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DESIGN OF AN ORIFICE AND WEIR OUTLET FOR POORLY DRAINED FORESTED WATERSHEDS

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Summary:

Orifice-weir structures at ditch outlets are being used to reduce peak drainage rates and to store water during the growing season in poorly drained managed pine plantations. Earlier studies have shown their effectiveness on reducing drainage outflows while conserving water during the growing season. This study reports on criteria and preliminary guidelines for designing such outlets. The guidelines were developed using both observed data and DRAINLOB (a forestry version of DRAINMOD) simulations for multiple combinations of outlet sizes and four different poorly drained organic and mineral soils. Main objective functions chosen were reducing frequency of peak drainage rates and wet days with water table within 30 cm from the surface, and maximizing the days water table were within desired range of 45 to 120 cm depth during the growing season. Results show that the size and the depths of the orifice and the weir at the outlet primarily depend upon the main objective function chosen followed by the soil type and drainage area of the watershed. Wet days increased with smaller orifice sizes and shallower weir depths, Analyses showed that for the same drainage density and area, a larger orifice may be required in the organic soil to achieve the same reduction in wet days as in the mineral soil.

Keywords:

Water Management, Pine Plantation, DRAINMOD, Peak Drainage Rate, Water Table Depth.

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Abstract: Orifice-weir structures are being used to reduce peak drainage rates and to store water during the growing season in poorly drained pine plantations. Earlier studies have demonstrated their effectiveness in reducing drainage outflows while conserving water during the growing season. This study reports on criteria and preliminary guidelines for designing such structures. The guidelines were developed using both observed data and results of DRAINMOD simulations for multiple combinations of outlet sizes and poorly drained mineral and organic soils. The main objective functions were reducing flow rates higher than 5 mm/day, minimizing wet days e.g. water table depths within 30 cm depth from the surface, and maintaining water table within 45 to 120 cm depth. Results show that the size and the depths of the orifice and the weir primarily depend upon the main objective function chosen followed by the soil type and the watershed area. Wet days increased with smaller orifice sizes and shallower weir depths. For example, for a watershed of 25 ha, a 7.5cm or a 10 cm diameter orifice in a flat weir with the crest 25 cm below the surface would result in the same % time having peak drainage rates for both the organic and the mineral soils. However, the number of wet days was 3 times higher in the organic soil than in the mineral soil. Although an orifice placed above ditch bottom yielded higher frequency of water table depth between 45 cm and 120 cm depth as desired compared to the one near ditch bottom, this must be weighted against two other objectives. This indicates two things: 1) for the same drainage density and area, a larger orifice size may be required in the organic soil to achieve the same reduction in wet days as in the mineral soil; 2) the orifice size and its location depends upon the primary objective function chosen.

Introduction

In recent years water management using controlled drainage with riser structures has been gaining in popularity on both agricultural and forested lands. Controlled drainage implies holding the water in the field drainage outlet at different levels for different periods of time based on the objective of the treatments. Past research (Drury et al., 1996; Skaggs et al., 1994; Gilliam et al., 1978; Gilliam and Skaggs, 1986) has shown that water can be conserved and both drainage rates and nutrient exports can be reduced by the use of controlled drainage. Several authors (Allen et al., 1990; Campbell and Hughes, 1980; Hughes, 1982; McCarthy and Skaggs, 1992) have similarly emphasized the importance of good water management in forested lands to provide the necessary drainage for tree production while conserving water and minimizing detrimental effects on the downstream ecosystem. Amatya et al. (1998) reported that controlled drainage reduced drainage outflows by as much as 88 % during the summer tree-growth period and 39 % during the spring period with annual average reductions of 20 to 25 %. Annual average fractions of nitrogen and phosphorus exports from watersheds under controlled drainage were reduced by 7 to 72 % as compared to the watershed with free drainage. It was concluded that water management using controlled drainage can be used to reduce total suspended solids (TSS) and nutrient exports from pine plantations, primarily through reduced drainage outflows.

The reduction in drainage outflows is achieved by installing an adjustable control structure at the watershed outlet to manage water level that may vary with season. Flash board risers are the typical example of such a structure. Each flash board, usually made of hard wood, is 2 to 3 cm thick, 15 cm wide and 60 to 120 cm long depending upon the width of the riser installed at the outlet. Water level at the outlet ditch is adjusted'manually by adding or removing these boards. These structures act like a sharp crested rectangular weir when used as a flow measuring structure. Since these structures cannot accurately measure flow rates during low flow events outlet structures with a sharp-crested V-notch weir have been widely used in forest water management research (McCarthy et al., 1991; Amatya et al., 1996, 1998; Chescheir et al., 1998; Lebo and Herrmann, 1998). Amatya and Skaggs (1997) reported that

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a structure with an orifice (near the ditch bottom) and a rectangular weir above it had advantages for managing water on poorly drained pine forests of the lower coastal plain. They demonstrated that such an outlet structure can not only store a large amount of water in the ditches during the growing season but also was able to significantly dampen the peak drainage rates compared to the system with standard flash board risers. This means that such an outlet structure may also have high potential to reduce the exports of nutrients and sediment downstream. Study on impacts of these outlets on forest water quality is continuing and results will be published in near future. The same study also reported results of the successful testing of DRAINLOB (McCarthy et al, 1992), a forestry version of DRAINMOD (Skaggs, 1978), for predicting flow rates and water table depths from the drained pine forest with an orifice/weir outlet structure. The forest research site used in this study is owned and managed by Weyerhaeuser Company. A similar structure was installed and is being tested in another 90 ha forest field, as part of an ongoing 10,000 ha watershed scale study near Plymouth in North Carolina (Chescheir et al., 1998).

The main objective of this study reported herein is to apply field verified DRAINLOB model and use its outputs for developing general guidelines for design of a combined orifice and flat weir structure for installation on the poorly drained watersheds of the lower coastal plains.

Methodology and Design Procedures

Controlled Drainaae with an Orifice+Weir

An orifice is classified according to size (small and large), shape (circular, rectangular, triangular etc.) and may act under different hydraulic regimes (under pressure or only partially full, free outlet or in submerged condition). If the head above the orifice is at least 5 times its diameter then it is a small orifice in which case the velocity of flow can be considered constant throughout the orifice, otherwise, it acts like a weir under pressure (Gupta, 1989). The orifice near the bottom of the weir would assure continuous, but reduced downstream discharge as base flow, until the ditch is empty. During normal rainfall events drainage water would be restricted to the orifice flow until the ditch water level rises to the top of the weir. For larger flow events, water would be discharged both from the orifice and over the flash board riser weir that acts much like an emergency spillway. After rainfall ceases, orifice discharge would continue at a reduced rate for a period of time. The water level in the ditch would be lowered and its capacity for storing water in subsequent events would be restored. In this way outflow rates are reduced compared to no control or to control with a flash board riser with no weir. When it is desirable to store the drainage water for use during the growing season (for ET and tree growth) the orifice can be plugged. The weir could be lowered or removed during the harvesting and regeneration planting period when the greatest drainage intensity is needed for trafficability. However, the magnitude of reduction in downstream peak drainage rate and the amount of water that can be stored upstream in the ditch and the soil profile all depend upon the sizing and location of the orifice/weir with respect to the lateral and outlet ditch size. A complete reduction in downstream drainage during wet events (with a very small orifice and a flat weir with its top near the ground surface) may result in flooding of the lands and excessive wet stresses for the trees. Furthermore, instantaneous peak drainage rates resulting from high surface runoff caused by the next storm event on already wet surface may be potentially worse for downstream eco-system than the alternative with somewhat larger orifice and/or lower weir crest. Similarly, a large size orifice near the ditch bottom may remove water as rapidly as it drains from the profile and perform very much like conventional drainage with no control. These extreme scenarios indicate necessity for trade off between different management objectives. Therefore, a design of an orifice/weir outlet first requires a clear definition of objectives to be achieved.

Objective Functions

Three objective functions (indicators) were chosen in this study for designing an orifice/weir system:

a. to minimize the percent time of occurrence of peak drainage rates higher than a threshold amount, 5 mm/day in our case. This value, that generally occurs less than l-l 0 % of the time on the poorly drained watersheds, was arbitrarily chosen although it may vary with weather, soils, vegetation, and watershed size. This parameter gives an indication of the watershed's ability to act as a buffer for reducing flow rates (McCarthy and Skaggs, 1992).

b. to minimize the percent time of occurrence of high water table conditions. Water table depth within 30 cm below the average ground surface was also arbitrarily chosen because tree roots are generally concentrated in this zone on poorly drained soils. Lorio, Jr., et al. (1972) reported similar values for depths of root distribution of the loblolly pine trees on wet flat sites.

c. to maximize the percent time when the water table is in optimum depth range for tree growth. Water table depth within 45 cm to 120 cm depth in the soil profile was chosen as the optimum zone for young to matured pine trees, which have an effective rooting depth of 30 to 60 cm on these poorly drained lands.

Desisn methods and assumptions:

Hydraulic equations can be generally used to design or size and an orifice/weir control structure based on estimated peak drainage discharge rate for a given watershed. Peak drainage rates are a function of rainfall intensity, soil type and cover, slope, and watershed area, and are often calculated by single event hydrologic models. These equations can provide information regarding maximum discharge capacity only for a given size of the outlet. Sizing and location of the structure will also be governed by the size and discharge capacity of the outlet ditch. But these equations alone cannot **be used** for the evaluations of above objective functions. Therefore, continuous rainfall-runoff simulation models are used, together with hydraulic equations for different outlet types, to determine the effect of various combinations of design parameters on objective functions.

DRAINLOB (McCarthy et al., 1992; Amatya et ai., 1994), the forestry version of DRAINMOD (Skaggs, 1978), modified with orifice and weir equations, was used to evaluate the performance of the orifice/weir in this study. The model predicts daily drainage, runoff, evapotranspiration, and water table depth based on a water balance at the midpoint between two parallel ditches. The model has been successfully tested with two years (1995-96) of field data from a 25 ha drained pine forest with an orifice/weir outlet at Carteret county in North Carolina (Amatya and Skaggs, 1997). The model was further verified with one additional year (1997) of water table elevations and flow data from the same site as shown in Figure 1.

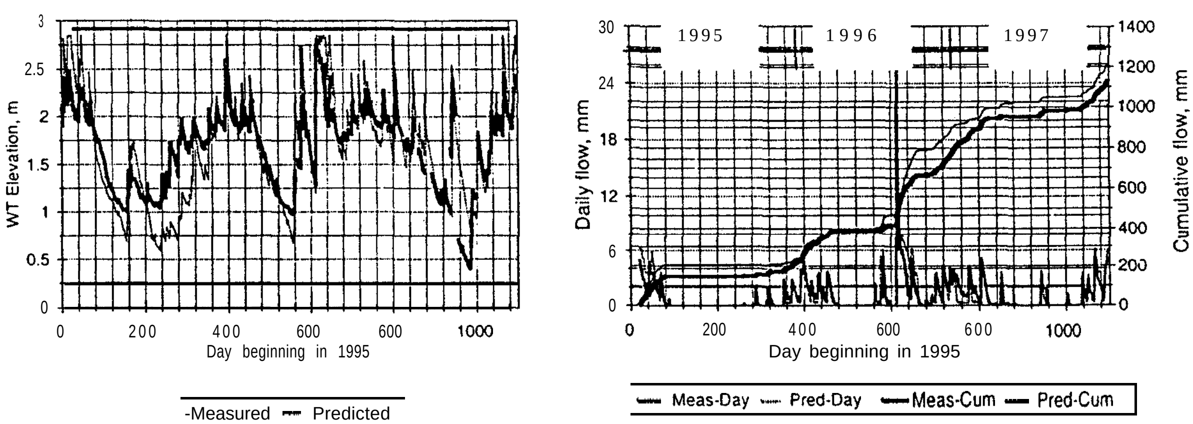

Fig. 1. Measured and predicted water table elevations (left plot) and daily and cumulative daily drainage rates (right plot) for watershed D3 with an orifice/weir outlet at Carteret site, NC. Straight solid line in the left plot is average ground surface elevation (2.80 m).

After validation, the model was used to simulate daily flow rates and water table depths for several different combinations of orifice and weir outlets. The combinations included different orifice sizes and depths with respect to ground surface and ditch bottom and different depths of the weir crest below ground surface. Hydrologic simulations were conducted using 10 years (1988-1997) of weather data for a Deloss fine sandy loam soil from the Carteret study site (Amatya et al., 1996; Amatya and Skaggs, 1997). The results showed the effects of year-to-year variation in weather on the hydrology of a mature (20 years of age) pine forest. In order to minimize the number of simulations, combinations were developed based on the lateral ditch dimensions. At the field study site the bottom of the lateral ditch is about 115 cm below average ground surface. A depth of at least 20 cm from the average ground surface to the weir crest was deemed necessary to avoid surface flooding during large storm events. A circular orifice was chosen because it was assumed to be hydraulically efficient compared to other shapes. Maximum orifice size for simulation was assumed to be 20 cm because at this size flow rates under partial flow conditions are already higher than that from a 120° V-notch weir. Other sizes simulated were 5cm, 7.5cm, 10cm, 12.5cm, and 15cm. Orifices were placed at depths below average ground surface of 115 cm (near ditch bottom), 90 cm and 75 cm depth. Note that with 90 and 75 cm orifice depths there will be some controlled drainage. Depths of the weir crest were varied at 20, 30, 40, and 50 cm below average ground surface. Similar analyses were conducted for another poorly drained soil, the Wasda series. Soil water properties for Wasda, which has an organic surface layer, were given by Skaggs and Nassehzadeh-Tabrizi (1986). Altogether 144 different combinations were simulated with 10 years of weather data from the Carteret site. Model outputs on daily drainage rates and water table depths were further analyzed using statistical tools (SAS, 1990) to evaluate the above mentioned objective functions for each of the combinations of outlet size and locations.

Other factors that need to be considered in the design of an orifice/weir outlet and assumptions made in the analysis presented herein include:

a. Drained forested watershed sizes in the lower coastal plain generally vary from 10 ha to 150 ha. For watersheds larger than 150 ha, effects of flow routing in the ditches may significantly influence the outputs of peak drainage rates. Note thai a large forest block surrounded by roadside collector ditches in the lower coastal plain may be 1600m by 800m (about 130 ha area). Although the indicator (a) for peak flow rate is on a per unit area basis, for larger watersheds this indicator may be biased due to attenuation of peak flow rates.
b. Ditch outlets are generally 0.9 to 1.5 m in depth and have 0.9 to 1.5 m bottom width. These dimensions may limit orifice and weir depths.
c. Lateral field ditches that provide conventional drainage are about 60 to 120 cm in depth from average ground surface, This depth will also constrain the orifice depth.
d. It is assumed in the analysis presented here that the outlet capacity is sufficient to minimize submerged and back flow conditions.

Simulation Results and Discussion

Results of a flow frequency analysis for the lo-year period for 6 orifice diameters located at a 115 cm depth (near ditch bottom) with 3 depths of the weir crest (20, 30 and 40 cm) are plotted in Figure 2.

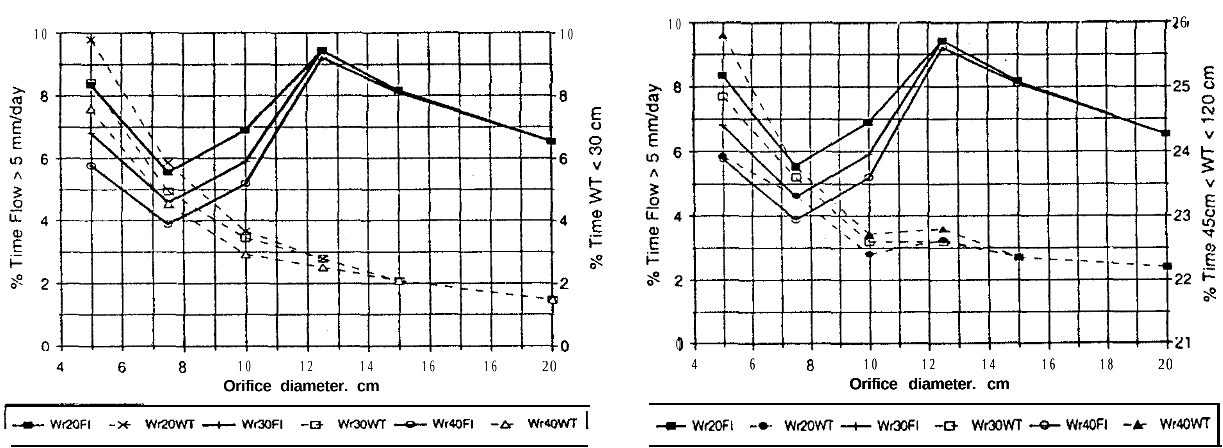

Fig. 2. Left plot shows percent time flow rates > 5 mm/day and water table depths within 30 cm. Right plot shows percent time flow rates > 5 mm/day and water table depths within 45 to 120 cm during the growing season. Plots shown are for 6 orifice diameters and 3 weir depths with orifices at 115 cm depth.

The results show that a 7.5 cm diameter orifice with a 40 cm weir depth (Wr40FI) would produce the least percentage of days (4%) with high drainage rates (Fig. 2 • left). The highest percentage of days with drainage rates greater than 5 mm/day (>9%) occurred for an orifice diameter of 12.5 cm. Small orifice diameters and higher weir elevations cause the system to be wetter so that there are a greater number of days with flow rates > 5 mm/day because water is flowing over the weir crest. As the orifice is increased in size there are fewer days with flow over the weir crest, yet the flow rate through the orifice, even when the water level is nearly up to the weir crest, is less than 5 mm/day. For a 10 cm orifice diameter a flow of 5 mm/day can occur through the orifice when water level is close to the weir crest. As the orifice is moved beyond 12.5 cm, drainage rates through the orifice increase and the number of days that water is held behind the weir at depths that will sustain a flow rate of > 5mm/day decrease.

When the objective of maintaining water table depths > 30cm (Fig.2 - left) was examined, the 20 cm diameter orifice yielded the least frequency (1.75%) for all weir depths. Frequency of wet days with water table within 30 cm decreased with increase in both the orifice diameter and the weir depth as expected. In order to compromise with both of these objectives a 7.5 cm diameter orifice with a 40 cm weir depth was considered to be the best combination. For that same combination, the frequency that water table depth was within the desired range of 45 to 120 cm (Fig.2 - right) was the highest (23.8%) of all three weir depths. Note that although diameters less than 7.5 cm yield higher frequency as desired for this indicator they would have been rejected because of higher frequency of shallower water tables and peak flow rates. Frequency of the water table **in** the desired range decreased with increase in orifice diameter and decrease in weir depth. Only a small variation in this indicator was, however, found among all weir depths for ail orifice diameters larger than 7.5 cm.

Comparison of simulated flow frequency duration data for a 1 O-year period using the Deloss and Wasda soils is shown in the left plot of Figure 3 for a 10 cm diameter orifice at 115 cm depth with 20 cm weir depth. Results showed that about 90 % of the time both soils yield about same flow rates that were less than 4 mm/day. This indicates that no difference between the two soils would have been found had this indicator been chosen. This means that the same orifice diameter can be chosen for both types of soils. This orifice size would result in a higher frequency of flow rates of 8 mm/day or higher for the Wasda than for the Deloss soil. However, this higher frequency occurs for only a small duration (less than 0.4 % of the time). With 5 mm/day as a chosen indicator, Wasda has a frequency of occurrence of less than 1 % compared to about 8 % for Deloss soil indicating that a smaller diameter orifice should suffice. However, the indicator of water table defined in objective function (b) would probably show much higher frequency of water table within 30 cm depth for Wasda as compared to Deloss as shown in the right plot of Figure 3 for a year in 1996.

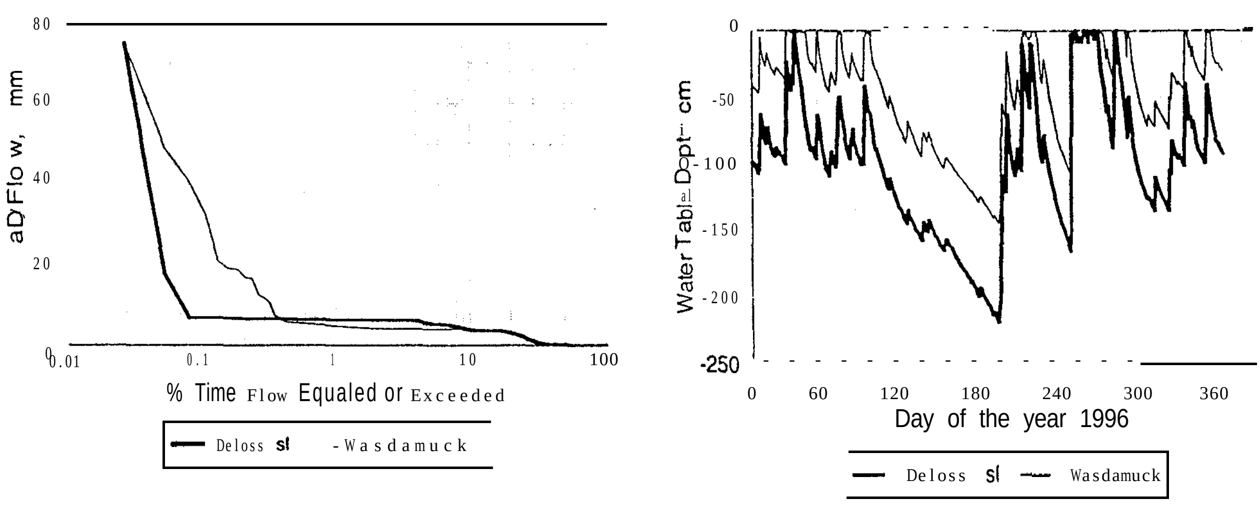

Fig. 3. Simulated daily flow duration data for a lo-year period (left) and daily water table depths for a year 1996 (right) for Deloss fine sandy loam soil and Wasda muck soil.

Flow frequency analysis for flow rates exceeding 5 mm/day using three weir depths and 6 orifice diameters are shown for the two soils in the left plot of Figure 4. For Wasda there was almost no difference among three weir depths for all orifice diameters. The frequency of drainage rates > 5 mm/day for Wasda was much lower than for Deloss for diameters up to 12.5 cm. For diameters larger than 12.5 cm the situation is reversed. However, the frequency of peak rates larger than about 8 mm/day is larger for Wasda than for Deloss soil (Fig. 3 - left). This phenomenon is basically explained by the differences in amounts and frequencies of peak flows occurring mostly as a result of surface runoff during high water table conditions in these two soils with different soil water properties.

The requency that the water table is within 30 cm of the surface for both soils is shown in right hand plot of Figure 4. The water table in the Wasda remained shallow much of the year (Fig. 3) and had almost 3 times higher frequency (28 %) within the top 30 cm than did the Deloss soil (less than 10 %). Frequency of wet days decreased with the increase in orifice diameter, as expected, for both the soils. This difference is mostly due to the fact that the drainage rates for the Wasda are limited by low saturated hydraulic conductivity (0.1 cm/hr) in the lower horizon (depth > 30 cm) for Wasda compared to 16 cm/hr for Deloss fine sandy loam soil. Because predicted subsurface drainage rates were limited due to the low K value the water table in Wasda remained shallow and surface runoff rates much greater than 5 mm/day were predicted much more frequently for the Wasda as compared to Deloss. Even for large diameter orifices (>20 cm) the frequency of high water tables for Wasda was much larger (near 12.5 %) than that for Deloss soil. Again, this is because the subsurface drainage rate is limited by the soil and the drain spacing, not the orifice diameter. To meet objective functions of both (a) and (b), a diameter of 12.5 cm would be the best choice for the Wasda soil. These results clearly demonstrate that the choice of an orifice diameter depends upon the objective functions chosen and the soil properties.

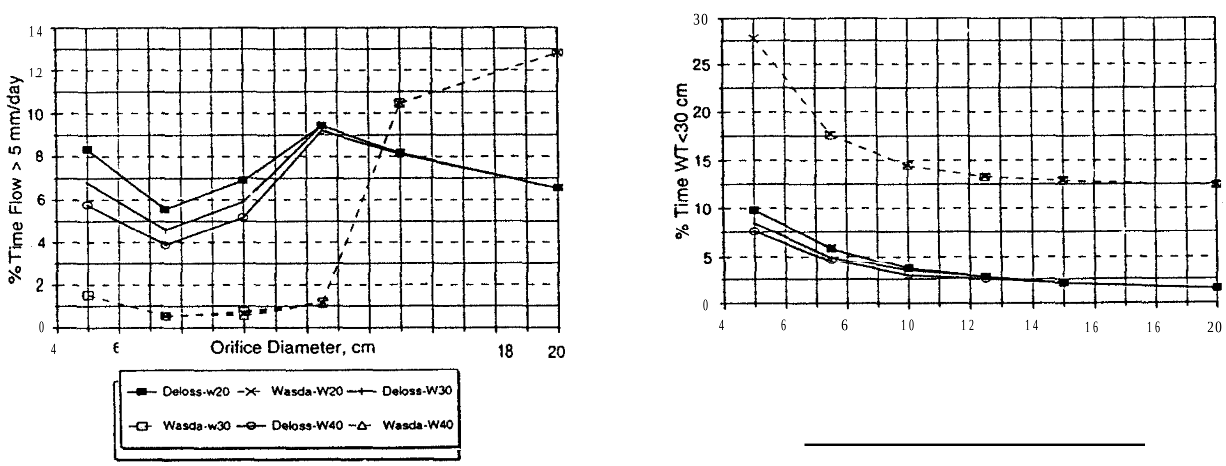

Fig. 4. Left plot shows percent time flow rates > 5 mm/day for two soils. Right plot shows percent time water table **depths were within 30 cm for two soils. Plots shown are for 6 orifice diameters at** 115 cm depth **and 3 weir depths.**

The effects of placing an orifice at different depths are shown in Figure 5 for the case with a weir depth of 30 cm. Decreasing the orifice depth from 115 to 90 cm increased the frequency of flow rates > 5 mm/day for all orifice diameters > 10 cm (solid lines in left plot). Simulation results for diameters less than 10 cm were not available. The increase was due to somewhat increased surface runoff for the 90 cm depth. However, a further decrease in the orifice depth to 75 cm increased the frequency of flow rates > 5 mm/day only for 10 cm diameter case. The frequency of high flows for diameter of 12.5 cm and greater was less than for the deeper orifice depths. Results showed that the frequency decreased with increase in depths of the weir crest for all orifice diameters (not shown). Data showed that the frequency was still the smallest for 10 cm orifice diameter placed 115 cm below the soil surface.

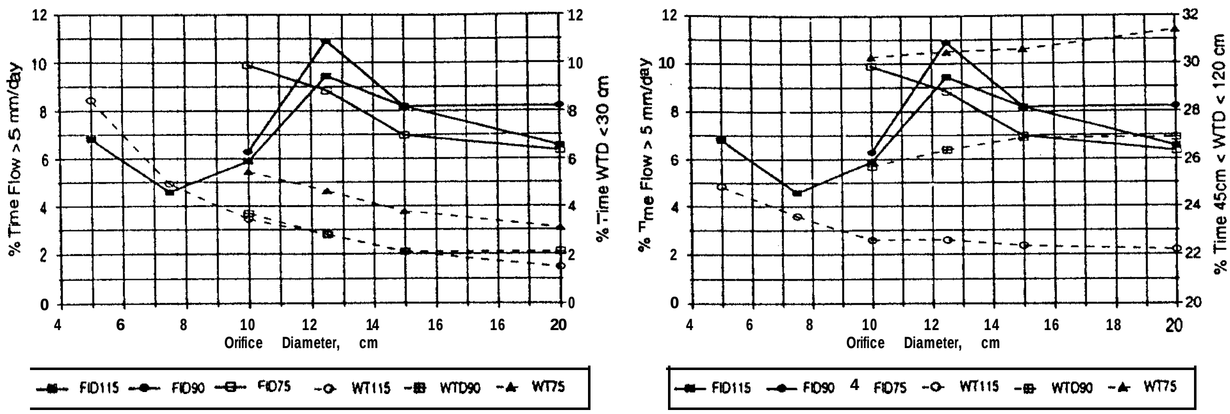

Fig. 5. Left plot shows percent time flow rates > 5 mm/day and percent time water table within 30 cm depth for different orifice diameters and three depths (75 cm, 90 cm and 115 cm) from the surface. Right plot shows the same but with water table within 45 cm and 120 cm depth. Both the plots shown are for a weir depth of 30cm from the surface.

Frequency of water table depths within 30 cm decreased with increasing orifice diameters for all 3 orifice depths (left plot of Fig. 5). The frequency was almost the same for orifice depths of 115 cm and 90 cm. However, the frequency increased by about 2 % for orifice depth of 75 cm for all diameters considered. The increase in frequency of shallow water table depths for orifice depth of 75 cm compared to 90cm and 120 cm depths did not necessarily coincide with increase in frequency of flow rates larger than 5 mm/day for orifice diameters smaller than 12.5 cm. Different results were obtained by using a flow exceedence of 7 mm/day as an indicator (not shown). The largest frequency (30 % and higher) of water table depths in the desired range of 45 cm and 120 cm was obtained for an orifice depth of 75 cm (Fig. 5 – right plot). The frequency decreased with increasing orifice depths. However, the frequency tended to both increase and decrease, depending on the depth, with increasing orifice diameters within each orifice depth. The results showed that while objective functions (a) and (c) favored an orifice depth of 75 cm for diameters of at least 12.5 cm, indicator (b) showed that this depth increased the frequency of water tables above 30 cm by 2 %. Results of the simulations showed that the expected frequency of water table depth within the desired range of 45 to 120 cm was about 8 % less for the 10 cm orifice that was installed at a depth of 115 cm at Carteret study site compared to the same orifice at a 75 cm depth. These analyses again demonstrate that the selection of a combination of an orifice and a weir and its location depends upon the objective functions to be considered.

These analyses have been conducted for a watershed size of 25 ha where an orifice size of 10 cm diameter at 115 cm depth with a 20 cm weir depth was installed. This design was shown to be at near optimum based on the objective functions discussed above. With larger watershed areas, the peak rates are generally reduced due to attenuation during flow through the fields and ditches, but the outflows occur for a longer duration due to larger volume of outflow. This means frequency of high flow rates may generally increase and that a larger diameter orifice may be required. Similar simulation analyses conducted in a 115 ha drained pine forest near Carteret study site showed that a 15 cm diameter orifice placed near a ditch bottom with a 30 cm depth of the weir crest was the optimum design. This site (reported by Amatya and Skaggs, 1997) was on a Dare muck soil. A 12.5 cm diameter orifice has been installed on a 90 ha drained forest on Wasda soil as part of our ongoing watershed scale study (Chescheir et al., 1998). Based on these analyses and other given assumptions the following general guidelines are recommended for the eastern North Carolina coastal plains.

For watersheds with relatively well drained soils • areas < 20 ha: diameter = 5 – 7.5 cm; 20 – 50 ha: diameter = 7.5 – 10 cm; 50 -100 ha: diameter = 10 – 12.5 cm; 100 – 150 ha: diameter = 12.5 – 15 cm, and > 150 ha: diameter = 15 -20 cm are recommended. There were almost no differences in values of the indicators for orifice diameters larger than 15 cm for all weir depths. The preferred weir depth is about 30 to 40 cm to reduce the wetness due to shallow water table conditions. A larger orifice diameter, however, is recommended for poorly drained soils, as demonstrated for the Wasda soil presented above.

The authors, however, strongly suggest that a simulation study should be conducted for a detailed design of orifice/weirs for watersheds larger than those considered herein.

Summary and Recommendations

A simulation study was conducted using a model DRAINLOB, a forestry version of DRAINMOD, that has been field verified for simulating daily drainage rates and water table depths from a drained pine forest with an orifice and a weir outlet at the Carteret experimental site in North Carolina. Ten years of weather data from the site were used to evaluate effects of different orifice and weir combinations. The indicators were frequencies of peak flow rates exceeding 5 mm/day, water table depths within 30 cm from the surface, and water table depths between 45 and 120 cm during the growing season. Results showed that the flow frequency of 5mm/day or higher generally tend to decrease with increase in diameter and increase in weir depths. The frequency of water table depths within the top 30 cm of the profile decreased with both increasing orifice diameters and weir depths. The greatest frequency of high flow rates was obtained for a 12.5 cm diameter orifice. Results show that the response of the objective functions depended on the size and the depths of the orifice and the weir, as well as the soil type and the watershed area. For example, for a watershed of 25 ha, a weir depth of 25 cm below the surface and an orifice diameter of 7.5 cm, the frequency of daily flows grater than 5 mm was the same both the organic and the mineral soils. However, the percentage of days with the water table within the top 30 cm of the profile was 3 times higher for the poorly drained organic soil than for the well drained mineral soil. Although an orifice placed above ditch bottom seemed to be better in terms of maintaining water table depth between 45 cm and 120 cm depth, this must be weighted against two other objectives. In general, orifice sizes rnay vary between 5 cm to 20 cm depending upon the objective functions, soil type and watersheds area. Detailed design of an orifice/weir system for larger watersheds should be accompanied by a simulation study such as this one along with predefined objective functions.

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References

Allen, H.L., P.M. Dougherty and R.G. Campbell. 1990. Manipulation of Water and Nutrients - Practice and Opportunity in Southern U.S. Pine Forests. Forest Ecology and Management, 30: 437-453.

Amatya, D.M., J.W. Gilliam, R.W. Skaggs, M.E. Lebo, and R.G. Campbell. 1998. Effects of Controlled Drainage on Forest Water Quality. J. of Environmental Quality, 27:923-935(1998).

Amatya, D.M. and R.W. Skaggs. 1997. Predicting Effects of Orifice/Weir Structures at the Outlets of Drained Pine Forests. In pp:149-152, Proc. of the Mini-Conference on “Applications of Emerging Technologies in Hydrology”, Ward and Wilson (ed.), 1997 ASAE Int'l Meeting, 2950 Niles Road, St. Joseph, MI.

Amatya, D.M., R.W. Skaggs, and J.D. Gregory. 1996. Effects of Controlled Drainage on the Hydrology of Drained Pine Plantations in the North Carolina Coastal Plain. Journal of Hydrol., 181:21 l-232.

Amatya, D.M., R.W. Skaggs, and J.D. Gregory. 1994. Hydrologic Modeling of Drained Forested Watersheds. In: Proc. of Workshop on Water Management in Forested Wetlands. pp:27-54. US EPA and USDA Forest Service, Atlanta, Georgia.

Campbell, R.G. and J.H. Hughes. 1980. Weyerhaeuser’s Forest Management Systems in North Carolina Pocosins. Tech. Rep., Regeneration South, 042-211 1/80/10, Weyerhaeuser Co., USA.

Chescheir, G.M., D.M. Amatya, G.P. Fernandez, R.W. Skaggs, and J.W. Gilliam. 1998. Monitoring and Modeling the Hydrology and Water Quality of a Lower Coastal PlainWatershed. In pp: 215-222, Proc. of the Conference on 'Watershed management:Moving from Theory to Implementation", Water Env. Federation, Denver CO, may 3-6, 1998.

Drury, C.F., C.S. Tan, J.D. Gaynor, T.O. Oloya and T.W. Welacky. 1996. influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss. J. Environ. Qual. 25:317-324.

Gilliam, J.W., R.W. Skaggs and S.B. Weed. 1978. An Evaluation of the Potential for using Drainage Control to Reduce Nitrate Loss from Agricultural Fields to Surface Waters. Water Resour. Res. Inst. of Univ. of North Carolina, Rep. No. 128, Raleigh.

Gilliam, J.W. and R.W. Skaggs. 1986. Controlled Agricultural Drainage to Maintain Water Quality. J. lrr. and Drain. Eng., 112:254-262.

Gupta, R.S. 1989. Hydrology and Hydraulic Systems. Prentice Hall, New Jersey, USA.

Hughes, J.H. 1982. Wetland Drainage - A Forestry Perspective. In Proc. of the 25th Meeting of the Soil Science Society of North Carolina. pp: 137-l 44. M.J. Vepraskas (ed.). Raleigh, N.C.

Lebo, M.E. and R.B. Herrmann. 1998. Harvest Impacts on Forest Outflow in Coastal North Carolina. J. of Environmental Quality, 27:1382-l 395 (1998).

Lorio, Jr., P.L., V.K. Howe, and C.N. Martin. 1972. Loblolly Pine Rooting Varies with Micro-relief on Wet Sites. Ecology, Vo. 53, No.3, pp:1134-1140.

McCarthy, E.J., R.W. Skaggs, and P. Farnum. 1991. Experimental Determination of the Hydrologic Components of a Drained Forest Watershed. Trans. Amer. Soc. Agr. Eng., 34(5):2031-2039.

McCarthy, E.J. and R.W. Skaggs. 1992. Simulation and Evaluation of Water management Systems for a Pine Plantation Watershed. Journal of Applied Forestry, 16(1):48-56.

McCarthy, E.J., J.W. Flewelling and R.W. Skaggs. 1992. Hydrologic Model for Drained Forest Watershed. ASCE J. of Irrigation & Drainage Engineering, 118(2): 242-255.

SAS Institute, 1990. SAS Procedures Guide, Version 6, Third Edition. SAS institute Inc., Cary, NC 27513.

Skaggs, R.W. and Nassehzadeh-Tabrizi. 1986. Design Drainage rates for Estimating Drainage Spacings in North Carolina. Trans. Of the ASAE, 29(6):1631 -1640.

Skaggs, R.W. 1978. A Water Management Model for Shallow Water Table Soils, Report No. 134, Water Resources Research Institute of the UNC, NC State University, Raleigh, NC.

Skaggs, R.W., M.A. Breve, and J.W. Gilliam. 1994. Hydrologic and Water Quality Impacts of Agricultural Drainage. In: Critical Reviews in Environ. Sci. and Tech., 24(1):1-32.