THE EFFECTS OF LAKES AND WETLANDS ON FLOODFLOWS AND BASE FLOWS IN SELECTED NORTHERN AND EASTERN STATES

Richard P. Novitzki*

Summary: The functions of wetlands in the hydrologic system must be understood so that they can be properly addressed in water-resources planning, management, and regulation strategies. This report discusses the effects of wetlands on floodflows and base flows in selected northern and eastern States.

Novitzki (1982) showed a relationship between flood peaks and base flows in Wisconsin streams and percentage of basin covered by lakes and wetlands. He developed his relationship from equations presented by Campbell and Dreher (1970) and Conger (1971), which were derived from analysis on long-term Wisconsin streamflow data. These earlier investigators developed equations to estimate streamflow characteristics at any point on a stream from basin characteristics and climate factors. The streamflow characteristics analyzed included mean annual and mean monthly flows, flood peaks of selected recurrence intervals, and low flows of selected durations and recurrence intervals. The basin characteristics included drainage area, stream-channel slope, stream-channel length, basin storage (area of lakes and wetlands), basin elevation, percent forest cover, and soil-infiltration rate. Climatic factors such as rainfall intensity and distribution, snowfall, and frost penetration, also were included.

The equations presented by these earlier investigators were developed through multiple regression techniques described by Benson (1962). The equation used was of the form:

$$Y = aA^{b1}B^{b2}C^{b3}...N^{bn}$$

where: Y = streamflow characteristic;

A to N = physical or climatic characteristics;

a = regression constant; and

b_1 to b_n = regression coefficents.

* U.S. Geological Survey, Ithaca, New York

Effect of Storage on Floodflows

One of the basic characteristics used by Campbell and Dreher (1970) and Conger (1971) in their analysis was basin storage, which they defined as

> ....percent of the drainage area, including lakes, ponds, and wetlands, determined for U.S. Geological Survey maps and U.S. Soil Conservation Service data.

In this study the earlier equations were analyzed to discern the relationship between streamflow chararacteristics and basin storage. The values for basin storage ranged from 0 to 47 percent (Conger, 1971, appendix IV). The equations relating floods peaks at selected recurrence intervals to basin characteristics are shown in Table 1.

Table 1. Equations relating flood peaks of selected recurrence intervals to basin characteristics in Wisconsin.

(From Conger, 1971, p. 12. A = Drainage area, S = Main-channel slope, ST = Lake and marsh area, and AF -= Area 1 factor)

Recurrence Interval		Equation	
2-year	=	$14.5A^{.89}\ S^{.36}\ ST^{-.30}\ AF^{.93}$	(1
5-year	=	$23.6A^{.89}\ S^{.38}\ ST^{-.34}\ AF^{.98}$	(2
10-year	=	$28.9A^{.89}\ S^{.41}\ ST^{-.35}\ AF^{1.00}$	(3
25-year	=	$49.1A^{.84}\ S^{.41}\ ST^{-.36}\ AF^{1.06}$	(4
50-year	=	$145A^{.71}\ S^{.40}\ ST^{-.43}\ AF^{1.03}$	(5
100-year	=	$188A^{.70}\ S^{.41}\ ST^{-.45}\ AF^{1.04}$	(6

Because all avalues in the equations are multiplied, one can vary the value of the storage term ST and calculate the proportional change in the value of the relationship. Values of the term $ST^{-0.43}$ within equation 5 for a flood peak with a 50-year recurrence interval are given below, with ST values from 0.40. (Note that the value of ST is the percentage of lake and wetland areas plus 1 percent, to avoid zero values as described by Conger 1971. p.7)).

Percentage of lake and wetland area (ST)	Value of term $ST^{0.43}$
0	1.00
5	0.46
10	0.36
20	0.27
30	0.23
40	0.20

These data show that computed flood peaks are 80 percent lower in a basin with 40 percent lake and wetland area than in a basin with no lake or wetland area (Novitzki, 1982, p.14).

Similar equations developed for other northern and eastern States were examined to determine whether wetlands in other areas, especially in areas tributary to Chesapeake Bay, also reduce flood peaks; these included New York (Darmer, 1970), Pennsylvania (Flippo, 1977), Delaware and Maryland (Forest and Walker, 1970), and Virignia (Nuckels, 1970). Although the storage term was evaluated in each of the State analyses, it was statistically insignificant and not included in relations developed for Delaware, Maryland, and Virginia, apparently because the percentage of basin covered by lake and wetlands was small and other factors more significantly affected floodflows. The values of the regression coefficient for the storage term in the equations developed for the remaining States are given in Table 2.

The regression coefficents in Table 2 range from -0.30 to -0.479, and the relative flood peaks calculated for coefficents ranging from -0.30 to -0.50 are plotted in Figure 1. The curve in Figure 1 indicates that flood peaks in basins with as little as 5 percent lake and wetland areas may be 40 to 60 percent less than in basins with no lakes and wetlands. It would also seem that in basins with little lake and wetland area, further losses of lake and wetland area may result in significantly increased flood peaks.

Table 2. Regression coefficients for storage term in equations for predicting flood peaks of selected recurrence intervals in six northern and eastern States.

Recurrence Interval	Wisconsin[1]	New York[2] (Region 1)	Pennsylvania[3] (Region 7)	Delaware, Maryland[4]	Virginia[5] (Atlantic Slope)
2 years	-0.30	-0.473	-0.404	--	--
5 years	-.34	-.376	--	--	--
10 years	-.35	-.396	-.402	--	--
25 years[6]	-.36	-.447	-.400	--	--
50 years	-.43	-.479	-.400	--	--
100 years	-.45	---	-.400	--	--
Range of lake and wetland area in percent* reported 1/	0-47	0-3	0-4	0-4	0-5

* If only one or two basins had very large storage values, they would have little influence on the relationship, and were neglected in determining the range of storage values.

1 From Conger, 1971, p.12.

2 From Darmer, 1970, Table A-3. (Note: Darmer defined storage = area of lakes and ponds).

3 From Flippo, 1977, p.6.

4 From Forest and Walker, 1970, Table A-3.

5 From Nuckles, 1970, Table 4.

6 The New York relation was developed for a flood of a 20-year recurrence interval.

Effect of Storage on Seasonal Flows

The equations developed for Wisconsin basins were analyzed to discern whether the effect of wetlands on streamflow varied seasonally. In Wisconsin, streamflow in spring and early summer is increased by snowmelt and overland runoff, whereas in fall and winter, streamflow consists largely of discharge from ground water (base flows). Therefore, if basins with a large percentage of lake and wetland area had relatively low spring streamflow but high base flows, this would suggest that wetlands might be a source of recharge for aquifers. Conversely, if basins with a large percentage of lake and wetland area had relatively high spring steamflow but low base flows, wetlands would more likely be groundwater discharge areas.

The analysis of mean monthly flows of Wisconsin streams by Campbell and Dreher (1970, Table A-4) included a storage factor. The regression coefficients for the storage term in the equations they developed (Table 3) were as follows:

Month	Storage coefficent
January	-.13
February	-.24
March	-.05
April	.09
May	.10
June	--
July	-.10
August	-.16
September	-.13
October	--
November	--
December	--

A negative storage regression coefficient means that the value of the term decreases as the value of the variable increases; that is, streamflow decreases as storage (percentage of lake and wetland area) increases. The sign of the storage coefficient varies seasonally--negative from summer through winter; positive in the spring. This suggests that in Wisconsin basins with large lake and wetland area, more water runs off in spring and only a small amount recharges the aquifer; thus, base flow is reduced in summer, fall, and winter. This pattern is evident in the plot of seasonal streamflow in relation to storage in figure 2.

Table 3. Equations relating monthly streamflow to basin characteristics in Wisconsin (From Campbell and Dreher, 1970, Table A-4).

Monthly mean flow		Equation	
January	=	$4.36A^{1.05}ST^{-0.13}P^{-0.86}T^{0.24}Si^{1.04}Fr^{-0.82}$	(1
February	=	$982A^{1.06}ST^{-0.24}E^{-0.65}P^{-0.95}T^{0.26}Si^{1.13}Fr^{-1.00}$	(2
March	=	$0.019A^{0.83}L^{0.35}ST^{-0.05}F^{-0.09}P^{1.21}T^{0.10}Fr^{0.33}$	(3
April	=	$0.024A^{1.03}ST^{0.09}E^{0.53}P^{0.93}I^{-2.73}T^{-0.12}Sn^{0.29}Si^{-0.19}$	(4
May	=	$0.015A^{1.02}ST^{0.10}E^{0.33}F^{0.22}P^{0.90}I^{-1.48}$	(5
June	=	$0.00193A^{1.03}E^{0.44}F^{0.22}P^{0.68}Si^{0.22}$	(6
July[1]	=	$0.25A^{1.05}ST^{-0.10}F^{-0.25}Si^{0.46}Fr^{-0.29}$	(7
August	=	$0.180A^{1.03}ST^{-0.16}F^{0.25}Si^{0.60}Fr^{-0.26}$	(8
September	=	$0.000157A^{1.02}ST^{-0.13}E^{0.97}F^{0.20}Si^{0.46}$	(9
October	=	$0.000953A^{1.01}E^{0.64}F^{0.23}T^{0.17}Si^{0.39}$	(10
November[1]	=	$0.0757A^{1.02}F^{0.21}P^{0.71}I^{-1.44}T^{0.14}Si^{0.38}$	(11
December	=	$0.553A^{1.02}F^{0.24}P^{-0.54}T^{0.25}Si^{0.62}Fr^{-0.44}$	(12

1 Corrected values. Published regression constants were in error.

Similar equations developed for other northern and eastern States were examined to determine whether wetlands, especially in areas tributary to Chesapeake Bay, have similar influence on seasonal streamflow. These included streamflow analyses for New York (Darmer, 1970), Pennsylvania (Page, 1970), Delaware and Maryland (Forest and Walker, 1970), and Virginia (Nuckles, 1970). The values of the storage coefficients developed in those studies are given in Table 4. Few of the monthly equations include the storage term (none for Pennsylvania), however, and the percentage basin area covered by lakes and wetlands in these studies was small (0 to 5 percent for all States except Wisconsin); thus, it appears that other factors overshadowed the influence of storage. In the few equations where storage is significant, the influence of lake and wetland area on seasonal stramflow is similar to that in Wisconsin. Storage coefficients are shown for November and December mean flows in New York, and both are negative, which suggest reduced ground-water recharge and, consequently, reduced base flow in basins with large percentage of storage. Two storage coefficients are also shown in equations reported for Virginia; the coefficient for February mean flow is positive, which suggests increased runoff in spring, and the coefficient for November mean flow is negative, which suggests reduced base flow in fall. Two coefficients are also shown in euqations reported for Delaware and Maryland; the coefficients, for August and December mean flows are positive, which suggests that wetlands may recharge ground water in that area. However, both coefficients are small, so their influence on streamflow is also small. Although the data are sparse, the evidence suggests that spring runoff is greater and recharge to ground water lower (as indicated by lower base flows) in basins with a large percentage of lake and wetland area than in basins with no lakes or wetlands.

Of the reports examined, only the one for Virginia (Nuckels, 1970) found the storage factor significant in equations for low-flow characteristics; it presented equations for the mininum 7-day mean flow at 2-year, 10-year, and 20-year recurrents intervals. The regression coefficients for storage were:

2-year	-.620
10-year	-.742
20-year	-7.18

The negative signs suggests that base flows in basins with large percentages of lake and wetland areas are lower than in basins with no lake or wetland areas. This corresponds to the conclusions reached from the analysis of the monthly flows.

Table 4. Regression coefficients for the storage term in equations for predicting monthly mean streamflow in six northern and eastern States.

Month	Wisconsin[1]	New York[2] (Region 1)	Pennsylvania[3] (Region 7)	Delaware, Maryland[4]	Virginia[5] (Atlantic Slope)
January	-.13	—	—	—	—
February	-.24	—	—	—	.076
March	-.05	—	—	—	—
April	.09	—	—	—	—
May	.10	—	—	—	—
June	—	—	—	—	—
July	-.10	—	—	—	—
August	-.16	—	—	—	—
September	-.13	—	—	.019	—
October	—	—	—	—	—
November	—	-.182	—	—	-.130
December	—	-.112	—	.014	—
Range of lake and wetland area, in percent*	0-47	0-3	0-4	0-4	0-5

* If only one or two basins had very large storage values, they would have little influence on the relationship, and were neglected in determining the range of storage values.

[1]From Conger, 1971, p.12.

[2]From Darmer, 1970, Table A-3. (Note: Darmer defined storage = area of lakes and ponds).

[3]From Flippo, 1977, p.6.

[4]From Forest and Walker, 1970, Table A-3.

[5]From Nuckles, 1970, Table 4.

[6]The New York relation was developed for a flood of a 20-year recurrence interval.

Conclusions

The regression equations described are too general to calculate the influence of a particular wetland on either floodflows or base flows, but are probably adequate for regional analysis of wetland influence on streamflow. Results suggest that in basins with large percentages of lakes and wetlands, (1) flood peaks are less, (2) runoff in spring is greater, and (3) base flow is less than in basisn with no lakes or wetlands. In basins with as little as 5 percent lake and wetland area, flood peaks may be only half as large as those in basin with no lake or wetland area, and further losses of lakes or wetlands may significantly increase flood peaks.

Comment

The information provided by analysis of streamflow data in the manner described above can be valuable for assessing the effect of wetlands on flood peaks and base flows on a regional basis. The U.S. Geological Survey has published similar analyses for many States, many about 1970 and, more recently, has published others, especially for flood-frequency or low-flow analyses.

More than 15 years of additional streamflow data have been collected since the early works cited herein, and reanalysis of these data may provide additional information on the effect of wetlands on streamflow. Interpretation could be substantially improved if the storage factor were separated into lake areas and wetland area, and if the wetlands could be categorized into hydrologic types such as those depicted in Figure 3. Such separation would be more likely to indicate whether different wetland types have different effects on streamflow. Subsequent studies should also account for the position of wetlands in the basin (e.g., headwaters or low basin reaches) to determine whether the position of the wetland influences its effects on streamflow.

U.S. Geological Survey offices throughout the country can help refine these relationships, possibly through jointly funded programs with local agencies. They can also provide access to streamflow data for those who wish to independently develop such relationships.

Figure 1. Relationship between floodflow and storage

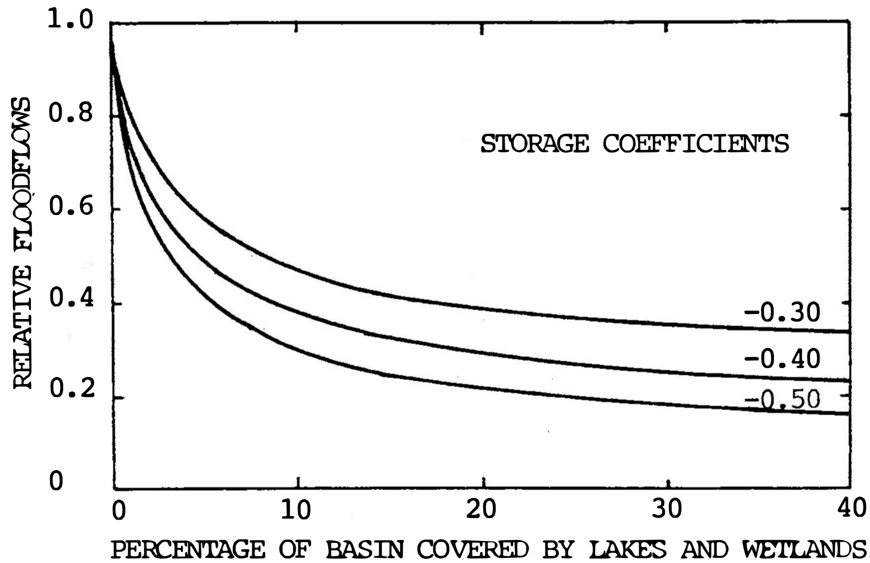


Figure 2. Relationship between seasonal streamflow and storage

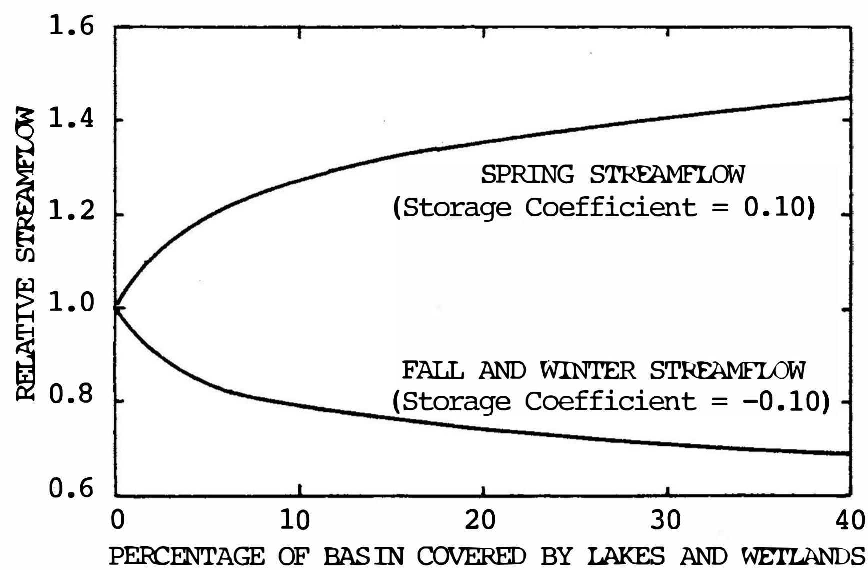
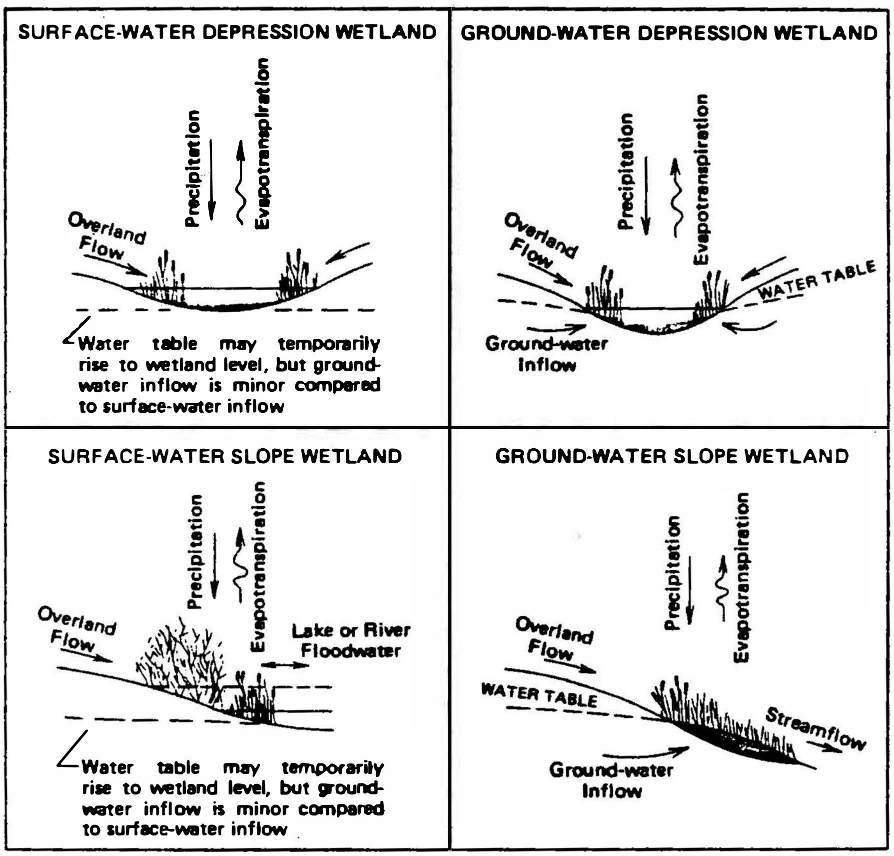


Figure 3. Hydrologic characteristics of four types of wetland
(From Novitzki, 1979)



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