North Wyke Research

Farm Platform
Hydrological Assessment

October 2008

DRAFT REPORT

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REVISION HISTORY

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Draft Final Report October 2008		Robert Orr (1 electronic copy)
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CONTRACT

This report describes work commissioned by the North Wyke Research. North Wyke's representative for the contract was Robert Orr. Steve Rose, Susan Wagstaff, Sam Bishop, Zdenka Rosolova and Jessie Kennedy of JBA Consulting carried out the work.

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PURPOSE

This document has been prepared solely as a Draft Final Report for North Wyke Research. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

ACKNOWLEDGMENTS

We would like to acknowledge the contribution of Storm Geomatics staff who undertook the GPS ground level survey of the Study Area and to North Wyke Research staff for their detailed local knowledge of the study area.

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1 INTRODUCTION

1.1 Background

North Wyke Research is proposing to set up a new farm platform experimental facility for the study of interactions among environmental processes in lowland temperate grassland agricultural systems. This will include investigating sustainable land use, the impacts of climate change and renewable bio-energy at a systems level.

In total, twelve individual experimental catchment blocks were originally envisaged (six @ 12 ha each and six @ 2 ha each) on land which borders the River Taw to the west of the research buildings and a small stream to the east of the research buildings.

1.2 Specification

North Wyke Research commissioned JBA to undertake an assessment of the surface water and potential groundwater interactions on the land where the twelve new experimental blocks have been proposed. North Wyke Research staff had undertaken the initial block separation based on their local knowledge, together with reference to some existing digital terrain model (DTM) datasets. In particular, the JBA assessment included the following tasks:

1. Identification of how the blocks could be hydrologically isolated in terms of the surface water.
2. Consideration of the possibility of any groundwater interactions within the blocks
3. Recommendations for the locations and outline specification for a flow monitoring station at the outlet to each block.

In order to accurately define the topographic boundaries the study area it was decided to commission Storm Geomatics to undertake a 15m gridded GPS ground level survey of all the fields in question, including some basic surveying of the existing open ditch network.

An initial site visit and field walkover was undertaken by Susan Wagstaff on 8 August 2008 to gather background information and speak to a number of the North Wyke Research staff prior to the JBA proposal being submitted. Storm Geomatics undertook their GPS ground level survey of the proposed experimental blocks during the week beginning 15 September 2008. Steve Rose and Sam Bishop then visited North Wyke to undertake the detailed site assessment over the period 30 September to 2 October 2008.

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2 STUDY AREA

2.1 Background

North Wyke Research is located just north of the village Taw Green near Okehampton in Devon. The proposed new experimental blocks within the farm platform facility are located in the fields to the west and east of the main North Wyke Research buildings (Maps A 1-1 and A 1-2). The North Wyke Research site receives on average about 1056mm of rainfall each year.

2.2 Topography

The experimental blocks straddle a clear topographic divide, which basically follows the line of the existing N-S road through the area. Blocks 1-4 generally drain westwards towards the River Taw, whereas Blocks 5-12 drain eastwards to an unnamed tributary of the Taw. Ground levels within the experimental blocks range from about 134m AOD to 185m AOD.

As part of this commission Storm Geomatics undertook a GPS ground level survey within the proposed experimental blocks. A 15m grid of spot levels was collected, which was subsequently used to generate a digital terrain model (DTM) of the area. Some additional spot levels were also taken of the existing open ditch network to gather information about the ditch channel depths and the ditch bed gradients.

All the new GPS mapped features have been heighted in relation to Ordnance Datum Newlyn (OSGM97). The precision of heights on hard surfaces may be taken, to a 98% confidence level, to be within ± 0.020m relative to the control station height (at Burrows Road Nail). Storm Geomatics produced an x,y,z datasets, which could be imported into GIS applications for the generation of a new DTM.

Figures A 1-1 and A 1-2 shows the topographic contours within the experimental blocks.

The experimental blocks exhibit a range of slopes from reasonably flat hilltop and slope bottom areas (less than 3% gradients) to quite steep mid slope areas (5-10% gradients).

2.3 Geology

Solid Geology

The study area is underlain by Carboniferous shales and sandstones of the Crackington Formation (BGS, 1969). Shale is the dominant lithology (BGS, 1969[1]; Harrod and Hogan, 2008[2]). The strata are vertical or subvertical and strike ENE-WSW (BGS, 1969). They have been intruded by an ENE-WSW-trending lamprophyre dyke, which passes beneath the North Wyke Research Centre (BGS, 1969; Harrod and Hogan, 2008). Lamprophyres are igneous rocks that contain relatively large crystals (phenocrysts) of ferromagnesian minerals (e.g. biotite, amphibole, clinopyroxene, olivine) in a groundmass of finer crystals (Farris Lapidus, 1987[3]). A NW-SE-trending fault occurs immediately to the south of the study area (BGS, 1969).

Superficial (Drift) Geology

Most of the area is free of superficial deposits, the soil being directly underlain by bedrock (BGS, 1969). However, river terrace deposits and (younger) alluvium are associated with the River Taw and with the river to the east of North Wyke (BGS, 1969). Such deposits may include clay, silt, sand and gravel. Harrod and Hogan (2008) note that “gravel and sandy alluvium” occur in the floor of the Taw Valley at North Wyke.

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[1] BGS (British Geological Survey) (1969). Okehampton. England and Wales Sheet 324, Solid and Drift Edition.

[2] Harrod, T. R. and Hogan, D. V. (2008). *The Soils of North Wyke and Rowden*. Revised edition of original report by T. T. Harrod, Soil Survey of England and Wales, 1981.

[3] Farris Lapidus (1987). Collins Dictionary of Geology. Collins, 565pp.

Hydrogeology

The bedrock is dominated by low-permeability shale, which will behave as an aquiclude or aquitard. Alluvial sand and gravel deposits will behave as minor aquifers. Subsurface water flow beneath North Wyke will mostly be restricted to the soil zone, above the low permeability bedrock. Water will move downslope – locally assisted by field drains – towards surface watercourses. The sand/gravel aquifers in the river valleys will receive water from infiltration, from downslope lateral flow (interflow or shallow groundwater flow) and potentially also from the river channel (e.g. bank storage associated with high river stage).

2.4 Soils

The first soil survey of North Wyke was completed in 1957 by Findlay and Clayden[4]. This was added to by Harrod (1981)[5] and then fully revised and updated by Harrod and Hogan (2008)[2].

The soils of the experimental blocks are almost entirely underlain by three soil series:

1. Halstow – clayey typical non-calcareous pelosol
2. Hallsworth – clayey pelostagnogley
3. Denbigh/Cherubeer – fine loamy typical brown earth/stagnogleyic brown earth

Only Block 3 has a small amount of Fladbury (clayey pelo-alluvial gley) along its lowest western boundary next to the River Taw. The distribution of soils across the experimental blocks is shown in Map Soils.

The very clayey and slowly permeable nature of the soils within the experimental blocks is further confirmed by their HOST classification (Boorman *et al.*, 1985)[6]. The HOST classification describes soils by their predominant pathway for water movement over and through the soil profile. Details of the HOST classification for the soil map units found on the experimental blocks are given in Table 2-1.

Table 2-1. HOST classes for the soils at North Wyke

National Soil Map Unit	HOST class	Description of HOST class
Halstow	21	Slowly permeable soils with slight seasonal waterlogging and low storage capacity over slowly permeable substrates with negligible storage capacity
Hallsworth	24	Slowly permeable, seasonally waterlogged soils over slowly permeable substrates with negligible storage capacities
Denbigh	17	Free draining permeable soils on hard (slate or shale) substrates with relatively low permeability and low storage capacity
Fladbury	9	Slowly permeable, seasonally waterlogged soils in unconsolidated clays with groundwater a less than 40cm from the surface

Source: Harrod and Hogan (2008)[2]

All the experimental blocks are therefore essentially surface water blocks with very little water travelling vertically down through the soil profile and beyond the subsoil. Only Block 3, with its small area of Fladbury soils on the flatter land next to the River Taw, might have a small groundwater component to the water balance.

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[4] Findlay, D.C. and Clayden, B. (1957). The soils of North Wyke Experimental Station. Unpublished report to Fisons Ltd.

[5] Harrod, T.R. (1981). Soils in Devon V: Sheet SS61 (Chulmleigh) Soil Surv. Rec. No 70.

[6] Boorman, D.B., Hollis, J.M. and Lilley, A. (1985). Hydrology of Soil Types: a hydrologically-based classification of the soils of the UK. Institute of Hydrology Report No. 126, Wallingford.

2.5 Drainage

Discussions with the North Wyke Farm Manager undertaken during the site visit in September identified that a few fields within the experimental blocks have been underdrained in the past. The fields that are known to be underdrained are:

1. Longland East (Block 12) – drained in 1987 with plastic pipes and secondary mole drainage
2. Longlands South (Block 10) – drained in 1987 with plastic pipes and secondary mole drainage
3. North eastern part of Burrows (Block 2) – drained in 1970's with clay tile pipes

Other individual field drain outfalls were identified during the site visit. These were found on the south western boundary of Golden Rove (Block 1a) and on the eastern boundary of Lower Wyke Moor (Block 5a). These outfalls may just represent the drainage of specific wet spots on the lower and less steep parts of these fields. *Ad hoc* drainage of specific wet spots may exist in other fields at North Wyke.

At the top (eastern) end of Poor Field (Block 3) a pipe was found that collects water from the open ditch on the western edge of the central woodland block here and transfers it to the open ditch along the bottom (western) edge of Poor Field. There is a possibility that, if this pipe is perforated (e.g. slotted), it might also gather some water from the soils in Poor Field.

A similar transfer pipe was found taking water from the ditch on the western edge of the thin strip of woodland between Top Burrows and Burrows (Block 2). This pipe appeared to be transferring water into the open ditch that runs along the northern boundary of Burrows (Map A 2-1). Similarly, a pipe was found that takes water from a ditch running SW-NE next to the woodland in Lower Wyke Moor (Block 5a) and discharges it through a field at the eastern boundary of Lower Wyke Moor in a topographic depression. (Map A 2-2).

A sealed plastic pipe takes water from the N-S road running just west of the North Research buildings and discharges it into the open ditch in the south western corner of Barn Field (Block 4). The pipe follows the natural depression in the land between Barn Field and Great Field (Map A 2-1).

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3 HYDROLOGICAL ASSESSMENT

3.1 Background

During the September site visit all the proposed experimental blocks were assessed to determine their surface water drainage catchment and the possibility of any groundwater interactions. Based on the site visit a number of alterations were made to the boundaries of the proposed block areas to permit the hydrological isolation (surface water) of one block from another and from other surrounding land areas (Maps A 3-1 and A 3-2). The presence of historic large hedgerows and associated hedgebanks made of heavy soil, stones and rocks would effectively seal the soil underneath them from near surface lateral flow. These features therefore negate the need for a number of new collector ditches along some of the block boundaries.

In addition, consideration was given to the location of a suitable flow measuring device at the outlet of each block. Free discharge of water from any new flow measurement structure would be required in order for it to remain operational during larger flow events.

Water from any roads or tracks in the vicinity of the experimental blocks should not be permitted to enter the blocks, for example, through gateways or via the existing open ditch network. This may require either the re-routing of some existing road or track side drains, or the installation of additional drains.

3.2 Block Assessments

3.2.1 Block 1

Block contains the three fields: Orchard Dean, Little Burrows and Golden Rove. Both Orchard Dean and Golden Rove had a number of outlets to flow along their southern and western boundaries. Also, the presence of the mature woodland strip between Golden Rove and Orchard Dean would make it very difficult to connect these two fields up to form a single block (with Little Burrows) At the top of Little Burrows there is a small area of land that actually drains generally westwards towards the N-S road. It would be difficult (due to topographic height differences) to reconnect this small area back to the rest of Little Burrows and so this small area should be excluded from the block. This discard area could be fenced off on top of a small bank created by shallow scrapes either side of the boundary.

As a result it is recommended that the original Block 1 is split into two smaller blocks (1 and 1a) with two flow measurement locations as shown in Map B1. New open ditches would be needed to channel water to the flow measurement structure and avoid the loss the water out of the blocks to some of the existing open ditches.

3.2.2 Block 2

Block 2 contains three fields, together with the Met station area. The three fields are: Top Burrows, Borrows and Lower Burrows. In order to hydrological isolate this block it would be necessary to construct a number of new open ditches along most of the boundaries (Map B2), which would remove small areas from the block along the western edge. However, it should be possible to make use of the existing ditch along the western boundary of Bottom Burrows and connect them to the new flow measurement structure.

3.2.3 Block 3

Block 3 contains two fields (Ware Park and Poor Field), together with a mature woodland block in the centre. The current Environment Agency Flood Map indicates that both the predicted 100 year and 1000 year return period floods could enter a narrow strip along the western edge of Poor Field. The potential flood risk along this boundary was confirmed by the North Wyke Farm Manager who has observed flood water from the river on the floodplain here. The situation is further complicated by the fact that there is a plastic drainage pipe that gathers water from the open ditch along the western edge of the central woodland (which will also gather some water from Ware Park field) and transfers it through Poor Field to discharge directly into the open ditch that runs along the western edge of Poor Field. There is also a possibility that this field drain is perforated along its length and so may collect soil water draining from Poor Field (NB. This would need to be confirmed with the Farm Manager or through a small amount of excavation).

Currently, it is proposed that the flow measurement structure is located in the north western corner of Poor Field, with a new open ditch constructed along the northern boundaries of Ware Park and Poor Field (Map B3). However, to avoid the possible flooding issues in the lowest (western) edge of Poor Field then a new open ditch (running south to north) could be constructed further to the east (above the 1000 year flood extent and possibly also upslope of the Fladbury soil boundary in this field (whereby removing any groundwater interaction). In this instance the flow measurement structure would then need to be located about 35m further east (and upslope) in the existing open ditch that runs east to west along the northern boundary of Poor Field. This new ditch would need to intercept the existing field drain originating from the central woodland area in this block. Moving the flow measurement structure further upslope would also improve the free outfall condition below the structure. It would also be possible to exclude the central woodland block from this block (if necessary), but this would require the construction of an additional open ditch.

3.2.4 Block 4

Block 4 includes the fields: Great Field, Josephs Carr (inc. the conservation area), Josephs Moor, Treestumps and Barn Field. The original block boundary runs very close to River Taw in the north west corner of Josephs Moor and the 100 year and 1000 year flood extents just reach into the lowest corners of Josephs Moor and Treestumps. In addition, the lowest, flattest, western parts of Josephs Carr, Josephs Moor and Treestrumps are underlain by Fladbury soils indicating a possible groundwater interaction in this area.

Given the presence of the conservation area, the tree blocks, the flood risk and the possible groundwater interactions it is recommended that the Block 4 boundary is moved eastwards to the boundary of Great Field (excluding a small area in the south west corner), and a new open ditch is constructed to gather the water towards the flow measurement structure in the north west corner of Great Field (Map B4). This would have the result of excluding Josephs Carr, Josephs Moor and Treestumps from the block. A significant topographic divide (watershed) in Barn Field requires Block 4 to be sub-divided into Blocks 4 and 4a. Great Field and the southern one third of Barn Field would become Block 4. To create the boundary on the ground you would excavate a small shallow collector ditch on both sides of new small bank that would form the actual boundary line.

The northern two thirds of Barn Field would become Block 4a and two new open ditch sections would be required to gather the water towards the flow measurement structure in the north western corner of Barn Field.

3.2.5 Block 5

Block 5 includes the following fields: Higher Wyke Moor, Middle Wyke Moor and Lower Wyke Moor. The topographic variation in this block, together with the presence of a reasonable block of mature woodland along the north eastern boundary of Middle Wyke Moor indicate that this block should be split into two. North Wyke Moor and Middle Wyke Moor would become Block 5 and Little Wyke Moor would become Block 5a (Map B5). To permit this separation would require new open ditches to be constructed along the northern and southern boundaries of North Wyke Moor and Middle Wyke Moor, together with a new open ditch along the eastern boundary of Middle Wyke Moor. The proposed flow measurement structure would be located in the north eastern corner of Middle Wyke Moor.

New open ditches would be required to be constructed along the southern and eastern boundaries of Lower Wyke Moor to take the water to the flow measurement structure in the centre of the eastern edge of the field. At this location, in a topographic dip, a number of existing field drains also discharge. These field drains would need to be connected into the flow measurement structure, which would require some excavation work upslope in Lower Wyke Moor. The eastern edge of the woodland (to the north west of this block) would require a new collector ditch to direct water from the woodland away from the experiment block. A small area of land in the north east corner of Lower Wyke Moor would need to be excluded from the block in order for the new open ditch to be set to the required gradient.

3.2.6 Block 6

Block 6 represents a single field – Dairy South. In order to collect the water from this field would require some small areas to be excluded in the south west and north east corners. New collector ditches would be needed along the southern and eastern boundaries of this field to transfer the water to the proposed flow measurement structure in the middle of the eastern boundary (Map B6).

3.2.7 Block 7

Block 7 also represents just half of a single field – the southern half of Dairy East. This field can be easily isolated by the constructed of new collector ditches along the northern southern and eastern boundaries, which would feed water to the flow measurement structure in the northern corner of the field (Map B7).

3.2.8 Block 8

Block 8 is essentially the northern half of Dairy East field. The original block boundary was extended to reach the topographic valley feature to the north of the field. Given the disturbance of the ground in the valley feature, to install a pipe that drains water from the main North Wyke Research buildings and hard standings it is recommended that the northern block boundary is moved south to the current fence line of Dairy East field. Two new collector ditches would be needed on the northern and eastern boundaries of this field to feed the water to the flow measurement structure in the northern corner of the field (Map B8). A small area of this block would also need to be excluded on the eastern boundary.

3.2.9 Block 9

Block 9 represents an area within Higher Wheaty field. To isolate this block from the other blocks near it (i.e. Blocks 6 and 7) would require a considerable amount of drainage intervention. New collector ditches to transfer water to the flow measurement structure (in the northern corner) would be needed on the northern, southern and eastern boundaries (Map B9). Downstream of the flow measurement structure a new open ditch or pipe would have to be installed to prevent this outflow water from entering Block 8. This pipe or open ditch would need to discharge into the valley feature to the north of Block 8. Upslope of the Block 9 western boundary two additional collector drains would be needed to prevent water from the top part of Higher Wheaty field entering Block 9. This water would have to be piped along the northern boundary of Block 6 and allowed to outfall into the woodland at the north eastern corner of Dairy South. This pipe may need to be perforated for the first 50m where it passes along the north eastern boundary of Dairy West to avoid water entering Block 8 from this field (by passing underneath the concrete track).

3.2.10 Block 10

Block 10, just north of the main North Wyke Research farm outbuildings, is Longlands South. It is proposed to locate the flow measurement structure in the north east corner of this field, with new collector ditches along the northern and eastern boundaries (Map B10). The presence of existing field drains in this field would make mean that considerable care will be needed when installing the eastern collector ditch as this will be following a similar line to the main field drain. To connect the existing main field drain into the flow measurement structure will require the existing field drain to be exposed at a suitable distance upslope of the flow measurement structure and then its gradient altered slightly to bring the drain closer to the surface by the time it reaches the structure. Care will also be needed to make sure that the existing laterals are not disconnected during this work. From the flow measurement structure a new pipe will probably be needed to take the outflow water from the structure eastwards and underneath the existing track to discharge into a ditch in the woodland. An additional length of collector ditch and pipe would be needed along the southern and part of the eastern boundary to avoid water from Longlands End and Dock Yard entering this block.

3.2.11 Block 11

Block 11, Longlands North is the experimental block with the lowest overall average gradient (at less than 4°). To hydrologically isolate this field would require new collector ditches along the northern and eastern boundaries, with the flow measurement structure in the north east corner of the field (Map B11). An additional ditch or pipe would be needed to take this outflow water from the structure and discharge it into the woodland in the north eastern corner of Longlands East (Block 12).

3.2.12 Block 12

Block 12 (Longlands East), like Block 10 (Longlands South) is underdrained. Care would be needed when constructing a new northern collector ditch as this would follow a similar line to that of the existing field drain. New collector ditches would also be needed on the southern and eastern field boundaries taking water to the flow measurement structure in the north eastern corner of the field

(Map B12). Again like Block 10, to connect the existing main field drain into the flow measurement structure will require the existing field drain to be exposed at a suitable distance upslope of the flow measurement structure and then its gradient altered slightly to bring the drain closer to the surface by the time it reaches the structure. Care will also be needed to make sure that the existing laterals are not disconnected during this work. A sealed pipe would be needed to take the water discharging from the flow measurement structure to the existing open ditch in the north east corner of Block 12.

3.2.13 Block 13

Discussions with North Wyke Research staff during the site visit indicated that it might not be economic to isolate Block 9 from its surrounding blocks with multiple collector ditches and drains. An alternative to Block 9 was put forward, namely Woodlands field just east of the main North Wyke Research buildings. It would be quite straight forward to isolate this field by constructing collector ditches along the northern, southern and eastern boundaries and locating the flow measurement structure in the eastern corner of the field (Map B13). An additional length of new collector ditch would be needed along the south western boundary and connected into the existing ditch that runs around the western and north western boundary of this block. This would ensure that drainage from the buildings and hard standing to the west of this block cannot enter it. It should be noted that this field is located on Hallsworth and Denbigh/Cheubeer soils, whereas Blocks 7, 8 and 9 are all virtually wholly located on Halstow soils.

4 DESIGN FLOW ESTIMATIONS

4.1 Background

In order to permit an outline specification for the flow measurement structures to be determined a design flow estimation was carried for each of the new proposed experimental blocks. The sizing of the flow measurement structure for the outlet of each block is dependant of the predicted flow peak for a specific design flood magnitude (or flood return period in years).

Given that the block catchment areas ranged from 1.5ha to 12.2ha the most appropriate flow estimation method is the ADAS Reference Book 345 method[7] developed in the early 1980's, which was specifically developed for agricultural catchments up to about 30ha in size.

Given the dominant clayey nature of the soils across all the experimental blocks it was decided to run the ADAS Report 345 method for each experimental block with two soil types – clay and silty clay to investigate how that would affect the design flow estimations. The ADAS method is based on a number of catchment (i.e. block) characteristics. These are:

1. Catchment area
2. Maximum catchment height
3. Lowest catchment height
4. Maximum catchment length
5. Catchment slope
6. Soil type (clay or silty clay)
7. Long term standard average annual rainfall (1056mm for North Wyke Research)
8. Land cover (grassland)

4.2 Block Characteristics

The block characteristics used in the ADAS method are given in Table 4-1.

Table 4-1. Experimental block characteristics

Block	Lowest elevation (m AOD)	Highest elevation (m AOD)	Maximum catchment length (m)	Slope (m/m)	Slope (%)	Area (km^2)	Area (ha)
1	143	179	394	0.091	9.1	0.076	7.57
1a	160	184	330	0.073	7.3	0.060	6.00
2	138	182	445	0.099	9.9	0.122	12.19
3	133	170	527	0.070	7.0	0.087	8.71
4	135	157	349	0.063	6.3	0.069	6.94
4a	133	149	279	0.057	5.7	0.029	2.93
5	161	188	425	0.064	6.4	0.078	7.79
5a	153	167	210	0.067	6.7	0.032	3.22
6	156	182	350	0.074	7.4	0.086	8.64
7	151	170	254	0.075	7.5	0.020	1.96
8	151	168	159	0.107	10.7	0.015	1.47
9	168	180	190	0.063	6.3	0.020	2.00
10	155	169	210	0.067	6.7	0.019	1.92
11	149	157	210	0.038	3.8	0.018	1.83

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[7] ADAS (1982). The design of field drainage pipe systems. ADAS Reference Book 345. Ministry of Agriculture, Fisheries and Food, London.

Block	Lowest elevation (m AOD)	Highest elevation (m AOD)	Maximum catchment length (m)	Slope (m/m)	Slope (%)	Area (km^2)	Area (ha)
12	144	154	210	0.048	4.8	0.018	1.83
13	141	166	305	0.082	8.2	0.046	4.62

4.3 Design Flow Estimations

Using the ADAS Reference Book 345 method design flow estimations were calculated for a range of flood magnitudes (flood return periods) and for two soil types (clay and silty clay). The results are given in the tables below.

Block 1	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	103.38	82.7
5	144.12	115.29
10	173.74	139
20	204.33	163.47
50	247.34	197.87
100	282.3	225.84

Block 1a	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	80.27	64.21
5	111.9	89.52
10	134.91	107.93
20	158.66	126.93
50	192.05	153.64
100	219.2	175.36

Block 2	Clay	Silty Clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	163.66	130.93
5	228.15	182.52
10	275.06	220.05
20	323.48	258.79
50	391.57	313.26
100	446.91	357.53

Block 3	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	93.5	74.8
5	130.35	104.28
10	157.15	125.72
20	184.81	147.85
50	223.71	178.97
100	255.33	204.26

Block 4	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	85.75	68.6
5	119.55	95.64
10	144.12	115.3
20	169.5	135.6
50	205.17	164.14
100	234.17	187.34

Block 4a	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	37.87	30.3
5	52.79	42.24
10	63.65	50.92
20	74.85	59.88
50	90.61	72.49
100	103.42	82.73

Block 5	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	89.03	71.22
5	124.12	99.29
10	149.63	119.71
20	175.98	140.78
50	213.02	170.41
100	243.12	194.5

Block 5a	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	47.42	37.94
5	66.11	52.89
10	79.7	63.76
20	93.74	74.99
50	113.47	90.77
100	129.5	103.6

Block 6	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	113.58	90.87
5	158.35	126.68
10	190.9	152.72
20	224.51	179.61
50	271.76	217.41
100	310.18	248.14

Block 7	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	29.11	23.29
5	40.58	32.46
10	48.92	39.14
20	57.53	46.03
50	69.64	55.71
100	79.48	63.59

Block 8	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	25.13	20.1
5	35.03	28.03
10	42.24	33.79
20	49.67	39.74
50	60.13	48.1
100	68.63	54.9

Block 9	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	29.95	23.96
5	41.75	33.4
10	50.34	40.27
20	59.2	47.36
50	71.66	57.33
100	81.79	65.43

Block 10	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	28.16	22.53
5	39.25	31.4
10	47.32	37.86
20	55.66	44.52
50	67.37	53.9
100	76.89	61.51

Block 11	Clay	Silty clay
Return Period (years)	Peak Flow (l/s)	Peak Flow (l/s)
2	22.41	17.93
5	31.24	24.99
10	37.67	30.13
20	44.3	35.44
50	53.62	42.9
100	61.2	48.96

Block 12	Clay	Silty clay
Return Period (years)	**Peak Flow (l/s)**	**Peak Flow (l/s)**
2	24.31	19.45
5	33.89	27.11
10	40.85	32.68
20	48.05	38.44
50	58.16	46.53
100	66.38	53.1

Block 13	Clay	Silty clay
Return Period (years)	**Peak Flow (l/s)**	**Peak Flow (l/s)**
2	65.36	52.29
5	91.12	72.89
10	109.85	87.88
20	129.19	103.35
50	156.38	125.1
100	178.48	142.79

It is not always possible, for a number of reasons (including cost), to construct flow measurement structures for experimental purposes that would capture the more extreme floods (i.e. ≥ 50 year return period events), as the channel capacity would often be exceeded for these floods, thereby allowing the flow measuring structure to be bypassed by the floodwater on the land surface and an inaccurate record to be collected.

Discussions with North Wyke Research staff have indicated a requirement to be able to measure flows up to at least the 10 year return period flood event. Based on the design flood estimates given in the tables above it is recommended that the 20 year return period event for clay soils is used to specify the required design flow for each experimental block. This would mean that all the proposed flow measurement structures would fall within the maximum discharge range of 44l/s (for Block 11) to 323l/s (for Block 2).

4.3.1 New Collector Ditches

To channel water to the new flow measurement structures will require the construction of a number of new open collector ditches along the borders of the experimental blocks. These collector ditches would not need to be any deeper than 1m. A reasonably narrow bed width would help to maintain an adequate flow velocity and reduce maintenance problems. Care is required to ensure that any new ditches cutting across slopes are cut with a vertical ditch axis, thus avoiding too steep a batter on the higher side and reducing the likelihood of bank slips. Livestock would need to be prevented from entering these new ditches by the installation of a new fence on the field side of each ditch.

The new collector ditches should be put as near to the existing block boundary as practical to maximise the block area. The centre line of a new ditch (with a top width of about 2m) would be about 3-4m from the block boundary. The spoil from the ditch excavation would be placed, forming a low linear bank, along a 2m strip next to the block boundary. This new bank could be seeded or planted with appropriate vegetation. The outer edge of the new ditch would therefore be 4-5m out into the field.

The recommended side slope ratio (or batter) for new ditches depends on the soil stability (Castle *et al.*, 1984[8]). Firm soils, like clay are usually relatively stable and can support ditches with a steeper batter. For clay soils the recommended channel side slope (horizontal : vertical) is 1 : 1.

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[8] Castle, D.A., McCunnall, J. and Tring, I.M. (1984). Field Drainage: Principles and Practices. Batsford Academic and Educational, London. 250pp.

Peak flow in an open ditch can be calculated from the discharge equation:

$Q = V \times A$

where:

Q = peak flow (m^3/s)

V = mean velocity (m/s)

A = cross-sectional area of water (m^2)

Mean velocity can be estimated from Manning's equation:

$V = (R^{⅔} \times S^{½}) / n$

where:

V = mean velocity (m/s)

R = hydraulic radius (A / P) (m)

A = cross-sectional area of flow in the ditch (m^2)

P = the measured distance around the ditch bed and sides in contact with the water (wetted perimeter) (m)

S = gradient of ditch bed (dimensionless)

n = Manning's n roughness coefficient

The roughness is a measure of the resistance to flow in the ditch due to variations in cross-section, amount and state of the vegetation in the ditch, roughness due to soil and ditch bed material, ditch alignment and other obstructions. In practice, roughness varies through the year due to changes in vegetative growth and the management of this vegetative growth (e.g. by cutting or livestock grazing). Newly excavated ditches would typically be given a roughness coefficient of 0.018, whereas it is normal practice when designing ditches to use a roughness coefficient of 0.03 that would provide some allowance for subsequent grass and weed growth.

An example calculation for a possible typical new collector ditch dimension at North Wyke is as follows:

Ditch depth = 1m

Bed width =- 0.3m

Depth of water = 0.6m

Bedslope = 0.05 (5%)

n = 0.03

Using the equations above then:

$A = 0.54m^2$

$P = 2m$

$R = A / P = 0.27m$

From Manning's equation: $V = 3.12m/s$

$Q = V \times A = 1.683m^3/s = 1683l/s$

This example indicates that the new collector drains at North Wyke do not need to be any deeper than 1m in order to be able to convey flow rates that are well in excess of the maximum discharge currently being specified for the flow measurement structures at the outlets to the experimental blocks. Being oversized will also allow for some infilling that will occur as a result of natural small scale bank slippages in the channels, especially before new vegetation can stabilise the banks. Some of the new ditches will require the provision of safe access across them in appropriate places (e.g. gateways) for livestock, vehicles and staff.

5 FLOW MEASUREMENT STRUCTURES & WATER QUALITY

5.1 Background

North Wyke Research are proposing to install high quality flow measurement structures at the outlet to each experimental block, with associated water level recorders which would be linked to a data logging and telemetry system that can be accessed, viewed and downloaded remotely from the nearby North Wyke Research buildings. In addition, it is proposed to locate water quality monitoring equipment at or near to the flow measuring structures which would also be linked to the same data logging and telemetry system.

5.2 Measurement of Flow

As mentioned in Section 4.3.1 the measurement of flow or discharge (Q) is based on the velocity - area principle:

$Q = V \times A$

where:

V = velocity

A = cross-sectional area of water

Both V and A can be measured directly or indirectly. A can usually be related to a function of stage (H) so that a stage-discharge relationship can be formulated.

The reliability of the stage-discharge relationship can be greatly improved if the water flow in the river or ditch can be controlled by a rigid, watertight, indestructible cross-channel structure of standardised shape and characteristics, i.e. weirs and flumes (Shaw, 1994[9]). The type of weir or flume structure chosen will depend on a number of factors, including the size and physical characteristics of the watercourse in question, the range of flows it is expected to measure, together with the consideration of the sediment load expected to be moving through the channel in question.

The basic hydraulic premise of all weirs and flumes is the setting up of critical flow conditions for which there is a unique and stable relationship between depth of flow and discharge. Flumes are particularly suitable for small watercourses carrying a considerable fine sediment load, which might be an important factor for consideration at North Wyke. Flumes generally work by creating critical flow through the constriction or narrowing of the width of the channel. Weirs act to restrict the depth of flow, causing critical flow conditions over the weir crest. Each weir or flume type will have a preferred position for the accurate measurement of the water level relative to the structure (or the head measurement). A wide range of robust, solid state water depth recording devices are now on the market, which can be linked directly to data logging and telemetry systems.

Given the potential presence of a reasonable fine sediment load in the North Wyke ditches (especially in the newly cut collector ditches) then flumes might be the preferred flow measurement structure for the experimental blocks. The flume types that would be applicable to most of the moderate channel slopes at North Wyke would be the supercritical flumes, which are generally trapezoidal in shape. Examples of supercritical flumes are the H-flume, Walnut Gulch flume or San Dimas flume. These three flume types all originate from experimental work in the United States in the 1970’s and require a free outfall condition on the downstream side of the structure. This free outfall condition should be possible at all the proposed flow measurement structures at North Wyke, with the possible exceptions of Block 3 (original position) and Block 11 where the gradient in the watercourse downstream of the structure could be limiting and requires further investigation. Some difficulties might also be encountered on Block 10 in order for the outflow water to be routed underneath the track to the east. Suppliers in the United States can supply H-flumes in fibreglass for a range of flow rates (e.g. Tracom: www.tracomfrp.com).

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[9] Shaw, E.M. (1994). Hydrology in Practice. 3rd Edition. Chapman & Hall, London. 569pp.

An example of a type of weir structure that has been designed for watercourses with a reasonable sediment load is the flat-V weir, which is a development from the Crump weir (with a triangular profile) with a V shaped crest allowing more accurate measurement of low flows. Flat-V weirs require extremely precise installation and are usually constructed out of concrete or glass reinforced plastic (GRP). Flowtech Plastics, for example, (www.flowtechplastics.com) can supply as range of flat- V weir types manufactured to BS specification in GRP. The supplier of a prefabricated weir or flume structure would also provide a detailed installation guide.

5.3 Water Quality Monitoring

A fundamental aspect of the proposed North Wyke experimental blocks is the monitoring of water quality, especially at the outlet to the blocks. Water quality can be considered in three forms – physical, chemical and biological (Shaw, 1984). Examples of physical forms include colour, odour, turbidity, conductivity and temperature. Examples of chemical forms include pH, dissolved oxygen, biochemical oxygen demand (BOD), nitrogen, phosphorus, chlorides, metals and pesticides. Examples of biological forms include flora, fauna and pathogens.

Water quality parameters (excluding most fauna and flora) can be monitored by the use of manually operated or solid state *in situ* sensors, or via the manual/automatic collection of discrete or composite water samples (of a required volume) which are then sent to a laboratory for analysis. Modern automatic water samplers (such as those manufactured by ISCO: www.isco.com) can also be linked to sophisticated data loggers which allow for considerable flexibility in the sampling regime (from discrete time based sampling to flow proportional sampling). In experimental situations, with automatic samplers, it may be possible to collect frequent water samples at the start of the monitoring period and then use the results to fine tune the sampling regime (timing and frequency) to meet both the scientific and cost considerations. However, temporal (over individual flood events) and seasonal changes in the flux of specific water quality parameters should also be taken into account when deciding the sampling regime. If resources permit then it might be possible to consider the installation of two automatic water sampling systems near each flow measurement structure, one to provide background temporal samples and the other to provide flow event based samples.

The location for the collection of a representative water sample is principally controlled by the flow condition in the watercourse in question. In the vicinity of flow measurement structures the flow condition is being artificially altered to produce a zone of critical flow where the depth of flow is directed related to the discharge and this is not representative of the naturally occurring flow conditions in the watercourse. Therefore, in many situations it is recommended that the water samples are collected either upstream of the zone of influence of the flow measurement structure (e.g. upstream of any backwater effect caused by a weir obstruction) or just downstream of the flow measurement structure where the water is well mixed (having pass over or through the flow constriction). The depth in the water column from which a water sample is collected can also be important, as the speed of flow varies with depth. This could be particularly pertinent to the study of sediment dynamics (and other sediment related parameters) within the runoff. However, it is not always possible to vary the depth from which a sample is taken in the water column based on the actual depth of water in the channel (which varies with time). A water sample taken at 0.6 x the water depth (measured vertically downwards from the water surface) has been cited as producing a representative sample in small, shallow streams (Shaw, 1984). Finally, the choice of material for the sample containers is important as some water quality parameters may adhere to certain materials and consequently produce inaccurate analytical results.

The design of the proposed data logging and telemetry system, which would link the water level recorders, water quality monitoring devices and any other monitoring devices in the experimental blocks to the nearby North Wyke Research buildings, should be flexible enough to be able to cover both the current and potential future research needs. Fortunately, due to the proximity of the experimental blocks to the North Wyke Research buildings then the servicing and maintenance of all the monitoring equipment should be straight forward.

6 SUMMARY

JBA have undertaken a review of the proposal to develop a number of new experimental blocks at North Wyke Research in Devon. In particular, the assessment has concentrated on exploring how the new experimental blocks could be hydrologically isolated from each other and from the surrounding land areas through the use of the existing open ditch network and the construction of a new network of collector ditches.

The detailed site assessment undertaken by JBA has identified where the original block layout should be adjusted to ensure the hydrological isolation and where new flow measurement structures should be located at the surface water outlet to each block. Three of the original blocks have also had to be sub-divided due to the inherent topographic and drainage limitations that were present. A number of new GIS datasets have been generated which provide information on the existing and proposed features of the experimental blocks.

Design flow estimations for a range of flood magnitudes have been calculated for each block (and sub-block) to provide the information needed for the sizing of the flow measurement structures. The use of supercritical flumes (such as H-flumes) is considered to be suitable for the majority of the experimental blocks due the channel gradient and fine sediment transport conditions prevalent at North Wyke. Careful consideration will be needed in two of the blocks where existing agricultural field drains would need to be connected into the new flow measurement structures.

The review has also provided some guidance on the considerations that would need to be explored with respect to the water quality monitoring aspects of the proposed new experimental facility. The design of the proposed data logging and telemetry system, which would link the water level recorders, water quality monitoring devices and any other monitoring devices in the experimental blocks to the nearby North Wyke Research buildings, should be flexible enough to be able to cover both the current and potential future research needs.

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APPENDICES

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APPENDIX A1: MAPS

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