Hydrologic Budget for Tenmile and Birch lakes

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INTRODUCTION

This report presents the results of a preliminary hydrologic budget for the Tenmile and Birch lake watersheds. The goal of this preliminary hydrologic investigation is to examine whether there is significant exchange of water between Tenmile and Birch Lakes. The simplest form of a hydrologic budget specifies inputs, outputs and storage changes over a reference period for a specific area. The reference area for this investigation is the lake surface, the reference period is one year, and the study was done for the water years (Oct. 1 – Sept. 30) 2000, 2001, and 2002. To most effectively determine the components of inflow and outflow to the lakes three separate hydrologic budgets were calculated.

First the watersheds of Tenmile and Birch Lakes were combined and an overall hydrologic budget was determined. The relatively large size of the watersheds and the good record of stream outflow of the Boy River at Hackensack make it easier to calibrate coefficients used for determining surface runoff and evapotranspiration. Over a one-year period the hydrologic budget should be relatively balanced with little change in storage.

Separate hydrologic budgets were then compiled for Birch Lake and Tenmile Lake and a modest sensitivity analysis was conducted by varying input and output parameter coefficients within accepted ranges. This analysis of individual watersheds allows identification of components of exchange between the two basins.

Results suggest that there is a large component of water exchange from Tenmile Lake to Birch Lake. The ratio of surface water to groundwater flow accounting for this exchange cannot be determined at this time. A detailed assessment of the groundwater flow systems including a groundwater flow model and placement of a stage recorder in the stream between Tenmile and Birch Lakes will help address this question.

HYDROLOGIC BUDGET

General Lakes Hydrology

Tenmile and Birch lakes occupy the headwaters of Boy River system. The Tenmile Lake watershed has and area of 100.7 km^2 and the Birch Lake watershed has an area of 23.6 km^2. Tenmile Lake drains to Birch Lake, which in turn drains the southeast along the Boy River. Because of the relatively low apparent flow through the river between Tenmile and Birch lakes, it is suspected that the groundwater flow component between them may be large. The geology of the watershed is a complex sequence of glacial sediment composed of relatively impermeable till and lacustrine sediment and permeable outwash gravels.

Water Balance Equations - General Introduction

All water balance equations are based on the premise that the difference between water inflow and water outflow over a given time period for the hydrologic system of interest (be it a watershed, lake, etc.) must equal the change in water storage in that system. That is

$$IN - OUT = \pm STORAGE$$

If inputs exceed outputs there will be an increase in storage and the right side of the equation will be positive. If outputs exceed inputs there will be a loss from storage and the left side of the equation will be negative.

The exact form of the water budget equation for any given hydrologic system varies depending upon the size of the system and the length of the time period for which the water budget is being constructed. For example, the equation for a long reference period (on the scale years to decades) and a large watershed (perhaps a major river drainage system) would contain only a few terms:

$$P - (ET + RO) = 0$$

where P = precipitation, ET = evapotranspiration, RO = surface runoff

This equation would apply for a case in which there was no significant change in total water storage in the basin (i.e. -no significant change in groundwater, lake, or river levels) over the time period for which the balance is set up. This assumes that there is no persistent climatic change in the basin that would cause amounts of water storage to change. Given these conditions, water entering the basin in the form of precipitation would simply equal to the amount of water leaving the basin in the form of evaporation or runoff.

The water balance equation for total water storage (both on the surface and in the subsurface) for a small watershed/basin over a short reference period would contain many more terms and might be as follows:

INFLOW OUTFLOW STORAGE

$$(P + q + g + i) - (ET + e + SRO + SSRO) = \pm (SS+GS+SM+DS+I)$$

INFLOW:

- P = precipitation
- q = direct inflow of surface water from other basins
- g = direct inflow of groundwater from adjacent basins
- i = water artificially imported from other basins (pipelines, etc.)

OUTFLOW:

- ET = evapotranspiration
- e = water artificially exported to other basins
- SRO = surface runoff leaving the basin
- SSRO= subsurface flow from basin to other basins

STORAGE:

- SS = change in surface storage (lakes, rivers, etc)
- GS = change in water storage in groundwater system in basin
- SM = change in amount storage of water as soil moisture
- DS = depression storage (water pooling in surface depressions after precipitation event)
- I = interception by plants and vegetative cover (water sticking to plant leaves)

During short reference periods many transient terms exist (such as I, DS, and SM) that become runoff or evapotranspiration over longer reference periods and therefore disappear. An additional feature to note is that for small watersheds that are part of larger basins surface water and groundwater divides do not always correspond (therefore even if q=0 it does not necessarily mean that there is no groundwater flow into the basin from adjacent basins).

The forms of the water balance equation shown above represent two extremes, the first being very general and the second being fairly detailed. For this study we will be constructing a water budget for the Tenmile and Birch watersheds on the time scale of one year and so will be using a form of the water balance equation of intermediate complexity.

METHODS

For our study all inputs and output volumes will be referenced to the lake area. Therefore lake-level change will be our primary storage term (i.e. If the lake level does not change over the reference period, then inputs and outputs balance). We use the following balance equation,

[1] $$LL^* A_L = (P^* A_L + P^* A_{LW} {}^*C_{LW}) + GWFC^*A_L - (PET^* A_L) + (SRO^*A_L),$$

where
LL: lake level
A_L: area of the lake
P: precipitation
A_{LW}: area of the lake watershed
C_{LW}: conversion factor for the lake watershed
PET: potential evapotranspiration
SRO: surface runoff.

Note that all measurements are referenced to lake level change. We can rearrange

[2] $$\pm GWFC^*AL = \pm LL^* AL - (P^* AL + P^* ALW {}^*CLW) + (PET^* AL) + (SRO^*AL)$$

and

[3] $$\pm GWFC = [\pm LL^* AL - (P^* AL + P^* ALW {}^*CLW) + (PET^* AL) + (SRO^*AL)]/A_L$$

GWFC is the groundwater flow component. Usually groundwater inputs and outputs are the most difficult to measure or estimate. Therefore we assume the residual to be groundwater flow. However, we also have no way quantify the surface water exchange between Tenmile and Birch Lakes, and this residual we call GWFC can include other components as well.

INPUTS

Precipitation (P) (Table 1)
The primary input to the watersheds is precipitation. Precipitation is recorded at several locations in the vicinity including Walker, Hackensack, and Nimrod. Data were obtained from the USGS, Minnesota Climatology Working Group, NOAA, and DNR. Precipitation records from 2000-2003 were used (Table 1).

OUTPUTS

Evapotranspiration (ET) (Table 2)
Since the lake surface area is our frame of reference, we must be able to determine the removal of water from the surface by evaporation. Evaporation from free water surfaces can be estimated by a number of methods. We used the Thornthwaite method, which provides an estimate of potential evapotranspiration based on average monthly temperature and climatologic indices. This method is approximate but provides a reasonable estimate where sophisticated measurement equipment is not available. The equation is shown below.

<u>THORNTHWAITE EQUATION FOR POTENTIAL EVAPOTRANSPIRATION</u>
PE = Potential Evapotranspiration

$$PEmonth = 16(10T/I)^a \times CF$$
$$PEannual = \Sigma\ PEmonth$$

Parameter	Definition	Units
T	Average monthly temperature	°C
i	$i = (T/5)^{1.514}$ **Note:** For any given month, if T<0 then i = 0; that is, there is no PE for a month with average temperatures below 0.	unitless
I	Sum of twelve monthly i's	unitless
a	$a = 6.751x10^{-7}I^3 - 7.711x10^{-5}I^2 + 1.7921x10^{-2}I + 0.49239$	unitless
UPE	$UPE = 16(10T/I)^a$ or unadjusted potential evapotranspiration	mm
CF	Latitude correction factor	unitless
PE = UPE*CF	mm	

Data were obtained from USGS, Minnesota Climatology Working Group, NOAA, DNR and the United States Naval Observatory (Table 2).

Surface runoff leaving the basin (SRO) (Table 3)
Surface runoff is recorded at the Birch Lake Dam outlet. Data were obtained from the DNR (Table 3).

RESULTS

The results of the hydrologic budgets are tabulated as lengths of lake level change in **Table 4**.

Combined Hydrologic Budget: Birch Lake and Tenmile Lake

When considered the Birch and Tenmile watersheds together, the hydrologic budget for the lakes basically balances. The GWFC ranges from –0.01 feet to 0.9feet (see Table 4). This indicates that in order for our system to balance –0.01 feet to 0.9 feet of water must enter our system from some source. These values are negligible for the scale and resolution of this study and suggest that the range of coefficients specifies for watershed runoff and evapotranspiration are very reasonable.

Hydrologic Budget: Tenmile Lake

Since we do not know the magnitude of surface water outflow from Tenmile Lake through the small channel to Birch Lake, this hydrologic budget was calculated two ways. First we include the stream outflow from Birch Lake as an output from Tenmile Lake and we then consider Tenmile to have no surface water outflow.

When including SRO from Birch Lake, Tenmile Lake's hydrologic budget indicates a nearly balanced system. The amount of GWFC (residual) is small, ranging from –0.34 feet to 1.15 feet (see Table 4).

When SRO from Birch Lake is excluded in the hydrologic budget for Tenmile Lake the residual (GWFC) becomes negative. The values are again small, ranging from –0.34 feet to –1.77 feet (see Table 4). However, this negative budget indicates that for the hydrologic budget to balance there must be loss of water from the basin amounting to –0.34 feet to –1.77 feet of lake level.

Therefore Tenmile Lake must lose water as surface water flow or groundwater flow or some combination of both.

Hydrologic Budget: Birch Lake

The results of the hydrologic budget for Birch Lake are shown in Table 4 and indicate a substantial influx of water is needed to balance the system. The values for GWFC range from 2.93 feet to 5.45 feet. These values are significant and must be accounted for.

CONCLUSIONS

The hydrologic budget for the combined Tenmile/Birch watershed essentially balances for each of the three years of record. The hydrologic budget for the Tenmile Lake watershed alone is balanced within the uncertainty of this method and these data and methodologies, whether SRO from the Birch Lake Dam is included or not. The outflow volume of the Boy River at Hackensack is small relative to the size of Tenmile Lake.

In contrast, an influx of water must occur to balance the hydrologic budget of Birch Lake. The amount that must be added to the lake is essentially equal to the outflow at the dam on the Boy River. That influx must come from watersheds upstream as either surface water or groundwater flow. Calculations of the residual (GWFC) in the Birch Lake hydrologic budget are shown in Table 5. The fact that the GWFC in the budget is the same amount as the outflow from the dam suggests that water is simply passing through the Birch Lake watershed from Tenmile Lake upstream. Whether the water is coming through the channel and swamps from Tenmile Lake as surface water or as groundwater is difficult to determine without further analysis and will be part of the ongoing investigation.