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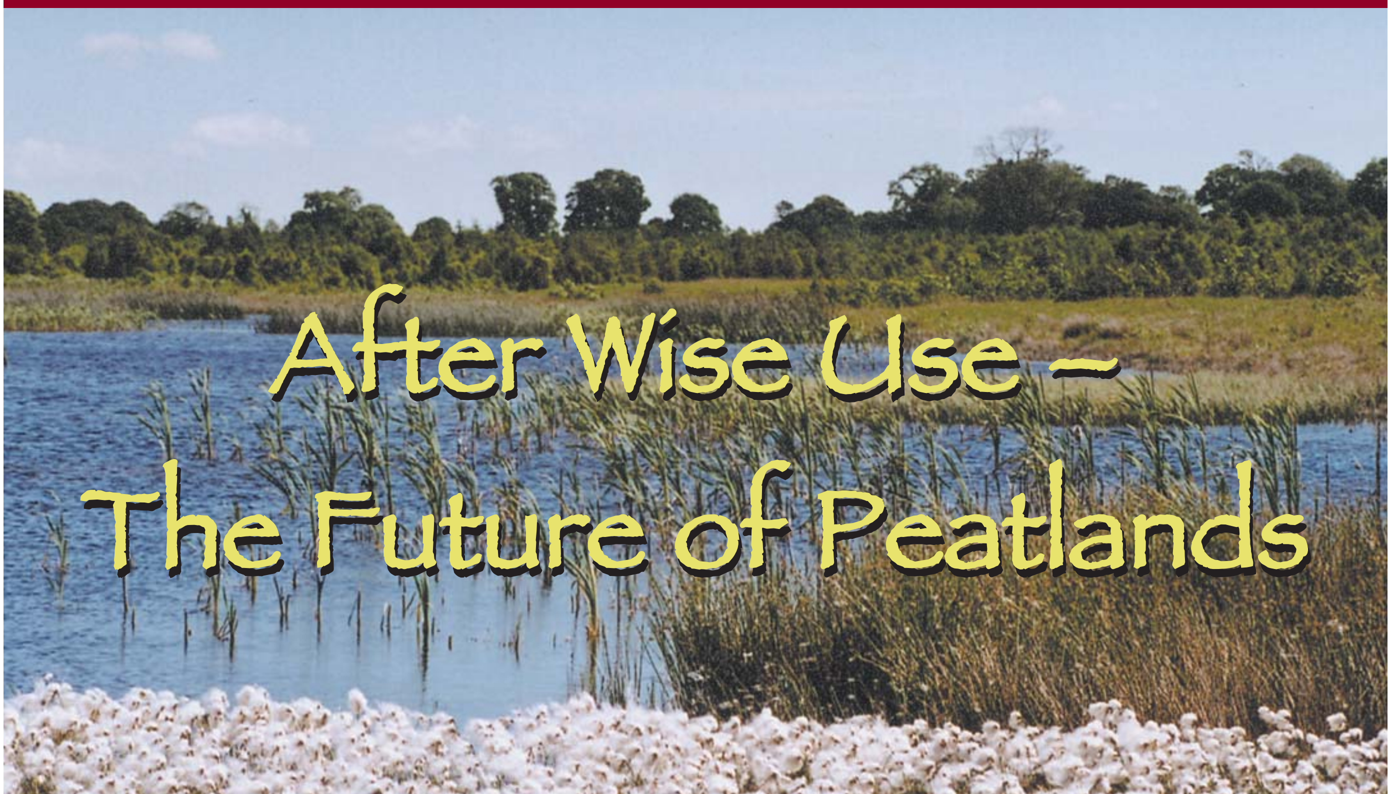

After Wise Use – The Future of Peatlands

Volume 1
Oral Presentations

Edited by Catherine Farrell (Bord na Móna)
and John Feehan (University College Dublin)

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Hydrology of a natural hardwood forested wetland

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Summary

This paper documents the hydrology of a natural forested wetland near Plymouth, NC, USA. The research site was located on one of the few remaining, undrained non-riverine, palustrine forested hardwood wetlands on the lower coastal plain of North Carolina. A 137 ha watershed within the 350ha wetland was selected for intensive field study. Water balance components including surface runoff, lateral seepage, soil air volume, rainfall, and evapotranspiration were monitored for a three year period. Water balance closure error over the 36 month period was 5%. The hydrology model DRAINMOD predicted that average annual outflow from the wetland would have been 23.3% of the average annual rainfall (1288 mm) during the 68 year period from 1933 to 2000.

Key index words: water balance, DRAINMOD, flow duration curve

Introduction

Natural wetlands are greatly valued for their role in attenuating drainage rates and improving water quality in receiving streams and estuaries. The importance of hydrology on the structure and function of wetlands is well documented and wetland hydrology is a significant part of the legal definition of wetlands (Mitsch and Gosselink, 2000). While the importance of wetland hydrology is recognized, complete and accurate hydrologic water balances have rarely been included in wetland studies (La Baugh, 1986). Wetland water balances are important parts of quantifying and understanding wetland hydrology.

The objective of this paper is to report the results of a field study in which the water balance components of a natural forested wetland were continuously monitored. The data from this study will be used to develop and validate models for simulating wetland hydrology.

Materials and methods

Site description

The study was conducted on a natural forested wetland located on the Tidewater Research Station near Plymouth, NC, USA. The research site is on one of the few remaining, undrained non-riverine, palustrine forested hardwood wetlands in North Carolina. The 350ha wetland has not been logged or otherwise disturbed for over 40 years. The wetland is essentially flat with a total variation in surface elevation of only about 0.5m. The predominant soil type is a Portsmouth sandy loam. The wetland is populated by an assemblage of swamp forest hardwood species and some pines. The wetland is bounded by agricultural land to the north, and by managed forest to the west, south, and east (Fig. 1).

A watershed within the wetland was selected as a site for intensive study (Fig. 1). The watershed is approximately 137

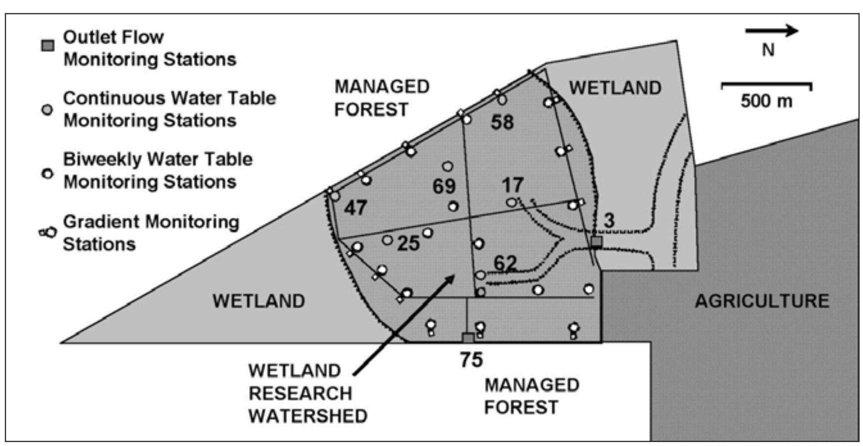

Figure 1. Diagram of the wetland research site at Plymouth, NC showing the wetland watershed and the locations of water table and flow monitoring stations.

ha and is delineated by ridges on the north and south and by managed forest on the east and west. Very shallow streams (less than 0.3m deep) form on the study site and lead to a well defined primary outlet on the northern end. A shallow abandoned canal (less than 45 cm deep) borders the site on the east forming a secondary outlet. A berm blocks most of the overland flow from the wetland to the canal; however, the canal receives seepage from the wetland and possibly some overland flow during large runoff events.

Field measurements

The primary outlet (Station 3) was equipped with wing walls and a trapezoidal flume to measure the flow of surface water from the site. The wing walls were treated plywood sheet pile inserted 45 cm into the soil and supported by 4 x 4 treated posts. The galvanized metal trapezoidal flume had a 2.7 m top width with a 0.3 m bottom width. The slope of the side walls was 4:1 to a height of 0.3 m above which they were vertical. Stage was measured continuously in the trapezoidal section and 25 m upstream of the section. Water velocity and stage in the section were manually measured weekly and these weekly measurements were used to develop a stage discharge relationship for the section. Flow from the secondary outlet (Station 75) was measured by a sharp crested V-notch weir.

Measurement stations were located along constructed trails (Fig. 1) and points of known elevations were determined at each station by survey. Wells for determining elevations of shallow groundwater and surface water were installed at 27 stations. Water elevations were measured at biweekly intervals at 19 stations and continuously at eight stations. Lines of two or three wells installed perpendicular to the wetland boundaries were located at fifteen points along the wetland boundaries. These wells were installed to determine shallow groundwater gradients at the boundaries for calculating subsurface inflow or outflow. A weather station that measures precipitation, air temperature, net radiation, relative humidity, windspeed, and wind direction is located 1.5km north of the center of the wetland site. Three other recording rain-gauges are located 3.1km east, 3.0km south, and 4.2km west of the wetland center.

Soil physical properties including bulk density, porosity, soil water characteristics, and saturated hydraulic conductivity were determined at six locations. Soil water characteristic curves were determined from undisturbed core samples of each horizon using the methods described by Klute (1986). The saturated hydraulic conductivity of the soil were measured with the auger hole method (van Beers, 1970) at each well location.

Calculations

Water balance calculations were performed biweekly during the 36 month period from May 25, 1993 to May 24, 1996. The water balance was performed for a control volume including the soil profile and the volume of surface ponding. The water balance is expressed as:

$$\Delta V_a = ET + RO + D + LS + DS - R \qquad (1)$$

Where: ΔV_a is the change in soil air volume, ET is evapotranspiration, RO is surface runoff, D is subsurface drainage, LS is lateral seepage, DS is deep seepage, and R is rainfall. All components have units of depth (mm) or volume per unit surface area (mm^3/mm^2)

Evapotranspiration (ET) for each biweekly period was the sum of calculated daily potential evapotranspiration (PET) values. Daily PET was calculated by the Thornthwaite method using daily maximum and minimum temperature values measured at the weather station. The daily PET values were adjusted using monthly factors developed by Amatya *et al.* (1995) for the North Carolina coastal plain for correcting Thornthwaite values to Penman-Montieth (grass reference) values.

The surface runoff (RO) for each biweekly period was the sum of the flow volumes measured at the primary (station 3) and secondary (station 75) outlets. While most of this flow was from surface runoff, a small percentage of the flow likely comes from subsurface drainage (D) that occurred at various locations on the wetland. We assume that the flow measured at the outlets includes D.

Lateral seepage (LS) volume from the wetland for each biweekly period was the sum of seepage volumes calculated at each series of gradient wells located on the wetland boundaries, and divided by the wetland area. Seepage rate at each series of gradient wells was calculated by Darcy's law using the measured gradient and the measured soil hydraulic conductivity near the wells. Biweekly seepage volume for each series of gradient wells was the average of the seepage rates at the beginning and end of the period multiplied by the time of the period and by the distance affected by each series of gradient wells. Deep seepage volume (DS) from the wetland was assumed to be negligible because of the presence of a thick silty clay layer starting at about 2.4m deep.

Rainfall (R) for each biweekly period was determined by averaging the biweekly rainfall volumes collected in the four rain-gauges located around the wetland. The averages were weighted by the distances of the rain gages from the center of the wetland.

The change in soil air volume (ΔV_a) was calculated using Equation 1 for each biweekly period and compared to the soil air volume determined using the measured water table depth and the depth to water table versus volume drained relationship. The average of water table depths was used to determine average soil air volume over the wetland. When the water table was higher than the soil surface, soil air volume was negative. At the beginning of the comparison period, the soil air volume for the water balance was set equal to the soil air volume determined from the measured water table depth.

The percent closure error for the water balance was calculated as:

$$\%\ Error = (\Delta V_a\ Calculated - \Delta V_a\ Measured \times 100)/Q \qquad (2)$$

Where Q is defined as the system flux and is expressed as:

$$Q = (R + ET + RO + D + |LS| + |\Delta V_a|)/2 \qquad (3)$$

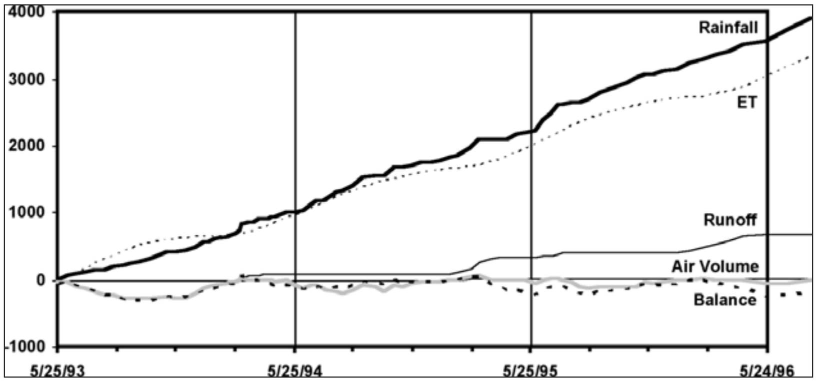

Figure 2. Water balance components measured biweekly at the wetland site during the three year study at Plymouth, NC. The balance component is the air volume calculated by the water balance equation (Eq 1).

Modeling

The hydrology of the wetland was simulated using the hydrology model, DRAINMOD. DRAINMOD was developed to simulate the hydrology of water management systems in high water table soils (Skaggs, 1978). The model predicts, on an hour-by-hour, day-by-day basis, the water table depth, soil water content, drainage, ET, and surface runoff for given climatological data, soil properties, plant cover and site conditions.

Inputs for DRAINMOD were taken from measured soil properties and observed site characteristics. Values for drain depth, drain spacing, surface storage, and root depth were 30 cm, 800 m, 4 cm, and 45 cm, respectively. Hourly rainfall and daily maximum and minimum temperature data were those collected at Plymouth, NC from 1933 to 2000. The daily PET values were calculated by the Thornthwaite method and adjusted using monthly factors developed by Amatya *et al.* (1995).

Results and discussion

Water table levels ranged from being above the soil surface during winter and spring seasons to being as much as 1.9 m below the soil surface during the dry summer of 1993. Annual rainfall amounts for the first two years were below average (1008 mm and 1226 mm compared to the annual average, 1288 mm). Rainfall for the last year was above average (1321 mm). Periods of higher rainfall occurred in the winter for the first two years of the study which resulted runoff flow only occurring in the winter and early spring (Fig. 2). A period of high rainfall occurred in the early summer of the third year of the study which resulted in runoff occurring in the summer as well as the winter and early spring of the third year.

Evapotranspiration accounted for most (86%) of the water loss from the wetland (Table 1). Surface runoff accounted for 19% of the rainfall and ranged from 11% of rainfall for the first year of the study to 25% of rainfall for the third year. Lateral seepage accounted for less than 1% of the rainfall. Closure errors for the three years of the study were 5.0%, 9.0%, and 1.4%. The greater potential sources for errors probably lie in the measurement of rainfall and the assumption that ET is equal to PET. Differences in measured annual rainfall between the rain-gauges were 5% for the first year, 10% for the second year and 7% for the third year.

Annual flow duration curves were different for the three years of the study (Fig. 3). Flow only occurred for 73 days (20% of the year) for the first year of the study. Flow occurred for longer periods during the second year (169 days, 46% of the year) and the third year (232 days, 63% of the year). Flow rates were greater than 12 mm/d for six days during the second year while flow rates never exceeded 8 mm/d during the wetter third year. The larger storm events occurred in the winter during the second year while the larger storms occurred in the summer during the third year; consequently higher flow rates occurred from the large winter storms that were not preceded by periods of high ET that would occur in the summer.

Table 1. Annual water balance components measured at the wetland site during the three year study at Plymouth, NC. Calculated water balance and closure error are also shown.

Time Period	Rain mm	ET mm	Runoff mm	Seepage mm	Water Balance mm	Air Volume mm	Closure Error mm	Closure Error %
5/25/93 5/24/94	1008	982	109	0	-84	-30	-54	5.0
5/25/94 5/24/95	1226	1066	250	12	-103	11	-114	9.0
5/25/95 5/24/96	1321	1012	332	2	-26	-7	-19	1.4
5/25/93 5/24/96	3554	3060	692	14	-213	-26	-187	5.1

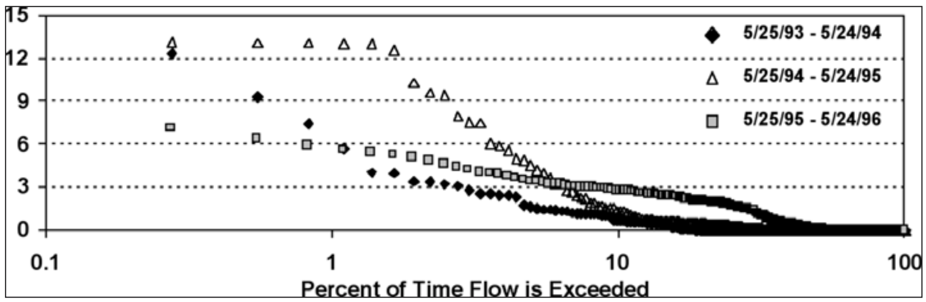

Figure 3. Annual flow duration curves observed at the wetland site during the three year study at Plymouth, NC.

Table 2. Distribution of monthly and annual flows predicted by a 68 year DRAINMOD simulation of the wetland using historical weather record (1933 to 2000) for Plymouth, NC.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Max	164	175	165	124	136	99	214	113	235	232	190	170	642
90th	114	116	107	55	28	25	45	43	66	42	55	76	517
75th	90	88	74	27	2	1	1	2	14	2	3	53	432
50th	40	52	47	9	0	0	0	0	0	0	0	2	262
25th	2	13	13	1	0	0	0	0	0	0	0	0	178
10th	0	0	1	0	0	0	0	0	0	0	0	0	100
Mean	50	57	48	20	10	9	14	12	22	15	16	27	299

Mean annual outflow predicted by the DRAINMOD simulations was 299 mm (Table 2) which was consistent with the measured outflows for the second year (250 mm) and the third year (332 mm). Rainfalls for these years were near the annual mean with rainfall being 62 mm below mean for the second year and 33 mm above mean for the third year. Predicted annual flows ranged from 0 mm to 642 mm with an interquartile range from 178 mm to 432 mm. Predicted monthly outflows reflect the variability of monthly rainfall in the region and the cycle of low ET in the winter and high ET in the summer. The wetland generally goes through an annual wetting and drying cycle with a period of drying from April through October and a wetting period from November to March. Mean monthly rainfall is greatest in July and August; however, year to year variability of rainfall is also great due to the convective nature of the storms. Rainfall is also high and variable in September due to intermittent tropical storms. In response to these variable summer rainfall patterns, the probability of flow increases in September and the highest predicted monthly outflows occurred in September and October. Tropical storms did not occur during field study.

Conclusions

Evapotranspiration accounted for most (86%) of the water loss from a natural forested wetland near Plymouth, NC, USA. Surface runoff accounted for 19% of the rainfall and ranged from 11% of rainfall for the first year of the study to 25% of rainfall for the third year. Lateral seepage accounted for less than 1% of the rainfall. Water balance closure error over the 36-month period was 5 %. The hydrology model DRAINMOD predicted that average annual outflow from the wetland was 299 mm (23.3% of the average annual rainfall, 1288 mm) during the 68 year period from 1933 to 2000. Predicted annual flows ranged from 0 mm to 642 mm with an interquartile range from 178 mm to 432 mm. DRAINMOD predicted that the wetland would generally go through an annual wetting and drying cycle with a period of drying from April through October and a wetting period from November to March.

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