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Visual drainage assessment: A standardised visual soil assessment method for use in land drainage design in Ireland

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Abstract

The implementation of site-specific land drainage system designs is usually disregarded by landowners in favour of locally established 'standard practice' land drainage designs. This is due to a number of factors such as a limited understanding of soil–water interactions, lack of facilities for the measurement of soil's physical or hydrological parameters and perceived time wastage and high costs. Hence there is a need for a site-specific drainage system design methodology that does not rely on inaccessible, time-consuming and/or expensive measurements of soil physical or hydrological properties. This requires a standardised process for deciphering the drainage characteristics of a given soil in the field. As an initial step, a new visual soil assessment method, referred to as visual drainage assessment (VDA), is presented whereby an approximation of the permeability of specific soil horizons is made using seven indicators (water seepage, pan layers, texture, porosity, consistence, stone content and root development) to provide a basis for the design of a site-specific drainage system. Across six poorly drained sites (1.3 ha to 2.6 ha in size) in south-west Ireland a VDA-based design was compared with (i) an ideal design (utilising soil physical measurements to elucidate soil hydraulic parameters) and (ii) a standard design (0.8 m deep drains at a 15 m spacing) by model estimate of water table control and rainfall recharge/drain discharge capacity. The VDA method, unlike standard design equivalents, provided a good approximation of an ideal (from measured hydrological properties) design and prescribed an equivalent land drainage system in the field. Mean modelled rainfall recharge/drain discharge capacity for the VDA (13.3 mm/day) and ideal (12.0 mm/day) designs were significantly higher (*P* < 0.001, s.e. 1.42 mm/day) than for the standard designs (0.5 mm/day), when assuming a design minimum water table depth of 0.45 m.

Keywords

design • land drainage • site-specific • visual soil assessment

Introduction

The successful design and implementation of site-specific land drainage systems is dependent on fully characterising soil physical properties with regard to their drainage characteristics (Martínez-Beltrán, 1988; Bos and Boers, 1994; Schultz *et al.*, 2007; Skaggs *et al.,* 2012). While methods for measuring relevant physical properties are long established (Bouwer and Rice, 1983; Van Beers, 1983; BS 1377-5:1990), the implementation of site-specific design is often disregarded in favour of locally established drainage design practices (Smedema *et al.,* 2004; Vlotman *et al.,* 2007), particularly for small-scale (< 10 ha) drainage schemes.

The principle of land drainage design in an Irish context is to exploit the soil layers with relatively high permeability by installing a groundwater drainage system (Mulqueen and Gleeson, 1982; Mulqueen and Hendricks, 1986; Cavelaars *et al.,* 1994) or where such layers are not present, to implement a suitable shallow drainage system. Consequently, two broad types of land drainage systems are commonly deployed (Smedema and Rycroft, 1983; Teagasc, 2013): (i) the groundwater drainage system, which facilitates the flow of groundwater from a high permeability soil layer to an outlet where excess water can readily infiltrate and percolate to the water table, and (ii) the shallow drainage system, where infiltration and percolation are impeded and action is taken to increase hydraulic conductivity by disturbing and fissuring the soil matrix, thereby allowing sufficient movement of water through the soil profile. Such improvements are brought about by disruption techniques (Childs, 1943; Spoor, 1982; Mulqueen, 1985; Robinson *et al.,* 1987; Tuohy *et al.*, 2016), which include mole drainage, gravel mole drainage and sub-soiling installed at close (1–2 m) spacings, normally supplementing more widely spaced in-field drains.

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In order to select the most appropriate system for a given site, it has been suggested that a full-site investigation to establish pertinent soil hydraulic properties be carried out (Mulqueen and Hendricks, 1986). This may involve the excavation of multiple soil test pits, examination of the soil profile, sampling of soil horizons in the profile and hydraulic conductivity measurements in the field (Bouwer and Rice, 1983; Oosterbaan and Nijland, 1994; Mulqueen, 1995) and laboratory (BS 1377-5:1990). Such data along with soil profile geometry parameters are used with drainage design formulae (Ernst, 1956; Kirkham, 1958; Toksöz and Kirkham, 1961; Toksöz and Kirkham, 1971a, b; Ritzema, 1994) to prescribe an idealised drain depth and spacing (distance between adjacent drains).

There has been little uptake of these scientific design methods by Irish landowners due to the financial cost, limited expertise, limited understanding of soil/soil–water interactions, lack of facilities for the measurement of soil physical and hydrological properties and imposition of rigid design schemes where state aid was supplied for land drainage (Galvin, 1966; Burdon, 1986; Ryan, 1986). In the absence of widespread or organised dissemination of expertise in drainage problem diagnosis and drainage system design, drainage schemes are usually installed by contractors who lack a scientific understanding of drainage design theory. The effectiveness of the drainage systems installed (typically shallow drains (<1.0 m) targeting localised depressions and other areas prone to waterlogging) can be extremely limited (Mulqueen and Hendricks, 1986).

Some expert practitioners have developed visual methods of deciphering pertinent soil characteristics and designing drainage systems in the field as an alternative (Gleeson, personal communication, 2011). However, such methods are subjective and as a result non-transferable. It is hypothesised that a standardised mechanistic visual soil assessment method, similar to established visual methods of soil assessment (Munkholm, 2000; Shepherd *et al.,* 2000; Shepherd, 2009; Guimarães *et al.,* 2011; Ball *et al.,* 2011; Ball and Munkholm, 2015), could be developed to approximate the permeability of various soil horizons under Irish field conditions. Such information could then be used as a basis for site-specific drainage system design that is accessible to all stakeholders and does not require laboratory or field measurement of soil physical or hydrological properties, thereby preserving such expertise and expanding its usefulness to a wide number of practitioners. Similar approaches have not been previously documented in the literature.

Therefore, the objectives of the current study were as follows:

1. To develop a visual method of land drainage system design, called visual drainage assessment (VDA) design, which is based on information gathered from a soil profile assessment in combination with background information on site and outfall conditions.
2. To evaluate the VDA methodology by comparing the drainage system designed by VDA on six dairy farms in south-west Ireland with an ideal site-specific drainage system designed using field data collected at each farm and a standard drainage system as used in common practice in the region (approximated as 0.8 m deep drains at 15 m spacing). The VDA methodology is evaluated by comparing model estimates of rainfall recharge/drain discharge capacity (mm/day) and water table (WT) control (minimum WT depth, m) across the three design methods for each site.

Materials and methods

Visual drainage assessment

The VDA method was specified to meet certain criteria: it had to be practicably applicable in the field; it would need to be reliant on inherent soil physical properties to ensure the prescribed designs were appropriate and it had to provide a clear unambiguous direction in terms of drainage system design. It was decided to base the method on a number of indicators that could be readily defined in soil test pits and which reliably predicted soil drainage characteristics.

The indicators used were chosen to permit inference of soil permeability and to identify characteristics that inhibit or promote particular drainage techniques. Each indicator (Table 1) is a commonly observed pedological attribute (FAO 2006; Mueller *et al.,* 2007; Hartemink and Minasny, 2014). Initially each horizon in the soil profile is classified with respect to each of the indicators outlined. Each classification corresponds to a VDA score from which, when combined, soil permeability can be inferred (Table 1).

The indicators are water seepage, pan layers, texture, porosity, consistence, stone content and root development (Table 1). The presence and depth of *water seepage* into each pit is noted. A score of 1 is given to horizons where seepage is observed and 0 to those without seepage.

Pan layers are noted, if present. Iron pans are the most easily identifiable as a black to dark reddish coloured horizon, 2–10 mm thick (Conry, 1996; Cunningham *et al.,* 2001). A score of –1 is assigned if a pan is present or 0 if not.

Soil texture is assessed by hand (DEFRA 2005). Here the 11 main texture classes are split into three broad categories for simplicity: the heavy soils (clay, sandy clay and silty clay), the medium soils (clay loam, sandy clay loam and silty clay loam) and the sandy and light silty soils (sand, loamy sand, sandy loam, sandy silt loam and silt loam) hereafter referred to as the light soils. Light and medium-textured soils receive a score of 1 while heavy textured soils receive 0.

Porosity is assessed as poor, moderate or good using the classifications of Shepherd (2009), and assigned a score of 0, 1 or 2 respectively.

Consistence, which is the strength with which soil materials are held together, is described using the classifications

Table 1. Visual indicators of soil permeability, their interpretation, assigned visual drainage assessment (VDA) score and weighting (A =10, B = 4, C = 1)

Indicator	Classified by	Classified as	VDA Score	Weighting
Water seepage	Presence	Water seepage evident	1	A
		No seepage evident	0	
Pan layers	Presence	Present	-1	A
		Not present	0	
Texture	Hand textured (adapted from DEFRA 2005)	Medium and light textured soils	1	B
		Heavy textured soils	0	
Porosity	Poor, moderate or good (Shepherd 2009)	Good	2	C
		Moderate	1	
		Poor	0	
Consistence	Stickiness & plasticity (FAO 2006)	Non-sticky, non-plastic soils	2	C
		Sticky *or* plastic soils	1	
		Sticky *and* plastic soils	0	
Stone content	Abundance (FAO 2006)	Stone content > 15%	1	C
		Stone content < 15%	0	
Root development	Presence	Present	1	C
		Not present	0	

of FAO (2006). Soils classified as non-sticky and non-plastic receive a score of 2, if stickiness or plasticity is observed a score of 1 is assigned and if both stickiness and plasticity are observed then a score of 0 is assigned. *Stone content* is characterised by abundance according to the classifications of FAO (2006). A score of 1 is assigned if the gravel content is greater than 15%; otherwise a score of 0 is assigned. *Root development* is characterised by presence and depth of roots. A score of 1 is given if roots are present and 0 if not.

Drainage design using visual drainage assessment information

Step 1: Soil permeability classification

The indicators that provide the most reliability for hydrological discrimination between soils (water seepage and presence of pan layers) are assigned the highest weighting (A, a value of 10) and therefore much greater influence on soil permeability classification, while those with less reliability are assigned the lowest weighting (C, a value of 1) and those of intermediate reliability are assigned an intermediate weighting (B, a value of 4) (Table 1). The total VDA score for each horizon is calculated by multiplying each indicator score by its corresponding weighting and summing the results. Soil horizons are then classified as poorly, moderately or highly permeable based on the total VDA score. Poorly permeable horizons have a total VDA score ≤ 5, moderately permeable horizons have a total VDA score > 5 and ≤ 10 and highly permeable soils have a total VDA score >10.

Step 2: Drainage system type

The VDA permeability class scores can then be used to prescribe a specific drainage system for a particular soil on the basis of inferred soil permeability. Where a shallow drainage system is prescribed, the details of its design are further described by reference to the specific indicator results used in the VDA assessment. A flow chart has been developed for this purpose (Figure 1). The method cannot be used to infer whether a site requires land drainage works or not as such a decision is based on many external factors such as climate, land use, intensity of production and economics. It can, however, be employed on sites where the landowner has decided that a drainage system is required and needs to be designed.

Step 3: Design spacing and depth

On grassland soils in Ireland, the minimum spacing of in-field drains, beyond which artificial drainage cannot be economically provided, is usually considered to be 15 m (Teagasc, 2013). Therefore, a 15 m in-field drain spacing is prescribed for relatively flat (< 4 %) sites and a 20 m in-field drain spacing is prescribed for sloping (≥ 4 %) sites (Mulqueen *et al.,* 1999). This applies to both groundwater drains and shallow drains acting as outfalls for shallow disruption techniques (mole drainage, gravel mole drainage and sub-soiling installed at close (1–2 m) spacing).

The depth of the groundwater drains is dependent on depth of the highly permeable soil layer; drains must sit in this layer. For shallow disruption techniques, the maximum intensity of disturbance (i.e. maximum depth (approximately 0.4–0.6 m) and closest spacing (approximately 1.2–1.5 m)) possible is prescribed, taking into account the depth limitations of the implement used, the width of the tractor available for drawing the implement and the need to avoid tracking over freshly installed disruption channels, which may undo much of the desired soil disturbance and fissuring. The depth of in-field shallow drains is set to provide sufficient outfall from the disruption channels.

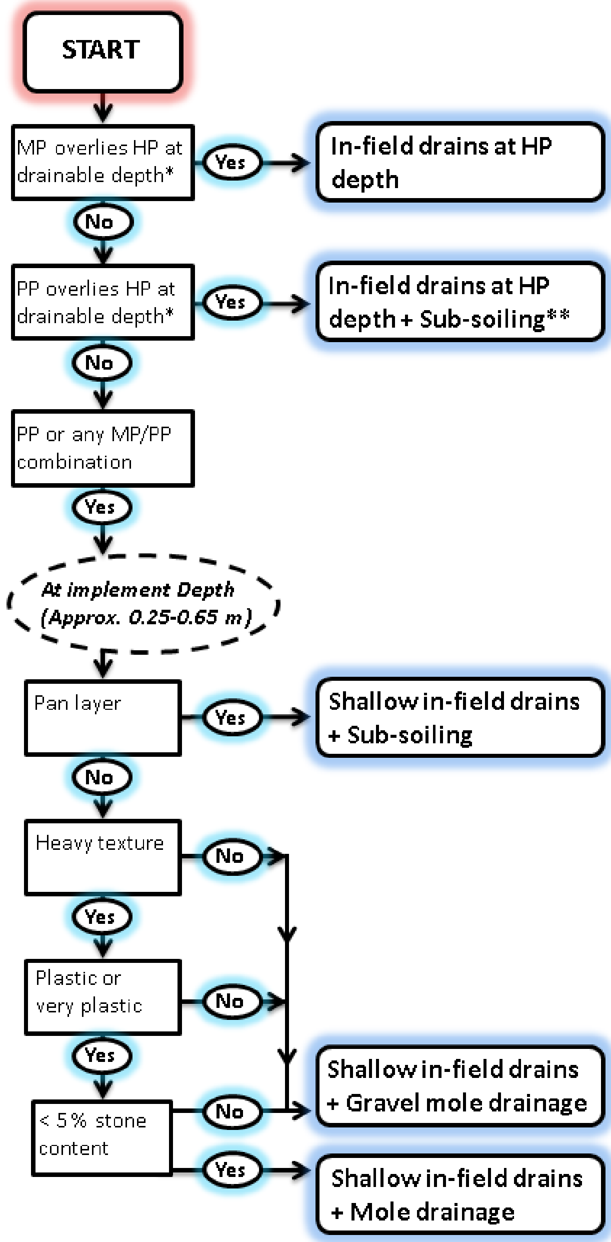

Figure 1. Flow chart to be used when prescribing a drainage system type given permeability classifications as defined by visual drainage assessment (VDA) score and indicator classification. HP = highly permeable, MP = moderately permeable, PP = poorly permeable. Note: *Dependent on outfall conditions, **practical limitations will limit sub-soiler application beyond approximately 70 cm.

Study sites

To validate the VDA method, it was deployed across a range of sites. Six dairy farms in south-west Ireland using permanent grassland for livestock grazing and silage production were selected for this element of the study. The farms were all participants in the Teagasc 'Heavy Soils Programme', which aims to demonstrate methods to improve grassland productivity and utilisation, decrease volatility and sustain viable farm enterprises on poorly drained soils. They were selected from within regions where poor soil drainage coupled with climate (principally precipitation less evapotranspiration) inhibits potential for production and on-farm profitability. All farms required land drainage works. In conjunction with each farmer an area of the farm with a history of impeded drainage was selected in which a new drainage system could be designed. The sites were (Table 2):

(1) 2.6 ha in Rossmore, Co. Tipperary with an existing open drain at 1.8 m depth along the north-eastern site boundary.
(2) 2.5 ha in Lisselton, Co. Kerry with an existing open drain at 1.9 m depth along the north-eastern site boundary.
(3) 1.5 ha in Ballinagree, Co. Cork with an existing open drain at 0.4 m depth along the eastern site boundary.
(4) 2.2 ha in Doonbeg, Co, Clare with an open drain at 0.7 m depth along the northern and western site boundaries.
(5) 2.1 ha in Athea, Co. Limerick with an open drain at 1.5 m depth along the eastern site boundary. Another open drain at 0.5 m depth spanned the site.
(6) 1.3 ha in Castleisland, Co. Kerry with an existing stream (1.2 m deep) along the southern site boundary.

Soil test pits were excavated at representative locations on each site, with a focus on areas with surface indications of poor drainage such as waterlogging, surface damage by machinery or livestock and plant indicators such as soft rush (*Juncus effusus*) and marsh thistle (*Cirsium palustre*) or poor grass growth. Typically, one pit was dug per hectare. The pits were excavated to at least 2.5 m depth unless impeded by bedrock.

As soil test pits uncovered relatively uniform profiles within the individual sites, the VDA methodology was carried out in only one pit per site to assign a permeability class to each soil horizon and prescribe a drainage design. Disturbed soil samples were also taken and analysed for particle size distribution (NRM laboratories, Berkshire, UK) to allow for the formulation of an ideal drainage design and comparison between drainage design methods. On

Table 2. Site details

Site	Location			Average annual precipitation (1981-2010)[a]		Slope (%)
	Northing (degree)	Westing (degree)	Elevation ASL (m)	Precipitation (mm)	Station distance from site (km)	
Rossmore	52°36’	08°01’	105	982	6.5	1-2%
Lisselton	52°28’	09°33’	8	1095	1.0	1-2%
Ballinagree	51°59’	08°56’	231	1757	5.5	7-9%
Doonbeg	52°44’	09°30’	9	1185	2.0	<1%
Athea	52°27’	09°19’	139	1320	4.3	4-6%
Castleisland	52°13’	09°28’	36	1298	2.5	4-6%

Note: ASL = above sea level, [a]Precipitation data was provided by Met Éireann.

each site, one composite sample was collected (across test pits and horizons) if the soil profiles uncovered were relatively uniform and two separate composite samples were collected if distinct differences in water ingress with depth were noted. The topsoil was not sampled. From this soil texture data, saturated hydraulic conductivity (k_s) equivalents were determined (Saxton and Rawls, 2006), assuming a soil organic matter content of 2.5 % (by weight). The pits were then photographed before backfilling. In order to assess the validity of the VDA permeability classification, VDA assigned permeability classes were compared with the estimated k_s (Saxton and Rawls, 2006) of soil samples collected at a comparable depth. Data were analysed using ANOVA with VDA permeability classification as a fixed effect.

Ideal and standard designs

The k_s parameters obtained were used as inputs to standard steady-state drainage design equations (Ritzema, 1994) to establish an ideal drainage design depth and spacing for the inherent soil properties assuming a desired rainfall recharge/drain discharge capacity of 12 mm/day (Mulqueen and Hendricks, 1986: Collins *et al.,* 2004) and a desired minimum water table depth of 0.45 m (Brereton and Hope-Cawdery (1988) have shown that grass production on a poorly drained soil will be limited until the water table depth reaches approximately 0.45 m). The most appropriate drainage design equation was used in each case. The Ernst equation (Ernst, 1956; Ritzema, 1994) was used for two layered soil profiles when the top layer had a lower k_s than the bottom layer (Rossmore, Lisselton, Ballinagree) and the equations and nomographs developed by Toksöz and Kirkham (1971a, b) were used in deep impervious soils where k_s was largely uniform at all relevant depths (Doonbeg, Athea, Castleisland) (Mulqueen and Hendricks, 1986). A standard drainage design was also prescribed for each site (approximated as 0.8 m deep drains at 15 m spacing) regardless of soil characteristics.

Comparison of design methodologies

As it is not possible to empirically evaluate the differences between the three design options, they were compared by model estimate of rainfall recharge/drain discharge capacity (mm/day) and water table control (minimum water table depth, m) capacity. The design equations, as described in the previous section, were used to model the designs formulated by VDA and the standard drainage design to calculate rainfall recharge/drain discharge capacity and minimum water table depth, given design depth and spacing parameters, and allow for comparison with the ideal design. The k_s values established from analysis of disturbed soil samples from soil test pits were used as inputs. To assess water table position, a rainfall recharge of 12 mm/day was assumed, and to assess rainfall recharge/drain discharge capacity, a minimum water table depth of 0.45 m was assumed. Modelled water table depth and rainfall recharge/drain discharge capacity data were analysed using ANOVA with design method as a fixed effect.

Results

Visual drainage assessment designs

Table 3 shows the classification of each indicator for each soil horizon and site with its VDA score and weighted score. The VDA total score and its associated permeability classification for each site and horizon are also presented. Table 4 presents measured texture and estimated k_s for distinct depths on each site with the permeability classifications based on the VDA score at a comparable depth. In Figure 2, the k_s of those soils, classified as highly, moderately and poorly permeable by the VDA methodology across the six sites is presented. Those soils classified as highly, moderately and poorly permeable using the VDA methodology had mean k_s of 0.91, 0.27 and 0.11 m/day respectively (P<0.05, s.e. 0.143 mm/day).

Having assessed the indicators and assigned permeability classifications to all horizons, an appropriate drainage

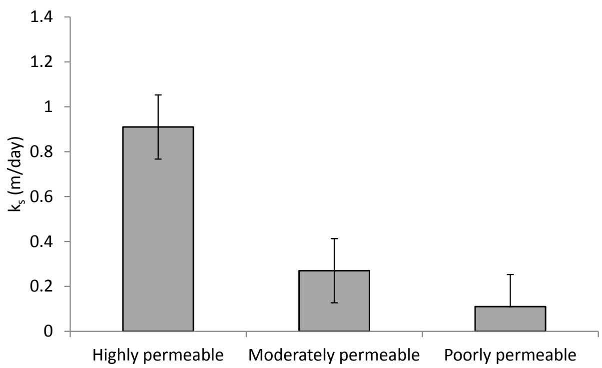

Figure 2. Mean estimated saturated hydraulic conductivity (k_s) (Saxton and Rawls, 2006) inferred from measured soil texture for those soils classified by the visual drainage assessment methodology as highly, moderately and poorly permeable. Error bars show permeability class s.e.m.

system could be prescribed using a decision tree approach (Figure 1). Groundwater drainage systems were prescribed for three sites. At Rossmore, Lisselton and Ballinagree, highly permeable horizons overlain by moderately permeable horizons were observed (Table 3). Consequently groundwater drains were prescribed at depths of 1.6, 1.7 and 1.7 m, respectively, given the need to place drains as deep as possible in the highly permeable horizons and the limitations imposed by outfall conditions (Figure 1). Suitably deep existing drains were available at Rossmore and Lisselton while the existing drains in Ballinagree had the potential to be deepened. Drain spacings of 15 m were prescribed for Rossmore and Lisselton while a spacing of 20 m was prescribed for Ballinagree given field slope (Table 2).

Shallow drainage systems were prescribed for the other three sites. At Doonbeg, a highly permeable layer was present but observed to be below the level of outfall. Furthermore, a thick poorly permeable layer of 0.3–2.1 m depth was not in reach of a sub-soiler and would prevent sufficient water percolation to a groundwater system (Table 3). Therefore, it could only be practicably drained using a shallow drainage system. The heavy texture, plasticity and low stone content at the relevant depth meant the site was suitable for shallow in-field drains and mole drainage (Figure 1). Mole drains at a depth of 0.6 m and 1.4 m spacing (the maximum depth and closest spacing attainable given the practical limitations of a typical tractor and mole plough arrangement) were prescribed. In-field drains at a depth of 0.9 and 15 m spacing were prescribed to act as an outfall from intersecting mole channels on this relatively flat site. The existing open drain had the potential to be deepened to cater for this arrangement. At Athea and Castleisland, only moderately or poorly permeable horizons were observed (Table 3). Consequently, a shallow drainage system was required at both sites. At Athea, the medium texture and non-plastic nature of the upper horizon indicated that it was suitable for shallow in-field drains and gravel mole drainage (Figure 1), while at Castleisland, the low plasticity and high stone content at the relevant depth also indicated that it was suitable for shallow in-field drains and gravel mole drainage (Figure 1). Gravel mole drains at a depth of 0.45 and 1.5 m spacing (the maximum depth and closest spacing attainable with a typical tractor and gravel mole plough arrangement) were prescribed at both sites. In-field drains at a depth of 0.9 and 20 m spacing were also prescribed, as field slope was > 4% (Table 2), to act as an outfall for gravel mole channels.

Ideal and standard designs

An ideal drainage system for each site (Table 5) was defined in terms of drain depth and spacing given a desired rainfall recharge/drain discharge capacity of 12 mm/day and a minimum water table depth of 0.45 m. Groundwater drains were prescribed for Rossmore (1.5 m deep, 17.2 m spacing), Lisselton (1.5 m, 14.1 m) and Ballinagree (1.6 m, 19.8 m), while shallow disruption techniques were prescribed at Doonbeg (0.5 m, 1.6 m), Athea (0.5 m, 1.7 m) and Castleisland (0.5 m, 1.6 m). The standard design was prescribed as 0.8 m deep drains at 15 m spacing, taken as an approximation of common practice in the region.

Comparison of design methodologies

The model estimates of rainfall recharge/drain discharge capacity and minimum water table depth for the prescribed VDA designs are presented in Table 5. Rainfall recharge/drain discharge capacity from the VDA designs ranged from 10.7 mm/day (Lisselton) to 15.6 mm/day (Rossmore), when assuming a minimum water table depth of 0.45 m, while minimum water table depths ranged from 0.29 m (Lisselton) to 0.73 m (Rossmore), when assuming a rainfall recharge of 12 mm/day.

The model estimates of rainfall recharge/drain discharge capacity and minimum water table depth for the standard designs at each site are presented in Table 5. Rainfall recharge/drain discharge capacity ranged from 0.0 mm/day (Castleisland) to 1.0 mm/day (Rossmore), when assuming a minimum water table depth of 0.45 m, while modelled minimum water table depth at all sites was 0.0 m, when assuming a rainfall recharge of 12 mm/day.

Across sites, mean estimated rainfall recharge/drain discharge capacity from the VDA (13.3 mm/day) and ideal (12.0 mm/day) designs were significantly higher (P < 0.001, s.e. 1.42 mm/day) than from the standard designs (0.5 mm/day), when assuming a minimum water table depth of 0.45 m. Mean estimated minimum water table depth from the VDA (0.49 m) and ideal (0.45 m) designs were significantly

Table 3. Classification of each indicator for each soil horizon and site including visual drainage assessment (VDA) score (S), weighted score (WS) and VDA total score and permeability classification. Poorly permeable horizons have a VDA score ≤ 5, moderately permeable horizons have a VDA score > 5 and ≤ 10 and highly permeable soils have a VDA score >10

Site	Horizons (m)	Water seepage	S	WS	Pan	S	WS	Texture	S	WS	Porosity	S	WS	Consistence	S	WS	Stone content	S	WS	Roots	S	WS	VDA total score	Classification
Rossmore	0.0–0.2	No	0	0	No	0	0	Medium	1	4	Good	2	2	Slightly sticky, non-plastic	1	1	Few (2–5%)	0	0	Yes	1	1	8	Moderately Permeable
	0.2–0.4	No	0	0	No	0	0	Medium	1	4	Poor	0	0	Slightly sticky, non-plastic	1	1	None	0	0	Yes	1	1	6	Moderately Permeable
	0.4–1.3	No	0	0	No	0	0	Medium	1	4	Moderate	1	1	Non-sticky, non-plastic	2	2	Few (2–5%)	0	0	No	0	0	7	Moderately Permeable
	1.3–2.5	Yes	1	10	No	0	0	Medium	1	4	Good	2	2	Non-sticky, non-plastic	2	2	None	0	0	No	0	0	18	Highly Permeable
Lisselton	0.0–0.8	No	0	0	No	0	0	Medium	1	4	Good	2	2	Slightly sticky, non-plastic	1	1	Very few (0–2%)	0	0	Yes	1	1	8	Moderately Permeable
	0.8–1.2	No	0	0	No	0	0	Medium	1	4	Poor	0	0	Non-sticky, plastic	1	1	Many (15–40%)	1	1	No	0	0	6	Moderately Permeable
	1.2–1.8	Yes	1	10	No	0	0	Heavy	0	0	Good	2	2	Slightly sticky, non-plastic	1	1	Many (15–40%)	1	1	No	0	0	14	Highly Permeable
	1.8–2.5	No	0	0	No	0	0	Heavy	0	0	Moderate	1	1	Slightly sticky, non-plastic	1	1	Many (15–40%)	1	1	No	0	0	3	Poorly Permeable
Ballinagree	0.0–0.5	No	0	0	No	0	0	Heavy	0	0	Good	2	2	Non-sticky, non-plastic	2	2	Many (15–40%)	1	1	Yes	1	1	6	Moderately Permeable
	0.5–1.5	No	0	0	No	0	0	Medium	1	4	Moderate	1	1	Slightly sticky, non-plastic	1	1	Few (2–5%)	0	0	No	0	0	6	Moderately Permeable
	1.5–2.0	Yes	1	10	No	0	0	Medium	1	4	Moderate	1	1	Slightly sticky, non-plastic	1	1	Few (2–5%)	0	0	No	0	0	16	Highly Permeable
	2.0–2.8	Yes	1	10	No	0	0	Medium	1	4	Poor	0	0	Slightly sticky, slightly plastic	0	0	Few (2–5%)	0	0	No	0	0	14	Highly Permeable
Doonbeg	0.0–0.3	No	0	0	No	0	0	Medium	1	4	Good	2	2	Slightly sticky, non-plastic	1	1	Few (2–5%)	0	0	Yes	1	1	8	Moderately Permeable
	0.3–2.1	No	0	0	No	0	0	Heavy	0	0	Poor	0	0	Sticky, very plastic	0	0	Few (2–5%)	0	0	No	0	0	0	Poorly Permeable
	2.1–2.5	Yes	1	10	No	0	0	Heavy	0	0	Moderate	1	1	Sticky, very plastic	0	0	None	0	0	No	0	0	11	Highly Permeable
Athea	0.0–0.6	No	0	0	No	0	0	Medium	1	4	Moderate	1	1	Non-sticky, non-plastic	2	2	Very few (0–2%)	0	0	Yes	1	1	8	Moderately Permeable
	0.6–2.0	No	0	0	No	0	0	Heavy	0	0	Poor	0	0	Slightly sticky, plastic	0	0	Very few (0–2%)	0	0	No	0	0	0	Poorly Permeable

Continued Table 3.

Classification of each indicator for each soil horizon and site including visual drainage assessment (VDA) score (S), weighted score (WS) and VDA total score and permeability classification. Poorly permeable horizons have a VDA score ≤ 5, moderately permeable horizons have a VDA score > 5 and ≤ 10 and highly permeable soils have a VDA score >10

Site	Horizons (m)	Water seepage	S	WS	Pan	S	WS	Texture	S	WS	Porosity	S	WS	Consistence	S	WS	Stone content	S	WS	Roots	S	WS	VDA total score	Classification
	2.0–2.9	No	0	0	No	0	0	Heavy	0	0	Moderate	1	1	Slightly sticky, slightly plastic	0	0	Few (2–5%)	0	0	No	0	0	1	Poorly Permeable
Castleisland	0.0–0.3	No	0	0	No	0	0	Medium	1	4	Good	2	2	Slightly sticky, non-plastic	1	1	Few (2–5%)	0	0	Yes	1	1	8	Moderately Permeable
	0.3–0.9	No	0	0	No	0	0	Heavy	0	0	Poor	0	0	Sticky, slightly plastic	0	0	Many (15–40%)	1	1	No	0	0	1	Poorly Permeable
	0.9–3.6	No	0	0	No	0	0	Heavy	0	0	Poor	1	1	Sticky, slightly plastic	0	0	Many (15–40%)	1	1	No	0	0	2	Poorly Permeable

Note: Texture is estimated by adapting the methods of DEFRA (2005), Stone content and consistence are described using the classifications of FAO (2006) and porosity is described using the classifications of Shepherd (2009).

Table 4. Measured texture and estimated saturated hydraulic conductivity (k_s; Saxton and Rawls 2006) data for composite soil samples collected on each site. Assigned visual drainage assessment (VDA) permeability classification at comparable depth is also presented, depth ranges of VDA assigned horizons and composite soil samples do not necessarily correspond

		Measured Texture			k_s	
	Depth (m)	Sand (%)	Silt (%)	Clay (%)	(m/day)	Permeability classification based on VDA score
Rossmore	0.2–1.3	52	27	21	0.33	Moderately permeable
	1.3–1.6	69	21	10	1.09	Highly permeable
Lisselton	0.4–1.2	29	44	27	0.17	Moderately permeable
	1.2–1.8	38	46	16	0.42	Highly permeable
Ballinagree	0.3–1.5	31	50	19	0.31	Moderately permeable
	1.5–2.0	66	26	8	1.23	Highly permeable
Doonbeg	0.3–2.1	12	52	36	0.11	Poorly permeable
Athea	0.3–2.0	18	54	28	0.15	Poorly permeable
Castleisland	0.3–3.1	12	47	41	0.08	Poorly permeable

Table 5. Comparison of drainage design methodologies

Site	Design methodology	Spacing (m)	Depth (m)	Rain recharge/ Drain discharge[a] (mm/day)	Minimum WT depth[b] (m)
Rossmore	VDA	15.0	1.60	15.6	0.73
	Ideal	17.2	1.50	12.0	0.45
	Standard	15.0	0.80	1.0	0.00
Lisselton	VDA	15.0	1.70	10.7	0.29
	Ideal	14.1	1.50	12.0	0.45
	Standard	15.0	0.80	0.6	0.00
Ballinagree	VDA	20.0	1.70	11.7	0.42
	Ideal	19.8	1.60	12.0	0.45
	Standard	15.0	0.80	0.9	0.00
Doonbeg	VDA	1.4	0.60	14.3	0.60
	Ideal	1.6	0.50	12.0	0.45
	Standard	15.0	0.80	0.1	0.00
Athea	VDA	1.5	0.45	13.9	0.45
	Ideal	1.7	0.50	12.0	0.45
	Standard	15.0	0.80	0.1	0.00
Castleisland	VDA	1.5	0.45	13.7	0.44
	Ideal	1.6	0.50	12.0	0.45
	Standard	15.0	0.80	0.0	0.00

Note: VDA = Visual drainage assessment, WT = water table, [a]assuming a minimum WT depth of 0.45 m, [b]assuming a rainfall recharge of 12 mm/day.

deeper (*P* < 0.001, s.e. 0.057 m) than from the standard designs (0.0 m), when assuming a rainfall recharge of 12 mm/day.

Discussion

The VDA method was applicable across the range of sites used. Each indicator could be readily classified in the field and when combined with the weighting system, a reasonable estimate of horizon permeability and a good approximation of an ideal drainage system design were delivered. The approach provides a standardised mechanistic method of land drainage design in the field.

The VDA methodology has, however, a number of weaknesses that will need to be overcome if its application is to be widely adopted. Firstly, it is possible that over a relatively small area (<10 ha), inherent differences in soil profiles could lead to divergent drainage solutions. In practice, such a scenario is a prospect with all design techniques that assume all soil layers, once defined, are homogenous and isotropic (Ritzema, 1994). However, where such scientific methods are being employed, it is likely that appropriate adjustments are made by suitably experienced persons. In the hands of less experienced practitioners, such a scenario may be insurmountable.

Furthermore, the selection of in-field drain spacing, using the VDA method, is simple but very crude and is principally made from an economic and not a hydrologic viewpoint. The minimum drain spacing (15 m) specified, beyond which artificial drainage cannot be economically provided (Teagasc 2013), is dependent on the cost of drainage implementation, climate, the crop grown and potential for increased returns in terms of improved yield, timelier field operations or reduced damage under traffic (Ramasamy *et al.,* 1997; Skaggs and Van Schilfgaarde, 1999; Peltomaa, 2007; Shaoli *et al.,* 2007). As these factors change with region and land use, this minimum will change accordingly (USBR 1993; Ritzema, 1994). Such drain spacings are intentionally conservative in order to ensure sufficient drain discharge and water table control; however, decreeing such a minimum to be used on all flat sites (< 4% slope) and a slightly wider 20 m spacing on sloping sites (≥ 4%) is likely to lead to significant over designs if applied to a broader range of soils and climatic conditions.

The modelled performance of the three design options varied from site to site. Comparisons showed that the modelled performance of the VDA designs was adequate in all cases being approximate to the desired rainfall recharge/drain discharge capacity (12 mm/day) and minimum water table depth (0.45 m). The VDA methodology leads to some over-design relative to the ideal design at the Rossmore, Doonbeg, Athea and Castleisland sites and slight under-design relative to the ideal design at the Lisselton and Ballinagree sites. Model estimates showed standard drainage systems to be wholly inadequate for these sites; incapable of discharging excess water from the soil to any practical extent and failing to offer any water table control capacity if employed on any of the six sites under the loading criteria outlined. While this type of system may remove surface water in ponded areas, it has little effect in terms of excess soil water removal and water table control in unsuitable soils and adverse weather conditions.

Conclusions

The ideal design is the benchmark against which all other design procedures should be compared. However, given the distinct challenges posed by unfamiliar, costly and time-consuming field measurement, sampling and analysis procedures, it is unappealing to landowners carrying out land drainage works. The current prevalence of standard practice drainage designs has developed in the absence of widespread or organised dissemination of expertise in drainage problem diagnosis and drainage system design. In this context, the justification for formulating an alternative approach, which, could be carried out at little cost while a site was being cleared prior to the commencement of land drainage works, is clear.

The VDA methodology developed and described herein provides such an approach to land drainage design where the permeability of the soil is not measured but interpreted by visually and manually examining the soil profile. The VDA methodology delivered a reasonable estimation of the permeability of soil horizons and provided a good approximation of an ideal design on all the sites examined. The VDA prescribed designs were shown by model estimate to offer significantly improved performance relative to standard drainage systems. The VDA method needs to be developed further and validated for a non-expert audience and over a range of site and soil conditions. Adoption of the VDA approach has the potential to improve effectiveness of land drainage works and thereby increase returns from capital invested in land drainage.

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