THE IDENTIFICATION OF SITES AND FARMING SYSTEMS PRONE TO POLLUTION BY SURFACE RUNOFF

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SUMMARY

There is mounting evidence that overland flow from land contributes to pollution of surface water. No convenient method exists to identify fields that generate overland flow. Therefore the WT model has been developed to predict overland flow from any small parcel of land.

Water table tubes and flow meters were installed in three sites in Wexford and Carlow. The water table data, along with rainfall and evaporation data, were entered into the WT model to calculate overland flow and other parameters over a 7-month period. Additional measurements of water table level were taken using maximum level indicators with a view to reducing field costs.

All three sites had layers of sand in the sub-soil. It is likely that the sand allowed water to flow under the soil and contributed to overland flow. Values from the WT model matched the field measurements of water table closely and predicted overland flow with reasonable accuracy. One pipe in each field was identified which could indicate when the field was sufficiently dry for spreading slurry. The maximum level indicators recorded water table accurately. However, the lack of synchronisation of this data, with weather data, reduced slightly the precision of the model.

The WT model can identify fields prone to overland flow and show when a field is sufficiently dry to accept slurry. Proposed economies promise to reduce the cost of investigation.

INTRODUCTION

The enrichment of surface water is still a problem in many parts of Ireland. In recent years, accidental spillage of slurry and silage effluent have been reduced but the flow of nutrients into surface water is increasing, causing eutrophication of rivers and lakes. A recent report listed 32% of rivers as polluted at a slight to moderate degree and 1% were seriously polluted (EPA, 1999). Moreover, the quantity of polluted channel increased steadily over the period 1987 to 1997 so there is clearly a problem. There are many sources of pollution and agriculture is among them, especially where slight to moderate damage is concerned. This source needs to be tackled if agriculture is to play its part in reducing pollution of surface water.

It is recognised internationally that the best way to prevent algal blooms and excessive weed growth is to limit the amount of phosphorus in the water. In agriculture, phosphorus occurs in the top few centimetres of the soil or in animal waste. It is carried into watercourses by overland flow from fields (Sherwood and Fanning, 1981) and animal standing areas, which are not properly controlled. The quantity of phosphorus entering the water from the land can be reduced by limiting the quantity of overland flow or by cutting down on the amount of phosphorus on the soil surface during wet periods. Nutrients are also exported from farmyards to surface water but this is not considered here.

The occurrence of overland flow is related both to climate and to soil properties. The more rainfall there is in a given region, the greater the likelihood of overland flow. Where soils are frequently wet due to high water table or low permeability, overland flow is likely to occur in wet periods. Compaction of soil by heavy traffic and certain tillage practices are known to increase the likelihood of overland flow. If land could be drained or loosened to reduce compaction the problem could be reduced. This is an expensive solution and is likely to be applied in only a few cases.

In recent years, leakage of phosphorus from soils is considered a threat to water quality. Soil phosphorus level is increased by fertiliser and manure and is reduced when crops are removed. It changes slowly over time. When water runs over the surface, soil particles, with phosphorus attached, are picked up and may be carried into a waterway. Work at Johnstown Castle is examining the manner in which phosphorus is transported by overland flow. As soil P values increase, the risk of pollution increases. If slurry or fertiliser lie on the surface during inundation, the risk of pollution is particularly high. The owners of pig and poultry units and farmers participating in the Rural Environmental Protection Scheme (REPS) are required to adopt a nutrient management plan to reduce the risk of pollution. This is done because management options can limit the amount of phosphorus picked up by water flowing over the surface.

It is accepted that overland flow can carry nutrients to surface waters from some fields. But which fields are affected and how serious is the problem? Answers to these questions are required if management of land for pollution control purposes is to be conducted in a rational manner. In many cases, a simple inspection of the land is sufficient to indicate whether land is very dry with a low risk of pollution or very wet with a high risk. Where there is doubt about a field, a more definitive assessment is required. In this report, a system is described, which can reliably identify fields prone to overland flow. Water table level in a field under investigation is monitored over several months. A model is used to compare these values to weather data and to calculate overland flow quantities.

This development is at an early stage. If it is successful, it will be possible to identify the risk of pollution from any field. It promises to be a low cost system requiring only water table tubes in the field and a few days work. This report describes progress to date. Further investigations are required to test the model and the field equipment under the full range of conditions.

METHODS

The WT model for identifying fields prone to overland flow was tested on three sites; the Cowlands and Warren sites in Johnstown Castle, Wexford and the Lawn at Oak Park, Carlow. These represented a range of hydrological conditions (Table 1). Each site was isolated from the surrounding land by constructing a small berm around the boundary. In the Warren field, open drains performed this function. The Cowlands site is shown in Fig. 1. A flow meter was installed at the outlet from the site to catch any overland flow (Fig. 2). Water samples were gathered at each flowmeter for phosphorus analysis and these were processed at Johnstown Castle. Only the data for the Lawn are given here. Two types of tube were installed in the soil extending to depths ranging from 0.3 m to 1.8 m. Water table tubes are perforated over most of their length below ground level and several of these were installed in each site. In the Warren and Cowlands fields, piezometer tubes, which are open only at the bottom, were installed at 4 different levels in the soil and at positions where upward flowing water was expected. Water level was recorded every 2 or 3 days as time allowed. The sequence of soil layers was determined on each site using a soil auger. Rainfall, evaporation and evapotranspiration for the 7-month monitoring period were obtained from local

Table 1: Summary of the site characteristics

Site	Location	Period	Area (ha)	Drainage status	Hydrology
Cowlands	Johnstown, Wexford	Dec. 96 - June 97	0.46	Moderate	Impeded soil layer
Warren	Johnstown, Wexford	Dec. 96 - June 97	1.45	Poor	Impeded drainage, seepage and spring
Lawn	Oak Park, Carlow	Nov. 98 – May 99	0.49	Moderate	Seepage and spring

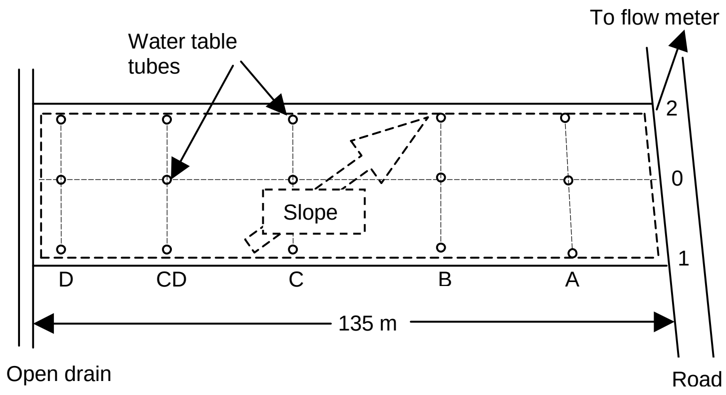

Fig. 1: Layout of the Cowlands overland flow site at Johnstown Castle

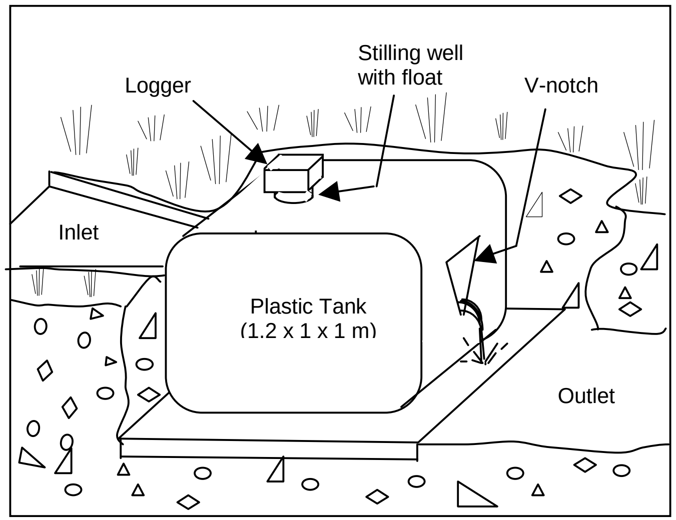

Fig. 2: The flow meter at the Lawn, Oak Park, with a V-notch, float and logger

meteorological stations. The sites at Johnstown Castle were monitored from December 1996 to June 1997 and monitoring at Oak Park took place 2 years later from November 1998 to May 1999.

The water table data and the weather data were combined in a water balance model called 'WT'. The model balanced rainfall with drainage in the soil. When rainfall exceeded drainage, the water table rose. If the water table reached the soil surface, further rain caused overland flow. The model calculated water table level on a daily basis. When these values matched as closely as possible the water levels measured in the field, the water balance was assumed to be accurate and the output recorded. The output data for water table level, air-filled pore space and overland flow at each pipe were analysed further to generate values for the entire field. Values from the model for overland flow were compared to data from the flow recorders.

During the earlier trials, water table level was recorded by hand with a dip meter or by electronic logger. Both these methods are expensive. One alternative is to insert into each water table tube a perspex tube with a small polystyrene float inside (Davies, 1969). When water rises in the perspex tube, the float rises with it. However when the water recedes, the float sticks to the perspex at the highest point reached by the water. This method was tested in three ways. A tank containing the perspex tubes and floats was filled and emptied at a controlled rate. The level of each float was then compared to the highest level reached by the water. In a second test, two perspex tubes were placed side by side in each of 5 water table tubes at the Lawn site. Levels in each pair of tubes were compared. Finally, the 39 values for each water table tube were used to predict daily water table values in the WT model. The calculations were repeated using water table levels recorded by dip-meter. Model parameters determined by the two methods were compared.

RESULTS AND DISCUSSION

Weather

The meteorological station at Johnstown Castle provided all the data required for the Wexford sites. The overland flow sites were 2 km from the meteorological station. At the overland flow site in Oak Park the required meteorological data were not available from the station. A comparison between rainfall at Kilkenny and at Oak Park showed that Kilkenny data were an acceptable replacement for rainfall data gathered on site. Evaporation data from three meteorological sites up to 80 km away were combined and added together. This was acceptable, as evaporation was less variable than rainfall and, in the period concerned, it represented only 25% of precipitation. The weather data used in Wexford are shown in Fig. 3. The key periods when overland flow might have been expected are immediately evident. High rainfall in December, February and June suggest that problem fields might have generated overland flow at these times. During the corresponding period at Carlow, 2 years later, the risk of overland flow was concentrated in the winter months.

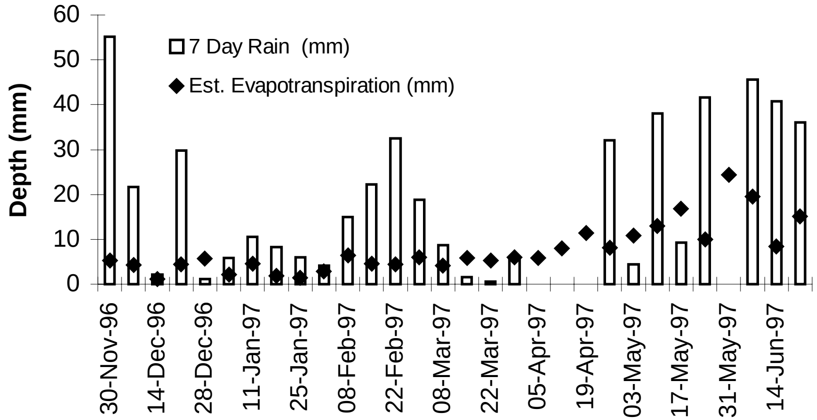

Fig. 3: Rainfall and evaporation at the Johnstown site, 7-day average

Sites

The Cowlands site had a slope of 3 degrees to the horizontal and produced a good sward of grass. It was dry in the middle but wet at the lower end. The subsoil consisted of a sandy material under the centre of the site and heavier less permeable material elsewhere. It is likely that rain, which fell on the centre of the site, moved underground to the lower section of the field adding to the wetness of the area. The Warren field had a similar slope but the vegetation was poor, with sedges and rushes dominating. The soil was stony and poorly permeable, although lenses of sandy material were found in a number of places, especially in the vicinity of the spring. The Lawn site was adjacent to the lake at Oak Park. It was almost flat with a hollow in the middle, which often held a pond formed by upward flowing water. A surface drain was installed to allow this overland flow to reach the flow meter. The key feature of the subsoil was a layer of sandy gravel underlying most of the site. The field was used for grazing and silage.

Dissolved phosphorus

The recommended method for sampling water for phosphorus involves taking samples in proportion to the rate of overland flow. This requires expensive equipment. Such instrumentation was not available to this project so simple grab samples were taken. These show the variation in the phosphorus content of the water but do not allow the quantity of phosphorus exported from the field to be calculated (Fig. 4). Values were high in October (0.48 mg/l) but declined over the following months to 0.02 mg/l, a level which is considered harmless to fish.

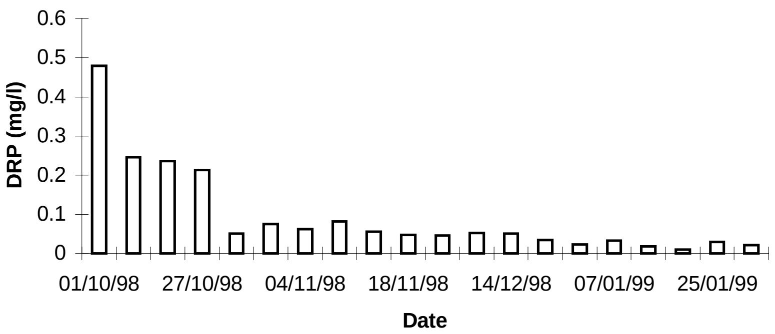

Fig. 4: Concentration of phosphorus (DRP) in overland flow at the Lawn

WT model

The model compiled a full data set for each water table tube in the field. The first output variable is water table level. Only a partial record of levels was available from field data, but the model calculated a value for every day (Fig. 5). Calculated data closely match the values gathered in the field. Deviation of the model from measured values in April and May reflects the shortage of water table data in this period. Data for every week seem to be necessary. This plot shows when the water table was at the surface and overland flow was likely.

Air-filled pore space is the second output variable. It shows how much space exists in the soil for water or slurry. As the soil dries out, water is drained from the pores and replaced by air. If the volume of air is large, on a given day, there is space for slurry and any rain that might fall. On the other hand, if the value of air-filled pore space approaches zero and the soil is saturated, there is no space for additional liquid. Rain would cause overland flow and an application of slurry could cause pollution.

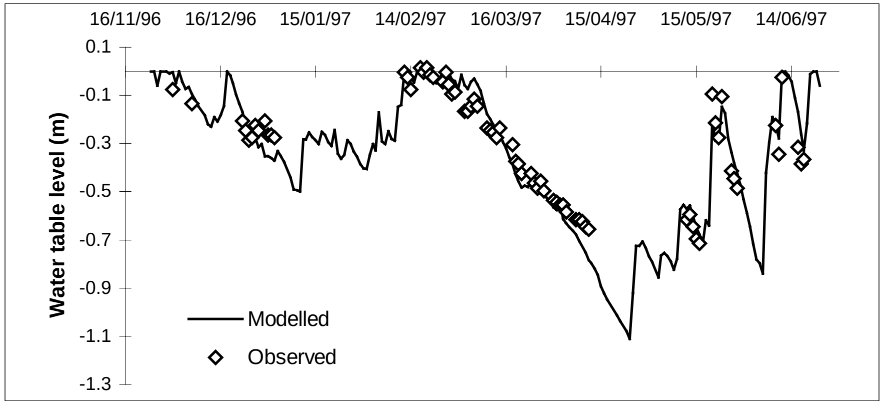

Fig. 5: Water table level from the WT model compared to observed values at pipe D2, Cowlands

Overland flow is identified in the model when there is no air-filled pore space left and more rain needs to be accommodated. Flow continues for as long as it rains and the water table remains at the surface. A weighted average of overland flow from the site was calculated. The resulting values are compared to measurements from a flow meter in Fig. 6. This gives the result for the Cowlands site at Johnstown Castle. These data were organised into events during which water flowed continuously. As suggested by rainfall data, overland flow occurred in December, February and June. There is moderate agreement between the two overland flow data sets. They follow the same trend and differ by less than 4 mm in most cases. Due to compensation between highs and lows, the total values

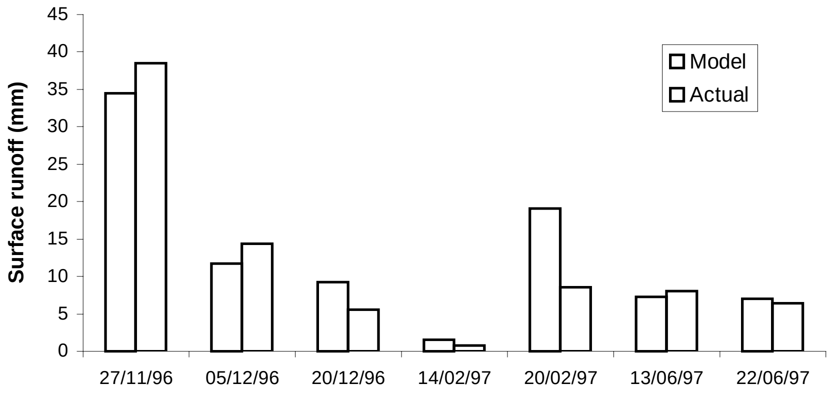

Fig. 6: WT model compared to actual flow events at the Cowlands site (flow greater than 0.5 mm)

converge. Total overland flow, calculated by the model at the Cowlands field, amounted to 90 mm while a value of 82 mm was recorded by the flow meter. At the Warren field, a value of 149 mm was calculated as against 144 mm measured, while at the Lawn, the WT model gave 95 mm compared to 92 mm by the meter.

As with any measurement, the WT model output is subject to error. It is a simple model using a few inexpensive input variables. More elaborate models exist which need greater amounts of data. They are more expensive to run but offer only a small improvement in performance in relation to the variables predicted by the WT model. Differences between measured and calculated values reflect the many variables that affect soil water and which are not included in this analysis. The output from the WT model is, nevertheless, close to measured values. This indicates that water table level, rainfall and evaporation are among the dominant variables controlling overland flow from sites similar to those included in this study.

In soil water measurements, variability is a serious problem especially on glacially derived soils such as occur in Ireland. The soils are stony and the volume of soil tested is often small. Large numbers of tests are required to obtain reliable results. In the case of water table measurements, a large block of soil is tested. Furthermore, the instrument is left in place throughout the monitoring period so water table levels have a long time to equilibrate. This reduces variability. The distribution of overland flow around the Warren field is illustrated in Fig. 7.

There is still a wide range of values from 4 to 266 mm, but much of this is due to variation in hydraulic pressure. A pattern is evident. High flow was concentrated in the area of the spring, where upward flowing water was indicated by the piezometers. Overland flow reduced in an outward direction from there. Similar comments apply to the other sites where ground water pressure is implicated in high rates of overland flow.

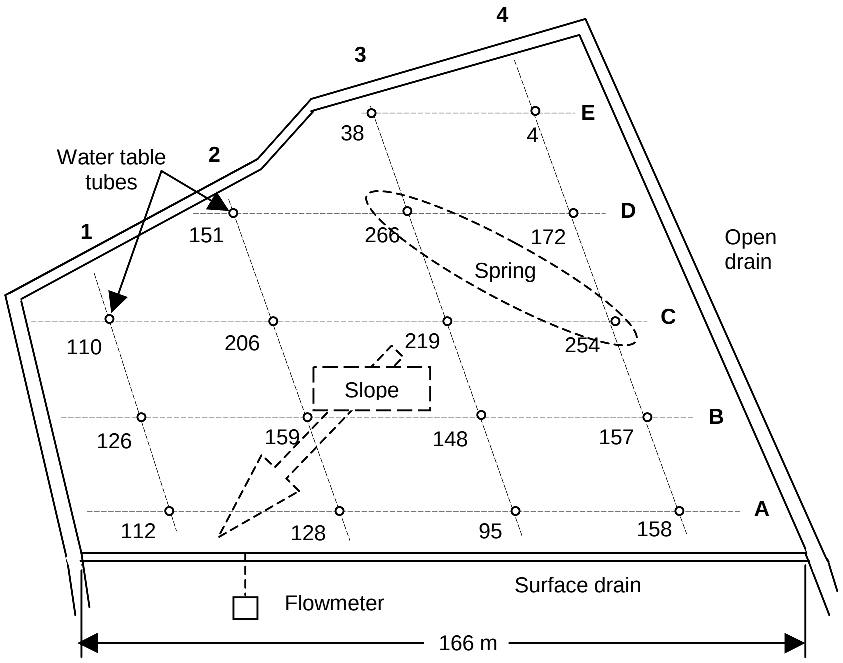

Fig. 7: Depth of overland flow at each water table tube (mm)

Application of the WT model

The WT model is not yet proven. It needs to be applied to more sites with a wider range of hydrologic conditions. Presently it operates in two ways. It indicates the source, quantity and timing of overland flow from a site for which water table data is available. In Fig. 7 the parts of the field generating overland flow are easily identified. This map allows the wettest parts of the field to be selected and fenced off if necessary. Table 2 lists the key output values from the model. This table probably understates the potential for overland flow from the Wexford sites, as the weather was relatively dry. The rainfall for the 7-month period was only 77% of average, although more rain than normal fell in December and January. At the Carlow site, rainfall for the full period was almost 10% below normal, but during the winter months rainfall was approximately 10% higher than average. The overland flow from this site is probably close to normal.

Table 2: Output values from the WT model over a 212-day period for each site

Site	Overland flow depth (mm)	Drainage at high WTL (mm/day)	Number of days when WTL = 0
Cowlands	86.4	1.39	115
Warren	138.2	1.22	58
Lawn	94.7	2.58	36

The second application of the model is the indication of spreading days, i.e. periods when a field is fit for spreading slurry. The relevant code of good practice (Department of the Environment, 1996) states that slurry should not be spread on wet or waterlogged soil or when heavy rain is forecast in the 48 hours following the event. For calculation purposes, a soil is assumed to be other than 'wet' when the air-filled pore space (AFPS) is over 15 mm and the water table is about 300 mm below the surface. This soil could absorb a typical slurry application of 3 – 5 mm of slurry and light rain not exceeding 10 mm over 3 days. The pipe with 15 mm of air-filled pore space least often was chosen to represent each field. The water table level corresponding to 15 mm of air-filled pore space in these pipes was identified. Slurry should be spread only when the water level is deeper than the level chosen. The representative pipes and the number of spreading days that would have been available at the experimental sites during the monitoring periods are shown in Table 3. For example, at the Cowlands site pipe CD2 satisfies the requirement. When air-filled pore space had a value of 15 mm in the soil around this pipe, the depth to the water table was 310 mm. Therefore, if slurry were to be spread on this field, the water table at pipe CD2 should be at least 310 mm below the surface and there should be a forecast of fine weather for the following two days. These conditions were satisfied on 76 days during the 212 days of the monitoring period at the Cowlands site.

Table 3: The number of spreading days available in the monitoring period based on the nominated pipe

Site	Nominated pipe	Minimum water depth (m)	No. of days when AFPS >15mm	3-day periods with rain <10 mm	No. of spreading days
Cowlands	CD2	-310	86	161	76
Warren	C4	-290	34	161	30
Lawn	E3	-221	93	147	70

Water running off the land does not, of itself, present a hazard to surface water. It is only because it carries nutrients, especially phosphorus, that it can give rise to pollution. Researchers at Johnstown Castle are assessing the quantity of phosphorus absorbed by overland flow. If some measure of the concentration of phosphorus in overland flow can be made, then the quantity of water flowing from a given parcel of land will indicate the total phosphorus export. The characteristics of the local catchment must then be considered. Some catchments can accept a large quantity of nutrient while others are overloaded already. Allowable discharges of nutrients from land or other sources must be determined on the basis of what the local rivers and lakes can absorb. Decisions could then be made as to which fields could be used for spreading slurry.

Maximum water level indicators

A polystyrene float in a perspex tube rises with the water and sticks to the highest point it reaches. The highest point reached by the water is thus recorded. The laboratory assessment of the accuracy of this system indicated that the random error in a single measurement is little more than 2 mm. In the field test, the difference between adjacent tubes in a pair was up to 14 mm. This was not as good as expected from the laboratory data and suggested that greater care should be taken when removing a perspex tube from a water table tube in the field. The final test involved using the WT model with data recorded by maximum level indicator and data from the dip meter. The maximum level data gave slightly more variation than the traditional data set. Maximum level values were recorded at any time of the day or night while all other input data were recorded at 9 a.m. This would have reduced the precision of model calculations. The use of maximum level data is important as it may allow the number of site visits to be reduced from 70, as at present, to less than 10. This might be viable where several sites are monitored in a district over the same period. Secondly, if the water table reaches the surface at any time, this is indicated by the maximum level indicator. The dip meter does not give this information.

Future work

This approach to identifying fields prone to overland flow involves the assumption that water table level and rainfall determine the risk of flooding on the land. There are other causes. Compaction by livestock or machinery in bad weather can cause a perched water table close to the soil surface. Soils can swell in wintertime reducing infiltration rate (Diamond, 1998) and pore space. It remains to be seen in future investigations whether they undermine the performance of the WT model.

CONCLUSIONS

- The WT model has predicted the overland flow from three sites with reasonable accuracy.

- The prediction of water table level from the model matches closely water table levels recorded in the field.

- A single water table tube can indicate when an entire field is fit for spreading slurry.

- The system involving water table measurements and modelling promises a practical method of predicting overland flow from problem fields and sites of special interest.

- A maximum water table indicator shows when the water table is at the surface. The WT model using data from the maximum level indicator is almost as precise as when using data from a dip meter.

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