Estimation of River Flow at Sequoyah Nuclear Plant
for NPDES Thermal Compliance
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A one-dimensional hydraulic model of Chickamauga Reservoir is used to estimate the River flow at Sequoyah Nuclear Plant for NPDES thermal comliance. The model implements a time-explicit predictor-corrector discretization originally applied to compressible flows (MacCormack, 1969). The MacCormack scheme is applied to the one-dimensional open channel continuity and dynamic equations,

$$B\frac{\partial H}{\partial t} + \frac{\partial Q}{\partial x} = q \text{ , and} \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) = -gA\left(\frac{\partial H}{\partial x} + S_f\right) + qV_x \text{ ,} \tag{2}$$

where

$H(x, t)$ = elevation of water surface relative to a datum,

$A(x, H)$ = wetted cross-sectional area,

$B(x, H)$ = width of channel at the water surface,

$Q(x, t)$ = volumetric flux (flowrate) through the cross section at x,

$q(t)$ = local volume inflow per unit time per unit length of channel,

V_x = downstream (positive x) component of the local inflow velocity vector,

S_f = slope of the energy grade line,

g = acceleration due to gravity,

x = distance along channel, and

t = time.

The slope of the energy grade line is computed from the Manning equation by

$$S_f = \frac{Q|Q|n^2}{\left(1.486AR^{2/3}\right)^2} \text{ ,} \tag{3}$$

where n is the roughness coefficient.

A significant feature of the MacCormack discretization scheme is the use of forward and backward differencing of the spatial derivatives in the predictor and corrector steps, respectively, to yield second-order spatial accuracy (Fletcher, 1991; Chaudry, 1987). The forward and backward differencing is switched between the predictor and corrector pseudo-steps from one real-time step to the next to promote numerical stability (Ferrick and Waldrop, 1977).

Fourteen computational reaches varying in length from 3.9 to 5.1 miles make up the discretized domain for Chickamauga Reservoir. The flow and water surface elevation time series from the computational nodes immediately upstream and downstream of the plant are interpolated to Tennessee River Mile 483.65, the approximate location of the submerged multiport diffusers. The model employs a constant time step of 12 minutes; however, boundary condition data are supplied in the form of hourly inflow and water surface elevation time series at the hydro plant at Watts Bar Dam (upstream) and hourly outflow time series at the hydro plant at Chickamauga Dam (downstream). The flows at the boundaries are assumed to remain constant between hourly readings.

When the model is used to provide flows for simulation of mixed temperatures at Sequoyah Nuclear Plant, no local inflows to Chickamauga Reservoir are specified. The absence of local inflow to the model leads to a discrepancy in the computed water surface elevations along the length of the reservoir, which is most significant at Chickamauga Dam. The discrepancy is corrected at midnight of each day by adding a value, equal to the discrepancy at Chickamauga Dam at midnight, to the water surface elevation for each node of the computational domain.

REFERENCES

Chaudry, M. H., *Applied Hydraulic Transients,* 2nd Edition, Van Nostrand Reinhold Company: New York, 1987.

Ferrick, M. G., and W. R. Waldrop, "Two Techniques for Flow Routing with Application to Wheeler Reservoir," Report No. 3-519, TVA Division of Water Management, Water Systems Development Branch, Norris, Tennessee, 1977.

Fletcher, C. A. J., *Computational Techniques for Fluid Dynamics. Volume 2 Specific Techniques for Different Flow Categories,* 2nd Edition, Springer-Verlag, New York, 1991.

MacCormack, R. W., *Effect of Viscosity in High Impact Cratering*, AIAA Paper 69-354, 1969.