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

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**ABSTRACT.** *In Ireland, the implementation of site-specific land drainage system designs is usually disregarded by landowners in favor 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 physical or hydrological parameters and perceived time wastage and high costs. There is a need for a site-specific drainage system design methodology which does not rely on inaccessible, time-consuming and/or expensive measurements of soil physical or hydrological properties. This requires a standardized 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 (utilizing 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 watertable 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 almost equivalent land drainage system in the field. Mean modeled 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 watertable depth of 0.45 m.*

**Keywords.** *Drainage design, drainage systems, site-specific, visual soil assessment*

# Introduction

The successful design of site-specific land drainage systems is dependent on fully characterizing soil physical properties with regard to their drainage characteristics (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 favor of locally established drainage design practices (Smedema *et al.* 2004; Vlotman *et al.* 2007), particularly for small scale (< 10 ha) drainage schemes.

Two broad types of land drainage system are commonly deployed in Ireland (Smedema and Rycroft 1983; Teagasc 2013), namely: a 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 watertable (Mulqueen and Hendricks 1986), and a 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 (Mulqueen 1985; Robinson *et al.* 1987) which include mole drainage, gravel mole drainage and sub-soiling installed at close (1-2 m) spacing, normally supplementing more widely spaced in-field drains. There has been little uptake of scientific drainage 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/hydrological properties and imposition of rigid design schemes where State aid was supplied for land drainage (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.

It is hypothesized that a standardized mechanistic visual soil assessment method, similar to established visual methods of soil assessment (Munkholm 2000; Shepherd 2009; 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.

Therefore, the objectives of the current study were:

- To develop a visual method of land drainage system design, called visual drainage assessment (VDA) design herein, which is based on information gathered from a soil profile assessment in combination with background information on site and outfall conditions.
- 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 watertable (WT) control (minimum WT depth, m) across the three design methods for each site.

# Materials & 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 clear unambiguous direction in terms of drainage system design. It was decided to base the method on a number of indicators which could be readily defined in soil test pits and which reliably predicted soil drainage characteristics. Each indicator (Table 1) is a commonly observed pedological attribute (FAO 2006; 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 (Tuohy et al., 2016). The indicators are water seepage, pan layers, texture, porosity, consistence, stone content and root development and their assigned scores are detailed in Table 1.

### Drainage design using visual drainage assessment information

Those indicators which 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 $\leq 5$, moderately permeable horizons have a total VDA score $> 5$ and $\leq 10$ and highly permeable soils have a total VDA score $>10$. 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 (Tuohy et al, 2016).

**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 | |

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 % slope) sites and a 20 m in-field drain spacing is prescribed for sloping (≥ 4 % slope) 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. This will be dependent on the implement used. The depth of in-field shallow drains is set to provide sufficient outfall from the disruption channels.

### 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 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 (Tuohy et al., 2016). Soil test pits were excavated at representative locations on each site. Typically one pit was dug per hectare, or 2-3 per site. The pits were excavated to at least 2.5 m depth unless impeded by bedrock. Disturbed soil samples were 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. 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).

### 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 and a desired minimum allowable watertable depth of 0.45 m. 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 watertable control (minimum watertable depth, m) capacity. Design equations were used to model the designs formulated by VDA and the standard drainage design to calculate rainfall recharge/drain discharge capacity and minimum watertable 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. Modelled watertable depth and rainfall recharge/drain discharge capacity data were analysed using ANOVA with design method as a fixed effect.

## Results

Table 2 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. Having assessed indicators and assigned permeability classifications to all horizons, an appropriate drainage system could be prescribed using a decision tree approach for each site (Table 3). An ideal drainage system for each site (Table 3) was defined in terms of drain depth and spacing given a desired rainfall recharge/drain discharge capacity of 12 mm/day and a minimum watertable depth of 0.45 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 (Tuohy et al., 2016).

### Comparison of design methodologies

Rainfall recharge/drain discharge capacity from the VDA designs ranged from 10.7-15.6 mm/day, while minimum watertable depths ranged from 0.29-0.73 m. Rainfall recharge/drain discharge capacity from the standard designs ranged from 0.0-1.0 mm/day, while modeled minimum watertable depth at all sites was 0.0 m. 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). Mean estimated minimum watertable depth from the VDA (0.49 m) and ideal (0.45 m) designs were significantly deeper ($P<0.001$, s.e. 0.057 m) than from the standard designs (0.0 m).

## 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 standardized 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 which 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; 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 watertable 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.

**Table 2. 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 | Horizon (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 |
| | 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 3. 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 = watertable, [a]assuming a minimum WT depth of 0.45 m, [b]assuming a rainfall recharge of 12 mm/day

The modeled performance of the three design options varied from site to site. Comparisons showed that the modeled 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 watertable depth (0.45 m). The VDA methodology lead 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 system designs to be wholly inadequate for these sites; incapable of discharging excess water from the soil to any practical extent and failing to offer any watertable 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 watertable 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 organized 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 in Ireland.

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