Mass Balance Model Version 1.01

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by
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BACKGROUND AND INTRODUCTION –Based on a mass balance, the Simplified Refuge Stage Model (SRSM) projects canal and marsh stage from observed inflow, outflow, precipitation, and evapotranspiration. The objective of this model is to provide a useful tool in support of Refuge water management decisions. At this time the model is implemented as an Excel workbook titled “WaterBudget.xls.” This report provides information necessary to use the model to implement new alternatives. Information on model theory, structure, and model calibration and verification are fully documented elsewhere (Arceneaux et al. 2007). A simple constituent mass and concentration model has also been developed and is documented elsewhere.

This report is in two sections. Section 1 very briefly reviews the model conceptualization and provides the background used in this model. Section 2 describes the details of the implementation of the model as an Excel workbook.

SECTION 1: Model theory and structure

The simplified Refuge water budget model divides the Refuge into two connected compartments or boxes (Figure 1). The model integrates net inflow minus outflow for each compartment to provide a daily estimate of stage and volume within each compartment. The user provides a daily time-series of pumped inflow, precipitation, evapotranspiration, and optionally provides total structure outflow. The model calculates flow between the canal and marsh, and groundwater recharge including levee seepage loss. Optionally, the model can calculate total structure outflow based on a simple model of historic gate operations under the current Refuge regulation schedule (Neidrauer 2004; USACE 1994; USFWS 2000).

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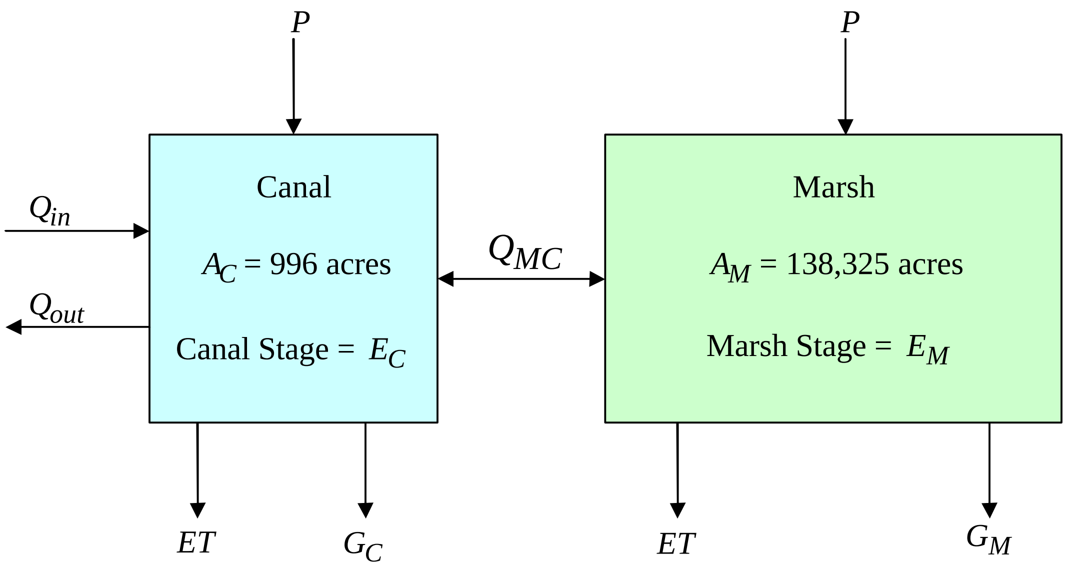

Figure 1. Refuge water budget model structure is composed of 2 compartments (boxes) representing the canal and marsh. Inflows and outflows are drawn as arrows pointing in the positive flow direction. Inflows include precipitation (P), pumped inflow (Q_{in}), and flow from canal to marsh (Q_{MC}). Outflows include evapotranspiration (ET), groundwater recharge (G_C and G_M), and structure flows (Q_{Out}). Figure copied from (Arceneaux et al. 2007).

Water budget equations:

Discharge between canal and marsh (into marsh is positive) is based on the "power law model" (Kadlec and Knight 1996, page 203)

$$C = 10^7\, BW / R = 2p\, 10^7\, B$$

$$H = Maximum(0, E_M - E_0)$$

$$Q_{MI} = CH^3(E_C - E_M)$$

Canal stage (also termed inflow tailwater stage) and marsh stage

$$\frac{dE_C}{dt} = P - ET - G + (Q_{in} - Q_{MC} - Q_{Out}) / A_C$$

$$\frac{dE_M}{dt} = P - ET - G + Q_{MC} / A_M$$

where

$$ET = f_{ET}\, ET_{obs}$$

$$f_{ET} = Maximum(f_{ET\min}, Minimum(1, \frac{H}{H_{ET}}))$$

$$G_i = r_{seep}(E_i - E_B) \qquad i = c \text{ or } m \text{ for canal or marsh, respectively}$$

Nomenclature:

Constants and initial estimates

B	30 $m^{-1}d^{-1}$, Transport coefficient (1 to 5)
W	8.15 10^4 m, Average marsh perimeter
R	1.30 10^4 m, Average radius of marsh (~Circular Geometry)
C	1.88 10^9 $m^{-1}d^{-1}$, B 10^7 W/R = 2p B 10^7
E_0	4.62 m, 15 ft, marsh ground elevation
A_C	4.03 10^6 m^2 (100 km long, 55 m wide), Area of the canals
Am	5.60 10^8 m^2, Marsh Area - assume 90% of Refuge
r_{seep}	0.000131527 d^{-1}, Seepage rate constant for marsh
l_{seep}	0.042 d^{-1}, Seepage rate constant for levee
E_B	3.5 m, Boundary water surface elevation
H_{ET}	0.25 m, depth above which ET is not reduced
F_{ETmin}	20%, minimum reduction of ET because of shallow depth
MaxdETdt	0.1 m, maximum canal daily stage change

Input time series

P	m/d, Precipitation
ET_{obs}	m/d, Marsh Evapotranspiration Rate (STA1W Data)
Q_{in}	m^3/d, External Inflows to Rim Canal
Q_{Out}	m^3/d, Outflows from Rim Canal

Calculated time series

H	m, Marsh water depth
Q_{MC}	m^3/d, flow from canal to marsh
E_C	m, Canal water surface elevation
E_M	m, Marsh water surface elevation
G_i	m/d, Rate of loss of groundwater recharge in canal or marsh
F_{ET}	dimensionless, reduction of observed ET at low depths

Computational methods

The differential equations for canal and marsh stage are calculated using the Euler numerical integration method with a one-day time step. This provides a fast solution and is easily implemented using the available daily average time-series data. This technique is reminiscent of the classic methods of cubatures (Rantz 1982), and level-pool routing (Chow et al. 1988; Zoppou 1999). However, one problem with these techniques is that when net canal flow is large, stage change over one day is so large that the assumption of "small" change in the integration algorithm is not satisfied. This can result in failure of convergence or instability. Here, a heuristic approach is used to stabilize the solution. This heuristic approach limits the magnitude of the canal stage, and maintains conservation of water volume by shifting flow directly to the marsh. Such an approach is reasonable because under these conditions flow between the marsh and canal is likely being underestimated by the Eulerian method with a daily time-step. Denoting the revised stage derivative with an asterisk, this heuristic scheme is

$$\frac{dE_C^*}{dt} = \frac{dE_C}{dt} \qquad when \left|\frac{dE_C}{dt}\right| \le E'_{C\max}$$

$$\frac{dE_C^*}{dt} = sign\left(\frac{dE_C}{dt}\right)E'_{C\max} \qquad when \left|\frac{dE_C}{dt}\right| > E'_{C\max}$$

The additional flow into the marsh, $Q_{MC}{}^*$, is

$$Q_{MC}^* = \left(\frac{dE_C}{dt} - \frac{dE_C^*}{dt}\right)A_C$$

and

$$\frac{dE_M^*}{dt} = \frac{dE_M}{dt} + \frac{Q_M^*}{A_M}$$

On the "Model" worksheet of the model, the column labeled "Q_{MC2}" is the canal to marsh flow that represents total flow to the marsh from the canal, and is the flow value that should be used for constituent transport modeling.

Literature cited:

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SECTION 2. Model implementation

The SRSM is implemented as an Excel workbook, water_budget.xls. This workbook calculates a water budget for the Refuge canals and marsh using data and mass balance equations. The distributed model version does not contain the observed calibration or verification data or statistics, and is intended for scenario analysis, rather than calibration. Worksheets in the model workbook include:

<u>ReadMe</u> - This informational sheet provides basic information concerning the model and model version.

<u>Constants</u> - Values of model constants are set on this sheet. For scenario analysis, few if any of these constants should be adjusted. Constant names and descriptions are provided on the worksheet.

<u>RegSched</u> - The Refuge regulation schedule is defined here as stage levels by Julian date. When the constant "Calc QRO" is True, the outflow from the Refuge is calculated (rather than equaling the historic time series). Analysis of alternative regulation schedules would likely require modification of this sheet. Columns are

Julian – the day-of-year value from 1 to 365 or 366
A1, A2, & B – the floor elevation of each zone in feet then meters
A1-B – the difference (m) between the A1 & B floor values

<u>TimeSeries</u> - Time series data used by the model are defined here. The input daily-value time series are in columns, with data values in rows. Columns are

Date – date for the row's values
Month/Year – the month and year of the data
Day – day of the month

P – precipitation (m/d)
ET – evapotranspiration (m/d)
Q_{in} – flow into the Refuge (m^3/d)
Historic Q_{Out} – historic data for flow out of Refuge (m^3/d)
Calc Q_{Out} (m^3/d) – Flow out of the Refuge based on the regulation schedule. Note that this flow does not include water supply or other non-regulatory outflows.
Q_{Out} (m^3/d) – model selected outflow based on the constant calcQ_{Out}
%iQ_{in}-%0Q_{RO} (m^3/d) – Net flow (in-out) of the Refuge adjusted by two percentages, InPct and OutPct. This is the flow that is used in the water budget calculations.

Year – the calendar year
FedWYear – the federal water year, October 1 to September 30
FlWYear – the Florida water year, May 1 to April 30

Model - Calculations related to model stages are performed here. Columns are

Date – daily date
Month-Yr – date value with day=1, month & year calculated from date
Day – day-of-month
Julian – day-of-year, used to look up regulation schedule values
A1 – floor of regulation schedule zone A1 (m)
B – floor of regulation schedule zone B (m)
H – marsh water depth (m)
Q_{MC} – flow from canal to marsh (m^3/day)
CanalQ – net canal flow, Q_{in} - Q_{Out} - Q_{MC} (m^3/day)
G_C – canal leakage/seepage (m/day)
G_M – marsh seepage/groundwater recharge (m/day)
EvapTranPct – shallow depth ET reduction factor
dE_Cdt – calculated rate of canal stage change (m/day)
dE_Mdt – calculated rate of marsh stage change (m/day)
dE_CdtStar – limited canal stage change rate (m/day)
dE_MdtStar – marsh stage change rate due to limited canal stage change rate (m/day)
E_C-Calculated – canal stage (m)
E_m-Calculated – marsh stage (m)
Position – position of canal stage within the regulation schedule zone B (percent)
E_C-Calculated2 – canal stage (ft)
E_m-Calculated2 – model stage (ft)
Q_{MC2} – Flow from marsh to canal including flow routed directly to marsh to improve model stability. This flow should be used in constituent modeling (m^3/day)
Year – year calculated from date column
FedWYear – Federal water year starting October 1
FlWYear – Florida water year starting May 1

DOY-YR-Marsh - Pivot Table of daily marsh stage with each calendar year in a column. This is included as an example for the user. The user should be familiar with use of pivot tables. Note that user may need to "Refresh" the table following changes in the model.

Charts provided as examples:

GERefPlot - Plot of number of days marsh stage exceeds a reference elevation

PctPlot - Plot of percentiles of marsh stage

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