## REPORTS

# Bog Hydrology: A Study of Cranberry Bog, Greenwoods Conservancy

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ABSTRACT

A hydrological budget was performed on Cranberry Bog, which receives runoff from a 600 acre area, throughout the summer of 1995. The hydrometeorology, soil physics, and vegetation of the area were all studied so that predictions of the area's hydrologic cycle might be made. An estimated model and various field data were used to approximate this budget. Actual field measurements showed that the bog lost about 8,057 cu.ft. of water/day between 7/6/95 - 8/6/95, and 5,098 cu.ft/day between 8/6/95 - 9/6/95. The estimated volumes of water loss during these intervals were 16,190 cu.ft/day and 9,179 cu.ft/day respectively. These figures show a consistent difference which may indicate a common source of error. An unmonitored groundwater component is probably responsible.

INTRODUCTION

The importance of wetlands to the environment has always been recognized, but only recently has the extent of their contributions begun to be accurately measured (Anon., 1994). Even more recent (the last decade) are State and Federal government legislative responses to the threat of losing these valuable resources (Anon., 1991). Finally, private landowners have seen the various values of protecting the land and have acted. A greater awareness of wetland ecosystems can only increase the desire to protect them.

Wetlands are areas where water is near, at, or above the level of the land (Smith, 1990). However, this definition is not sufficient to represent areas of such diverse nature. The U.S. Fish & Wildlife Service and U.S. Army Corps of Engineers both define wetlands as those areas that are covered with water for a period long enough to support hydrophytes (vascular plants requiring water-logged soils). These are general definitions; specific classifications of various wetlands become more difficult because of political and legislative reasons. Wetlands are typically known for their rich floral diversity. The transition between aquatic and terrestrial ecosystems allows this biological

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richness to be sustained. Often referred to as the "edge effect", this phenomenon occurs when two or more vegetational communities are adnate to each other. These areas have greater abilities to sustain a more diverse species population (Smith, 1990). A lesser known value of wetlands is their water filtering capacity. Wetlands can remove many different kinds of organic and inorganic pollutants from the water (Cole, 1983). Importantly, they serve as one of the earth's recharge areas for water.

Cranberry bog is a pristine wetland located within the thousand acres that make up Greenwood Conservancy. This land is protected via a conservation easement through the Otsego Land Trust. This land is included under New York State Environmental Conservation Law for protection of water quality and fragile and important wetland ecosystems. In accordance with the purposes of the Conservation Easement, maintenance of the pristine landscape is one objective of the involved parties. There are values to be gained for society by the maintenance of beauty, as well as from the knowledge that the ecosystem continues to operate without undue degradation.

It is therefore logical to include a study of the area's hydrology. This work will provide a perspective on ecosystem dynamics at Greenwoods Conservancy and will provide information necessary for future management.

METHODS

<u>Estimated Water Budget</u>

A monthly water budget was estimated so that comparisons could be made with empirical data that were collected. A method for calculating the water balance was introduced by Thornthwaite in the early 1940s (Dunne, 1978). The formula involved with this method has since been modified to include a correction factor (c) in calculating the potential evapotranspiration (McCoy, 1994). The corrected formula is shown below.

$$E_t = 1.6\left[\frac{10T_a}{I}\right]^a * C$$

where $E_t$ = potential evapotranspiration in cm/mo

$T_a$ = mean monthly air temperature (°C)

$I$ = annual heat index = $\sum_{i=1}^{12}\left[\frac{T_{ai}}{5}\right]^{1.5}$

$a = 0.49 + 0.0179I - 0.0000771I^2 + 0.000000675I^3$

C = Correction factor for monthly sunshine duration

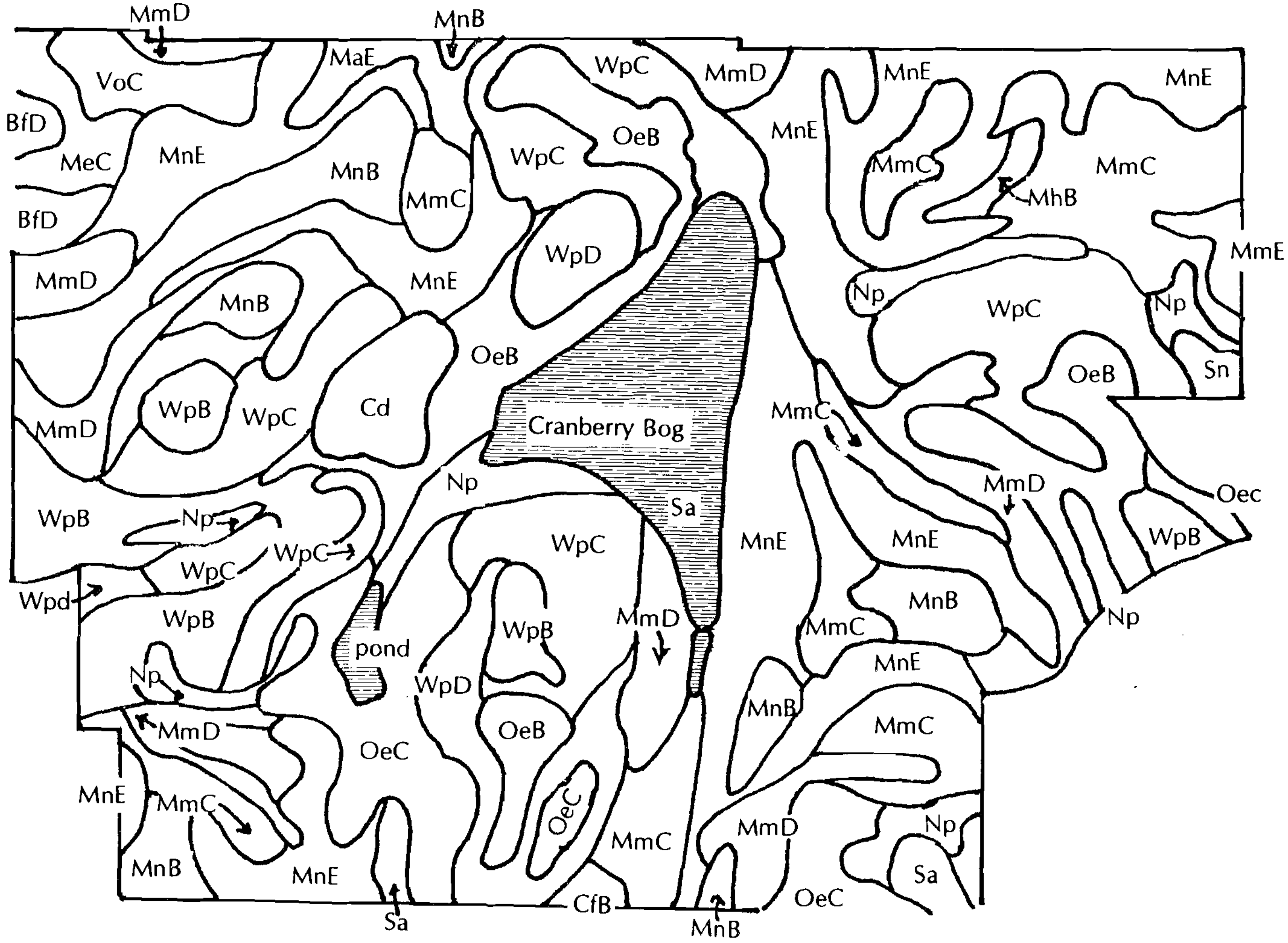



Figure 1. Soils identification map of the Greenwoods Conservancy, around Cranberry Bog, Burlington, Otsego County, NY.

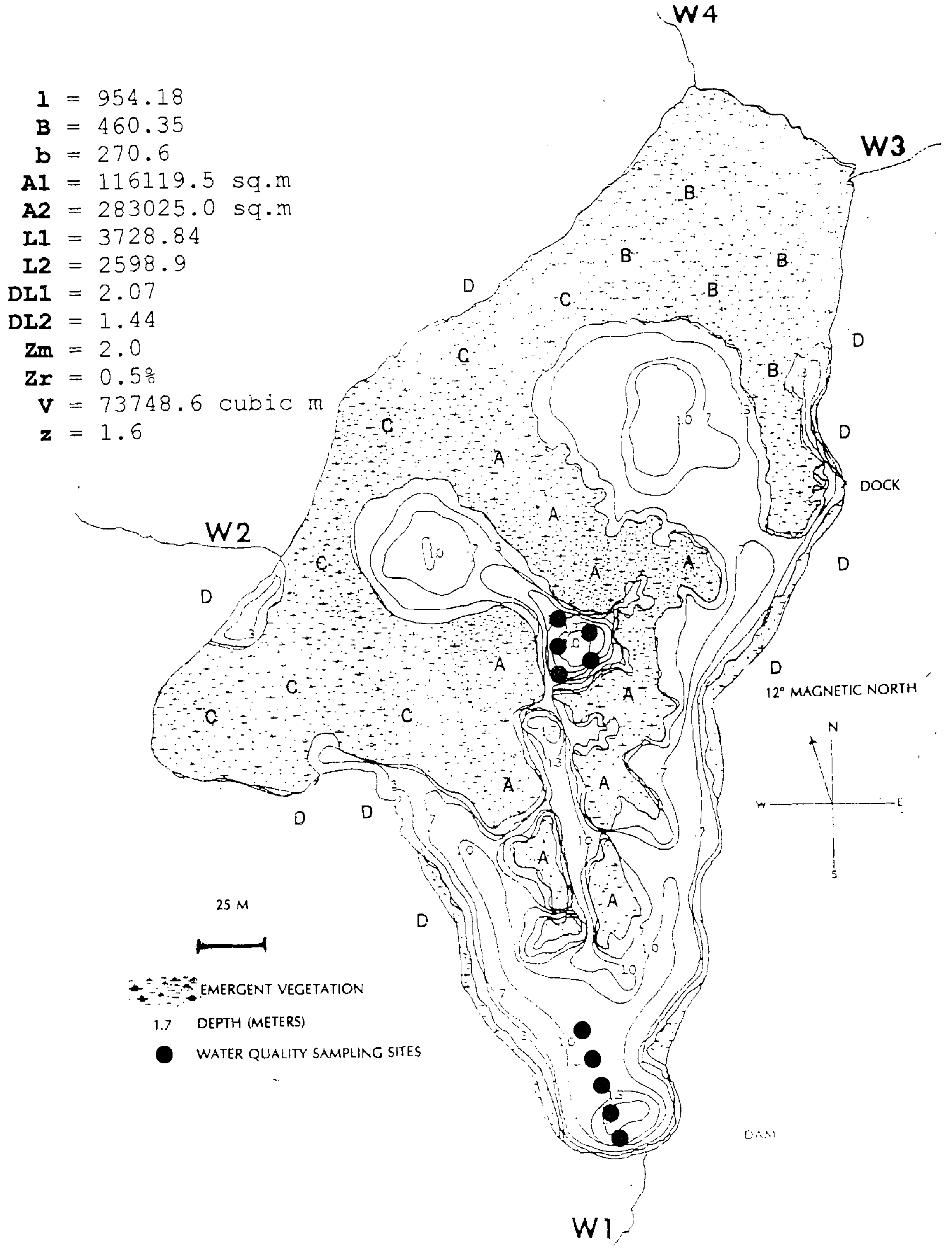


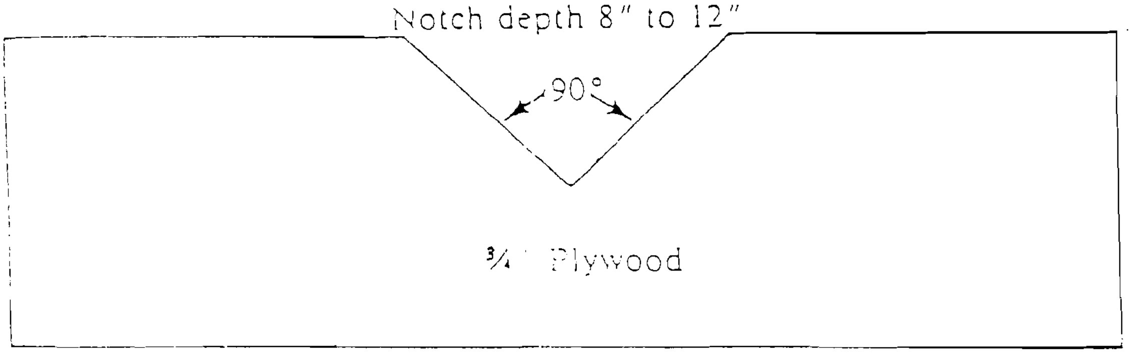

Figure 2. Cranberry Bog, Greenwoods Conservancy. Weir locations represented by W1, etc.

Most of the work involved with this was done primarily at the field station. Aerial photographs (USDA, 1983) and NY USGS topographic quadrangle maps were used in watershed delineation as well as surface area determinations. Soil maps of the area (Figure 1) were obtained from the NY USGS (USDA, 1995) and were used to show different soil types present so that accurate assessments of the water capacities of the different watersheds could be made. For more information concerning the use of these formulae and constructing a water balance sheet (Table 1), consult Dunne and Leopold, 1978.

Field Apparatus

In order to obtain a perspective on the hydrologic cycle of the area, as well as to compare the estimated water budget, several devices were installed to collect field data. First, the contributing streams were fitted with weirs to ascertain their flow rates. This is done by measuring stream height over the weir crest per unit time with an automated sampler and using the data to calculate discharge (Anon., 1967). This was done on a regular basis so that an accurate account of all surface water flowing into the system was obtained. A weir was also placed at the outflow. Altogether, four weirs were placed, and the amounts of water going into and coming out of the bog were recorded. Figure 2 shows the location of the weirs. A rough diagram of a weir is shown Figure 3. Information about weirs may be obtained from either Grant, 1989, or Anon., 1967.

FIGURE 3




*Weir*

A rain gauge was placed in the area to monitor precipitation. The bog is divided into two sections, one large body of water (about 30 acres standing water) drains into a much smaller body (about 0.5 acres). A staff gauge was placed in each body of water so that the level of water could be constantly recorded during the course of the study. This helped determine how much the volume of water fluctuated over time.

In addition to the weirs, two automated water samplers were utilized. These devices were programmed to record stream flow every ten minutes. One of these was placed at the outflow and one was placed at the major contributing stream. The data were then transferred to processing software at the Biological Field Station. The other two incoming streams were monitored daily by recording the stream's height over the weir (via installed staff gauge). The collected data were manually used in a flow conversion formula.

Evaporation was taken from a standardized set of values for this latitude and time of year. Evapotranspiration was assumed to be equal to the estimated potential evapotranspiration calculated in the water balance. All together, these data provided measurements of all surface water going into and out of the bog.

Bog Dimensions

A previously produced bathymetric map (from Pagan and Ferluge, 1994) was modified to account for seasonal changes in water depth (Figure 2). This was done with a calibrated rod. The map was then used for the calculation of water volume at various depths.

Several methods have been advanced for volume determination (Cole, 1983); graph paper, paper weighing, planimetry and rotometry are examples of these methods. Remarkably, all the methods used obtained differences of less than 9%. Morphometric data has also been included. All formulae and methods were taken from Cole (1983).

Nutrient Cycle

As yet incomplete, this part of the study will result in the establishment of the area's phosphorus, nitrogen, and calcium budgets. The budgets will account for the volume of total phosphorous, nitrates, and calcium entering and leaving the system, as well as that resident in the bog. Weekly samples taken at each of the inflow and outflow streams, and within the bog, will enable current baseline levels to be measured. This will be accomplished in the laboratory at the BFS to ascertain nutrient concentrations and integrating these values (using onsite spreadsheet software) as a function of time and flow rate to obtain volume. The values obtained for the monitored portions of the watershed will serve as models for the unmonitored areas so that values can be obtained, through interpolation, for these areas.

The two automated sampling systems mentioned above will be used to measure the response of the area's nutrient cycle to storm events. One sampler is placed at the outflow and the other at the major contributing stream. These samplers are programmed to begin collecting a series of water samples upon significant rise in water levels. These samples will be composited and analyzed for nutrient concentrations and total volume for each storm event. The sampler system placed at the inflow will serve as the only model upon which to base all interpolated values for all unmonitored regions, as well as for all storm events not large enough to cause the sampler to activate. This section of the study could not be completed this season due to dry weather conditions. During the summer months the temperature was such that evaporation and evapotranspiration rates were at their peak. The vegetation retained greater amounts of water for its own purposes. Because the amount of rain was not enough to account for the increased water demand, stream flows were radically diminished. This made it impossible to make reasonable measurements of the nutrient loading for the time frame in question. This part of the study, as well as further compilations of data, will be continued into the fall 1995 season when discharges increase.

## RESULTS

### Hydrological budget

The water balance sheet is shown below in Table 1.

TABLE 1
Water Balance
(all figures expressed in cm)

| YEAR | JAN. | FEB. | MARCH | APRIL | MAY | JUNE |
|---|---|---|---|---|---|---|
| P | 6.17 | 5.66 | 7.77 | 8.36 | 9.35 | 10.69 |
| TEMP. | -6.5 | -5.4 | 0.167 | 6.39 | 12.72 | 17.3 |
| PET | 0 | 0 | 0.06 | 3.29 | 7.42 | 10.70 |
| P-PET | 6.17 | 5.66 | 7.71 | 5.07 | 1.93 | -0.01 |
| APWL | 0 | 0 | 0 | 0 | 0 | -0.01 |
| SM | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 36.99 |
| <SM< | 0 | 0 | 0 | 0 | 0 | -0.01 |
| AET | 0 | 0 | 0.06 | 3.29 | 7.42 | 10.70 |
| TD | 0 | 0 | 0 | 0 | 0 | 0 |
| TS | 6.17 | 5.66 | 7.71 | 5.07 | 1.93 | 0 |
| TAR | 12.06 | 11.69 | 13.56 | 11.85 | 7.85 | 3.93 |
| RO | 6.03 | 5.85 | 6.78 | 5.92 | 3.93 | 1.96 |

Water Balance (cont.)

| YEAR | JULY | AUGUST | SEPT. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|
| P | 8.89 | 8.79 | 9.42 | 7.87 | 8.61 | 7.92 |
| TEMP. | 19.9 | 19.0 | 14.9 | 9.05 | 3.28 | -3.4 |
| PET | 12.21 | 10.87 | 7.60 | 4.01 | 1.23 | 0 |
| P-PET | -3.32 | -2.08 | 1.82 | 3.86 | 7.38 | 7.92 |
| APWL | -3.33 | -5.41 | 0 | 0 | 0 | 0 |
| SM | 33.85 | 32.01 | 33.83 | 37.0 | 37.0 | 37.0 |
| <SM< | -3.14 | -1.84 | 1.82 | 3.17 | 0 | 0 |
| AET | 12.03 | 10.63 | 7.60 | 4.01 | 1.23 | 0 |
| TD | 0.18 | 0.24 | 0 | 0 | 0 | 0 |
| TS | 0 | 0 | 0 | 0.69 | 7.38 | 7.92 |
| TAR | 1.96 | 0.98 | 0.49 | 0.69 | 7.73 | 11.78 |
| RO | 0.98 | 0.49 | 0.25 | 0.345 | 3.86 | 5.89 |

(a summary of the above procedure is outlined in the appendix)

* P= PRECIPITATION, TEMP.= TEMPERATURE, PET= POTENTIAL EVAPOTRANSPIRATION, APWL= ACCUMULATED POTENTIAL WATER LOSS, SM= SOIL MOISTURE, <SM<= CHANGE IN SM, AET= ACTUAL EVAPOTRANSPIRATION, TD= SM DEFICIT, TS= SM SURPLUS, TAR= TOTAL AVAILABLE RUNOFF, RO= TOTAL RUNOFF

The figures from the last row (RO) were then converted from cm to cubic feet per second (CFS), using the following formula, to yield Q1.

$$Q1 = \frac{(RO) \text{ in ft.} * (SA) \text{ in sq. ft.}}{\frac{86400 \text{ sec.}}{\text{day}} * \text{no. of days in month}}$$

The mean monthly precipitation and evaporation were converted to discharge, using above formula, to yield Q2 and Q3 respectively. The total net discharge from the outflow (Q4) was then reached by (Q1+Q2)-Q3=Q4. This is shown in Table 2.

TABLE 2
Q4=Total net discharge from outlet

| YR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q1 | .99 | 1.0 | 1.1 | .97 | .64 | .31 | .15 | .10 | .05 | .05 | .67 | .9 |
| Q2 | .18 | .19 | .22 | .25 | .28 | .32 | .26 | .26 | .29 | .23 | .26 | .2 |
| Q3 | 0 | 0 | 0 | .17 | .36 | .54 | .60 | .53 | .38 | .20 | .07 | 0 |
| Q4 | 1.2 | 1.2 | 1.3 | 1.1 | .56 | .09 | 0 | 0 | 0 | .08 | .86 | 1 |

The last row of Table 2(Q4) are the estimated amounts (cubic feet per second) of water that will flow out of the bog.

Figure 4 is a hypsographic curve of Cranberry Bog. This graph is a visual depiction of the volume of impounded water at the beginning of this study. The area underneath the curve represents the water volume and was found by integrating with data processing software and manual calculation. Table 3 shows this data.

Field Data

Although precipitation and water level data have been collected since 6/12/95, the only data used were those from the time that all monitoring devices were in place, and water flow had become stabilized. These conditions were met on July 6, 1995. All water measurements are the combined values for the bog and the downstream impoundment. In other words, the two bodies of water were considered to be continuous. Staff gauges show how much water was being impounded at each site. These combined volumes are given in Table 3.

A total of 6.05 inches of rain fell on Cranberry Bog between 7/6 - 9/6/95. (2.84 in. for period 7/6 - 8/6, and 3.21 in. for 8/6 - 9/6/95). Table 3 shows the approximate volumes of water that have fallen on the bog each month during the study.

At the same time,(according to the U.S. Weather Bureau), about 4.81 in. of water evaporated between 7/6 - 8/6/95, and about 4.28 in. between 8/6 - 9/6/95. Table 3 shows the volume of water that has evaporated for each period.

Figure 2 shows the location of each of the weirs used in this study. Below is an example of the kind used to calculate the water volumes flowing over the weirs for each time period (Figure 5). Table 3 shows the water volumes flowing over each weir, for each time period.

The weirs used in this study enabled the measurement of surface runoff for only a portion of the total watershed. The measurements shown in Table 3 were used to estimate the runoff in the unmonitored watershed areas. Figure 6 contains a watershed delineation map. The map specifies which areas were monitored, and provides the estimated runoff figures for each unmonitored area. These figures were based on monitored areas with similar characteristics (soil capacity, vegetation, etc.). Table 3 gives the estimated volume of water these areas contributed to the bog, for each time period.

TABLE 3
DETERMINATION OF ESTIMATED NET WATER VOLUME
(all values in cubic feet)

| TIME PERIOD | 7/6 - 8/6 | 8/6 - 9/6 |
|---|---|---|
| INITIAL VOLUME | 2,599,288 | 2,357,568 |
| RAIN VOLUME | 674,056 | 809,604 |
| EVAP. VOLUME | 1,123,426 | 1,079,472 |
| WEIR 1 VOLUME | 160,623 | 69,032 |
| WEIR 2 VOLUME | 31,886 | 19,131 |
| WEIR 3 VOLUME | 6,371 | 3,334 |
| WEIR 4 VOLUME | 22,879 | 6,560 |
| UNMONITORED VOL. | 63,160 | 34,520 |
| NET VOLUME | 2,113,591 | 2,082,212 |

In Table 3, net inflow was found by adding the volumes for rain, weirs 2, 3, and 4, and the unmonitored area runoff to the initial bog volume. Evaporation and weir 1 (the outflow) volumes were subtracted from this number to yield net volume.

For the end of each time period the change in volume was determined by measuring the bog water level and calculating the volume using the hypsographic curve and associated formula. These volumes are compared to Table 3's net volume in Table 4.

TABLE 4
ACTUAL VOLUME vs. ESTIMATED VOLUME (Table 3)
(values expressed in cubic feet)

| PERIOD | 7/6 - 8/6 | 8/6 - 9/6 |
|---|---|---|
| INITIAL VOL. (a) | 2,599,288 | 2,357,568 |
| FINAL VOL. (a) | 2,357,568 | 2,204,644 |
| CHANGE VOL. (a) | -241,720 | -152,924 |
| FINAL VOL. (e) | 2,113,591 | 2,082,212 |
| CHANGE VOL. (e) | -485,697 | -275,356 |
| % DIFFERENCE | 10.3% | 5.6% |

(a) = Actual measurements based on water level of bog
(e) = Estimated measurements based on data in Table 3

Related Data

Figure 2 shows the bathymetric map with morphometric data included in the legend. The following provides a brief explanation of each of the values. All of the descriptions have been summarized from (Cole, 1983).

Max length (l) - This serves as the wind-effective length. The amount of water exposure to the wind may have indirect effects on the biota of the bog. The longer the length the greater the effect.

Max width (B) - Perpendicular to l, the max width is the greatest distance between shores.

Mean width (b) - Equal to A/l

Surface area (A1),(A2) - As indicated before, several methods were used in calculating this value, all of which had less than 9% difference! Two measurements were made, A1 is standing water only, A2 includes all emergent vegetation.

Shoreline length (L1),(L2) - L1 is standing water only, L2 includes emergent vegetation.

Shoreline development index (DL1),(DL2) - This is a figure compared to the circumference of a circle, which equals 1.0. Impoundments, such as Cranberry Bog, whether artificial or natural often have a high index. DL1 is standing water, DL2 includes emergent vegetation.

Max depth (Zm) - As a water body ages this value becomes less due to sediment accumulation.

Relative depth (Zr) - This is the ratio of Zm to the average diameter of the water surface.

Volume (V) - This is the volume of water impounded at the beginning of this study.

Mean depth (z) - Equals A1/V, it is an important dimension in determining what portion of the water volume is in the photosynthetic zone.

## DISCUSSION

The estimated mean monthly discharges calculated using the Thornthwaite method (Table 2) show no appreciable discharge outflow during the months of July, August, and September. Because of the large surface area, soil, and vegetative characteristics of the watershed, as well as contributing weather conditions, it could be expected that low flow would be the norm. This turns out to be partially true as flow falls to zero at the outflow sometime in mid-August and even earlier for the contributing streams. The flow versus time graphs (Figures 5a-d) show this trend.

The area's hydrologic cycle does not respond exactly as the model indicates. This may be due in part to varying weather conditions or errors due to lack of refinement of this method for use with wetlands. An extremely large portion of Cranberry Bog is inhabited by hydrophytic vegetation. Evapotranspiration coupled with the very high water capacities of the organic substrate (in part *Sphagnum* spp.), might very well lead to significantly different estimates of discharge. This method has demonstrated its abilities as a valuable tool in estimating hydrologic processes in many situations (Dunne, 1978), and with further enhancement may become better adapted for our use.

The data in Table 4 shows two different values for final volume (a) as calculated using the hypsographic curve. The numbers for both time periods are constantly higher than the final volume (e), as estimated using direct measurements of field data. It would seem that whatever error is accruing is constantly present. Without considering all possible sources of error, there is one obvious explanation, the potential contribution of unmonitored groundwater. Groundwater constitutes 97% of all unfrozen fresh water on earth. In the United States, 80-90% of the total available water comes from this source (Dunne, 1978). It is therefore logical to assume that groundwater plays a role in any area's hydrologic cycle. Because of the nature of our protocol, it was difficult to identify any groundwater contribution, let alone quantify it. Observations made during the winter of 1995 indicated the possibility that significant groundwater flow into the bog may exist. Open water found in areas on the bog when the rest of the water was covered with six inches of ice can be attributed to the higher temperatures of incoming groundwater and/or the absorbtion of energy by stumps and other dark objects (Harman, per comm.).

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## REFERENCES

Anon. 1967. United States Bureau of Reclamation. Water Measurement Manual 2nd ed. Department of the Interior, Denver, Colorado.

Anon. 1983. United States Department of Agriculture. Aerial photographs of Cranberry Bog. Natural Resources Conservation Service in Otsego County, New York.

Anon. 1991. United States House of Congress. Committee on public works and transportation, subcommittee on water resources. Status of nation's wetlands and laws related thereto. US G.P.O.

Anon. 1994. United States House of Congress. Committee on agriculture, subcommittee on environment and rural development. Review of the impact of wetlands and non-point source pollution regulations on agricultural land. US G.P.O.

Anon. 1995. United States Department of Agriculture. Otsego County soil survey. Natural Resources Conservation Service in Otsego County, New York.

Cole, Gerald A. (1983). Textbook on Limnology 3rd ed. Waveland Press, Illinois.

Dunne, Thomas and Luna B. Leopold. 1978. Water in Environmental Planning.
W. H. Freeman and Company, San Francisco.

Goldman, Charles R. and Alexander J. Horne. 1983. Limnology. Mcgraw-Hill Book Company, New York.

Grant, Douglas M. 1989. ISCO Open Channel Flow Measurement Handbook 3rd ed. ISCO Environmental Division, Lincoln, Nebraska.

Hammer, Donald A. 1989. Constructed Wetlands for Wastewater Treatment. Lewis Publishers, Michigan.

Harman, Willard N. 1995. Notes taken from discussions. SUNY Oneonta. Biological Field Station, Cooperstown, New York.

McCoy, C. Mead. 1994. Moe Pond Drainage Estimated Monthly Water Budget. SUNY Oneonta Biological Field Station, SUNY, Oneonta.

Mitsch, W. J. and J. G. Gosselink. 1993. Wetlands 2nd ed. Van Nostrand Reinhold, New York.

Pagan, R. and C. Ferluge. 1994. The bathymetry of Cranberry Bog. SUNY Oneonta independent study project, winter 1994.

Smith, Robert L. 1990. Ecology and Field Biology 4th ed. Harper and Row Publishers, New York.

Taylor, Linda A. 1966. Biological Survey of Cranberry Bog. SUNY Oneonta Biological Field Station, SUNY, Oneonta

Welsh, Paul S. 1952. Limnology. Mcgraw-Hill Book Company, New York.

Wetzel, Robert G. 1975. Limnology. W.B. Saunders Company, Philadelphia.