court abstraction. Where data is available on abstraction the measured flows can be “naturalised”, that is the abstracted water be added back to the measured flows, in order to generate a “natural” flow. In this case, no naturalisation of flow has been carried out due to abstraction data only being available for the Pennoxstone Court abstraction for the years 2004 – 2006 (inclusive) and no data being available to JDIH on actual abstraction by the many other abstractors from the river. The lack of naturalisation will result in the calculated impacts being conservative. The degree to which this effects the assessment is discussed below.

The standard measure of low flow that is generally accepted by the Agency and hydrologists is the flow in a watercourse which is exceeded 95% of the time (Q95 flow). That is, flows are less than this figure for only 5% of the time. The Q95 flow is derived from a statistical analysis of the gauged flow record. Because the Q95 flow is based upon analysis of real flow data it is sensitive to the period of data used in the calculation.

5.2 Impact Calculations

The abstraction totals (cumulative over both abstraction points) spanning 2004 to 2006 for irrigation at Pennoxstone Court are shown in Table 2 below. Abstraction rates will not change in the future as a result of the planning application being granted.

Table 2 Abstraction rates from the River Wye & annual total gauged flow in the Wye

Year	Hourly Abstraction m^3	Daily Abstraction* m^3	Annual Abstraction m^3	Annual Estimated Total Flow** in River Wye at Abstraction Point (m^3)	Annual Total Flow** in River Wye at Redbrook Gauge (m^3)
2004	150	2,250	95,928	1,820,766,695	2,334,316,276
2005	150	2,250	97,181	1,480,515,693	1,898,097,042
2006	150	2,250	95,928	1,737,261,531	2,227,258,373
Mean	*150*	*2,250*	*96,346*	*1,679,514,640*	*2,153,223,897*

** Estimated from pump capacity and pumping hours*
*** Total flow estimated from annual average daily mean gauged flow in the Wye at Redbrook*

The impact of abstraction on the flow in the River Wye at Pennoxstone Court is shown in Table 3 below.

Two measures of impact have been used. The first is the point impact of the abstraction on the low flow (Q95) in the river and the second is on the overall annual water resource in the river. The total annual water resource has been taken as the mean annual total flow measured at Redbrook (Table 2) and reduced to compensate for catchment area at Pennoxstone Court (areal reduction).

Table 3 Impact of abstraction

	Q95 gauged flow at Redbrook (Table 1) (m^3/s)	Estimated Q95 gauged flow at the abstraction point (Table 1) (m^3/s)	Percentage Impact at Redbrook Gauge	Percentage Impact at the abstraction point
Abstraction @ $150m^3/hr$	11.40	8.89	0.365%	0.469%
Annual Water Resource	-	-	0.004%	0.006%

Table 3 shows that the point impact on flow in the Wye at Pennoxstone Court is 0.47% and that the impact on the annual water resource is 0.006%.

As stated above, the calculations are based on measured rather than naturalised flows. If naturalisation were carried out, then the flow rates would be higher as a result of adding back the abstraction and therefore the impact would be less. Taking account of the Pennoxstone Court abstraction in isolation, that is taking no account of other abstractions upstream of the Redbrook gauge, the naturalised Q95 value at Pennoxstone Court is $8.94m^3/s$ and the impact reduces to 0.466%. This accuracy is beyond the accuracy of the flow gauging and it is considered that the conservative approach being adopted by not undertaking naturalisation is appropriate.

Because gauged data is being used, account is already being taken of any other abstraction upstream from the Redbrook gauge.

These flow reductions are considered by JDIH to be insignificant in terms of flow rates or volumes.

More general information on the River Wye is discussed in Section 5.3 below.

5.3 Potential Impact on the River Wye SSSI/SAC

Together the River Wye (Lower Wye) and the River Wye (Upper Wye) SSSIs and several of their tributaries represent a large, linear ecosystem which acts as an important wildlife corridor, an essential migration route, and a key breeding area for many nationally and internationally important species, including Otters. The Wye is of special interest for its associated plant and animal communities. The River Wye Special Area of Conservation (SAC) status has been designated based on the fact that the River Wye is one of the best locations for a variety of aquatic fauna and flora.

The abstraction at Pennoxstone Court is ongoing and pre-dates the SAC designation and therefore the SAC was defined based on the flow regime which includes the Pennoxstone Court abstraction.

The previous section provides a quantitative assessment of the impact on flow in the River Wye. The impact on the Q95 flow, at the abstraction point is 0.47%. At flow rates greater than Q95, the impact will be proportionately less.

The reduction in flow will result in a proportionate impact on dilution, at Q95 of 0.47%. However, we are not aware of any significant consented discharges upstream from the abstraction point which might result in such an impact causing problems relating to pollution.

It must be stressed that these abstractions have been operational for several years at these rates and that no specific impacts relating to pollution have been reported.

The abstraction will have no significant impact on higher flows in the river and therefore will not change the ability of the river to flush silt accumulation.

The proposals covered by the planning application will not increase abstraction over historic levels, which have been occurring since 1987. JDIH has not been made aware by the Agency that historic abstraction has resulted in unacceptable impacts on water resources, or the fauna and flora of the river.

Table 4 shows that the lowest flow years within the data set for the last 8 years were 2002 and 2003, based on the minimum recorded daily mean flow at the Redbrook gauge.

Table 4 Minimum, mean and maximum daily mean flow at Redbrook

Year	Agency Daily Mean Flow (m^3/s)		
	Minimum	**Mean**	**Maximum**
1999	8.4	103.4	624.6
2000	11.2	124.2	817.6
2001	12.3	84.1	497.6
2002	6.5	97.0	912.6
2003	6.2	45.7	467.9
2004	12.5	74.0	651.5
2005	9.8	60.1	485.9
2006	9.2	70.6	437.4

In order to protect low flows in rivers, the Agency often applies hands-off flow (HOF) restrictions to abstraction licences. That is, the licence states that if the flow falls below a stated level, that abstraction must stop. As discussed earlier, trickle irrigation abstraction is currently exempt from licensing control and therefore HOF restrictions cannot be applied to these abstractions. Abstraction licences in the River Wye catchment have 4 levels of HOF condition, and the particular one applied to a licence is based primarily on the age of licence. The lowest HOF condition applies to the oldest licences and is set at 604,630m^3/d (7m^3/s) over the Agency gauge at Redbrook. Even during the low flow years of 2002 and 2003 this HOF was only triggered on 7 days in total across both years. This fact is presented to illustrate that the historic abstraction within the catchment, including the abstraction at Pennoxstone Court has not resulted in frequent exceedence of the low flow protection put in place by the Environment Agency and its predecessors.

5.4 Potential Impact on the Ecology of the Wye SSSI/SAC

The small reduction in flow volume caused by the Pennoxstone Court abstraction, as calculated above, is not considered to be having a significant effect on the local habitat and/or species for which the SSSI and SAC are designated. Furthermore, what impact the abstraction does have is reduced further downstream where the flow rate increases with an increase in catchment size.

The Pennoxstone Court abstraction was already active when the River Wye was assigned SAC status and as such any possible impact it was having on the River Wye SAC was already occurring prior to designation. Furthermore, although the abstraction was not active prior to the River Wye originally being assigned SSSI status in November 1978, it was active before further designation in November 1996 and it is not considered a cause of the SSSI's current 'unfavourable with no change' condition. The reason for the adverse condition is due to fertiliser use, the presence of invasive freshwater species, siltation and water pollution from agriculture/run off and sewage discharge, particularly at Hereford. Abstraction is not listed as an issue. Although there is agricultural run off from the Pennoxstone Court site, this run off is clean with respect to suspended solids and nutrient enrichment. The very nature of well managed polytunnel growing reduces the risk of suspended solids generation and nutrient runoff.

The factors affecting the condition of the SAC according to its citation comprise water quality issues caused by nutrient run off, increased siltation and the run off from sheep dips in the area, an increased demand for recreational activities in particular fishing activities and finally increased demand for abstraction. As stated above, the abstraction at Pennoxstone Court has no bearing on nutrient runoff, increased siltation, sheep dip and increased recreational demand. As has been stated several times in this document the abstraction of water will not increase with the granting of this planning application and the Pennoxstone Court abstraction has been ongoing since prior to the designation of the River Wye SAC. Thus granting the permission will not increase the impact on the SAC.

In conclusion, there is no change proposed to the abstraction regime and statutory designations were made after the operation had commenced in the 1987. Consequently, it is considered that the continuation of the abstraction and growing processes will not have any additional impact on the River Wye SSSI or SAC.

5.5 Mitigation

The insignificant impact of abstraction is mitigated through the water efficient method of growing used and the water management system employed at Pennoxstone Court which matches irrigation to the plant requirement.

6 ASSESSMENT OF APPROPRIATE USE (WATER AUDIT)

The 'ideal' irrigation depth and water requirement for the cropping at Pennoxstone Court is shown in Table 5 below. The irrigation depth shown here are those given in the Environment Agency Best Practice Manual [Technical Report W6-056/TR: Optimum Use of Water for Industry & Agriculture: Phase III Best Practice Manual (2002)] for Agroclimatic zone 4, medium AWC soil.

Table 5 Ideal irrigation depths for cropping in 2008

	Acres	Ha	Agency Irrigation Depth (mm/Ha)	Volume (m^3)
Strawberries	76.9	30.75	235	72,623
Raspberries	32	12.8	180	23,040
Blueberries	3.0	1.2	235*	2,820
Total	*111.9*	*44.75*		*98,123*

* *No recommended depths but past experience has shown usage to be in line with that for Strawberries*

These irrigation depths are comparable to those used at the site in previous years (Table 2) and it is therefore considered that the quantities of water being applied are both appropriate and justified.

The irrigation depths given by the Environment Agency have often been shown to be lower than those historically applied by growers in the area due to many crops being grown under polytunnels rather than out in the open. With polytunnel growing the irrigation depth required in years with particularly high temperatures and light levels can be greater. Table 6 below presents the water usage that might be expected in a particularly bright and hot year; this is approximately 7% higher than the recommended volumes in Table 5 and would also be considered appropriate and justified.

Table 6 Possible elevated irrigation depths

	Acres	Ha	Pennoxstone Irrigation Depth (mm/Ha)	Volume (m^3)
Strawberries	77.0	30.75	251	77,321
Raspberries	31.9	12.8	193	24,653
Blueberries	3.0	1.2	251	3,017
Total	*111.9*	*44.75*		*104,991*

7 SUMMARY

In summary, the key points of clarification are:

- Although the abstraction at Pennoxstone Court is unregulated, it complies with the current legal framework.
- Irrigation at Pennoxstone Court is very carefully controlled using measurements of soil moisture deficit, ensuring the exact amount of water required is applied.
- The abstraction at Pennoxstone Court has been in operation since 1987 and has been at its current levels since 2004. The granting of planning permission will not result in an increase the abstraction over what is currently occurring and well established within the environmental and ecological system.
- Changes in the regulatory control of trickle irrigation means that the trickle irrigation abstraction at Pennoxstone Court will be reviewed in detail between 2010 and 2012 when an abstraction licence application will have to be submitted and determined, within the context of a much more detailed water resources management strategy and policy framework, than can be established at present.
- This report has demonstrated the historical and ongoing need for the water and presents estimates of abstracted volumes.

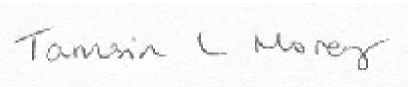
ü The impact of abstraction on the Q95 flow in the River Wye at the point of abstraction is 0.47%. This is considered to be insignificant in terms of flow rate and volumes.

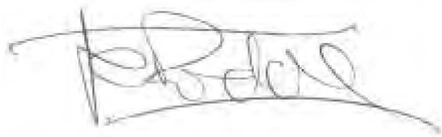
ü At higher flow rates the impact is less, and there is no significant risk to the ability of the river to flush silt.

ü It is considered that the continuation of the abstraction and growing processes will not have any additional impact on the River Wye SSSI or SAC.

We hope that the response presented above meets your requirements, but as ever if you or your colleagues have any queries or wish to discuss any aspects, please feel free to contact us.

Yours sincerely





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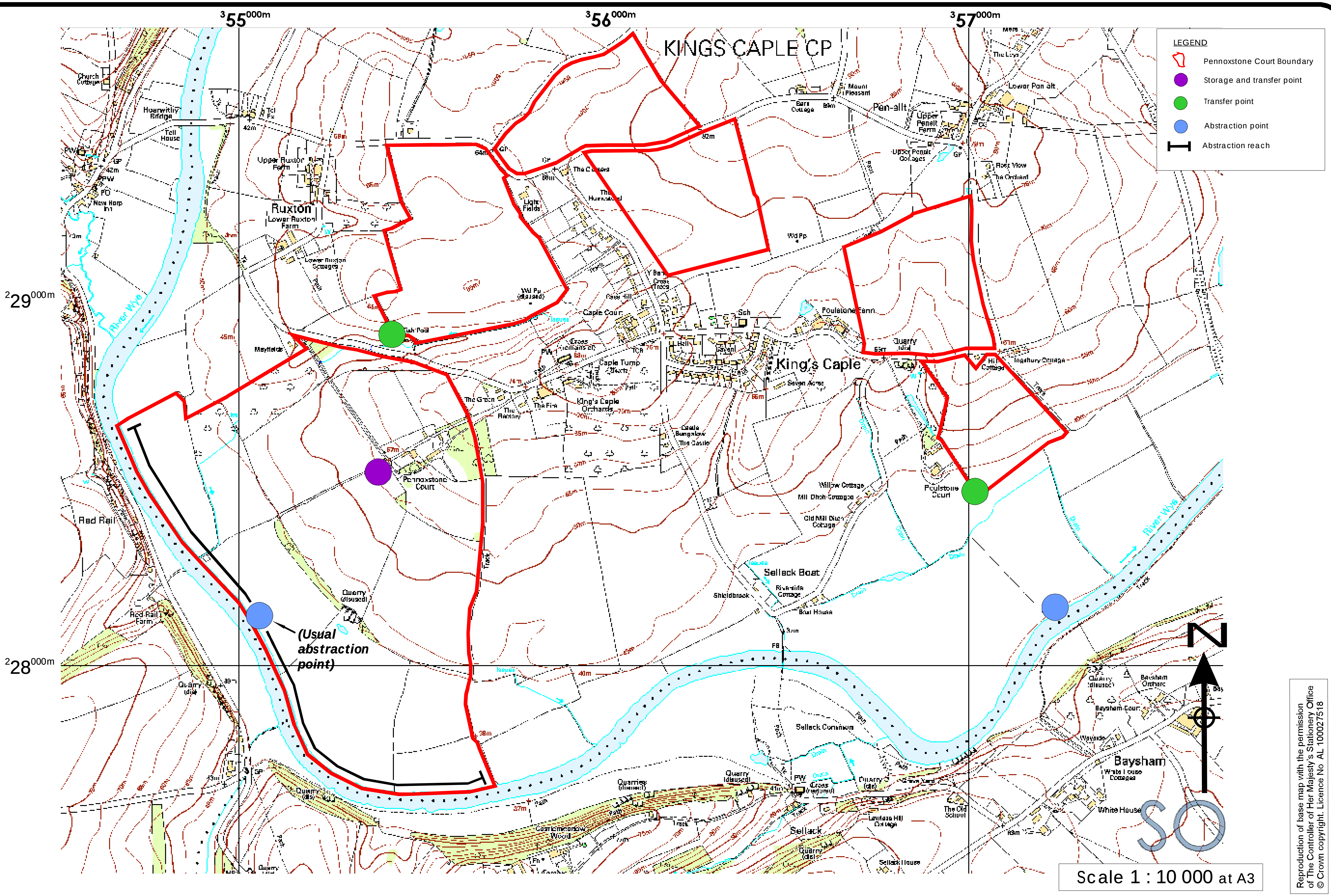
2. National River Flow Archive. Available at: http://www.nwl.ac.uk/ih/nrfa/station_summaries/055/002.html and http://www.nwl.ac.uk/ih/nrfa/station_summaries/055/023.html Accessed: 14/05/07.



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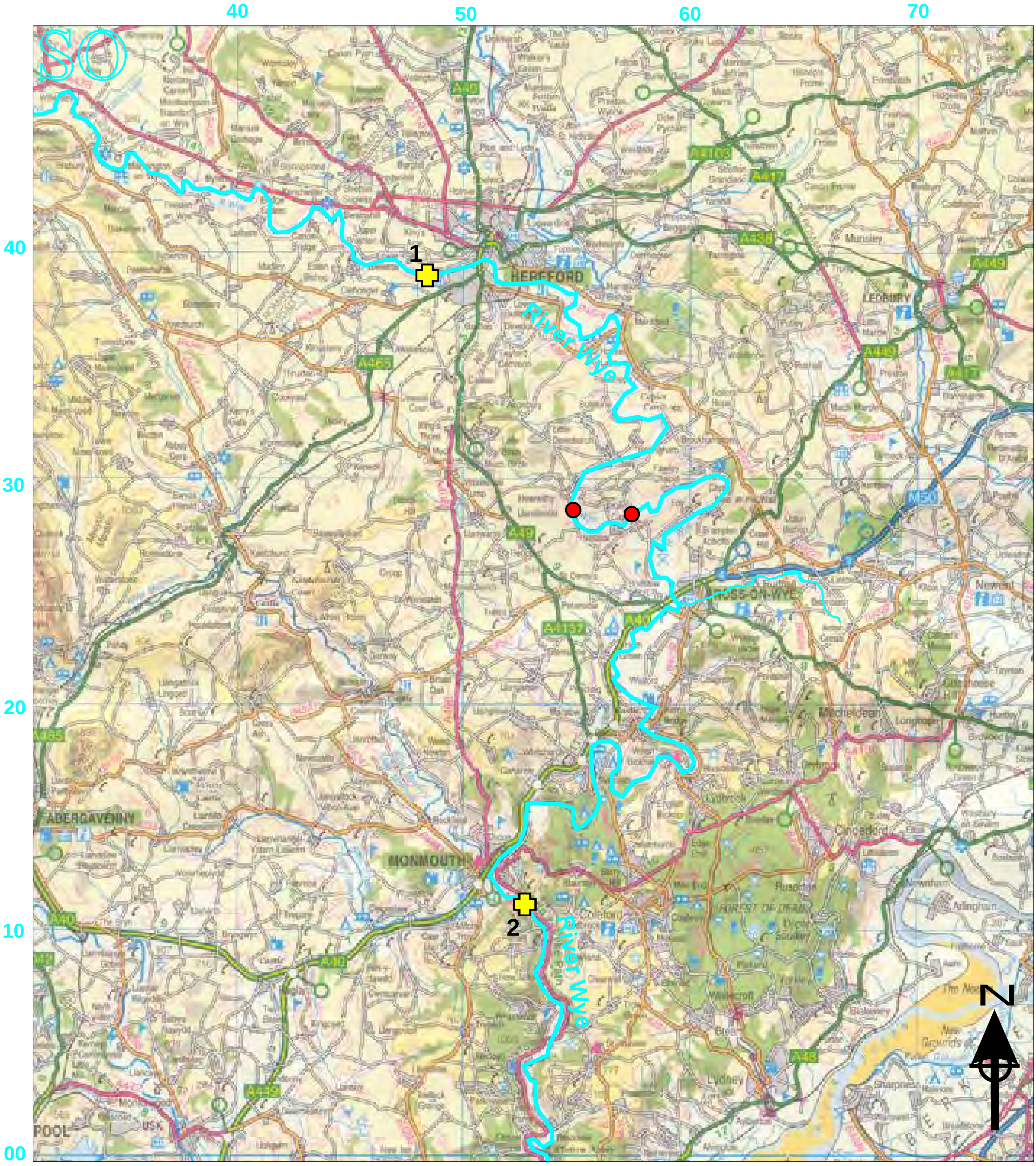
Pennoxstone Court

Figure 1

Site location plan showing abstraction points and other locations of interest



Scale 1:250 000 at A4

Environment Agency gauging station
1. Belmont (55002)
2. Redbrook (55023)

Trickle irrigation abstraction location

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Figure 2	ABSTRACTION & GAUGING LOCATIONS

POLYTUNNEL DEVELOPMENT AT PENNOXSTONE COURT, KING'S CAPLE

DRAINAGE APPRAISAL

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NON TECHNICAL SUMMARY

A planning application for 25ha/year of polytunnel (Spanish Tunnel) developments at Pennoxstone Court, King's Caple is being submitted on behalf of Mr N. Cockburn by planning consultants Antony Aspbury Associates. This drainage appraisal has been undertaken to support the application and has been written and submitted in accordance with FRA1 Guidance Note "Development greater then 1 hectare in Flood Zone 1". The principal objective of this appraisal is to demonstrate that the amount of water running off the site for the polytunnel development will not exceed the amount running off in a "Greenfield" scenario.

This report has been prepared by JDIH Envireau [JDIH], a specialist independent water resources and water management consultancy.

The appraisal follows guidelines laid out in Planning Policy Statement 25 (PPS25) and sets out calculations that were undertaken to assess "Greenfield" runoff rates for the development area and to then compare the predicted runoff rates to that of the polytunnel scenario. 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 analysis does not take account of the polytunnels only being erected between February and November. In addition, it is estimated that only 19% of the polytunnels are erected at any one time. This makes the analysis conservative.

The emphasis is that the polytunnel drainage at Pennoxstone Court is an agricultural drainage issue and not an urban drainage issue. Polytunnel drainage will be actively managed and a series of flow restrictors/dams in the polytunnel leg row channels along with wide buffer zones will aid this.

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 uses a 1 in 100 year storm as a basis, and takes into account a 20% climate change surcharge in accordance with PPS25.

This assessment has demonstrated that if the drainage of the polytunnel area is actively managed, that the peak runoff rate associated with the polytunnel development is equal too or less than that for an open meadow scenario or "Greenfield" runoff. Flow restrictors/dams placed in polytunnel leg row channels will act to reduce the rate at which runoff leaves the polytunnel area and will also provide additional storage within the channels themselves. Therefore, the leg row channels in effect become swales throughout the polytunnel areas. Polytunnel development at Pennoxstone Court will not have a detrimental impact on drainage and flooding on or off site providing the site is actively managed.

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PENNOXSTONE COURT DRAINAGE APPRAISAL

1 INTRODUCTION

A planning application for 25ha/year of polytunnel (Spanish Tunnel) developments at Pennoxstone Court, King's Caple is being submitted on behalf of Mr N. Cockburn by planning consultants Antony Aspbury Associates. This drainage appraisal has been undertaken to support the application and has been written and submitted in accordance with FRA1 Guidance Note "Development greater then 1 hectare in Flood Zone 1". The principal objective of this appraisal is to demonstrate that the amount of water running off the site for the polytunnel development will not exceed the amount running off in a "Greenfield" scenario.

The drainage appraisal includes:

1. Location plans showing geographical features, watercourses, the existing site and the development proposals.

2. 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;

3. Topographic data showing surface water flow routes from polytunnels to receiving watercourses;

4. Details of how runoff is collected and stored.

This report has been prepared by JDIH Envireau [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.

The approach taken for this study duplicates that taken in other areas, which has been reviewed and accepted by the Environment Agency.

2 SITE DESCRIPTION

2.1 General

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 85mAOD.

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 0.2˚ to 5.5˚. 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 Devonian 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.

3 QUALITATIVE ASSESSMENT OF PROPOSED POLYTUNNEL DEVELOPMENT

3.1 Hydrological characterisation of the site

Based upon a combination of Ordnance Survey topographic mapping and a detailed walk-over survey of the site undertaken by JDIH, the polytunnel area has been subdivided into ten sub-catchment areas, which are shown in Figure 2. These areas (Areas A to J) 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 2, 3 and 4.

Table 1 Characteristics of sub catchment areas A and J

Location	Hedgerow & Headland (m^2)	Thick Grass & Woodland or Grass & Orchard (m^2)	Small Grain Crop (m^2)	Hard standing (m^2)	Polytunnel Coverage for given Area (m^2)	Meadow (m^2)	Row Crop (m^2)	Track (m^2)	Total area (m^2)
Area A	840	0	2700	0	6000	0	0	460	10000
Area B	2250	0	61950	0	49000	0	0	800	114000
Area C	17700	70300	0	0	103500	88700	0	7300	287500
Area D	3330	22710	79000	0	49000	0	0	2960	157000
Area E	6300	0	254000	0	0	0	53000	3700	317000
Area F	4000	0	33000	0	46000	25000	0	2000	110000
Area G	4200	0	30300	0	72000	20000	0	3500	130000
Area H	4200	0	33300	0	71000	20000	0	3500	132000
Area I	200	0	7800	0	0	0	0	0	8000
Area J	3600	8000	43300	0	18000	0	0	1100	74000
Catchment Total	**46620**	**101010**	**545350**	**0**	**414500***	**153700**	**53000**	**25320**	**1339500**

***Note: The polytunnel areas given in this table are to assess individual sub-catchments as stand alone catchments and do not reflect the total area covered by polytunnels at any one time. The individual polytunnel coverage areas provided in this table when totalled = 41.45ha, representing 87% of the designated polytunnel area. However, the actual whole farm polytunnel coverage will be no more than 25ha (of which 3.5ha is leg row channel/swale) in the designated polytunnel areas at any one time, a percentage of 52% of the designated polytunnel area and 18.6% of the total farm area. The designated area is 35.6% of the whole farm area.**

Figure 2 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 3 complements Figure 2 and shows the areas of polytunnel development, together with the direction of overland runoff and drainage directions associated with the polytunnels. The polytunnel areas illustrated in Figure 3 forms the basis of the quantitative assessment of runoff from the site.

It is important to recognise that the hydrological characteristics of the polytunnel growing system is characterised by rural hydrology and not urban hydrology. While the polytunnels themselves form a high runoff cover, the drainage from the site is controlled by the processes at ground level, which is generally grassed, or vegetated soil, with or without artificial channels. This results in an overall low runoff velocity system. This is different from an urban setting, where development generally leads to high runoff surfaces, with drainage controlled by pipes, resulting in high runoff velocities.

Pennoxstone Court uses polytunnels to grow soft fruits in the ground. When soft fruits are grown in the ground, the drainage from the polytunnels is achieved by a series of vegetated/grass lined, straw lined or Mypex lined channels that run along the line of the polytunnel leg stands. The line of the leg stands, are commonly referred to as “leg rows”. The leg row channels will have flow restrictors in the form of dams placed at regular intervals along them (Figure 5) and if straw lined, will allow straw to accumulate at the dam. The overall result in the leg row channels is to reduce the effective gradient; increasing the resistance to flow; and therefore reduce flow velocities. In addition to straw, some leg row channels also have vegetation growing within them, which further reduces the channel velocity.

With flow restrictors in place, the leg row channels also provide storage. The net result is to reduce the flow velocities and runoff rate of the overall polytunnel area, when compared to simple open channels. The “in the ground” growing concept is summarised schematically on Figure 6. In essence the polytunnel growing system produces a series of drainage routes spaced 8m apart, which act as retention zones, seepage zones, and velocity reduction zones. Therefore, the leg row channels become swales. However, the principal difference between rural development and an urban development is that the ratio of impermeable area to swale is generally greater and more favourable than that provided in urban developments. The polytunnel leg row swales also have an advantage over urban swales in that they can also provide water storage. This is often undesirable in urban areas where there may be a health and safety issue associated with the depth of standing water.

This conceptualisation is important, as the drainage system following the establishment of the polytunnels is an agricultural drainage system and not an urban drainage system. It is therefore important that the analysis approach and technique reflects this. The polytunnel development represents one land use type. If polytunnels were not present then the land would still be farmed and this would need to be productive. The alternative land use at this site would be for the growing of lettuce, small grain crops or potatoes.

All 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”.

3.2 Polytunnel layout

Figure 3 shows 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 farm catchment area within which the polytunnels are located extends to approximately 134ha (the sum of areas A to J) of which the planning application polytunnels represent 41.45ha (Table 1). Of this, only 25ha (19% of total farm area) will have polytunnels erected at any one time.

Where applicable, the polytunnels have been placed to provide extensive buffer strips between the polytunnels and roads or property, to further aid attenuation of runoff and mitigate potential sediment mobilisation and visual impact.

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. Therefore, the polytunnels will not be sheeted for the winter months when fields are generally at field capacity and precipitation surpasses potential evapotranspiration and infiltration to ground. In these conditions, the fields will not operate hydrologically as if there were no “development”.

3.3 Polytunnel orientation and drainage

The polytunnel orientations at Pennoxstone Court are illustrated in Figure 3. 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/swales. During rainfall events the leg row channel storage comprising storage within the grass and/or straw and/or flow restrictors as well as storage related to micro-topography, will be filled, and then flow will be initiated parallel to the tunnel orientation.

At the open end of each polytunnel block, the runoff from each leg row channel/swale is dispersed by a wide vegetated headland. This is shown graphically in Figure 6.

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 in the leg row channels/swales and a bund at the low point of the area. A resulting overflow of this bund in an extreme event would cause the overspill to pond within the area.

For Area B, after initial accumulation in the leg row channels/swales 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, after initial accumulation in the leg row channels/swales runoff from polytunnels generally accumulates in natural drainage channels and ponds before entering the River Wye.

For Areas D, E and F, after initial accumulation in the leg row channels/swales runoff from the polytunnels is dispersed into overland flow and enters the floodplain of the River Wye.

For Area F, after initial accumulation in the leg row channels/swales runoff is dispersed at the end of each leg row and allowed to flow as overland flow over grassland or through small grain crops to the field boundary and adjacent highway. Runoff then makes its way to natural drainage channels before entering the River Wye.

For Area G, after initial accumulation in the leg row channels/swales runoff is dispersed at the end of each leg row and allowed to flow as overland flow over grassland or through small grain crops to the field boundary and adjacent highway at King Caple. Runoff then follows the Highways drainage route.

For Area H, after initial accumulation in the leg row channels/swales runoff is dispersed at the end of each leg row and allowed to flow as overland flow over grassland or through small grain crops to the field boundary and adjacent highway. From here, it follows the path of least resistance to a ponded area with a large freeboard and attenuation capacity at Poulstone Court before draining to the River Wye floodplain.

No polytunnels are located in Area I.

For Area J, after initial accumulation in the leg row channels/swales runoff is dispersed at the end of each leg row and allowed to flow as overland flow over grassland to the field boundary before draining to the River Wye floodplain.

The planning application for Areas A to E and J are retrospective, i.e. the polytunnels have been in place and rotated for several years. During this time, there has been no history of the polytunnels having a detrimental effect on flooding and erosion.

Wherever practical, the polytunnels have been placed and orientated to provide the optimum management of runoff water.

3.4 Sediment erosion and mobilisation

The use of grass and/or straw and/or Mypex and flow restrictors in the polytunnel leg row channels/swales, together with wide grassed headlands around the polytunnels, at Pennoxstone Court, will have a significant positive effect on further reducing the potential for soil erosion and sediment mobilisation.

Additionally, for those polytunnels situated in fields adjacent to roads and property there is provision of an extensive buffer zone providing a further reduction in potential for 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 grass and/or straw and/or Mypex and flow restrictors, leg row channel velocities are reduced. By dispersing the flow over the heavily vegetated areas or extensive buffer strips and initiating overland flow, potential rilling is alleviated and velocities are reduced. As a result, soil stability is greatly increased. Soil stability is increased further by the binding effects of the roots.

4 NEW WATER STORAGE

4.1 Proposed Runoff Storage

It is recognised that by placing flow restrictors in the leg row channels/swales in the form of small dams will provide storage within the polytunnel development. This approach has been undertaken elsewhere in the UK and agreed as suitable by the EA.

The storage in the leg row channels/swales will be developed by placing sand bags across the leg row at regular intervals to compartmentalise the channel. This forms a small dam behind which runoff is intercepted and water is stored in the leg row channels/swales and allowed to infiltrate to ground. This is illustrated schematically in Figure 5. This allows the full width of the channel to become available for infiltration, and will significantly reduce peak flows from the channel area.

Therefore, rainfall will fall on the polytunnel area with runoff from the polythene covers assumed to be instantaneous. Rainfall will then enter into the leg row channels/swales where it will accumulate behind the sand bags. Once the storage capacity behind the sand bags is exceeded flow will then enter into the next dammed compartment. At the open, lower end of the polytunnels there will be a sand bag dam. Once the capacity behind this dam is breached, flows will leave the site as overland flow via natural drainage channels.

An additional advantage to this method is that the soil moisture content directly adjacent to the leg row channels/swales will be proportionally elevated during rainfall events. This will mean that during and directly after these events less irrigation water will be required. This essentially provides a crude form of rainwater harvesting and recycling.

4.2 Leg Row Channel/Swale Storage Calculation and Design

The volume of storage in the leg row is dependent on 1) the dimensions of the leg row channel; 2) the height and spacing of the sand bags in the leg row channel; and 3) the gradient of the leg row channel. At Pennoxstone Court, the maximum and minimum gradients of the leg row channels/swales are 0.2˚ and 4.5˚ respectively, with an average gradient across the site at approximately 1.9˚ as calculated from the OS data and the site walkover survey.

Storage calculations have been undertaken using this range and incorporating sand bags placed at discrete lengths. The summary of the calculations are shown in Table 2.

Table 2 Additional storage provided by sandbag height and spacing.

Polytunnel Gradient	Sandbag Height (m)	Sandbag Spacing (m)	Additional Storage provided (m^3/ha)
Max (4.5˚)	0.2	20	17
Min (0.2˚)	0.2	20	215
Mean (1.9˚)	0.2	20	39

The methodology to calculate the additional storage area provided is as follows:

1. The total number of leg row channels/swales per polytunnel block are counted and measured to give a leg row channel length (in metres) per polytunnel block.

2. The leg row channel length per polytunnel block is then divided by the polytunnel block areas (in hectares) to give a leg row channel length per hectare of polytunnel.

3. The leg row length per hectare along with the average leg row gradient; basic trigonometry; the leg row dimensions and the sandbag height and spacing are used to calculate the additional storage that can be provided by damming the leg row channels/swales.

For the practical guidance of the tractor driver who "rows up" and the labour gangs which place and maintain the bags, notes regarding compulsion, the purpose of the bagging, the need to form effective dams, maintenance requirements, and the origin of the underlying calculations are provided in Appendix D.

5 SEQUENTIAL TEST AND EXCEPTION TEST

Land characterised by the Environment Agency (EA) as a flood risk zone that are located in the vicinity of Pennoxstone Court at illustrated in Figure 1. The flood risk zone is split into two areas that are classified by the EA as Flood Zone 2 (Medium Probability) and Flood Zone 3a (High Probability) which represent a 1 in 1000 and a 1 in 100 year flooding event, respectively. Located in Flood Zone 3a is Flood Zone 3b (The Functional Floodplain) that represents a 1 in 20 year event.

The Sequential Test from PPS25 guides new development to areas at the lowest probability of flooding (Flood Zone 1); the zones being listed in Table D.1.

When trying to identify potential areas for the polytunnel development, the majority of the proposed site was identified to be available and within Flood Zone 1 therefore meeting the criteria of the Sequential Test.

No polytunnels will be located within Flood Zone 3a or 3b. 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 Flood Zone 2 rises above this levee. Figure 3 illustrates that at certain locations, the lower edges of the polytunnels at the base of the slope infringe on Flood Zone 2.

Under guidelines laid out in PPS25, the polytunnel development has been classified (in Table D.2 in PPS25) as “less vulnerable” and the development is considered appropriate (in Table D.3 in PPS25) for Flood Zone 2.

Table D.3 of PPS25 indicates that the Exception Test is not relevant to this development.

The polytunnels located within the fringes of Flood Zone 2 will remain operational and safe during times of flood, will result in no net loss of storage from the floodplain, will not impede flood water flows and will not increase the flood risk elsewhere.

6 QUANTITATIVE DATA ANALYSIS

6.1 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 proposed polytunnel scenario versus open grassed meadow.

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.

A drawback of using the Rational method is that peak runoff rates are often over-estimated. For this reason, the polytunnel scenario is compared directly with a "Greenfield" scenario using the same approach. However, because the Rational method over estimates peak runoff rates, the approach provides a conservative analysis.

6.1.1 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.

6.1.2 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 3.

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/

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.

Table 3 Runoff coefficients used in the Rational Method

Land Use	Runoff coefficient
Track	0.55
Row Crop	0.5
Meadow	0.35 – 0.5
Polytunnels incorporating leg row swales	0.5 – 0.56 (Weighted Runoff Coefficient)
Hard Standing	0.95
Small Grain Crop	0.3
Thick Grass and Woodland	0.15
Grass and/or Orchard	0.4
Hedgerow and Headland	0.25

The weighted runoff coefficient will vary between the different runoff scenarios that have been assessed and is dependent of the extent and type of land usage within a particular catchment. By incorporating the use of flow restrictors/dams in the leg row channels/swales, the weighted runoff coefficient has been assessed to be 0.5 to 0.56 which is a significant reduction when compared to polytunnels without flow restrictors (~0.79 to 0.81). The weighted runoff coefficient employed in the calculations is slightly elevated above that of a meadow or row crop runoff coefficient to maintain a conservative approach to the comparative analysis.

6.1.3 Time of Concentration

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 4 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/swales 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/or 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 4 Overland flow velocities

Source: Hydraulic Design Manual (Texas Department of Transportation – Design Division, 2004. http://www.dot.state.tx.us/services/general_services/manuals.htm)

	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

6.2 Rainfall events and associated peak runoff rates

The peak runoff rates for the two scenarios (existing polytunnel; open meadow) 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 I 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/swales through the system; and storage in the form of ponds and leg row channels/swales before the runoff exits downstream at the farm boundary.

Table 5 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 6 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.

The results show that the range of peak runoff rates for the critical storm events for the polytunnel scenario generally falls in the same range as the open meadow scenario.

For the meadow scenario, the low return period 1 in 10 year storm gives a peak runoff of between 9 and 16l/s/ha. This can be considered as the "Greenfield Runoff". The equivalent for a 1 in 100 year storm (plus 20%) is 20 to 40l/s/ha.

For the polytunnel scenario, the low return period 1 in 10 year storm gives a peak runoff of between 9 and 14l/s/ha. The equivalent for a 1 in 100 year storm (plus 20%) is 20 to 34l/s/ha.

Table 5. 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%
Area A	Meadow Scenario	10	20	24
	Polytunnel Scenario	9	18	22
Area B	Meadow Scenario	10	19	23
	Polytunnel Scenario	10	19	23
Area C, D, E	Meadow Scenario	9	17	20
	Polytunnel Scenario	9	17	20
Area F	Meadow Scenario	11	23	27
	Polytunnel Scenario	11	23	27
Area G	Meadow Scenario	11	21	25
	Polytunnel Scenario	10	21	25
Area H	Meadow Scenario	11	22	26
	Polytunnel Scenario	10	20	24
Area J	Meadow Scenario	12	23	29
	Polytunnel Scenario	11	23	28
		mm/hr		

Table 6. Comparison of ranges of peak runoff rates for the critical storm intensities for various storm events and scenarios

		FEH Storm Event		
		1 in 10 year	1 in 100 year	1 in 100 year plus 20%
Area A	Meadow Scenario	10 - 14	19 - 27	23 - 32
	Polytunnel Scenario	11 - 12	22 - 24	26 - 29
Area B	Meadow Scenario	10 - 14	19 - 27	23 - 32
	Polytunnel Scenario	11 - 11	21 - 22	25 - 27
Area C, D, E	Meadow Scenario	9 - 12	16 - 23	20 - 28
	Polytunnel Scenario	9 - 10	17 - 18	20 - 22
Area F	Meadow Scenario	11 - 16	22 - 32	27 - 38
	Polytunnel Scenario	12 - 14	25 - 29	30 - 34
Area G	Meadow Scenario	10 - 15	20 - 29	24 - 35
	Polytunnel Scenario	12 - 14	24 - 27	29 - 33
Area H	Meadow Scenario	11 - 15	21 - 30	26 - 36
	Polytunnel Scenario	12 - 14	24 - 27	29 - 33
Area J	Meadow Scenario	11 - 16	24 - 34	28 - 40
	Polytunnel Scenario	11 - 11	22 - 23	26 - 27
		litres/second/hectare		

7 QUALITATIVE ASSESSMENT

The conclusion that the peak runoff rate when areas of land are covered by polytunnels is less than or the same as that of an open meadow 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 and maximise infiltration in the leg row channels/swales and is discharged over extensive buffer zones and meadow areas. 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 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/swales and the dispersal of drainage across meadows and buffer zones. This is different from urban drainage systems where the provision of hard standing and drains, increases flow velocities and results in the need for large storage/balancing areas 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/swales, damming the leg rows at discrete intervals and encouraging overland flow across grassland and buffer zones. Also, due to health and safety implications, urban swales are not designed to provide storage, however, the polytunnel leg row channels/swales do not have the same constraints and as such provide a degree of long term storage encouraging greater infiltration and less runoff.

8 OTHER POTENTIAL SOURCES OF FLOODING.

8.1 Streams and rivers

As previously discussed runoff from the polytunnel areas gravitates towards the River Wye floodplain with the EA Flood Zone 3a lying adjacent to the polytunnel area. This flood zone encroaches into the Pennoxstone Court field boundary but will not generate flooding for the polytunnel area.

There are no streams up gradient of the polytunnel areas that will generate direct surface runoff to the planning application area during flood events.

8.2 Sewers and road drainage

Pennoxstone court is a rural, agricultural development and as such there are no sewer systems or road drainage associated with the polytunnels areas.

The nearest sewer network and road drainage outside of the Pennoxstone Court field boundaries is that associated with the small village of King's Caple. With the exception of Area G, the polytunnels are down gradient of Kings Caple. In the absence of a sewer network, sewage is dealt with by way of a soakaway.

The village of Kings Caple and the hamlet of Ruxton are located in EA Flood Zone 1 and any flooding of the road or sewage systems will not, by nature of their development, flow into the polytunnel areas.

8.3 Reservoirs and canals

There are no reservoirs and canals up gradient of polytunnel areas.

8.4 Groundwater

Groundwater levels on the River Wye floodplain are expected to be 1 to 2m below ground level. Groundwater levels associated with the polytunnels with the lowest elevation (in closest proximity to the River Wye and the shallowest ground water) are estimated to be around 4 to 5m below ground level. These estimates are based on topography and proximity to the River Wye and its associated stage.

In the event of flooding, groundwater flooding will be that associated with the EA Flood Zone 3. It is unlikely that groundwater will be raised sufficient to induce flooding of the polytunnel areas.

9 ENVIRONMENT AGENCY CONSENTS

The polytunnel areas and associated works are not located within 10m of the River Wye river banks.

There is no requirement for an impoundment, land drainage or flood defence consent.

10 DRY ISLANDS

In the event of flooding, EA Flood Zones 2 and 3 do not surround any of the polytunnel areas therefore, no dry islands will be produced and no emergency flood ingresses/egresses are required.

11 CONCLUSIONS

This assessment has demonstrated that the polytunnel development at Pennoxstone Court will not have a detrimental impact on drainage and flooding providing that flow restrictors are provided within the polytunnel leg row channels/swales and buffer zones are located between polytunnels and field boundaries.

It is important that the drainage system is actively managed to reduce flow velocities and provide storage in the leg row channels/swales. With active water management, runoff rates for storm events will be equivalent to or less than the “Greenfield” runoff rate.

It has been shown that storage can be provided within the leg row channels/swales by using sand bags placed at specific heights and spacing to dam the channels. This restricts flows and provides an element of rainwater harvesting and recycling.

Overall, Pennoxstone Court is actively engaged in providing and maintaining a water management system at the site.

A small proportion of polytunnels are located along the boundary of Flood Zone 2.

Under guidelines laid out in PPS25, the polytunnel development has been classified (in Table D.2 of PPS25) as “less vulnerable” and the development is considered appropriate (in Table D.3 in PPS25) for Flood Zone 2. With the current and recommended water management systems at the site, these polytunnels will remain operational and safe during times of flood; will result in no net loss of floodplain storage; will not impede water flows and will not increase the flood risk elsewhere. In the very unlikely event that polytunnels are carried off during flood events, the wooded areas and hedgerows will act as barriers to polytunnel movement off site.

The planning application for the polytunnels is retrospective i.e. the polytunnels have been in place at Pennoxstone Court for several years. During this time, there has been no history of the polytunnels having detrimental effects on flooding and erosion.

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Appendix A

Methodology for Rational Method

Methodology for Rational Method

- The polytunnel catchment area has been sub-divided into ten sub-catchments (Areas A to J). 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 0.5) and for polytunnels (0.5 to 0.56) 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/swales that have flow restrictors in place at discrete horizons (low 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	B	C	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/swales 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 1.9° to a maximum slope of 5.5°) representing those found at Pennoxstone Court; a Manning's coefficient of 0.06 to 0.08 for straw lined or vegetated channels/swales; 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 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 once the freeboard storage has been utilised. 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, G, H, J and the combined sub-catchment areas C, D and E to their respective outfall point at the farm boundary illustrated in Figures 1 and 2. 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. http://manuals.dot.state.tx.us). 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, G, H and J and the combined sub-catchments 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.

Appendix B

Detailed Analysis Criteria

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

Meadow Scenario. Starts at 64.5mAOD. Rainfall falls onto meadow 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 =	720	s
From 64.5mAOD to 63.5mAOD runoff travels a mean distance of 170m over grassland to the field boundary to accumulate and pond at low point of field.	Hydraulic Gradient =	0.0059	m/m
	Overland flow velocity =	0.05	m/s
	Time over pathway =	3400	s
	Time of concentration for area =	68.67	minutes

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/swales			
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/swales decreases runoff generation time, however, this is offset by straw filled and dammed polytunnel leg row channels/swales.	Runoff generation time =	720	s
From 64.5mAOD to 64mAOD runoff travels a mean distance of 80m along polytunnel leg row channels/swales (trapezoid shaped with 1000mm bed base). Straw in the channels/swales naturally accumulate at sand bag dams spaced at 25m intervals producing storage, a reduced runoff slope angle and a weir effect thereby reducing velocities. Additionally, the land is extremely flat lying allowing a large proportion of the runoff to be stored in the leg row channel/swale.	Hydraulic Gradient =	0.0039	m/m
	Leg Swale flow velocity =	0.09	m/s*
	Time over pathway =	872	s
Any flow leaving the leg row channel/swale is dispersed by vegetation and wide headland at polytunnel 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
Bundage area storage capacity = 75m^3. When bundage capacity is breached overspill feeds back into the field and accumulates and pond on low point of field.	Time to overspill =	1875	s
*leg row channel/swale 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 damming and accumulation of straw at dams.	Time of concentration for area =	91.12	minutes

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

Meadow Scenario. Starts at 64.5mAOD. Rainfall falls onto meadow 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 =	720	s
From 64.5mAOD to 59mAOD runoff travels a mean distance of 200m over grassland to point where gradient decreases	Hydraulic Gradient =	0.0275	m/m
	Overland flow velocity =	0.12	m/s
	Time over pathway =	1667	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 =	0.0158	m/m
	Overland flow velocity =	0.1	m/s
	Time over pathway =	1900	s
	Time of concentration for area =	71.44	minutes

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/swales			
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/swales decreases runoff generation time, however, this is offset by straw filled and dammed polytunnel leg row channels/swales.	Runoff generation time =	720	s
From 64.5mAOD to 60.5mAOD runoff travels a mean distance of 150m along polytunnel leg row channels/swales (trapezoid shaped with 1000mm bed base). Straw in the channels/swales naturally accumulate at sand bag dams spaced at 25m intervals producing storage, a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient =	0.0067	m/m
	Leg Swale flow velocity =	0.15	m/s*
	Time over pathway =	1030	s
Leg swale 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 =	0.0147	m/m
	Overland flow velocity =	0.09	m/s
	Time over pathway =	1889	s
From 58mAOD 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 =	0.0182	m/m
	Overland flow velocity =	0.15	m/s
	Time over pathway =	733	s
*leg row channel/swale 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 damming and accumulation of straw at dams.	Time of concentration for area =	72.86	minutes

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

Description	Parameter	Value	Unit
Meadow Scenario. Starts at 64.5mAOD. Rainfall falls onto meadow 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 =	720	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 =	0.0559	m/m
	Overland flow velocity =	0.19	m/s
	Time over pathway =	895	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 ponded area (Pond No.1).	Hydraulic Gradient =	0.0140	m/m
	Channel flow velocity =	0.25	m/s
	Time over pathway =	1720	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	Storage capacity =	60	m3
	Pond recession time =	603	s
	i.e. capacity/(area*ROC*critstormintensity/secinhr)		
From 49mAOD to 48.5mAOD runoff leaves ponded area and travels a mean distance of 30m through small heavily vegetated trapezoid 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.	Hydraulic Gradient =	0.0167	m/m
	Channel flow velocity =	0.51	m/s
	Time over pathway =	59	s
From 48.5mAOD to 48mAOD flow enters drainage pipe and travels a mean distance of 7m, flowing to small heavily vegetated trapezoid shaped channel (400mm wide bed base with 1m/m channel sides). Maximum pipe flow = 1000m^3/hr or 43l/s/hectare for farm catchment	Hydraulic Gradient =	0.0714	m/m
	Max pipe flow velocity =	3.90	m/s
	Time over pathway =	2	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.2).	Hydraulic Gradient =	0.0091	m/m
	Channel flow velocity =	0.52	m/s
	Time over pathway =	212	s
At 47mAOD, the channel enters a large pond (rectangular to oval in plan view) that is surrounded by woods and heavy vegetation. Pond 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)	Storage capacity =	150	m3
	Pond recession time =	643	s
	i.e. capacity/(area*ROC*critstormintensity/secinhr)		
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 approximately 20m and outfalls into small overflow storage area (capacity ~ 3m^3) on opposite side of embankment. From here flow enters a 150mm smooth edge pipe at 45mAOD. Maximum pipe flow = 860m^3/hr or 20l/s/hectare for farm catchment area.	Hydraulic Gradient =	0.0500	m/m
	Max pipe flow velocity =	3.32	m/s
	Time over pathway =	6	s
From 45mAOD to 41mAOD flow enters 150mm smooth edge ceramic drainage pipe and travels a mean distance of 280m, flowing to small heavily vegetated trapezoid shaped channel (1000mm wide bed base with 1m/m channel sides). Maximum pipe flow = 72m^3/hr or 1l/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.	Hydraulic Gradient =	0.0143	m/m
	Max pipe flow velocity =	1.13	m/s
	Time over pathway =	248	s
From 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 =	0.0214	m/m
	Channel flow velocity =	0.42	m/s
	Time over pathway =	667	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.	Hydraulic Gradient =	0.0043	m/m
	Channel flow velocity =	0.42	m/s
	Time over pathway =	1119	s
	Time of concentration for area =	110.74	minutes

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/swales	
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/swales decreases runoff generation time, however, this is offset by straw filled and dammed polytunnel leg row channels/swales.	Runoff generation time = 720 s
From 64.5mAOD to 57.5mAOD runoff travels a mean distance of 170m polytunnel leg row channels swales (trapezoid shaped with 1000mm bed base) and is dispersed at end of channel before reaching field boundary and a heavily vegetated and wooded area. Straw in the channels/swales naturally accumulate at sand bag dams spaced at 25m intervals producing storage, a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient = 0.0110 m/m Leg Swale flow velocity = 0.22 m/s* Time over pathway = 773 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 = 0.0357 m/m Overland flow velocity = 0.14 m/s Time over pathway = 1214 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 ponded area (Pond No.1).	Hydraulic Gradient = 0.0140 m/m Channel flow velocity = 0.3 m/s Time over pathway = 1433 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	Storage capacity = 60 m3 Pond recession time = 527 s i.e. capacity/(area*ROC*critstormintensity/secinhr)
From 49mAOD to 48.5mAOD runoff leaves ponded area and travels a mean distance of 30m through small heavily vegetated trapezoid 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.	Hydraulic Gradient = 0.0167 m/m 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 trapezoid shaped channel (400mm wide bed base with 1m/m channel sides). Maximum pipe flow = 1000m^3/hr or 43l/s/hectare for farm catchment	Hydraulic Gradient = 0.0714 m/m Max pipe flow velocity = 3.90 m/s Time over pathway = 2 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.2).	Hydraulic Gradient = 0.0091 m/m Channel flow velocity = 0.57 m/s Time over pathway = 193 s
At 47mAOD, the channel enters a large pond (rectangular to oval in plan view) that is surrounded by woods and heavy vegetation. Pond 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)	Storage capacity = 150 m3 Pond recession time = 450 s i.e. capacity/(area*ROC*critstormintensity/secinhr)
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 approximately 20m and outfalls into small overflow storage area (capacity ~ 3m^3) on opposite side of embankment. From here flow enters a 150mm smooth edge pipe at 45mAOD. Maximum pipe flow = 860m^3/hr or 20l/s/hectare for farm catchment area.	Hydraulic Gradient = 0.0500 m/m Max pipe flow velocity = 3.32 m/s Time over pathway = 6 s
From 45mAOD to 41mAOD flow enters 150mm smooth edge ceramic drainage pipe and travels a mean distance of 280m, flowing to small heavily vegetated trapezoid shaped channel (1000mm wide bed base with 1m/m channel sides). Maximum pipe flow = 72m^3/hr or 1l/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.	Hydraulic Gradient = 0.0143 m/m Max pipe flow velocity = 1.13 m/s Time over pathway = 248 s
From 47mAOD to 41mAOD, in the event of an overspill, flow becomes overland flow and channel flow over 280m. Channel is a short grassed, ephemeral V channel with 0.7m/m side slopes.	Hydraulic Gradient = 0.0214 m/m Overland flow velocity = 0.52 m/s Time over pathway = 538 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.	Hydraulic Gradient = 0.0043 m/m Channel flow velocity = 0.52 m/s Time over pathway = 904 s
*leg row channel/swale 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 damming and accumulation of straw at dams.	Time of concentration for area = 113.54 minutes

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

Meadow Scenario. Starts at 82mAOD. Rainfall falls onto meadow 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 =	720	s
From 82mAOD to 62mAOD runoff travels a mean distance of 370m over grassland to hedgerow field boundary and beyond the farm catchment.	Hydraulic Gradient =	0.0541	m/m
	Overland flow velocity =	0.19	m/s
	Time over pathway =	1947	s
	Time of concentration for area =	44.46	minutes

Polytunnel Scenario. Starts at 82mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface. Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels/swales			
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/swales decreases runoff generation time, however, this is offset by straw filled and dammed polytunnel leg row channels/swales.	Runoff generation time =	720	s
From 82mAOD to 70mAOD runoff travels a mean distance of 200m along polytunnel leg row channels/swales (trapezoid shaped with 1000mm 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/swales naturally accumulate at sand bag dams spaced at 25m intervals producing storage, a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient =	0.0150	m/m
	Leg Swale flow velocity =	0.16	m/s*
	Time over pathway =	1250	s
Leg swale flow is dispersed to overland flow at polytunnel ends. From 70mAOD to 62.5mAOD runoff travels a mean distance of 140m as overland flow over grassland to hedgerow field boundary and beyond the farm catchment.	Hydraulic Gradient =	0.0536	m/m
	Overland flow velocity =	0.18	m/s*
	Time over pathway =	778	s
*leg row channel/swale 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 damming and accumulation of straw at dams.	Time of concentration for area =	45.80	minutes

Brief description of the pathways for the time of concentration for sub-catchment area G for the meadow and polytunnel scenario.

Meadow Scenario. Starts at 85mAOD. Rainfall falls onto meadow 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 =	720	s
From 85mAOD to 67mAOD runoff travels a mean distance of 440m over grassland to hedgerow field boundary and beyond the farm catchment.	Hydraulic Gradient =	0.0409	m/m
	Overland flow velocity =	0.16	m/s
	Time over pathway =	2750	s
	Time of concentration for area =	57.83	minutes

Polytunnel Scenario. Starts at 85mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface. Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels/swales			
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/swales decreases runoff generation time, however, this is offset by straw filled and dammed polytunnel leg row channels/swales.	Runoff generation time =	720	s
From 85mAOD to 77mAOD runoff travels a mean distance of 220m along polytunnel leg row channels/swales (trapezoid shaped with 1000mm 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/swales naturally accumulate at sand bag dams spaced at 25m intervals producing storage, a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient =	0.0091	m/m
	Leg Swale flow velocity =	0.13	m/s*
	Time over pathway =	1692	s
Leg swale flow is dispersed to overland flow at polytunnel ends. From 77mAOD to 67mAOD runoff travels a mean distance of 220m as overland flow over grassland to hedgerow field boundary and beyond the farm catchment.	Hydraulic Gradient =	0.0455	m/m
	Overland flow velocity =	0.18	m/s*
	Time over pathway =	1222	s
*leg row channel/swale 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 damming and accumulation of straw at dams.	Time of concentration for area =	60.58	minutes

Brief description of the pathways for the time of concentration for sub-catchment area H for the meadow and polytunnel scenario.

Meadow Scenario. Starts at 74mAOD. Rainfall falls onto meadow 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 =	720	s
From 74mAOD to 50mAOD runoff travels a mean distance of 450m over grassland to hedgerow field boundary and beyond the farm catchment.	Hydraulic Gradient =	0.0545	m/m
	Overland flow velocity =	0.19	m/s
	Time over pathway =	2316	s
	Time of concentration for area =	50.60	minutes

Polytunnel Scenario. Starts at 74mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface. Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels/swales			
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/swales decreases runoff generation time, however, this is offset by straw filled and dammed polytunnel leg row channels/swales.	Runoff generation time =	720	s
From 74mAOD to 68mAOD runoff travels a mean distance of 220m along polytunnel leg row channels/swales (trapezoid shaped with 1000mm 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/swales naturally accumulate at sand bag dams spaced at 25m intervals producing storage, a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient =	0.0068	m/m
	Leg Swale flow velocity =	0.12	m/s*
	Time over pathway =	1833	s
Leg swale flow is dispersed to overland flow at polytunnel ends. From 68mAOD to 50mAOD runoff travels a mean distance of 240m as overland flow over grassland to hedgerow field boundary and beyond the farm catchment.	Hydraulic Gradient =	0.0750	m/m
	Overland flow velocity =	0.20	m/s*
	Time over pathway =	1200	s
*leg row channel/swale 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 damming and accumulation of straw at dams.	Time of concentration for area =	62.56	minutes

Brief description of the pathways for the time of concentration for sub-catchment area J for the meadow and polytunnel scenario.

Meadow Scenario. Starts at 61mAOD. Rainfall falls onto meadow 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 =	720	s
From 61mAOD to 39mAOD runoff travels a mean distance of 310m over grassland to hedgerow field boundary and beyond the farm catchment.	Hydraulic Gradient =	0.0710	m/m
	Overland flow velocity =	0.21	m/s
	Time over pathway =	1476	s
	Time of concentration for area =	36.60	minutes

Polytunnel Scenario. Starts at 61mAOD. Hits polytunnels with assumption of instantaneous run-off to ground surface. Rainfall intercepted by polytunnels accumulates in straw filled polytunnel legs channels/swales			
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 =	720	s
From 61mAOD to 41mAOD runoff travels a mean distance of 250m along polytunnel leg row channels/swales (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/swales naturally accumulate at sand bag dams spaced at 25m intervals producing storage, a reduced runoff slope angle and a weir effect thereby reducing velocities.	Hydraulic Gradient =	0.0200	m/m
	Leg Swale flow velocity =	0.17	m/s*
	Time over pathway =	1471	s
Leg swale flow is dispersed to overland flow at polytunnel ends. From 41mAOD to 39mAOD runoff travels a mean distance of 50m as overland flow over grassland to hedgerow field boundary and beyond the farm catchment.	Hydraulic Gradient =	0.0400	m/m
	Overland flow velocity =	0.15	m/s*
	Time over pathway =	333	s
*leg row channel/swale 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 damming and accumulation of straw at dams.	Time of concentration for area =	42.07	minutes

Appendix C

Tabulated Results

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

Meadow Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area A									
							Time of concentration =	68.67	minutes
							Additional inflows from =	0	m^3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow =	0.25	280
		0.347	0.396	0.444	0.493		Meadow=	0.35 - 0.5	9720
FEH Storm Event	1 in 10 year	*9.7*	*11.0*	*12.4*	*13.7*	10	Hard Standing =	0.95	0
	1 in 100 year	*19.0*	*21.7*	*24.4*	*27.0*	20			
	1 in 100 year + 20%	*22.8*	*26.0*	*29.2*	*32.4*	24			
		litres/second/hectare							

Polytunnel Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area A									
							Time of concentration =	91.12	minutes
							Additional inflows from =	0	m^3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow and headland =	0.25	840
		0.441	0.455	0.468	0.482		Polytunnels incorporating leg row swales =	0.5 - 0.56	6000
FEH Storm Event	1 in 10 year	*11.4*	11.7	*12.1*	*12.4*	9	Track =	0.55	460
	1 in 100 year	*22.0*	*22.7*	*23.3*	*24.0*	18	Meadow =	0.35 - 0.5	0
	1 in 100 year + 20%	*26.4*	*27.2*	*28.0*	*28.8*	22	Grass and/or Orchard =	0.4	0
		litres/second/hectare					Thick Grass and Woodland =	0.15	0
							Small Grain Crop =	0.3	2700
							Hard Standing =	0.95	0

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

Meadow Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area B							Time of concentration =	71.44	minutes
							Additional inflows from =	0	m3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow =	0.25	750
		0.349	0.399	0.449	0.498		Meadow=	0.35 - 0.5	112250
FEH Storm Event	1 in 10 year	*9.6*	*11.0*	*12.4*	*13.7*	10	Hard Standing =	0.95	0
	1 in 100 year	*18.9*	*21.6*	*24.3*	*27.0*	19			
	1 in 100 year + 20%	*22.7*	*25.9*	*29.1*	*32.4*	23			
		litres/second/hectare							

Polytunnel Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area B							Time of concentration =	72.86	minutes
							Additional inflows from =	0	m3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow and headland =	0.25	2250
		0.386	0.394	0.403	0.411		Polytunnels incorporating leg row swales =	0.5 - 0.56	49000
FEH Storm Event	1 in 10 year	*10.6*	10.8	*11.0*	*11.3*	10	Track =	0.55	800
	1 in 100 year	*20.7*	*21.2*	*21.6*	*22.1*	19	Meadow =	0.35 - 0.5	0
	1 in 100 year + 20%	*24.9*	*25.4*	*26.0*	*26.5*	23	Grass and/or Orchard =	0.4	0
		litres/second/hectare					Thick Grass and Woodland =	0.15	0
							Small Grain Crop =	0.3	61950
							Hard Standing =	0.95	0

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

Meadow Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area C, D & E							Time of concentration =	110.74	minutes
							Additional inflows from =	0	m^3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow =	0.25	9110
		0.349	0.398	0.448	0.497		Meadow=	0.35 - 0.5	748890
FEH Storm Event	1 in 10 year	*8.5*	*9.7*	*10.9*	*12.1*	9	Hard Standing =	0.95	0
	1 in 100 year	*16.3*	*18.6*	*20.9*	*23.2*	17			
	1 in 100 year + 20%	*19.5*	*22.3*	*25.1*	*27.8*	20			
		litres/second/hectare							

Polytunnel Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area C, D & E							Time of concentration =	113.54	minutes
							Additional inflows from =	0	m3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow and headland =	0.25	27330
		0.358	0.369	0.380	0.390		Polytunnels incorporating leg row swales =	0.5 - 0.56	185500
FEH Storm Event	1 in 10 year	*8.7*	*9.0*	*9.2*	*9.5*	9	Track =	0.55	13960
	1 in 100 year	*16.6*	*17.1*	*17.6*	*18.1*	17	Meadow =	0.35 - 0.5	88700
	1 in 100 year + 20%	*19.9*	*20.5*	*21.1*	*21.7*	20	Grass and/or Orchard =	0.4	61010
		litres/second/hectare					Thick Grass and Woodland =	0.15	32000
							Small Grain Crop =	0.3	353000
							Hard Standing =	0.95	0

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

Meadow Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area F									
						Time of concentration =	44.46	minutes
						Additional inflows from =	0	m^3/hr
	Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
						Hedgerow =	0.25	1000
	0.349	0.399	0.448	0.498		Meadow=	0.35 - 0.5	108000
FEH Storm Event: 1 in 10 year	*11.0*	*12.5*	*14.1*	*15.6*	11	Hard Standing =	0.95	
FEH Storm Event: 1 in 100 year	*22.2*	*25.3*	*28.5*	*31.6*	23			
FEH Storm Event: 1 in 100 year + 20%	*26.6*	*30.4*	*34.2*	*37.9*	27			
	litres/second/hectare							

Polytunnel Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area F								
						Time of concentration =	45.80	minutes
						Additional inflows from =	0	m3/hr
	Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
						Hedgerow and headland =	0.25	4000
	0.397	0.417	0.436	0.456		Polytunnels incorporating leg row swales =	0.5 - 0.56	46000
FEH Storm Event: 1 in 10 year	*12.3*	*13.0*	*13.6*	*14.2*	11	Track =	0.55	2000
FEH Storm Event: 1 in 100 year	*24.9*	*26.2*	*27.4*	*28.7*	23	Meadow =	0.35 - 0.5	25000
FEH Storm Event: 1 in 100 year + 20%	*29.9*	*31.4*	*32.9*	*34.4*	27	Grass and/or Orchard =	0.4	0
	litres/second/hectare					Thick Grass and Woodland =	0.15	0
						Small Grain Crop =	0.3	33000
						Hard Standing =	0.95	0

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

Meadow Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area G							Time of concentration =	57.83	minutes
							Additional inflows from =	0	m^3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow =	0.25	1200
		0.349	0.399	0.448	0.498		Meadow=	0.35 - 0.5	127800
FEH Storm Event	1 in 10 year	*10.2*	*11.6*	*13.1*	*14.5*	11	Hard Standing =	0.95	
	1 in 100 year	*20.3*	*23.2*	*26.0*	*28.9*	21			
	1 in 100 year + 20%	*24.3*	*27.8*	*31.3*	*34.7*	25			
		litres/second/hectare							

Polytunnel Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area G							Time of concentration =	60.58	minutes
							Additional inflows from =	0	m3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow and headland =	0.25	4200
		0.423	0.442	0.461	0.479		Polytunnels incorporating leg row swales =	0.5 - 0.56	72000
FEH Storm Event	1 in 10 year	*12.2*	*12.7*	*13.3*	*13.8*	10	Track =	0.55	3500
	1 in 100 year	*24.2*	*25.3*	*26.3*	*27.4*	21	Meadow =	0.35 - 0.5	20000
	1 in 100 year + 20%	*29.0*	*30.3*	*31.6*	*32.9*	25	Grass and/or Orchard =	0.4	0
		litres/second/hectare					Thick Grass and Woodland =	0.15	0
							Small Grain Crop =	0.3	30300
							Hard Standing =	0.95	0

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

Meadow Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area H									
							Time of concentration =	50.60	minutes
							Additional inflows from =	0	m^3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow =	0.25	1200
		0.349	0.399	0.448	0.498		Meadow=	0.35 - 0.5	129800
FEH Storm Event	1 in 10 year	*10.6*	*12.1*	*13.6*	*15.1*	11	Hard Standing =	0.95	
	1 in 100 year	*21.2*	*24.2*	*27.2*	*30.3*	22			
	1 in 100 year + 20%	*25.5*	*29.1*	*32.7*	*36.3*	26			
		litres/second/hectare							

Polytunnel Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area H									
							Time of concentration =	62.56	minutes
							Additional inflows from =	0	m3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)		ROC	Area (m^2)
							Hedgerow and headland =	0.25	4200
		0.420	0.438	0.456	0.475		Polytunnels incorporating leg row swales =	0.5 - 0.56	71000
FEH Storm Event	1 in 10 year	*12.0*	*12.5*	*13.0*	*13.6*	10	Track =	0.55	3500
	1 in 100 year	*23.7*	*24.8*	*25.8*	*26.9*	20	Meadow =	0.35 - 0.5	20000
	1 in 100 year + 20%	*28.5*	*29.7*	*31.0*	*32.2*	24	Grass and/or Orchard =	0.4	0
		litres/second/hectare					Thick Grass and Woodland =	0.15	0
							Small Grain Crop =	0.3	33300
							Hard Standing =	0.95	0

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

Meadow Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area J								Time of concentration =	36.60	minutes
								Additional inflows from =	0	m^3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)			ROC	Area (m^2)
		0.348	0.398	0.447	0.496			Hedgerow =	0.25	1200
								Meadow=	0.35 - 0.5	72800
FEH Storm Event	1 in 10 year	*11.5*	*13.2*	*14.8*	*16.4*	12		Hard Standing =	0.95	
	1 in 100 year	*23.6*	*27.0*	*30.3*	*33.6*	24				
	1 in 100 year + 20%	*28.3*	*32.3*	*36.3*	*40.4*	29				
		litres/second/hectare								

Polytunnel Scenario. Critical Storm Peak discharge (in *litres/second/hectare*) for Area J								Time of concentration =	42.07	minutes
								Additional inflows from =	0	m3/hr
		Weighted ROC's				Critical Storm Rainfall Intensity (mm/hr)			ROC	Area (m^2)
								Hedgerow and headland =	0.25	3600
		0.334	0.339	0.343	0.348			Polytunnels incorporating leg row swales =	0.5 - 0.56	18000
FEH Storm Event	1 in 10 year	*10.6*	*10.8*	*10.9*	*11.1*	11		Track =	0.55	1100
	1 in 100 year	*21.6*	*21.9*	*22.2*	*22.5*	23		Meadow =	0.35 - 0.5	0
	1 in 100 year + 20%	*25.9*	*26.3*	*26.7*	*27.0*	28		Grass and/or Orchard =	0.4	0
		litres/second/hectare						Thick Grass and Woodland =	0.15	8000
								Small Grain Crop =	0.3	43300
								Hard Standing =	0.95	0

Appendix D

Practical Guidance Notes for Polytunnel Developer

This section is for the practical guidance to the developer and the tractor driver who "rows up" and the labour gangs which place and maintain the sand bags for damming the leg row channels.

1. Compulsion

It is a requirement that adequate and appropriate flow restrictors for rainfall runoff is achieved for the polytunnel development in the form of dams in the leg row channels. This will slow runoff down and provide storage within the leg row channel. This is to satisfy requirements laid out by the Environment Agency.

In order to meet the requirement that runoff from the polytunnels is less than or equal the “Greenfield” runoff rate, the leg row channels that run the full length of the polytunnel parallel to the orientation of the polytunnel will need to be dammed at appropriate intervals by sand bags.

2. The purpose of the sand bagging

The purpose of the sand bagging is to retain rainfall runoff water and to provide barriers to flow along the leg row channels. This should compartmentalise the leg row channel into storage sections. This slows down runoff and allows more water to seep into the soil.

3. The need to form effective barriers

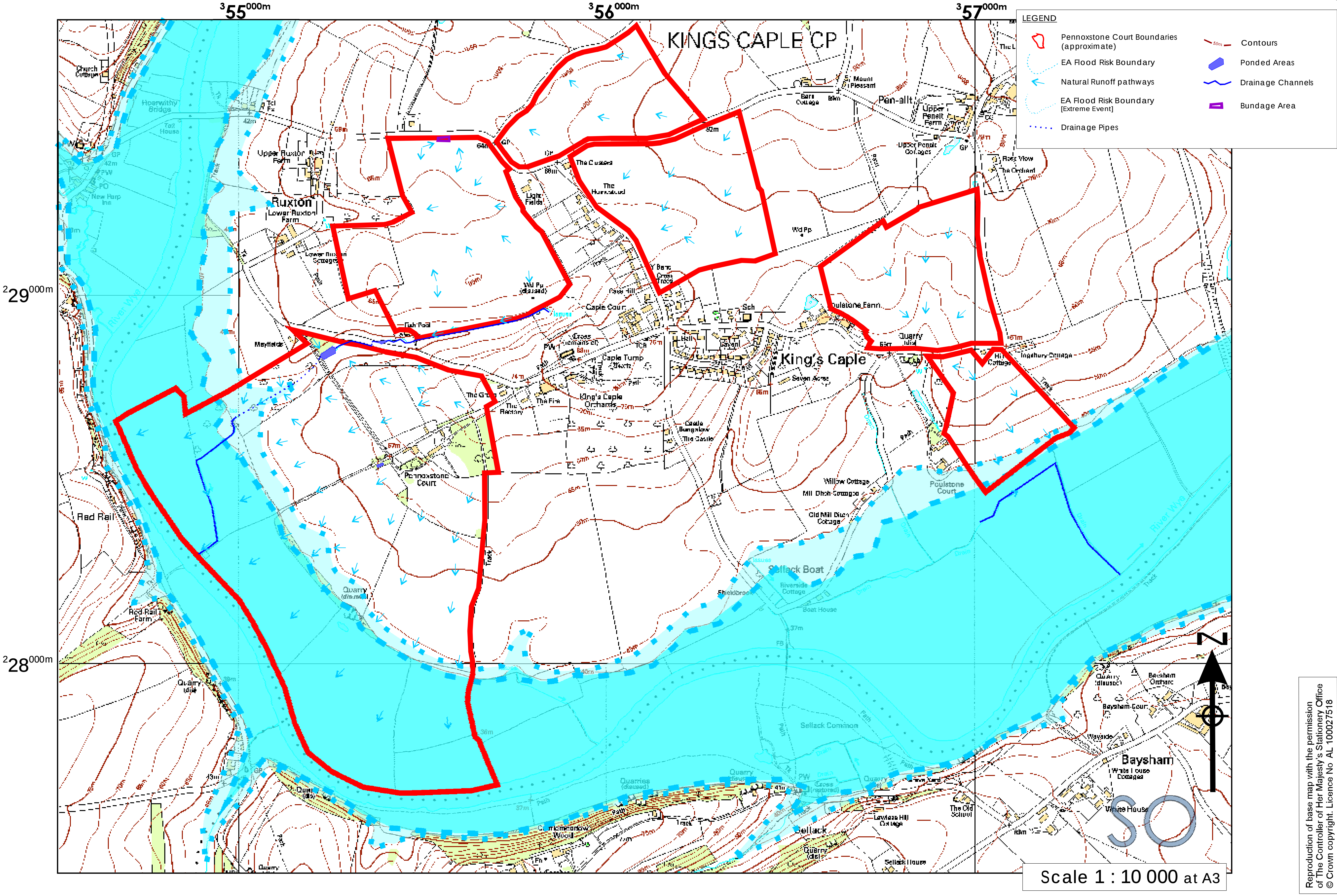
The sand bags need to form effective barriers to retain water behind them. If they do not they will **not** fulfil their purpose.

4. The origin of the storage calculations.

The volume of storage in the leg row is dependent on 1) the dimensions of the leg row channel; 2) the height and spacing of the sand bags in the leg row channel, and 3) the gradient of the leg row channel. To meet the active water management requirement the sandbag height and spacing in each polytunnel block is given in the table below.

Polytunnel Gradient	Sandbag Height (m)	Sandbag Spacing (m)	Additional Storage provided (m^3/ha)
Max (4.5˚)	0.2	20	17
Min (0.2˚)	0.2	20	215
Mean (1.9˚)	0.2	20	39

It is a requirement of these calculations that a sandbag dam must be placed at the lowest point of the leg row channel at the downstream and open end of the polytunnel i.e. where runoff would naturally leave the polytunnel leg row channel.



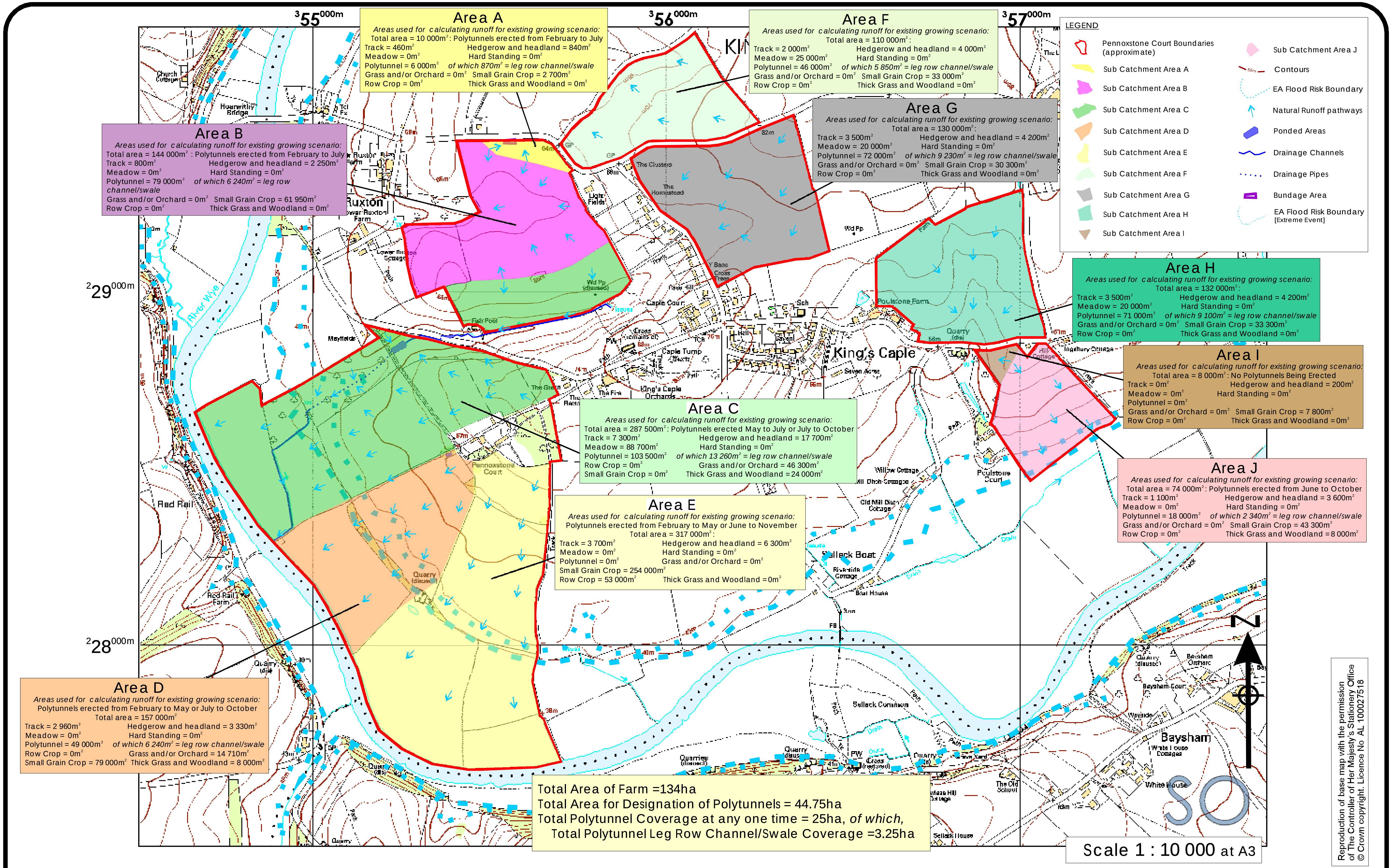
JDIH ENVIREAU

Ref: P:/Cockburn Pennox (5785)/ New ES 8-4-2010/Fig1
Date: 14/04/2010

Pennoxstone Court - Revised DA

Figure 1

Farm Boundaries, Natural Drainage and Flood Risk Zones



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Date: 14/04/10

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Figure 2

Sub Catchments and Land Usage used in the Rational Method

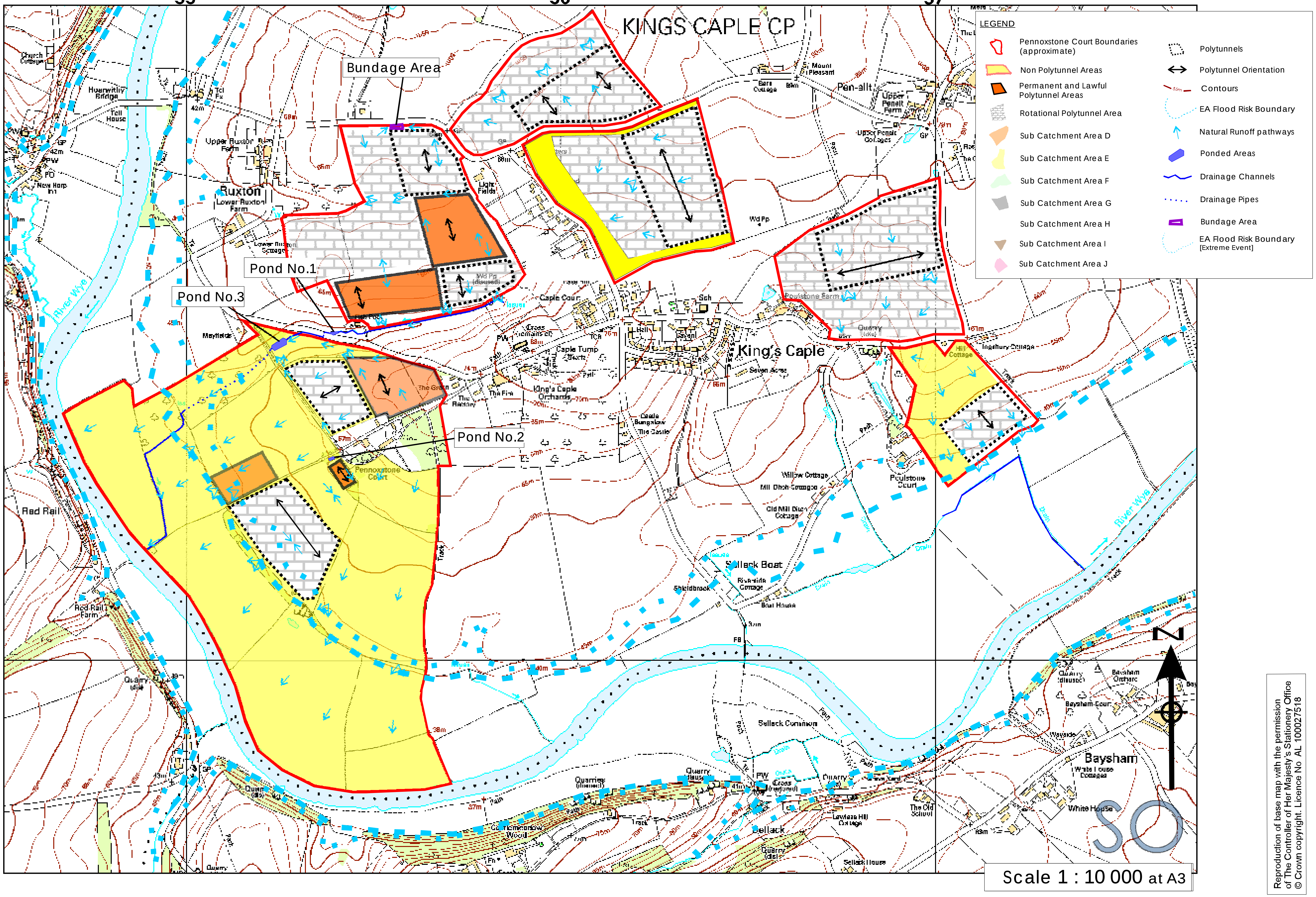

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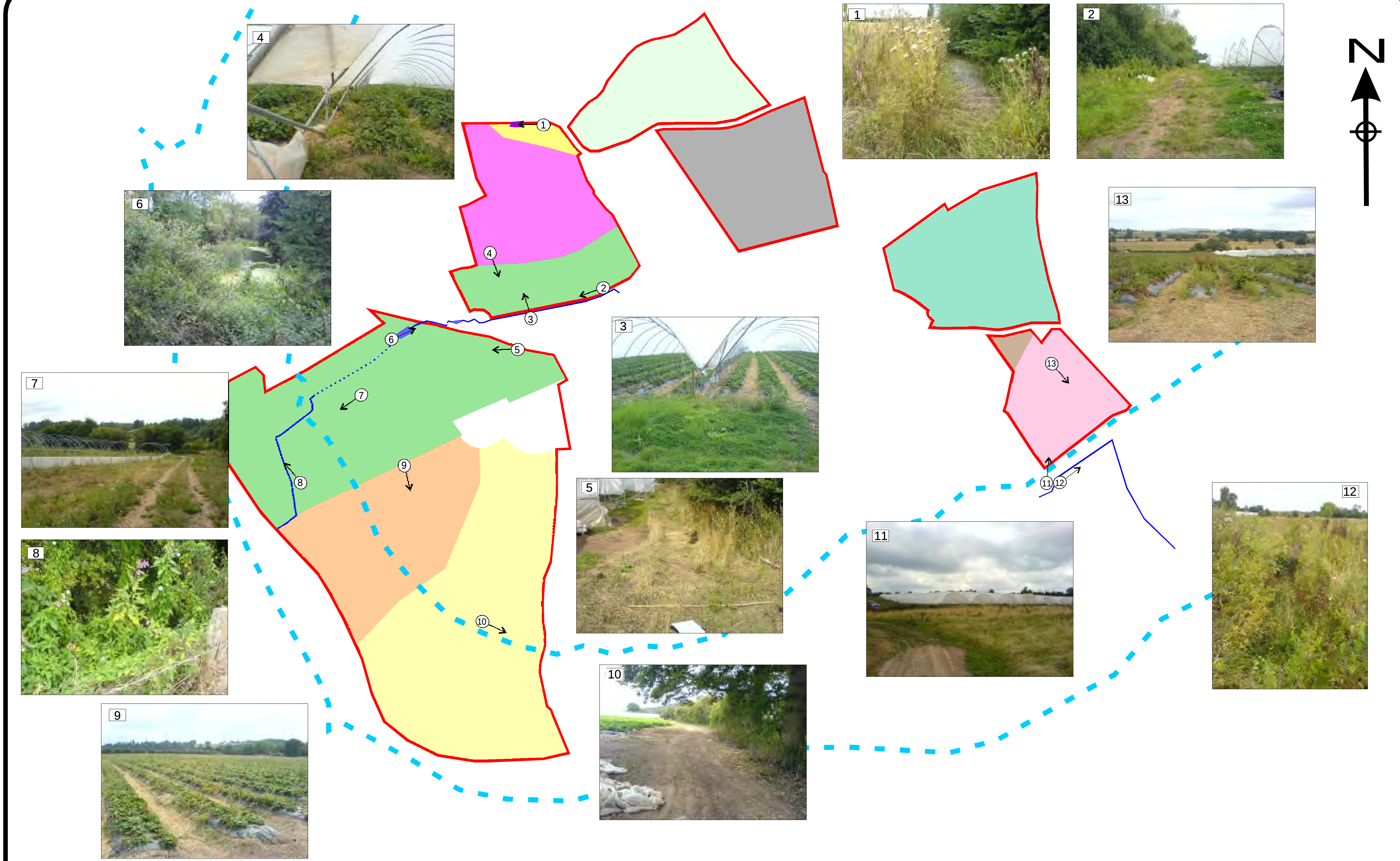
Figure 3

Polytunnel Placement, Orientation and Drainage Pathways



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New ES 8-4-2010\Fig4
Date: 14/04/10

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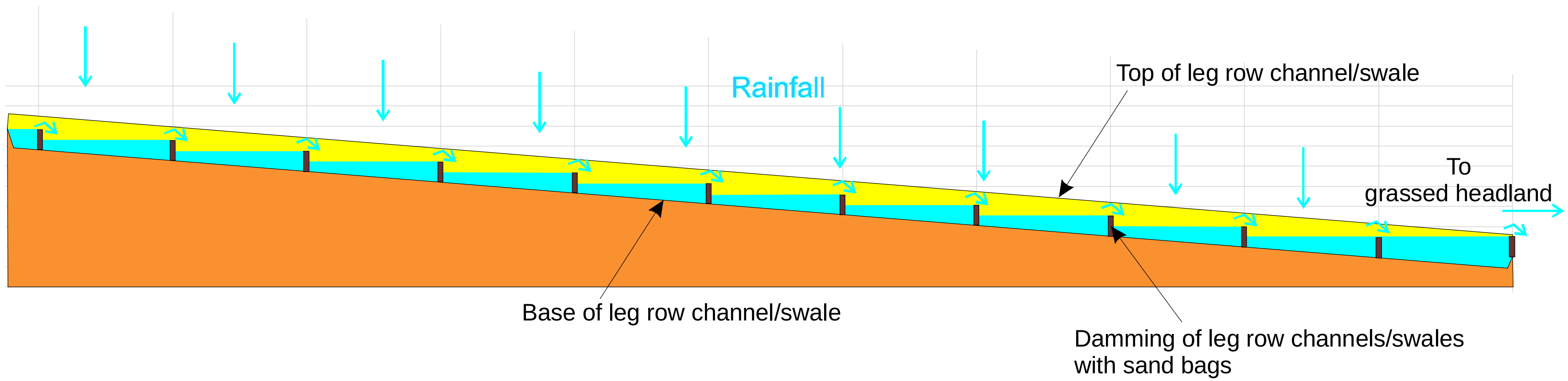
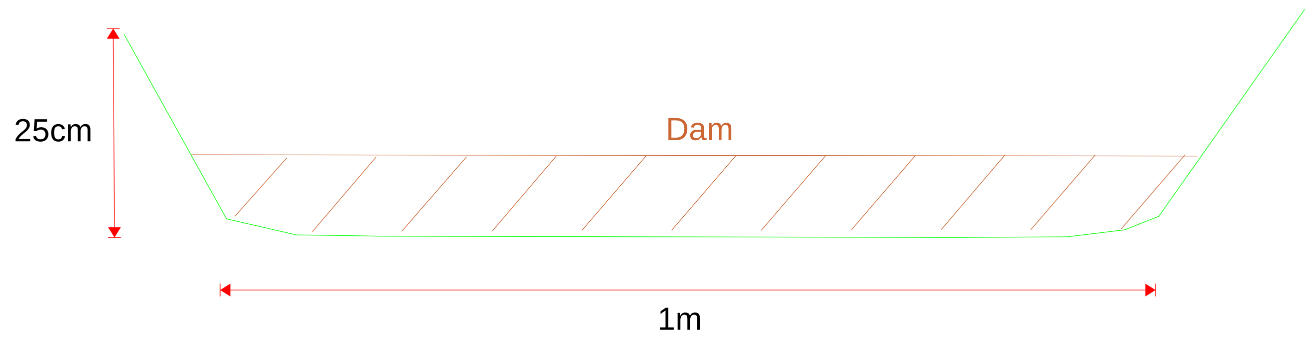
Figure 4

Photographs of Land Use, Watercourses and Drainage

Longitudinal Profile of Damming of Leg Row Channel/Swale



Cross Section of Leg Row Channel/Swale



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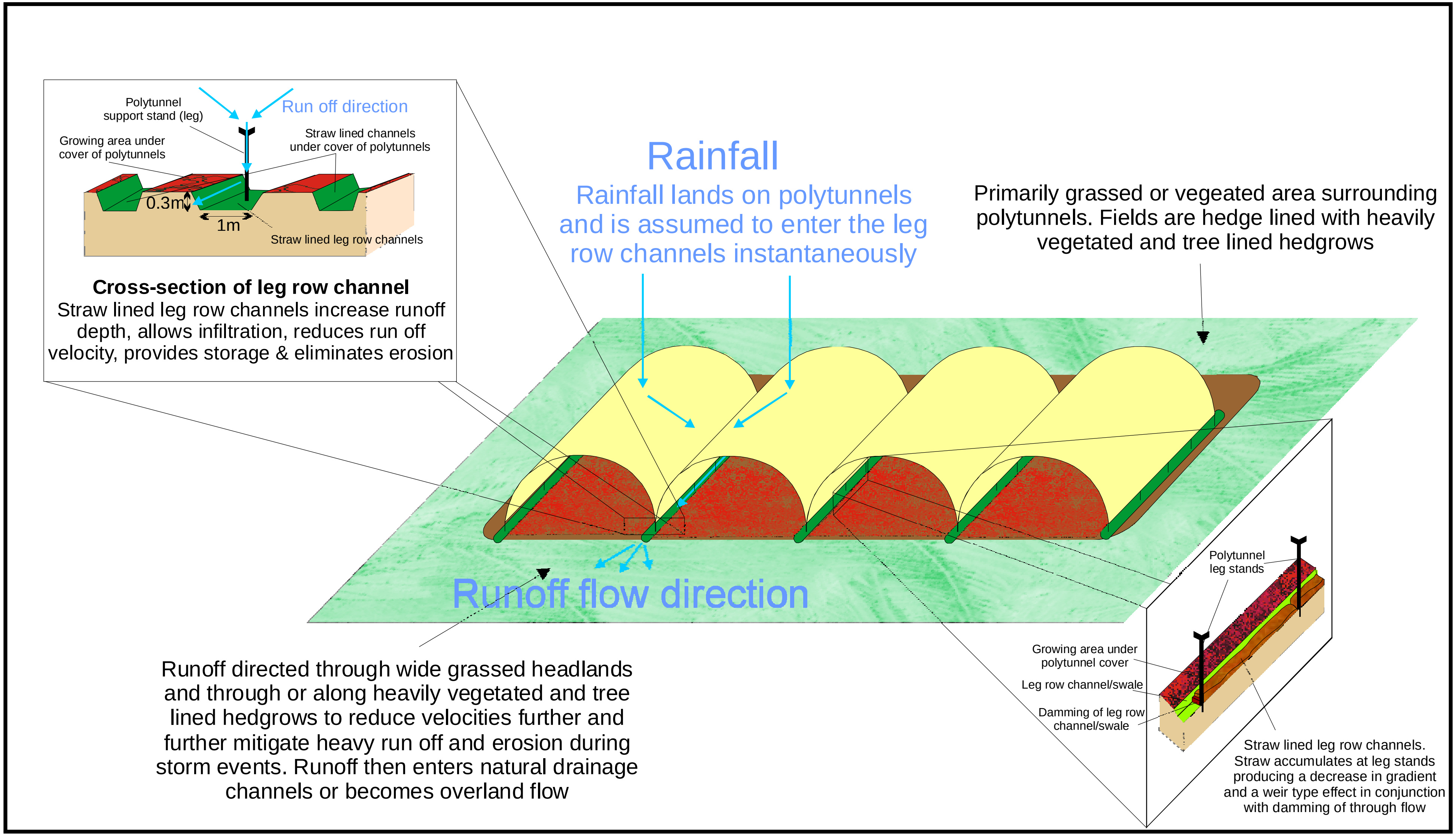
Ref: P:\Cockburn Pennox (5785)\ New ES 8-4-2010\Fig5 Date: 14/04/10	**Pennoxstone Court - Revised DA**
Figure 5	Polytunnel Leg Row Channel/Swale Runoff Flow Restrictor and Storage Schematic



JDIH ENVIREAU

Ref: P:\Cockburn Pennox (5785)\ New ES 8-4-10\Fig6 Date: 14/04/10	**Pennoxstone Court - Revised DA**
Figure 6	Schematic Diagram of Polytunnel Runoff and Drainage