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ELECTRONIC WATER TABLE CONTOUR MAPPING AND GROUNDWATER NITRATE INTERPOLATION AT A DAIRY FARM IN TEAGASC, JOHNSTOWN CASTLE, WEXFORD, IRELAND

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The objective of the present study was to construct electronic groundwater maps for the 60.5 ha dairy farm in the Teagasc Environment Research Centre at Johnstown Castle, Wexford, Ireland. Monitoring wells were drilled to a maximum density of 0.28 well/ha. A two dimensional groundwater data model of the study area was created with a data visualization and interpolation tool using water table and surface water elevations. Groundwater transport vectors were constructed by dividing effective porosity and hydraulic conductivity into three zones. The resulting maps may be used in future experimental design.

INTRODUCTION

The Teagasc research centre at Johnstown Castle, Wexford is divided into a dairy farm (60.5 ha), a conventional beef farm (63.3 ha) and an organic beef farm (59.6 ha) (Figure 1). The subsurface drainage system and surface water features are presented in Figure 2.

The dairy farm comprises undulating slopes with grey-green shale bedrock of low permeability covered by glacial drift. The soil profile consists of fine loam to a depth of 40 cm underlain by a loam-to-clay loam subsurface soil (Culleton and Diamond, unpublished). Well to moderate drainage occurs centrally on the farm with poor drainage enclosing this central area. A primary subsurface collector drainage system runs the length of the farm with herringbone secondary drains alleviating adjacent poorly drained areas (Figure 2).

These drains also receive discharge from the beef unit to the northwest and discharge to a natural woodland area (Bogwood, 0.3 ha) (Shaded area, Figure 2). The primary drainage system conveys water below the plough layer (2 m bgl) from the secondary drains of the drainage system.

A monitoring network may be used to optimize experimental design, plot selection and orientation at any proposed study site. The groundwater quality at a given location can thereby be justified by considering management practices at the surface and groundwater flow patterns. Therefore the source of nutrient concentrations entering and leaving an area of the farm can be accounted for.

Bartley (1996) confirmed that groundwater flow generally mirrored topography on site. The positions of the wells DF1, DF2A and DF3A (Figure 3) with total drilling depths to approximately 7 m represent the shallow saturated zone, with DF2B and DF3B (Figure 3) although deeper within the same zone. DF2C and DF3C (Figure 3) represent groundwater from the grey green shale aquifer.

MATERIALS AND METHODS

Before drilling, elevation maps were used to locate the wells. An initial phase of drilling created a network of 7 boreholes (DF1, DF2A-C, and DF3A-C) (at a density of 0.12 well/ha) (Bartley, 1996). A second phase of drilling enhanced this network by installing a number of watertable observation wells (DF1A, 3PH, C2, B21, B22, 14C1-2, and C4) at 0.28 well/ha. In addition to this main network, three observational wells (EBT1-3) were drilled beside an earthen lined store on a site beside the dairy farm buildings. The wells were levelled using TOPCON AT-G4 equipment (TOPCON Ltd, Ireland) and the locations of the wells were input into ArcGIS™ 9.1 (ESRI, Ireland). On the date of levelling (8th June 2006), the water level was determined using a V10/10 electric water-level indicator with acoustic and light signal (Van Walt Ltd, Surrey, U.K.).

Two dimensional groundwater data models using block kriging were generated using GW-Contour 1.0 software (Waterloo Hydrogeologic, Waterloo Ontario, Canada), which is a new data interpolation and visualization tool. A topographic base map with field boundary overlay was generated with ArcGIS™ and merged with well location and groundwater head input files. Groundwater heads were calculated after levelling and were assigned to an input file at a given point in time and corrected for height of the well pipe above the soil surface. Surface water features such as streams, lakes, open drains and marl holes were also levelled on 8th June, 2006. Trial holes (4 m bgl) were excavated for the purposes of identifying potential sites for a further earthen lined store on the dairy farm. Soil profiles were described and each horizon was sampled for texture and

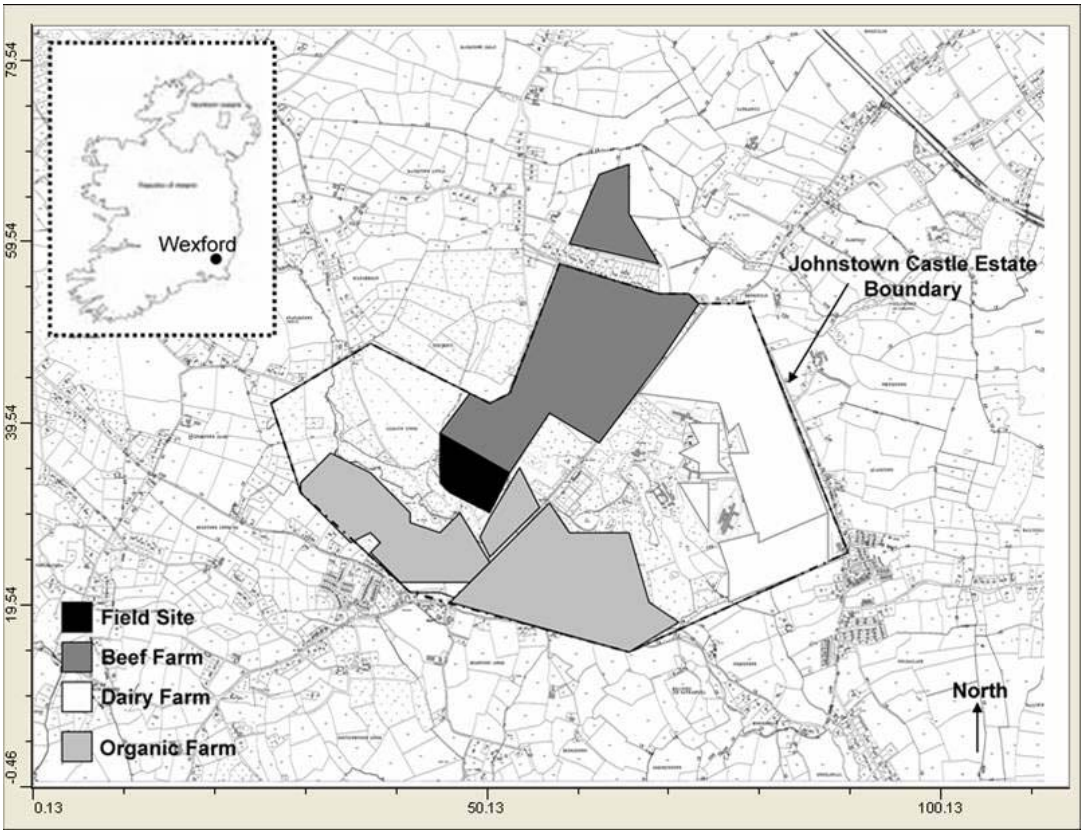

Figure 1. Johnstown Castle boundary, field site, dairy, beef and organic farms. Map reproduced under O.S Licence No. SU 0000805.

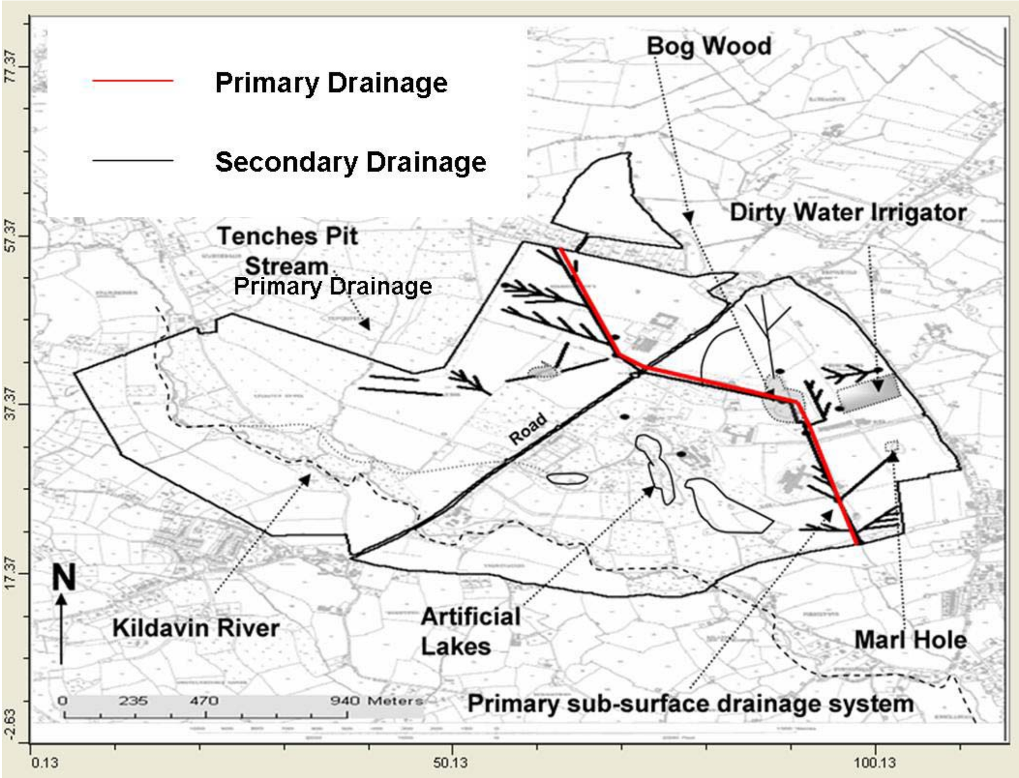

Figure 2. Sub surface drainage system and surface water features on the Johnstown Castle Estate.

Atterberg limits (Table 1). This information was used to define three effective porosity zones around the farmyard. Slug tests defined hydraulic conductivity values for these zones.

A dirty water irrigator (Briggs, U.K.) with run length of 200 m is located northwest of the dairy farm. Routine photometric tests of water samples were analyzed on a water analyzer, Thermo, Konelab 20 (Technical Lab Services, Ontario, Canada) for chloride, nitrite, orthophosphate, total organic nitrogen and potassium.

RESULTS

As a result of the second phase of drilling (0.28 well/ha), groundwater flow across the farmyard and in specific areas of interest may be assessed. The watertable map of the dairy farm is presented in Figure 3. The drainage system causes the contours to break (dashed lines Figure 3) across this area and groundwater flow changes to accommodate drainage. Depth to bedrock varies (from 12 m to greater than 20 m).

A mean annual nitrate fluctuation map using data from the first and second drilling phases is shown in Figure 4. Highest fluctuations occur south of the farmyard and to the southwest mirroring groundwater flow direction. Nitrate/chloride ratios in this region are also high (C5, 14C1 and 14C2) and low elsewhere (C4).

Despite topography, groundwater flow northwest of the farmyard flows in two different directions (irrigated area shown in Figure 5). An area is identified where nutrient status from the irrigator source develops in the direction of groundwater flow. This helps to distinguish the nitrate

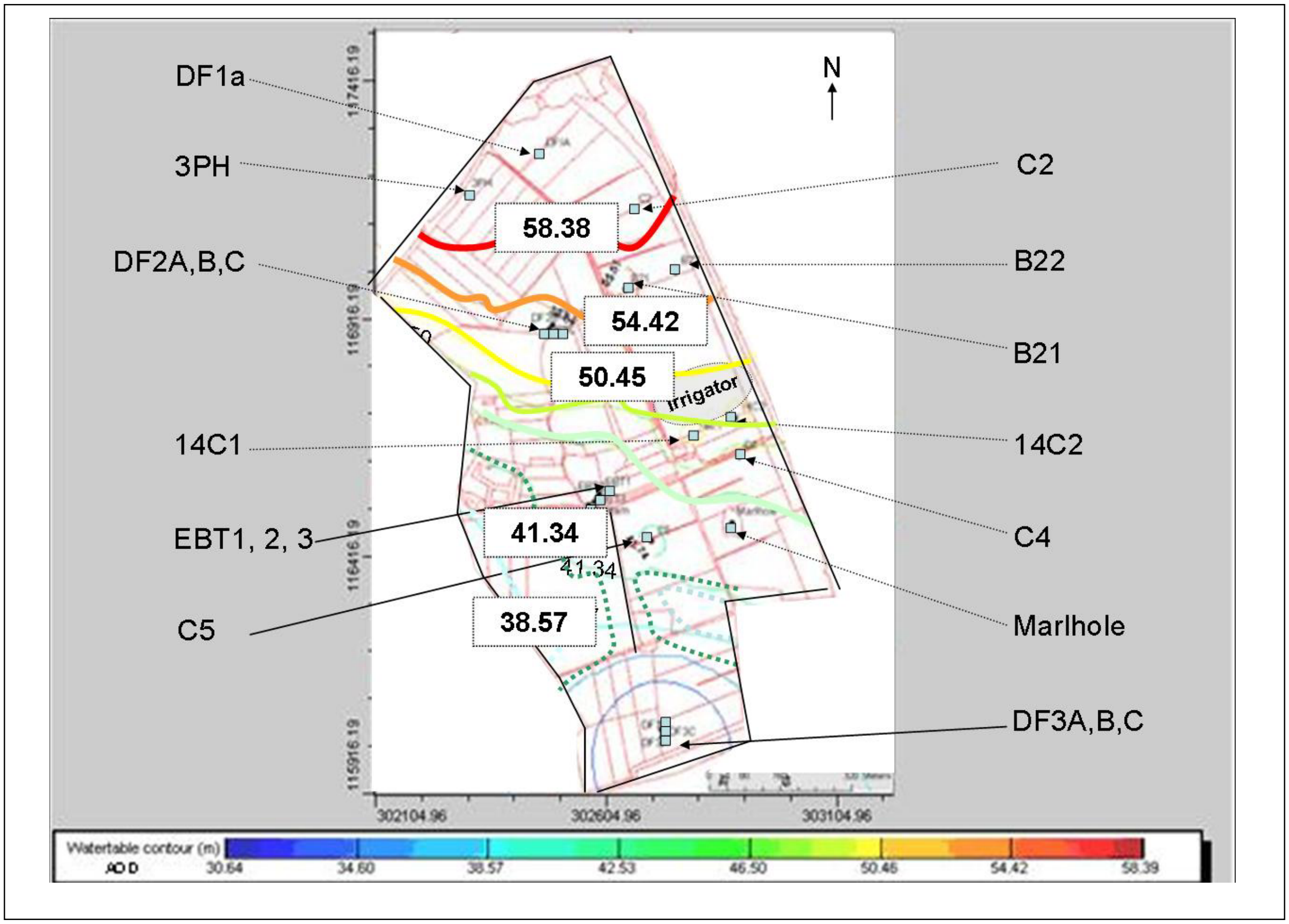

Figure 3. Watertable contour map of Johnstown castle and well locations.

Table 1. Zone 1 and 3 trial profile description, plasticity index (PI) and particle size analysis.

Zone 1						Zone 3					
				PI	Particle Size Analysis (%)					PI	Particle Size Analysis (%)
Horizon	A11	Depth	0-20cm			Horizon	A1	Depth	0-15cm		
		Texture	Loam					Texture	Loam		
		Colour	7.5 yr 4/2					Colour	5 yr 4/2		
		Structure	Coarse granular					Structure	granular		
		Roots	Plentiful					Roots	Plentiful		
		Stones	Occasional					Stones	few		
		Boundary	Diffuse					Boundary	Sharp undulating		
	A12	Depth	20-37cm				A2	Depth	15-41cm		
		Texture	Sandy Clay Loam					Texture	Loam		
		Colour	7.5yr 4/2 mottled					Colour	75yr 5/3, 5yr 5/8 mottles		
		Structure	Weak granular					Structure	granular to weak prismatic		
		Roots	few, fine					Roots	few, fine		
		Stones	few					Stones	few		
		Boundary	Abrupt					Boundary	clear smooth		
	Bw	Depth	37-82cm	20.6			Bw	Depth	41-91cm	19.3	
		Texture	Clay Loam		38.7(sand), 44.9(clay), 16.2(silt)			Texture	Sandy Clay		52.7(sand), 37.5(clay), 9.7(silt)
		Colour	7.5yr 5/4, 5yr 5/8 mottles					Colour	7.5yr 4/4, 5yr 6/8 mottles		
		Structure	Coarse prismatic					Structure	Coarse prismatic		
		Roots	None					Roots	sparse & fibrous		
		Stones	Shale, few					Stones	few		
		Boundary	Clear sharp					Boundary	diffuse		
	Bs	Depth	lens, variable, 82-91-100cm								
		Texture	Sandy to sandy loam								
		Colour	7.5yr 5/4, 5yr 4/6 mottles								
		Structure	weak coarse prismatic								
		Roots	none								
		Stones	shale, few								
		Boundary	uneven								
	Bt	Depth	95-210cm	21.7			Bt	Depth	91-200cm	22	
		Texture	Clay Loam		38.5(sand), 27.1(clay), 34.39(silt)			Texture	Clay		33.4(sand), 52.6(clay), 13.9(silt)
		Colour	5yr 5/6, 7.5 yr 6/4 mottles					Colour	7.5yr 4/4		
		Structure	very weak coarse prismatic					Structure	weak coarse prismatic		
		Roots	none					Roots	none		
		Stones	few					Stones	shale, few		
		Boundary	uneven					Boundary	uneven		

plume. Surrounding wells not in direct groundwater flow (C4, 14C2) as shown in Table 2 have lower nitrate concentrations.

Boreholes B2 (1) and B2 (2) receive groundwater up gradient from the irrigated area (Figure 5).

When all wells are used in the nitrate status contour map a plume is seen consistent with groundwater flow direction across the farmyard. This can be combined with the nutrient fluctuation map to interpolate groundwater concentration ranges at a point at a given time.

The velocity vector map for the dirty water irrigation area is presented in Figure 6. Deflections in groundwater flow come predominantly from the artificial lake system to the west and surface water features. Surface and groundwater interactions due to the elevation of the artificial lakes have been altered. Instead of a groundwater sink the lakes recharge to groundwater. A more natural sink occurs on the farm where the marl hole is situated (shaded area, Figure 2). This has important implications for nutrient concentrations in the vicinity of the lake system.

Large differences in elevation exist between the boreholes DF (1), DF (2) and DF (3) (Table 3). The base of DF2C (37.21 m AOD) is above the ground elevation at DF3A (33.3 m AOD). The boreholes DF2C and DF3C were drilled to below the bedrock at 34.7 m AOD and 21.3 m AOD, respectively (Bartley, 1996). Two scenarios exist with groundwater stratification. For boreholes DF2A and DF2B the watertable level on 8th June, 2006 was at 52.79 m AOD whereas the borehole

Table 2. Nitrate status (mg/l) in first and second phase drilling network.

	2004					2005											2006
Well	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Nov.	Dec.	Jan.
DF1A	1.07		0.99	2.21	2.09	1.83	1.00		0.90		0.81	0.94	0.58	0.66	2.07	0.75	0.70
DF2C	1.79		1.32	2.16	2.37	2.81	2.01		2.54		2.03	3.49	0.41	2.56	2.74	2.82	2.94
DF2B								5.11	4.58		4.41	5.32	4.01	4.17	4.54	4.61	4.99
DF2A								5.11	4.58		2.94	4.45	3.07	2.63	3.32	3.37	3.50
EBT1			4.07	3.87	1.71	5.07	4.85		5.07		4.85	5.70	5.05	4.85	4.78	4.82	4.86
EBT2			4.37	4.11	3.39	6.13	2.69		4.80		4.99	5.84	4.78	4.54	4.38	4.68	4.98
EBT3			5.09	4.49	4.01	6.25	2.71		5.15		4.64	6.01	5.18	5.10	5.12	5.34	4.92
DF3C	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.34	<DL	<DL	<DL	<DL	0.07	<DL
DF3B	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.39	<DL	<DL	<DL	<DL	<DL	<DL
DF3A	0.70	0.67	1.29	1.40	1.73	1.17		1.84	1.42	1.31	1.05	1.05	0.81	1.86	1.86	1.86	1.86
	2004					2005										2006	
Well	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jul.	Aug.	Oct.	Dec.	Jan.	Feb.	Mar.
3PH										10.71	6.38	7.76	8.12	9.60	10.49	9.61	11.77
C2										6.63	6.86	0.95	1.87	1.68	2.08	1.68	2.50
B2(1)														8.92	7.86	8.62	4.65
B2(2)										5.36	6.02	4.18	1.11	9.23	7.58	10.09	10.57
14C(1)										12.14	9.52	8.73	8.03	15.76	17.38	15.32	19.68
14C(2)										1.04	1.58	2.64	2.36	1.26	2.11	7.42	4.31
C4										<DL	<DL	<DL	0.09	0.00	0.08	0.02	0.01
C5										5.93	6.53	6.54	7.22	8.11	7.92	6.05	11.55

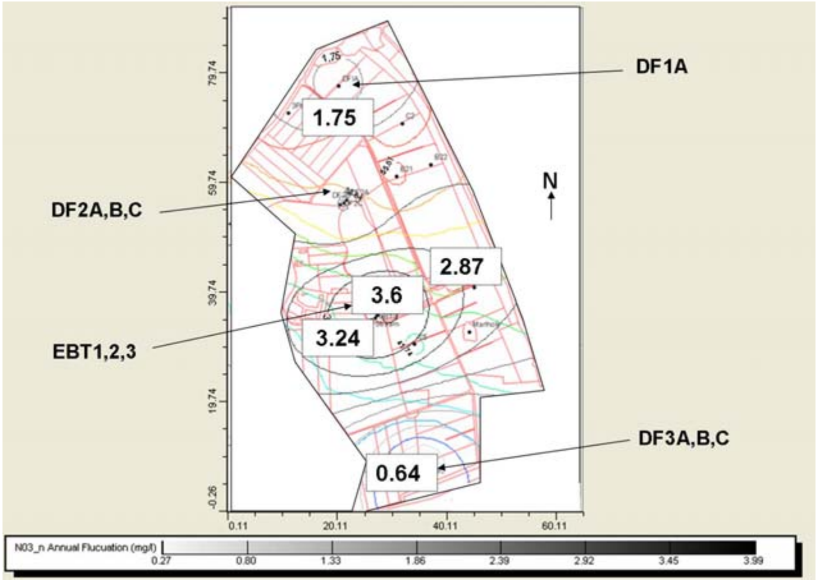

Figure 4. Mean annual Nitrate fluctuations from December 2004 to January 2006.

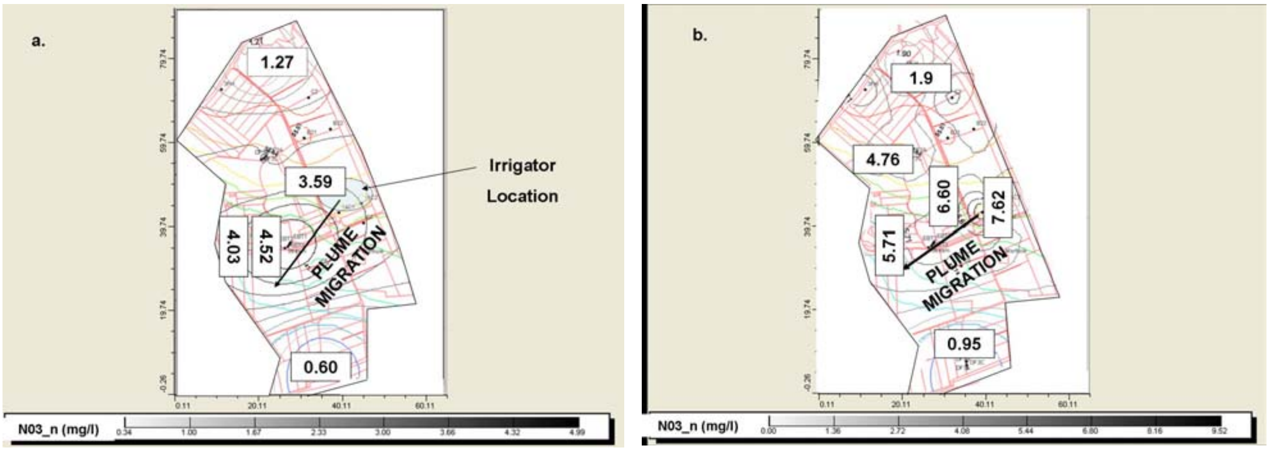

Figure 5. NO_3 status for initial monitoring network (a) and final network (b).

DF2C was at 52.35 m AOD. Total depths indicate downward movement of groundwater (see Table 3). Nutrient concentrations appear stratified in these multi level wells (Table2). The reverse is true for the relationship between boreholes DF3A and DF3B (30.63 m AOD) and borehole DF3C (30.93 m AOD) (see Table 3). Groundwater is shown to move upwards in this area from depth diluting the shallower unsaturated zone water (Table 3). Consequently nutrient concentrations at borehole DF3B may be diluted by the lake system and upward seepage from the bedrock aquifer. The reverse can be seen for boreholes DF2 A-C where nutrient concentrations increase with depth (Table 2).

Higher groundwater nutrient concentrations in this area may be explained due to a depression around borehole C5 where a continuous sand lens connects the area around the farmyard down gradient to the southwest. However borehole C4 receives lower concentrations along the dilution front of groundwater flow.

In the northeast of the farm borehole 3PH has high groundwater nutrient concentrations whereas DF1A and C2 have lower concentrations due to the fact a point source is orientated to the

Table 3. Well and map parameters for 8th June 2006.

Well	Elevation m AOD	Total depth m bgl	Watertable height m AOD
3PH	63.2	4.68	58.3
DF1A	59.7	6.94	58.1
C2	62.8	8.23	56.9
DF2C	54.2	16.5	52.3
DF2B	54.2	12	52.7
DF2A	54.1	6.56	52.7
B2(1)	59.4	3.2	56.1
B2(2)	57.6	6.61	53
14C(1)	52.1	3.25	50.8
14C(2)	52.3	4.81	50.7
EBT1	47.2	5.46	44.2
EBT2	46.3	5.95	42
EBT3	45.9	5.95	42.5
C4	47.5	3.33	46.1
C5	45.9	8	41.2
DF3C	33.3	16.6	30.9
DF3B	33.3	11.93	30.6
DF3A	33.3	5.95	30.6
MarlHole	42.5	-	-
Stream	42.1	-	-
Irrigator	52.5		

northwest (Table 2). The area surrounding DF1A has a soil thickness of greater than 20 m with low permeability zones at depths greater than 7 m. Zones 1 and 3 have fine loamy and coarse loamy over fine loamy textures and are moderately drained. Zone 2 has a sand texture (flowing sands in places) and is well drained. Each zone was allocated an effective porosity (Zone 1(0.25), Zone 2 (0.35) and Zone 3(0.20). Each zone was also allocated a hydraulic conductivity from slug test results (Zones 1 and 2 (10^{-3} cm/s) and Zone 3 (10^{-4} cm/s).

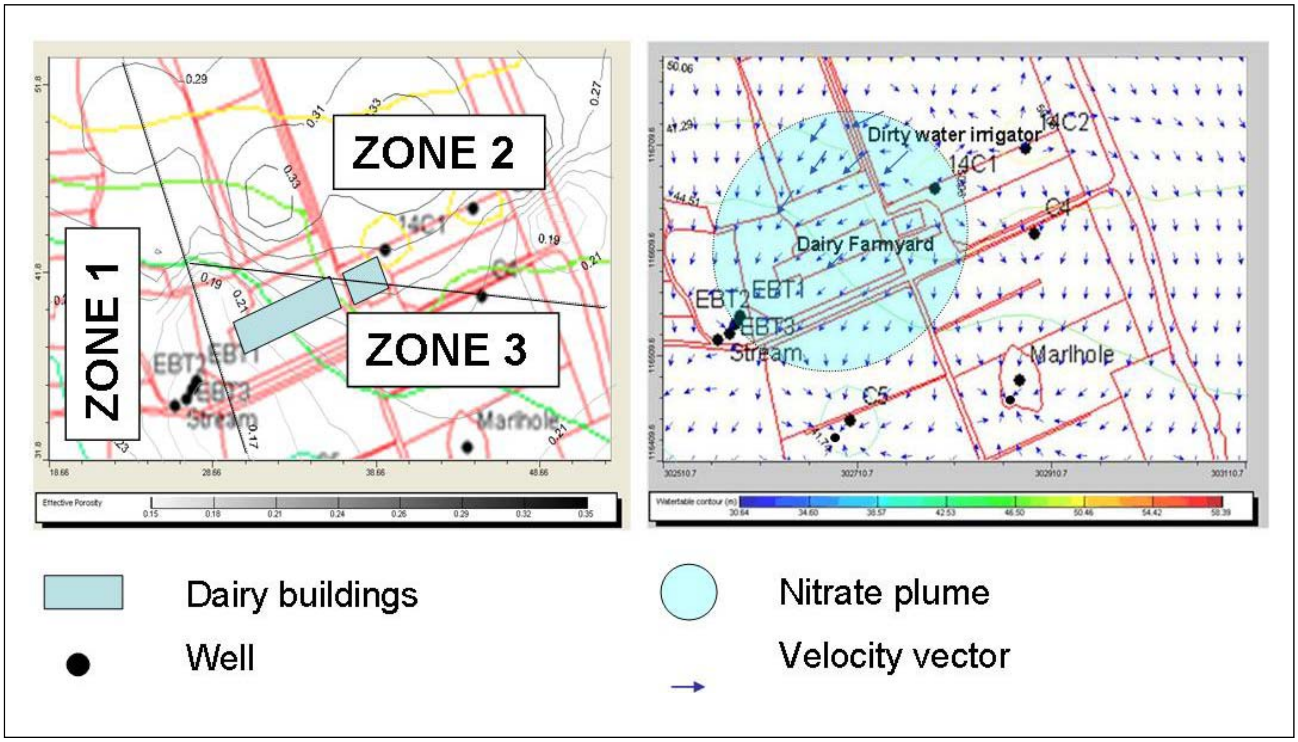

Figure 6. Effective porosity and velocity vector map of area surrounding the dairy farmyard. Arrows denote groundwater flow, direction and velocity.

DISCUSSION

A groundwater map may be used to interpolate nutrient concentrations at a study site. A monitoring network that is designed with a map as its primary objective, and which is used as a reference for site suitability, plot location and orientation can attempt to account for nutrient concentrations in different areas. A monitoring network of high density and coverage attempts to define nutrient transport to certain areas of the farm and decreases the bias related to interpretation. Therefore outside influences are monitored by a peripheral well network, which then extends internally to form a grid. A monitoring network design should precede experimental design and include surface water features and subsurface drainage system. The influence of this drainage system must be accounted for whilst constructing any watertable maps.

The type, extent and function of these drains must be taken into account. A clearer understanding of the groundwater flow pathways may lead to a better understanding of nutrient concentration at monitoring wells. Groundwater entering and leaving the farm and nutrient migration may be monitored. Areas where upward or downward seepage should also be identified and the connection between surface and groundwater defined. Longer term monitoring will produce watertable fluctuation, head differences and groundwater quality maps. The use of automatic loggers will enable accurate watertable fluctuation maps to be constructed seasonally/annually aiding experiments relating to groundwater response to certain agricultural practices.

Now that the basic hydrogeology of the site is understood, more detailed studies could be carried out by dividing the farm into hydraulic conductivity zones.

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REFERENCES

Bartley, P. 1996. Groundwater Investigation at Johnstown Castle. M.Sc. Thesis, Trinity College, Dublin

Culleton, E, and S. Diamond. (in press). Soils of Johnstown Castle Estate, Soil Survey Bulletin. Teagasc, Johnstown Castle. www.teagasc.ie

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