HEC-RAS DAM BREAK MODELING OF GWINNETT COUNTY'S NRCS FACILITIES

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Abstract. The potential flood risk caused by dam failure is often more severe and can behave very different to that of natural flooding events. The tragedy of dam failure is all too familiar to Georgia with the failure of the Kelly Barnes dam near Toccoa Georgia which resulted in 39 deaths in the early hours of November 6th 1977. Floodplain maps issued by FEMA only show the 1% and 0.2% annual chance floods and assume all dams and culverts function perfectly and therefore the risk of dam break is often forgotten.

Recent developments in the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS) has included the addition of unsteady 1-dimensional hydraulic modeling and dam breach modeling.

Gwinnett County's recent flood study program and spatial database developments has provided steady state HEC-RAS models and supporting spatial data that have provided the foundation for the creation of unsteady HEC-RAS models for dam break analysis. The conversion from a steady state flood study model to a dynamic dam break model required some careful modifications to account for differences in flood routing methodologies between the two model states. These unsteady models have been used to simulate both sunny day failures and storm in progress failures at all 14 of Gwinnett County's NRCS facilities.

These models have enabled flood inundation maps to be created which include peak elevation, floodwave arrival time and floodwave time to the peak for both sunny day and storm in progress failures. This has identified homes and businesses at risk enabling emergency evacuation plans to be created.

HEC-RAS DAMBREAK MODELING

Since HEC-RAS version 3.0 was released, users have had the opportunity to perform unsteady hydraulic simulations based on the equations for continuity and momentum first published by Saint-Venant in 1848. Despite the relative ease of use and similar set up to steady state hydraulic simulations, few people venture into exploring the unsteady capabilities of HEC-RAS. The addition of dam breach modeling to HEC-RAS has also allowed users to expand the use of HEC-RAS even further to simulate dam failure. Dam break situations can behave very different to a natural flood. The most noticeable difference being the often very rapidly changing discharges associated with dam failure.

Gwinnett County has flood study models which model the NRCS dams, developed using both HEC-HMS and the steady state component of HEC-RAS. In these models, all floodplain storage and routing was determined using a combination of Muskingum-Cunge channel routing and reservoir storage coded into the HEC-HMS model. The cross sections in the HEC-RAS flood study models were all located at critical locations that provided lower conveyance potential creating bottle neck effects. This included modeling all structures and the narrow or obstructed portions of the floodplain that were critical to accurately modeling the hydraulic grade of the rivers and creeks. Using the unsteady component of HEC-RAS required a totally different approach to cross section location because no longer was flow to be routed in the HEC-HMS models but was instead going to be modeled by HEC-RAS. Backwater areas and wide areas of the floodplain again become critical to the model because all of these areas provide potential for floodplain storage and attenuations. Since HEC-RAS is a 1-dimentional model, adding cross sections to the model that were located at wide areas of the floodplain and extending into backwater areas would overestimate floodplain conveyance since HEC-RAS would assume the entire cross section to convey floodwaters, which would be unrealistic. Therefore ineffective flow areas were used to define conveyance areas. The addition of ineffective flow to the cross sections allowed the entire floodplain to be considered as storage but without considering areas of slow water as conveyance.

Traditionally dam break models were made with a minimum number of cross sections and interpolates were used liberally with interpolates often being in the order of 20-30 times more common that surveyed cross sections. With the availability of 2-ft quality LIDAR data for the entire county and the implementation of GIS technology, a more accurate approach could be taken. Instead of using interpolates, large numbers of cross sections were cut from the digital terrain model using HEC-GeoRAS ensuring that all areas of minimum conveyance were captured and all areas of maximum storage were also captured. This resulted in cross sections being spaced at intervals often less than 200 feet. Although this did make the task of stabilizing the models more challenging than the use of interpolates, the results could be seen to be more accurate with more frequent and less linear changes in the hydraulic grade lines.

The volume of water stored in the lake behind the dam was critical to the flood routing. Therefore the lake bathymetry which was normally ignored during steady state hydraulic modeling was critical to the models. Lake bathymetry was not unavailable for the lakes, therefore a linear assumption of the lake bed was made by considering the channel invert at the downstream face of the dam and the natural channel at the upstream edge of the lake. This linear assumption of lake bed elevation was then burnt into the digital terrain model to create a triangular channel shape below the normal pool. Unlike level pool reservoir routing as used in HEC-HMS where some type of elevation-storage-outflow relationship is determined, HEC-RAS determines the storage capacity of the lake by simply considering the average wetted area between cross sections and multiplying this by the distance between them. As the lake drains rapidly following dam failure, a hydraulic grade can often be observed within the lake, particularly on long narrow lakes. If level pool routing was to be used instead, this would assume the lake elevation to drop uniformly across the entire lake resulting in higher peak elevations. Although level pool routing may be suitable for analyzing wide lakes with a slow draw down time, the irregular shape of Gwinnett County's NRCS facilities made them more suited to the HEC-RAS method of storage consideration.

Both sunny day and storm in progress dam failures were modeled. The NRCS dams in Gwinnett County contain two main spillway components: the principle and the auxiliary spillways. The principle spillway generally consists of a vertical concrete box with small orifices and a typically 2ft concrete pipe in the bottom of the riser passing through the dam to the natural creek on the downstream face of the dam. The principle spillway typically can contain floods up to about the 50-year return period without engaging the auxiliary spillway. The auxiliary spillways are typically 50 to 200 feet wide broad crested or sharp crested weirs and normally only engage on flood events exceeding the 50-year return period. The Sunny Day failure assumes the principle spillway to be completely blocked with the water elevation being at the elevation of the auxiliary spillway. Only pilot flows in the magnitude of 50-150 cfs are assumed to be coming into the lake resulting in only several inches of water passing over the auxiliary spillway and allowing downstream flows to be contained within the natural channel of the creek. Dam failure is triggered by a set time resulting in a breach that forms over a 30 minute time period. Breaches are assumed to occur at the highest point of the dam and have a final elevation equal to the invert of the channel on the downstream face of the dam. The final breach width is assumed to be as wide as the dam is high and has side slopes equal to 1:1. Storm in progress failures assume a full 6-hour PMP storm to be centered over the watershed upstream of the dam. The dam is triggered to breach at the peak of the hydrograph at the dam and uses the same breach parameters as the sunny day failures. Unlike the sunny day failure, the storm in progress failure assumes the lake behind the dam to be at its normal pool elevation prior to the start of the rainfall event. When analyzing the downstream results of the dam failure, it is difficult to differentiate between the flooding effects of the rainfall event and the effects of the dam failure. Therefore an additional simulation is performed using the PMP event where the dam does not fail during the rainfall event. When comparing the No Breach simulation with the breach simulation, the effects of the failure can be clearly seen as the breach hydrograph separates from the no breach hydrograph as seen in figure 1.

The failure of a dam and the violent turbulence experienced downstream of the dams can be very destructive to downstream structures and vegetation such as trees. Therefore debris blockage at downstream structures is modeled assuming all structures to be 50% blocked as the hydrograph rises. When the flood wave causes more than 2 feet of overtopping at downstream structures, it is assumed that these structures are washed clean of debris and also breach. Similar breach parameters are used for downstream structures as are used for the dams. The main difference is that the formation time is reduced to just 6 minutes compared to 30 minutes for the dams. Downstream structures were often observed to produce large amounts of attenuation, particularly on sunny day breaches although almost all structures breach during storm in progress failures resulting in greatly reduced attenuations and greater inundations.

One limitation with using HEC-RAS to model dam failure is the inability to breach structures coded in using the HEC-RAS bridge and culvert routines. Only inline and lateral structures can be breached using HEC-RAS and therefore simple assumptions are required to enable structures to be breached. Bridges were coded in as inline structures by ignoring the road deck and coding in piers as part of the inline structure. Bridges with a rectangular opening and culverts were modeled as inline structures with the openings being modeled as orifices. HEC has indicated that they intend to add breach functionality to inline structures in future releases of HEC-RAS.

Unsteady hydraulic models are most commonly used to model flat sub-critical river reaches for natural flood events which exhibit gradually changing hydrographs. Steep reaches and rapidly changing flows are often associated with model instability and more complex modeling. Many reaches of rivers and creeks in Gwinnett County exhibit moderate to steep hydraulic grades with occasional short reaches of super critical flow and occasional hydraulic jumps. The sometimes steep reaches and rapidly

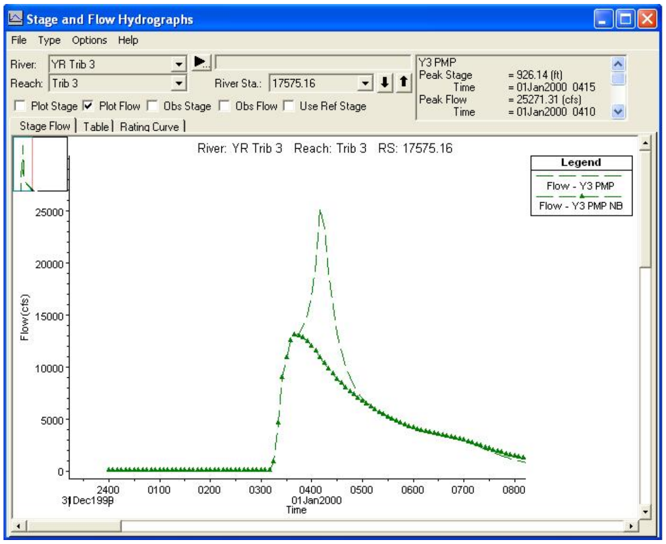

Figure 1. Model Stability

changing hydrographs caused by the dam failures created challenging conditions to model with HEC-RAS. Instabilities were commonly experienced when the flood wave caused by the dam failure first hits a cross section. On further analysis it could be seen that the use of contours for cutting cross sections in wide floodplain areas was not an efficient way to determine cross section geometry. This was because of the perfectly flat overbanks that often occurred where the change in elevation across the floodplain was less than a contour interval. This caused large changes in model parameters relative to minor changes in stage just as the flow came out of channel. To overcome these problems, flat areas of the overbanks were raised at one end no more than one half of a contour interval to give a positive slope towards the channel which improved model stability. Steep reaches proved by far to be the most challenging areas to model. Increased numbers of cross sections in these areas were often required to obtain stability. Samuels equation (Samuels, 1989) gives a simple formula based on flood depth and bed slope to suggest a minimal cross section spacing for unsteady flow modeling and provided an excellent starting point for approximating cross section spacing:

$$\Delta\chi \leq \frac{0.15D}{S_0}$$

Where $\Delta\chi$ is the cross section spacing, D is the bankfull depth and S_0 is the bed slope

In addition to this, Jarret's equation (Jarrett, 1984) was successfully applied. Jarrett suggested a formula for determining Manning's N values in very steep river reaches based on bed slope and hydraulic radius:

$$n = 0.39S^{0.38}R^{-0.16}$$

Where S is the energy slope and R is the hydraulic radius. Higher Manning's values were generally determined when using Jarrett's equation when compared to those determined using commonly used values suggested by Chow in the book "Open Channel Hydraulics", (Chow 1959). This increased the hydraulic grade and reduced the Froude number often reducing super critical flow to sub critical flow and increasing model stability.

The graphical displays and tables available in HEC-RAS provide the modeler with an extensive system for diagnosing, reviewing and bug fixing a model. Graphical displays such as the hydraulic property plots allow the user to compare parameters that include conveyance, area and top width against stage and discharge to identify any irregularities that may cause instabilities. Animated profiles and cross sections allow the user to view the flood event and easily identify areas where instabilities and irregularities occur allowing the modeler to focus in and bug fix efficiently

Emergency Plans

In addition to mapping the inundations created by each of the 14 NRCS facilities in Gwinnett County for both Sunny Day and Storm in Progress failures, floodwave arrival time and time to peak were determined. This information will be used as a tool for creating emergency evacuation plans providing the county with accurate maps identifying inundated homes and businesses and indicating the time that is required to evacuate the properties in the event of dam failure.

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