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TRADITIONAL AND NUMERICAL APPROACHES FOR ESTIMATING RESERVOIR ROUTING PARAMETERS

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Abstract

Reservoir routing is a strategy that calculates the outflow hydrograph from a reservoir based on the inflow hydrograph, taking into consideration the elevation, storage, and discharge characteristics of the reservoir and spillways. The conservation of mass equation is solved assuming that outflow discharge and storage volume are precisely proportionate. According to this paper, the conventional approaches for reservoir routing, parameter analysis, and evaluation require solving a transcendental equation at each time step. A differential equation's numerical solution is reservoir routing. Any numerical technique can be applied, and they are all easier to understand than the old way. The study also shows that there are benefits to using reservoir surface elevation to define the governing equation rather than the conventional approach of using storage capacity. A situation is shown in which reservoir outflow can be controlled by gates or sluiceways. Reservoir routing using numerical techniques are evaluated using Math lab program version (7.12) and compared with conventional approach for reservoir routing. The inflow from one of Iraq's dams was analyzed, and the outflow was estimated, with the results demonstrating that the numerical methods are identical, simpler, and more reliable than conventional method.

Keywords:

Reservoir routing; traditional methods; numerical methods; MATLAB program; Differential equation.

1 Introduction

Reservoir operations are crucial for managing uneven water distribution in flood control, supply, and hydropower. As a result, the effective growth of water resources in a river basin depends on the reservoirs' optimum functioning. Reservoir inflows and water levels are the primary determinants of reservoir operations decision-making, particularly during catastrophic flood or drought events. As a result, accurate predictions of reservoir inflow and water level seem to be crucial for the administration and operation of water systems in real time.

Flow routing is a method for tracking a wave's properties in a river at various spatial locations as it is overlaid on the flow itself. These qualities might include distribution, duration, and magnitude. The features of flood wave from various storm occurrences are examined for downstream areas in a typical usage of flow routing. As the wave caused by a flow change travels downstream, Water Rights Analysis Package uses routing to examine the impacts of water removal or addition by upstream users at downstream sites [1].

Reservoirs and their operations are essential strategies to address the unequal temporal and geographical distributions of water resources for flood control, water supply, environmental flow, and hydropower production. Therefore, it is crucial for reservoirs to operate at their best to effectively develop a river basin. The main factors affecting decision-making for reservoir operations, especially throughout catastrophic flood, or drought events, are reservoir inflows and water levels. As a result, accurate reservoir inflow and water level predictions are crucial for the timely operation and management of water systems.

For forecasting reservoir water level and input, two methods have been extensively used: (1) data-driven models, and (2) physically based models. Models based on data have been used to predict reservoir water levels [2]. The traditional statistical methods, such as auto-regressive (AR) and auto-regressive moving average (ARMA) models [3], have been used to predict water level [4] as instances of data-driven models.

The rate at which reservoir storage volume changes is governed by the storage equation:

dt = I(t) – O(t, s) (1)

where:
S - amount of water contained the storage with regard to unspecified data,
t – time,
I - amount of influx rate, this is either a time function or a known quantity at specific a period of time,
O - outflow flow rate.

In order to answer the equation, the outflow must be related to the storage volume, the formula of (O), (t, S). Typically, each is dependent on the level of the surface of the water. The outflow (O) has been assumed to be solely dependent on (S) many debates of the storage equation have taken place. The discharge characteristics of a reservoir operated by a sluiceway or a gate, on the other hand, may be controlled manually or automatically after that, the discharge is a well-known function of both time (t) and space(s). (S) as a function of (t) is defined by relation (1), which is a differential formula of the first order. It is possible to solve it numerically using a variety of methods ranging in complexity and precision, the most basic of which are extremely simple. The idea that perhaps the problem is simply a matter of resolving a differential equation, as well as the simplicity with which this can be accomplished, doesn't seem to have been widely appreciated or manipulated in water resources.

The goal of this research study is to show that numerical approaches for solving equations are ideal for reservoir routing. Using the conventional approach has provided pupils with an explanation and execution much complex and it takes longer than it should. needs to be. It is recommended that the conventional approach not be used any longer.

2 The conventional approach

The conventional equation-solving approach (1), which is defined in about widely references on hydrology, is very difficult. The interpretation of the differential formula:

I(T)+I(T + A) + 2S(T)/A-O[S(T)] = 2S(T + A)/A + O/S(T + A)] (2)

where:
A - time limited stage with no externally regulated discharges assumed,
O - could be articulated solely regarding (S).

All of the amounts of equation (2), the left side, can be measured at a specific time, (T) [5], [6]. The formula then becomes a nonlinear equation for [S (t + A)], the amount of storage after the following time point, which exists existentially on the other side. Thus, many approaches to solve similar formulas, while never especially complicated in theory, in practical appear to confuse the simplicity of reservoir routine with computational specificity. At early level, textbooks present techniques for solving these formulas using statistical method, while at the expert stage, a range of several issues arise [7], [8], when solving the complicated equations, specific emphasis must be applied to pathological situations. Although some of the approaches are recursive. A number of function evaluations are necessary for every step on the right side of equation (2).

2.1. The Operating Equation in a New Form

A number of differential equation formulations (1), Furthermore, to the (S) preparation just presented [9], [10], are easily derived. The storage change, (dS), is given by: When the pool elevation of surface, (h), fluctuates by a value dh in the limit as dh-» 0, it is said to be fluctuating by a value dh.

dS = A_o (H) dh (3)

where:

A_o(H)- Water surface's territory at altitude h. Setting the discharge, (O), in the case of controlled flow, as a function of (t) and (h) [(frequently a straightforward mathematical process)] similar $(h - y_{outlet})^{0.5}$ and/or $(h - y_{crest})^{1.5}$], (y_{oulet}) is the height at which pipeis outlets exposed to the atmosphere and(y_{crest}) is the summit hight of the outfall [11, 12], substituting into equation (1).

$\overline{dt}$ = [I(t) – O(t, s)]/A(h) (4)

For the elevation, it's a differential equation of the surface [13], [14] introduced this equation, but only as a complement to equation (1). Indeed, it also has some benefits over the whole process, and this equation (4) configuration for (h) may be favored in most cases. It doesn't use storage volume (S), so routing isn't necessary. Volume storage (S) as a function of (h) must be obtained using the integral. if the standard equation (1) form is used [15]:

$S(h) = {}^{h}\int A(y)\, dy$ (5)

for different surface elevations using a limited numerical approximation. Then you must transmit (S) as a property of (O), which is normally done by constructing a table of predicted value. This must be done every time a gateway or valve is changed in situations where the discharge is controlled. Writing a valve characteristic or a vertical gate opening as a straightforward time function allows one to determine the reliance on (t). In almost the similar manner the effect for (O) to (S) typically expressed by a list of sets of numbers, the (h) definition, generally, necessitates a similar list for each water surface area (A) and altitude (h), to yield Ai(h), which is fined from plan metric knowledge from geographic maps. Though, for the causes listed in the following argument, this strategy is less likely to be wrong.

The overall capacity of the reservoir limits the whole operational height range of the spillway, and the crest level of almost all spillways remains higher than the reservoir bottom. Although numerous contour intervals may be used to estimate reservoir capacity, the spillway's operational height range may only have a few.

The outflow (O) must be estimated as a function of (S) inside this domain if the standard (S) approximation was employed, and there may only be a few values of (S) accessible. Because (O) is typically discrete and substantially increased in recent functions, idea of (O) as a function of (S) may have to be acquired from a small number of data points and thus be incorrect. It's possible that the precision of the computations will suffer as a result. As the following model problem shows, this is not an issue with the h implementation [16].

Assume a basin with a surface area of A = 103 h0.5 during normal operation. After integration, the storage volume is S = 667 h1.5. In most cases, contour area knowledge is provided in the form of numerical values rather than the specific function presented here in a typical practical example. It is believed that they will be located at 1 m intervals between the lowest and highest water levels in this situation. A 3.5-meter-tall spillway was built. The rating curve looks like this:

$O = I \times (H_o - 3.50)^{1.5}$ for $H_o > 3.5m$ and O = 0 for H< 3.5m (6)

In Figure 1, showed the points that constitute rating curve for (O) as a function of (S), as well as the linear interpolation between them, which is frequently employed in practice. The lack of (S) facts in the spillway's working sort, along with the rapidly changing character of (O) as a function of (S), would inevitably result in inaccurate interpolated values of (O). even in the event that higher order interpolation was applied. At a value of (S), the spillway starts to discharge below the crest. according to a numerical solution based on linear interpolation. Errors, most likely with negative (O) values, would occur from the process's distinct presence at the crest. The specification of the sinusoidal and rapid variable (O) as a function of the possibly sparsely described (S) appears to be a cause of error, even though linear interpolation may be used to provide an additional value of (S) at the spillway crest level. The spillway or other outlet functions may be appropriately evaluated as power law functions (H) for any value of, in contrast to the (H) formula. The pairs of (A) and (H) values are the sole additional interpolation in the reservoir. which are generally very well connected. Figure 2 depicts the values for the model issue, illustrating the accuracy of linear interpolation.

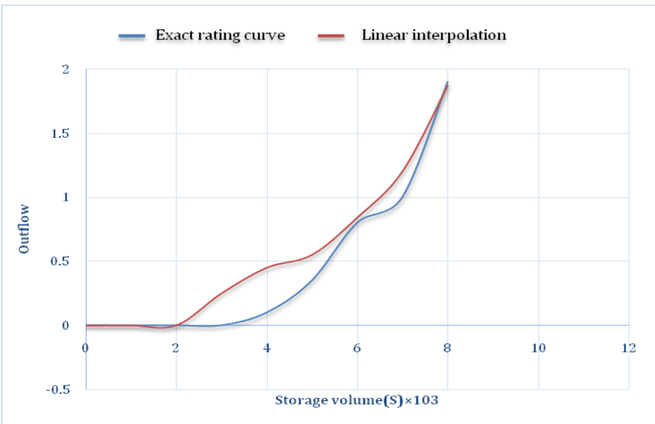

Fig. 1: The relation between storage and outflow.

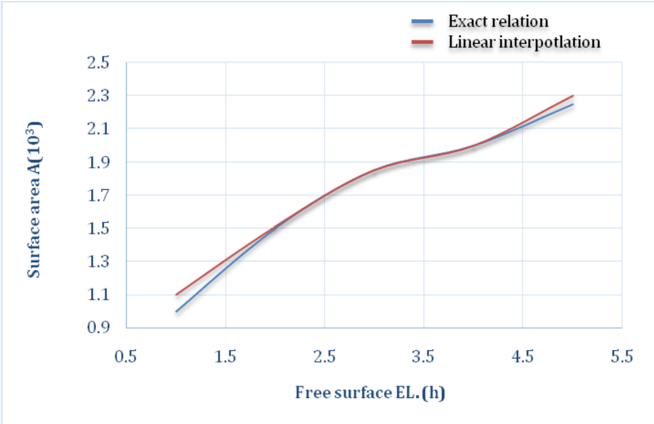

Fig. 2: The relation between stream area and free surface.

Although high precision isn't needed in most hydrological applications, simpler methods should be preferred over the methods outlined below, as well as computations and needless inaccuracies. Because of the difficulties and errors involved with the (S) formulation, the (H) type looks to be preferred, but both are accurate.

2.2 Differential Equation Solution Methodology

Whatever methodology is employed, S or h, the issue now has a numerical solution of a governing equations, which necessitates a variety of approaches and computer programs. The following expression can be used to generalize the forms of the storage equation [17], [18]:

$$\frac{d_x}{d_t} = f(t, x) \tag{7}$$

where:

X - The dependent variable is x, which can be either S or h.

The conceptual model in formula (7) is applicable to both regulated and unregulated outflows Any of the following approaches can be used to regulate the outflow function form over time, whether it is modifying the shape of the outflow function over time. To start solving, you must identify the boundary values which are either S's values, or h at t = 0, denoted by S0 and h0. The meaning at time t is denoted by the subscript n, and n + 1 is denoted by the subscript tn = nΔ = and n+1, at time tn +Δ = tn+1= (n+1)Δ.

Interpolating in a table of attribute value is the most challenging element of solving a differential equation, regardless of system. Obtaining A (h) for any arbitrary h or Q (t, S) for any arbitrary S is required. If time increments other than the inflow hydrograph's interval was used, I (t) would have to be computed from data pairs for arbitrary values of t. Linear interpolation gives precision that is compatible with the numerical approach for first and second order operations in a table of data pairs. Higher-order techniques need a more accurate approximation to maintain consistency. Linear interpolation may be more stable in reservoirs with gradient discontinuities, such as those when a higher spillway or pipe replaces a lower spillway or pipe. It is a well-liked option for flood routing due to its simplicity of use.

2.3 Theoretical Analysis

Several reservoir routing issues with numerical solutions that can be used to compare the accuracy and efficiency of various numerical methods. The inflow hydrograph resembles a traditional real hydrograph, so it could be used as a test for designing computer programs and comparing methods. There are specifics.

- Inflow Hydrograph

$$I(t) = I_0 + q\, t^W e^{-Kt} \tag{8}$$

Where

q, w and k are the flood hydrograph's constants,

I_0, is a ground flow that has been applied to this work in order to make it more general;

• Area and storage functions

$S(h) = b\ h^Z \qquad A(h) = b\ z\ h^{z-1}$ (9)

where b, z are constants,

• Discharge function

$Q(h) = n\ h^Z$ (10)

where n, z are constants

As a result, Q = C.S, with C equal to n/b as a constant. Although this is uncommon, it is typical in detention reservoirs and does not make the problem any easier to compute. It means that the outflow level is getting close to the reservoir's lowest point. By rewriting the differential equation with Q as the dependent variable and solving it using an integrating factor form, it is possible to show that there is an empirical solution in this case.

$$Q= I_0 + e^{-ct}[Q_0 - I_0 + \frac{w\ C_q}{(K\text{-}c)^{w}+1}] - e^{Kt}[1+(k\text{-}c)t] \qquad (11)$$

Q0 = Q (t = 0) where w is a positive number and Q0 is the very first release. If w is not an integer, It is possible to find a solution using incomplete gamma functions. It should be noted that the solution of eq. (11), given by the previous hydrological studies.

To evaluate their accuracy, several numerical methods were used to solve the problem described by equations (8) to (10) and compared to the exact solutions, equation (11). The following are the results of solving the differential equation using the S formulation (2). Table 1 lists the numerical values used in the calculations.

Table 1: Values of parameters using in computation.

value	Quantity	Units
21	N, number of time intervals	-
280 s	Step of time Δ	[sec]
1.0 cumcs	Q_0	[m³/sec]
1.0 cumcs	I_0	[m³/sec]
2×10^{-13} m³/s	Q	[m³/sec]
5	W	-
1.5	Z	-
0.003 1/s	K	[1/s]
5000 (SI units)	B	[m]
4 (SI units)	N	[m]
0.0008 1/s	C	[1/s]

If the reservoir is 2 meters deep, the storage needs are comparable to those of a small detention reservoir with a single, 2.5-meter-long sharp-crested weir and plan dimensions of around 100 m × 100 m. Through trial and error, the inflow hydrograph's numerical constants were chosen to be typical of those observed during a single, brief downpour. Rather than using equations (9) and (10), the reservoir and discharge characteristics were determined using interpolation in a table of ten pairs of values. Similarly, hydrograph input was defined using 20 numeric data points of I(t) from equation (8), with interpolation used to produce intermediate values as needed. Of course, in fact, between calculated data points, the numbers will be interpolated. Equation (8)'s inflow hydrograph, equation (11)'s outflow hydrograph, and other mathematical solutions for the outflow hydrograph are shown in Figure 3. Nearly every method covered here yields results that are accurate enough for real-world applications. The different approaches will be recognized and contrasted.

Euler's Approach

It is the easiest and reliable approach, as it only provides first-order accuracy. It is a process that is defined explicitly by:

$X_{n+1} = X_n + \Delta F(t_n, Xn) + O(\Delta^2)$ (12)

The differential equation's right side only needs to be evaluated once for each time phase. The second and higher powers of the time phase are examples of neglected concepts A, as shown by the Landau order symbol $O(\Delta^2)$, eq. (1) to eq. (12) becomes the following basic interpretation [19, 20]:

$S(t + \Delta) = S(t) + \Delta \{I(t) - Q_o[t, S(t)]\} + 0_o(\Delta^2)$ (13)

It is considerably more difficult to solve the transcendental equation (2) numerically than it is to evaluate the other side of equation (13) to yield S (t + A). However, the test case findings in Figure 3 reveal that Euler's system's accuracy isn't very good. The results are wrong by more than 10% at their most extreme. Smaller computation steps than those used to depict the inflow hydrograph can be used to achieve higher precision (when the hydrograph's intermediate values might be obtained using linear interpolation).

Runga-kutta 2nd order approach

It's a procedure that is also explicit that only requires one additional evaluation of a function over time stage.

The scheme is:

$X_{n+}1 = x_n + 1/2\ (k_1 + k_2) + 0(A^3)$ (14a)

where:

$k_1 = \Delta F(t_n, x_n)$ (14b)

$k1 = \Delta F(tn+\Delta, x_n+k_1)$ (14c)

The variance of the findings in Figure 4 indicates that this is a second order process, with the error changing like 1/N2, as seen in Figure 3. It is useful to assess the function F at t and x intermediate values using straightforward linear interpolation without compromising the order of precision; Compared to Euler's technique, the method is obviously more accurate. The results of this strategy were achieved using linear interpolation in both Figures 3 and 4 [21, 24].

Higher order Runga-kutta approach

The solution is found using these methods at (t +) from the solution at time t and the evaluation of F (t, x), and the acquired results are illustrated in Figures 3 and 4, where they are identical to the precise expression (11) [25, 26].

3 Traditional method

This is a method for solving nonlinear transcendental equations (2). The usual technique is difficult to implement at an intermediate level (needing a nonlinear transcendental equation to be solved numerically or graphically at each time step) and at a more advanced level (requiring the resolution of a nonlinear transcendental equation at every time step) (treating abnormal examples requires fairly sophisticated programming). The practicality of the conventional approach based on equation (2) has been hotly debated when the discharge is regulated; nonetheless, in this case, it is shown to be a reasonable approximation to the governing differential equation. implicit scheme is substituted with Equation (1), the differential equations S formulation:

$x_{n+l} = x_n + \Delta/2[F_i(t_n,x_n) + F_i(t_n + \Delta,x_{n+l})]+0_i(\Delta^3)$ (14)

And when you group terms together, you get:

$I(t)+I(t + \Delta) + 2S(t)/\Delta\text{-}Q[t,S(t)] \approx 2S(t + \Delta)/\Delta + Q[t+\Delta, S(t + \Delta)]$ (15)

This demonstrates how easily equation (2) may be changed to permit controlled discharge. The regulated discharge characteristics at time t on the left and the discharge characteristics at time t + on the right in the unknown term are used to determine the value of Q from the store S. This has been achieved in practice, but it seems to have caused some controversy in technical literature. It is a consistent second-order approximation when viewed through the prism of differential equation theory. [27, 28].

4 Results and Discussion

Several numerical methods were used to solve the problem described by equations (7) to (10) and their output was compared to the analytical solution, equation (11). The results shown below are those obtained from solving the differential equation using the S formulation (1). Table 1 shows the in the computations, there are a number of numerical quantities that are employed. The inflow hydrograph's numerical constants were selected through trial and error. to be representative of those seen during a single short-duration rainstorm. The reservoir and discharge characteristics were calculated using interpolation in a table of 10 pairs of values rather than equations (9) and (11). This might be the situation in a real-world scenario when storage or reservoir area values are only determined at a few sites. The input hydrograph was similarly defined using 20 numerical I(t) values taken from equation (8), with interpolation applied to produce intermediate values when necessary. The numbers will be interpolated between computed data points in practice, of course.

Equation (7)'s inflow hydrograph, equation (10's) outflow hydrograph, and several numerical solutions for the outflow hydrograph are displayed in Figure 3. Nearly all of the techniques discussed here produce outcomes with a respectable degree of functional accuracy. The different approaches will be defined and compared. Using high order precision methods for reservoir routing appears to be pointless for realistic calculations. It's important to note that all of the approaches covered here yielded good results on Figure 3, with the exception of Euler's method. Even Euler's approach gave acceptable precision if a smaller time phase was used. The precision of the usual procedure for Yevjevich's test issue is depicted in Figure 4. Compared to the second order Runge-Kutta method, it was far more accurate. Its error was frequently half that of the Runge-Kutta approach across the entire spectrum of calculations. They are both second-class citizens.

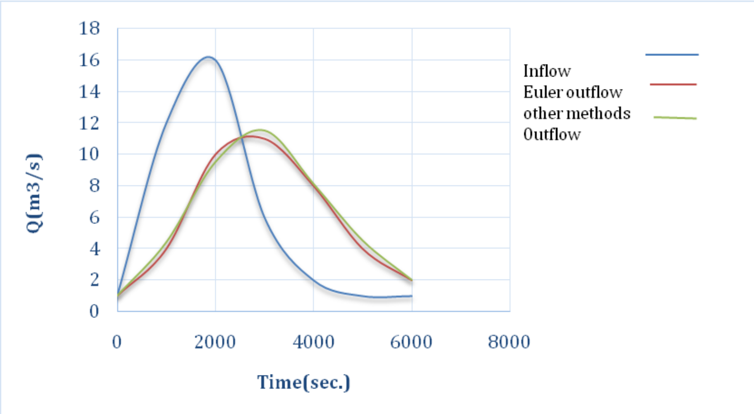

Fig. 3: Outflow hydrograph results generated using various calculation methods.

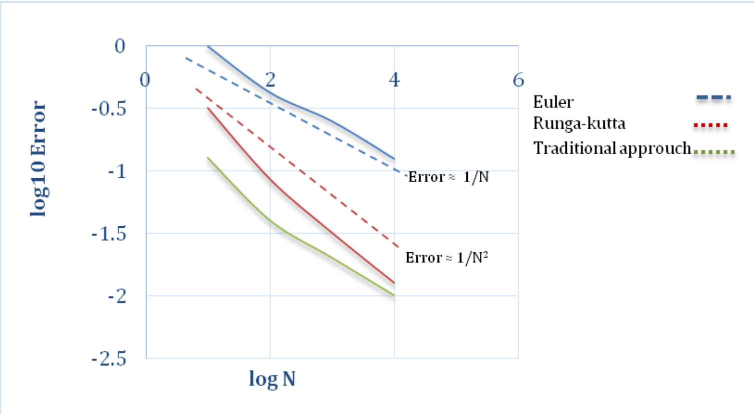

Fig. 4: The accuracy of various schemes is compared, as is the accuracy's dependence on time step.

5 Conclusions

The traditional technique to reservoir routing distorted the problem's inherent simplicity and demanded special attention to the solution process's intricacies. The techniques become simpler, more varied, and automated after it is determined that the process involves solving a differential equation. The findings are summarized as follows:

• A differential equation can be numerically solved using reservoir routing, which can be done in a number of common ways with differing levels of precision and complexity. The most basic tactics are rather straightforward.

• Compared to the traditional S formulation, there are advantages to using the governing equation written in terms of the reservoir surface height, h. It has been shown that the accuracy of the storage's numerical determination greatly influences the validity of the governing equation and the outcomes when Q and S are connected using point data.

• A wide range of analytical approaches were examined and compared. The traditional technique has been found to be preferred to simple explicit approaches. The 2nd order Runge-Kutta system has been shown to strike a fair compromise between simplicity of use and adequate accuracy. In most cases for practical reservoir routing, higher-order methods offer marginal accuracy improvements at increased computational cost.

• Explicit techniques become unstable in specific circumstances of a severe nature for which parameters have been provided. However, they may be made more accurate and stable by cutting down on computation time. To guarantee the accuracy of the results, at least two different time steps should be used.

• Controlled discharges: the presentation shows a situation where valves or spillway gates can be used to manually or automatically regulate the reservoir's outflow. In this case, any of the previously listed techniques—including the traditional method—can be applied.

• The traditional method, which entails numerically solving the transcendental equation (2), is suggested that the traditional method is less favorable compared to numerical techniques, particularly for real-time applications. In fact, it seems useless to express it in books or seminars.

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