Flow Rating for Interior Culverts in Stormwater Treatment Areas

Background

South Florida Water Management District (District) operates and maintains flow monitoring and rating development for six large stormwater treatment areas (STAs). These STAs are designed to remove mainly phosphorus and nitrogen from the agricultural water released from the Everglades Agricultural Area (EAA). Accurate flow rating of hydraulic structures in STAs is key to water quality modeling and pollutants reduction assessment. This presentation is partial work of the District's project "Flow data improvement at STAs and other District structures".

Currently, flow ratings at the District's hydraulic structures mainly rely on physically-based equations. However, parameter calibration needs good representative streamgauging measurements by high-tech acoustic flow meters: ADCP, ADFM or other instruments.

Due to budget and staff limitations, streamgauging is not conducted for all of existing hydraulic structures in the STAs. Flow measurements for exterior culverts generally have a higher priority than interior culverts because they are crucial structures for pollution control. To date, there are 9 field measurements for interior culverts, in comparison to over 900 for exterior ones. However, flow estimation of interior culverts is also important for simulation and assessment of treatment cell performance.

Overview of STA-3/4

Overview of STA-6

Objectives

- to supplement discharges for rating analysis of interior culverts at STAs through water mass balance (WMB)
- to provide and improve interior culvert ratings with the added discharges using physically-based flow equations and statistical methods

Methodology

An approach is proposed to perform flow rating at interior culverts using WMB and statistical methods . A case study of culvert group G375 A-F is presented to illustrate the practical application. Firstly, daily or 15-minitue discharge time series are calculated after balancing the water budget for each treatment cell. Then, these discharge series are used to generate interior culvert rating equations by multivariable regression and artificial neural network (ANN), respectively. In doing so, we are able to:

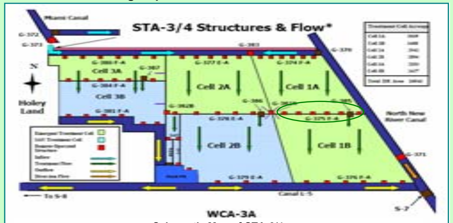
- produce reasonable discharges of interior culverts, which can guarantee water balance within treatment cells and STAs
- make flow rating analysis possible for interior culverts by taking advantage of well-calibrated ratings at exterior structures and high-quality telemetry data
- provide more options (e.g., regression method and ANN) for interior culvert rating
- apply the approach to interior culverts with limited or without measurements at other STAs

Benefits

- A cost-effective way to supplement discharge data for rating analysis of interior culverts
- A good tool for WMB calculation and rating analysis of hydraulic structures (e.g., interior culvert and exterior structure)

CaseStudy

Interior box culvert group G-375 A-F in STA-3/4



Schematic Map of STA-3/4

Inflow Control Pump G370

Inflow Control Culvert G374

Interior Culvert G375A

Interior Culvert G375C

Results

Water Mass Balance

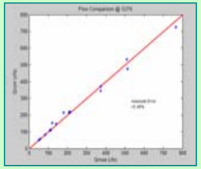
$$\varepsilon = Q_{inflow} - Q_{outflow} + P - ET \pm I + \Delta S$$

$$Q = f(\mathrm{H, h, G_0}); \quad I = c\frac{\Delta H}{\Delta L}; \quad \Delta S = A\frac{\Delta H}{\Delta t}$$

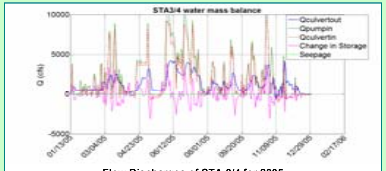
where: Q_{inflow} is the inflow; $Q_{outflow}$ is the outflow; P is the direct precipitation over water surface; ET is the evapotranspiration; I is the seepage; ΔS is the change in storage volume; ε is the total residual; H is the headwater stage; h is the tailwater stage; G_0 is the gate opening; c is the seepage coefficient, A is the area of the water surface.

All terms on the right-hand side in the WMB equation can be obtained or calculated based on telemetry data.

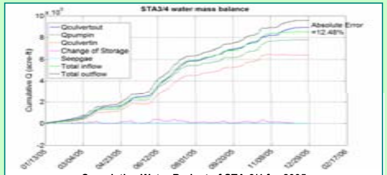
Interior Culvert Rating Program



Flow Rating at G374



Flow Discharges of STA-3/4 for 2005



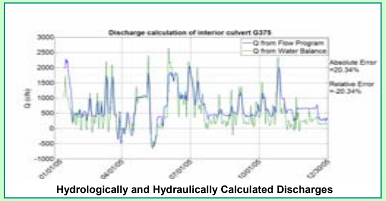
Cumulative Water Budget of STA-3/4 for 2005

Cumulative Water Budget of Cell 1B at STA-3/4 for 2005

Discharge Calculation

An assumption is herein that flow rating at exterior control structures and hydrometerologic measurements are accurate enough with negligible errors. Therefore, discharge through interior culverts can be derived from water budget computation, which is hydrologically calculated.

Rating equations in the District's Flow Program can be applied to populate discharges through interior culverts based on telemetry data and structure parameters. This is a typical physically-based hydraulic method.



Hydrologically and Hydraulically Calculated Discharges

Multi-variable Nonlinear Regression

Regression analysis allows for an approximate fit by minimizing the difference between the data points and regression curve. Nonlinear models were defined by referencing to well-verified flow equations of culvert in curve fitting. For example, full pipe flow (98% of occurrence frequency in the South Florida)

$$Q = CA_0\sqrt{\frac{2g(H-h)}{1+2C^2\frac{gn^2L}{(1.49)^2R_0^{4/3}}}}$$

$$R_0 = \frac{B*D}{2(B+D)} \qquad A_0 = B*D$$

where: B is the width of culvert; D is the height of culvert; H is the headwater depth; h is the tailwater depth; L is the length of culvert; g is the gravitational acceleration; C is the discharge coefficient; and n is Manning coefficient; R_0 is hydraulic radius.

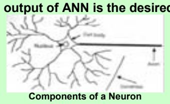
In multi-variable regression, the fitted constants are C and n, H and h are variables, Q is the function.

Regressed Discharges and Hydrologically Calculated Discharges

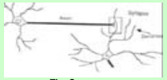
Artificial Neural Network (ANN)

ANN is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information (Stergiou and Siganos, 2007).

By deducing the essential features of neurons and their interconnection, a typical three-layer back propagation (BP) ANN is determined to simulate discharge series. Headwater, tailwater and gate opening are included as the input layer of ANN model. Five neurons are set on the hidden layer between input and output layers. The single output of ANN is the desired discharge.

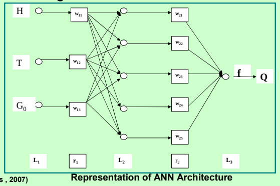


Components of a Neuron



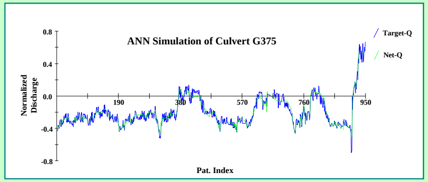
The Synapse

(from Christos Stergiou and Dimitrios Siganos , 2007)



Representation of ANN Architecture

Similarity between Human and Artificial Neuron



Hydrologically Calculated and ANN Computed Discharges

Future Work

- Genetic Algorithms (GA) will be integrated with ANN (GA-ANN) for parameter optimization (or architecture improvement)
- Analysis and improvement of interior culvert rating combining with more other flow equations (e.g., Chen's universal equation)
- Application to interior culverts at other STAs

Acknowledgement

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The authors wish to express appreciation to Larry Deaton[2] for suggestions and comments on technical approach.