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Problem Chosen

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2005 Mathematical Contest in Modeling (MCM) Summary Sheet
(Attach a copy of this page to each copy of your solution paper.)

Type a summary of your results on this page. Do not include
the name of your school, advisor, or team members on this page.

Flood Has A Big Say? No, We Have!

We probe into a dam-breach flooding problem in this article. Adopting classic hydraulic and hydrologic knowledge, we establish a parametrically-based model and through step-by-step analysis, obtain the relationship between peak discharge, the distance along downstream channel reach and water flow depth:

$$\frac{Q}{Q_o} = \exp\{-\alpha * \frac{X}{L_0}\} \qquad Q = \frac{\sqrt{i}}{n} \frac{((b+mh)h)^{5/3}}{(b+2h\sqrt{1+m^2})^{2/3}}$$

To get a vivid picture of the actual flooding process， we create a simulation system, which employs Grid Stretch Method (GSM) coded in Matlab. This method is physically-based, and constructs time-stepping solutions of the actual breaching process and the breach outflow hydrograph.

Both of our models are grounded in theory and research, easy to use and quite robust, but we also suggest that some improvement may be needed to adapt our models to wider use.

Keywords: peak discharge parametrically-based physically-based GSM

Flood Has A Big Say? No, We Have!

Introduction

No matter how well a dam is built or maintained, the risk of failure cannot be reduced to zero. Thus dam-breach modeling and the associated routing of the unsteady outflow through the downstream river is a continuing concern to many aspects of life. However, since all dams pose some risk, no matter how small, they present a hazard to the public or property, many people say dam-breach flood has a big say.

But, we can’t agree with this opinion. In our models, we have made a delicate research into the consequential effects that breach of a large earthen dam could have, which surrounds Lake Murray in Central South Carolina. And, through careful analysis, we have had a good grasp of the flood behavior. Therefore in our combat against dam-breach flood, we are confident to claim that we will be the winner, we have a big say!

Our Tasks

1. Examine the types of conditions or factors that contribute to a dam breach.
2. Make step-by-step modeling to illustrate the flooding downstream in the event that there is a violently destructive earthquake which breaches the dam.
3. Decide the quantity and extension of flooding that will occur in Rawls Creek as a result.
4. Demonstrate whether or not S.C. State Capitol will be inundated.
5. Propose some emergency action plans to alleviate the sufferings caused by the flooding.

Assumptions and Hypotheses

1. Neglect the influence of rainfall, i.e., rainfall during the dam breach is considered to be zero.
2. The remains in the dam fail do not have any effect on the hydrological data (for instance, water storage) of Lake Murray and Saluda River.

The Models

1. Analysis of the large dam

The earthen dam is composed of clay, loess, gravel and crashed stones, with the upper and lower reaches adaptable to its slope, as to keep stability. The dam is of huge volume and wide base, bringing not too much pressure to the foundation. At the same time, the building materials constructing the dam are not coalesced, making it flexible to deformation.

Now we take a closer look at the dam. Earth vibration can take on two forms and thus cause two kinds of seismic waves.

Vertical vibration: (P wave)

1. **Stability of subsidence**

By this, we are discussing the vertical compressing deformation (quantity of subsidence) and uneven deformation (difference of deformation) of the dam under its own gravity and other loading forces.

2. **Factors contributing to the compressing deformation**

When the dam is made up of homogeneous rocks, the uneven deformation is so small as to be neglected; therefore we only have to examine the compressing deformation. The quantity of the dam deformation is subject to two conspicuous considerations: one is the height and the shape, the other is the deformational property.

3. **Decide the allowable load**

In order to secure construction, the dam foundation needs to specify the range of deformation, which is usually termed as the allowable load in engineering.

We have the following formula:

$[R]=KR_C$

Where[R] is the allowable load of the rock in kPa

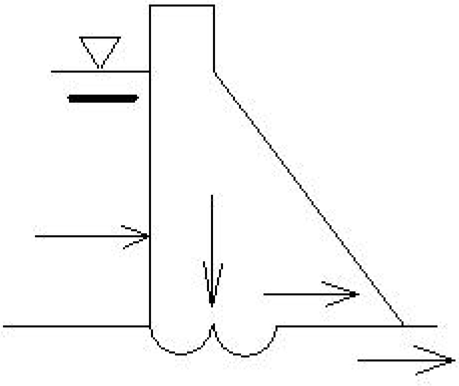
R_C is the saturated anti-pressure resistance in kPa

K is the reduction coefficient

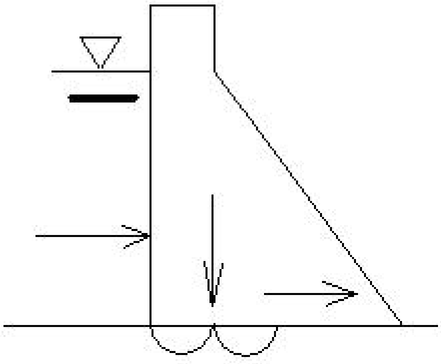
Horizontal vibration: (S wave)

1. **Forms of sliding destruction**

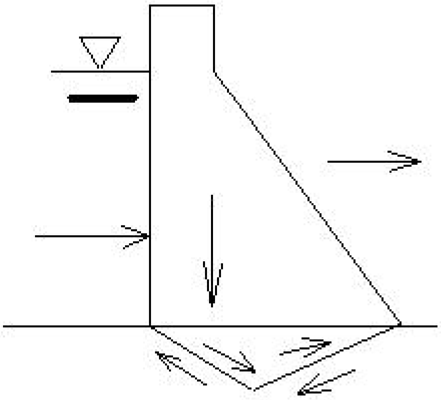
We have three fundamental kinds of earthen dam destructions: superficial sliding, shallow sliding and deep sliding. They are illustrated below:



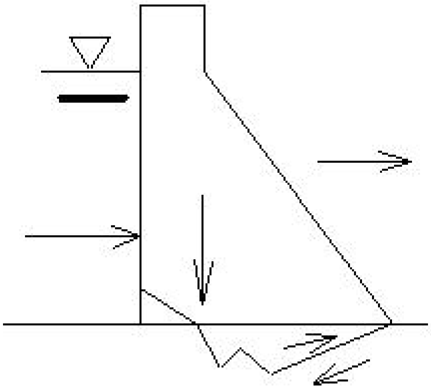
Superficial sliding



Shallow sliding



Deep sliding



Complex sliding

2. Analysis of sliding resistance

Usually, we adopt the method of static equilibrium limitation, projecting all kinds of forces acting on the dam, distinguished by their characteristics as sliding forces and anti-sliding forces, to a potential sliding surface. The ratio η of anti-sliding forces to sliding forces is called the anti-sliding coefficient, as follows:

$$\eta = \frac{\text{anti-sliding}}{\text{sliding}}.$$

In conclusion, the breach of the dam may be caused mainly by either geographical and geological circumstances, or hydrological and meteorological conditions.

2. Catastrophic earthquake induced by the reservoir

When the reservoir is in storage, the volume of the stock water in the very district increases in proportion. The water permeates the ground, adding pressure exerted upon the underground cleavage. Moreover, it can also soften, corrode the rocks, influence the geothermal heat and temperature, swell and contract the geological bodies, even inflict vaporization and hydration. All these can induce earthquake.

However, it is worth pointing out that earthquake can also be caused by many other reasons.

3. Preliminary dam-breach analysis

Dam breach modeling methods can be conveniently categorized as either parametrically-based or physically-based.

1. **parametrically-based modeling**

It utilizes key parameters to represent the hydraulics and breach formation in earthen dams, and thus compute the breach outflow hydrograph using a numerical time-stepping solution procedure or a single analytical equation.

Walder and O'Connor have used various regression equations to compute the peak breach discharge using only the breach-outflow hydrograph volume (V_w) and the dam height (H_w). Also, other analytical equations were presented by Singh and Quiroga (1988).

2. **physically-based modeling**

It uses hydraulic, sediment erosion, and soil stability principles to construct time-stepping solutions of the actual breaching process and the breach outflow hydrograph.

Dam-breach flood routing models (e.g., DAMBRK and FLDWAV) have utilized numerical solutions of the complete one-dimensional St. Venant equations of unsteady flow (e.g., Fread 1977, 1988, 1993); peak breach discharge attenuation curves coupled with the Manning equation to compute peak flow depths, e.g., SMPDBK (Wetmore and Fread 1984; Fread et al.1991); and simplified Muskingum-Cunge routing and Manning equation depth computation, e.g., BEED (Singh et al. 1988). Flood routing is essential for assessing the extent of downstream flooding due to dam-breach outflows because of the excessive amount of peak attenuation that such unsteady flows experience during propagation through the downstream river.

Future research orientations to better the prediction abilities for dam-breach floods most efficiently and efficaciously are considered to be the following, in order of sequence:

1. **Use prototype physical experiments to develop breach predictors for dams including both breach "initiation" time and "formation" time.**
2. **Employ both historical data from such floods and theoretical approaches to determine the Manning flow resistance values for dam-breach floods and procedures to account for flood debris blockage effects on Manning values and the damming effect on bridge openings.**
3. **Develop methodologies, e.g., Monte-Carlo simulation (Froehlich 1998), to produce the intrinsic probabilistic features of dam-breach flooding owing to uncertainties in reservoir inflows, breach formation, and downstream Manning debris effects.**

4. Parametrically-based modeling

Flash floods happen with little warning and may result in considerable damage to life and property. A dam-breach flood wave propagates along a river reach with velocity and depth usually decreasing with time and distance.

The breach-outflow hydrograph is a function of the geometric and hydraulic properties of the reservoir and of the geotechnical characteristics of the embankment. Its determination is usually subject to great uncertainty. From a practical standpoint, given a reasonable range of breach-outflow hydrographs at a site, there is a need to evaluate the propagation of these flood waves.

For any given reservoir, the dam-breach flood peak is inversely related to the flood duration and, by extension, to the time-of-rise of the outflow hydrograph. Since the flood wave attenuation is inversely related to the time-of-rise (Ponce et al. 1978; Ponce 1989), it follows that several assumed breach-outflow hydrographs at a site may eventually attenuate to about the same peak discharge. This fact has been experimentally corroborated in the literature (Chen and Armbruster 1980; Petrascheck and Sydler 1984). So we use an analytical model of flood wave propagation to study the sensitivity of dam-breach flood waves.

Our aim is to show, using dimensionless parameters, that a flood stage resulting from a dam-breach failure becomes eventually, i.e., at a certain distance downstream, independent of the magnitude of the peak discharge at the breach site.

The equations of gradually varied unsteady flow in a prismatic channel of a rectangular cross section, expressed with respect to unit width, are

Equation of continuity

$$\frac{\partial d}{\partial t} + d\frac{\partial u}{\partial x} + u\frac{\partial d}{\partial x} = 0$$

And equation of motion

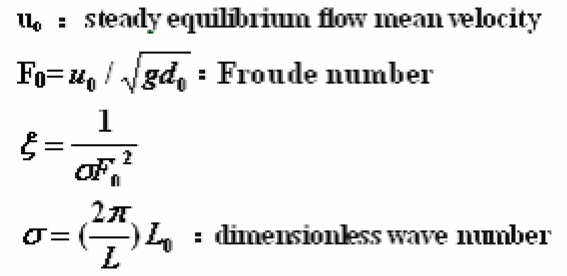
$$\frac{1}{g}\frac{\partial u}{\partial t} + \frac{u}{g}\frac{\partial u}{\partial x} + \frac{\partial d}{\partial x} + S_f - S_0 = 0$$

In which u is mean velocity; d is flow depth; g is gravitational acceleration; S_f is friction slope; S_0 is bed slope, subject to change on account of different geographical and geological conditions; x is space; and t is time.

We designate the following formulae:

$$M = \frac{1}{F_0^2} - \xi^2 \qquad N = [(\frac{1}{F_0^2} - \xi^2)^2 + \xi^2]^{1/2}$$

In which



u_0 : steady equilibrium flow mean velocity

$F_0 = u_0 / \sqrt{g d_0}$: Froude number

$$\xi = \frac{1}{\sigma F_0^2}$$

$\sigma = (\frac{2\pi}{L}) L_0$: dimensionless wave number

The following definitions apply: d_0 is steady equilibrium flow depth; L_0 is reference channel length, i.e., the length in which the steady equilibrium flow drops a head equal to its depth, such that

$$L_0 = \frac{d_0}{S_0}$$

Following Ponce and Simons (1977), the flood wave attenuation follows the following formula:

$$\frac{Q}{Q_o} = \exp\{-\alpha * \frac{X}{L_0}\}$$

$$Q_0 = 0.0443 g^{0.5} V_w^{0.367} H_w^{1.40}$$

$$\alpha = |\frac{2\pi}{r^2}(\frac{L_0 d_0 B}{V_w})[\zeta - (\frac{N - M}{2})^{1/2}]|$$

In which

B : bankfull width

H_w : dam height,

V_w : breach-outflow hydrograph volume

Q : peak discharge

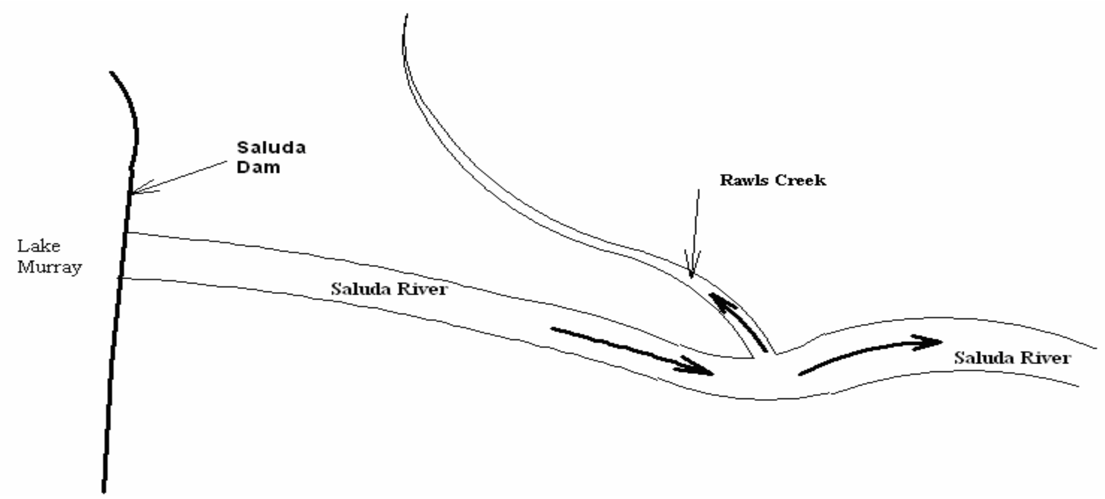
Q_0 : initial peak discharge

X : distance along downstream channel reach

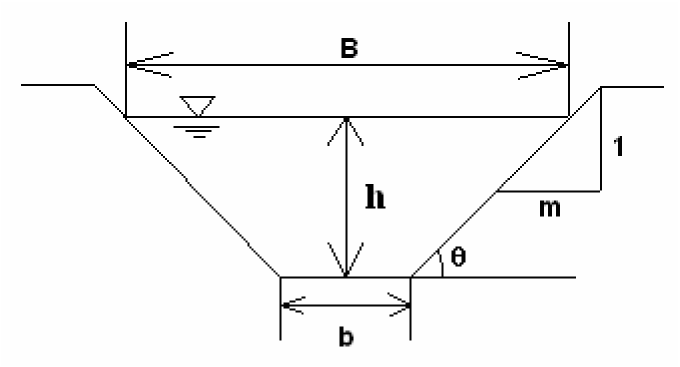
α : discharge attenuation factor

r=5/3 : applicable to Manning friction in hydraulically wide channels (Chow 1959)

Here is a topographical map of the district we are discussing.



We postulate that the intersection of Saluda River and Rawls Creek is a isosceles trapezoidal transverse section with bottom edge constant, depicted below:



Transverse section

We take the following formulae into consideration:

Bankfull width	$B = b + 2mh$	(1)
Drainage area	$A = (b + mh)h$	(2)
Hydraulic radius	$R = \dfrac{(b + mh)h}{b + 2h\sqrt{1 + m^2}}$	(3)

The definitions of m, b, h, A, B, R and θ are shown in the above picture.

As water flow in open channel is always in areas with turbulent flow resistance equally divided, we can base our calculation on Chezy Formula:

$$v = C\sqrt{RJ}$$

Where:

C is the Chezy coefficient

J is the hydraulic slope

v is the average velocity in the transverse section

Considering homogeneous open channel in particular, using J=i, we can get from above

$$v = C\sqrt{Ri}$$

Where i is the local bed slope.

Therefore, we know the bankfull discharge is $Q = AC\sqrt{Ri}$

Substituting, employing Manning's Formula $C = \frac{1}{n}R^{1/6}$, we obtain

$Q = \frac{A}{n}R^{2/3}i^{1/2}$ (4)

Where the roughness coefficient n relates to the local vegetation.
Substituting (2), (3) into (4),

$$Q = \frac{\sqrt{i}}{n}\frac{((b+mh)h)^{5/3}}{(b+2h\sqrt{1+m^2})^{2/3}} \tag{5}$$

Where b, m, n, i are all definite constants, thus, $Q = f(h)$ i.e., Q is a function of h.

We have already known that:

$$Q = Q_0 e^{-\alpha \bullet \frac{x}{L_0}} \tag{6}$$

It is not difficult to know the value of Q by utilizing (6), going a step further by utilizing (5), we will get the flood level h.

5. Physically-based modeling

With today's ever increasing utilization of and investments in areas which have a flooding risk there is a rising demand for computer simulation of flooding.

Complex local flux field possessing excessive 3-dimensional motion is always present in the lower reaches of floodway. In theory we should employ 3-dimensional modeling method to look into this kind of problem, but, considering the extreme difficulty in 3-dimensional numerical analysis, and the immaturity of this method in engineering application, the more powerful 2-dimensional method is in wider use instead.

However, simply using ordinary 2-dimensional simulation is not possible to reflect the virtual flow, needless to say to satisfy engineering demand. In view of this situation, we have made some reasonable adjustments.

Dealing with tortuously connected flood area, we have set up a method called Grid Stretch Method (GSM). Its core idea is that by endowing the source point with specific attributes, such as elevation, we try to find the point set that satisfies the designated conditions and is in accordance with the water level stipulated, then the plain this point set gives is the flood area we are looking for. Please note that other consecutive plains, satisfying the water level condition but not directly connected to the source point can not be classified into the above set.

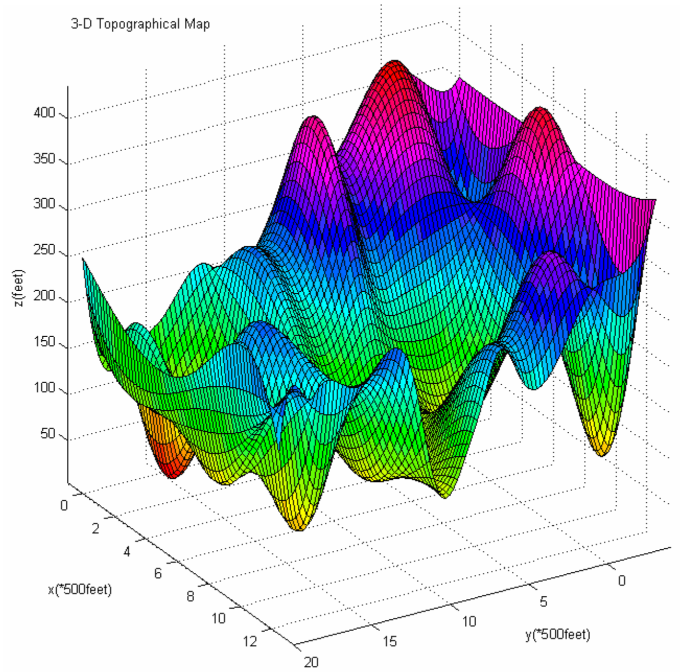
Usually the source point is selected to be at the intersection of Saluda River and the dam, by inputting data and using interpolation method, gradually we

will get the ever expanding flood area.

Please be aware that we do not take any forms of resistance into consideration and that the soil does not absorb any moisture.

Here we illustrate our GSM method more thoroughly:

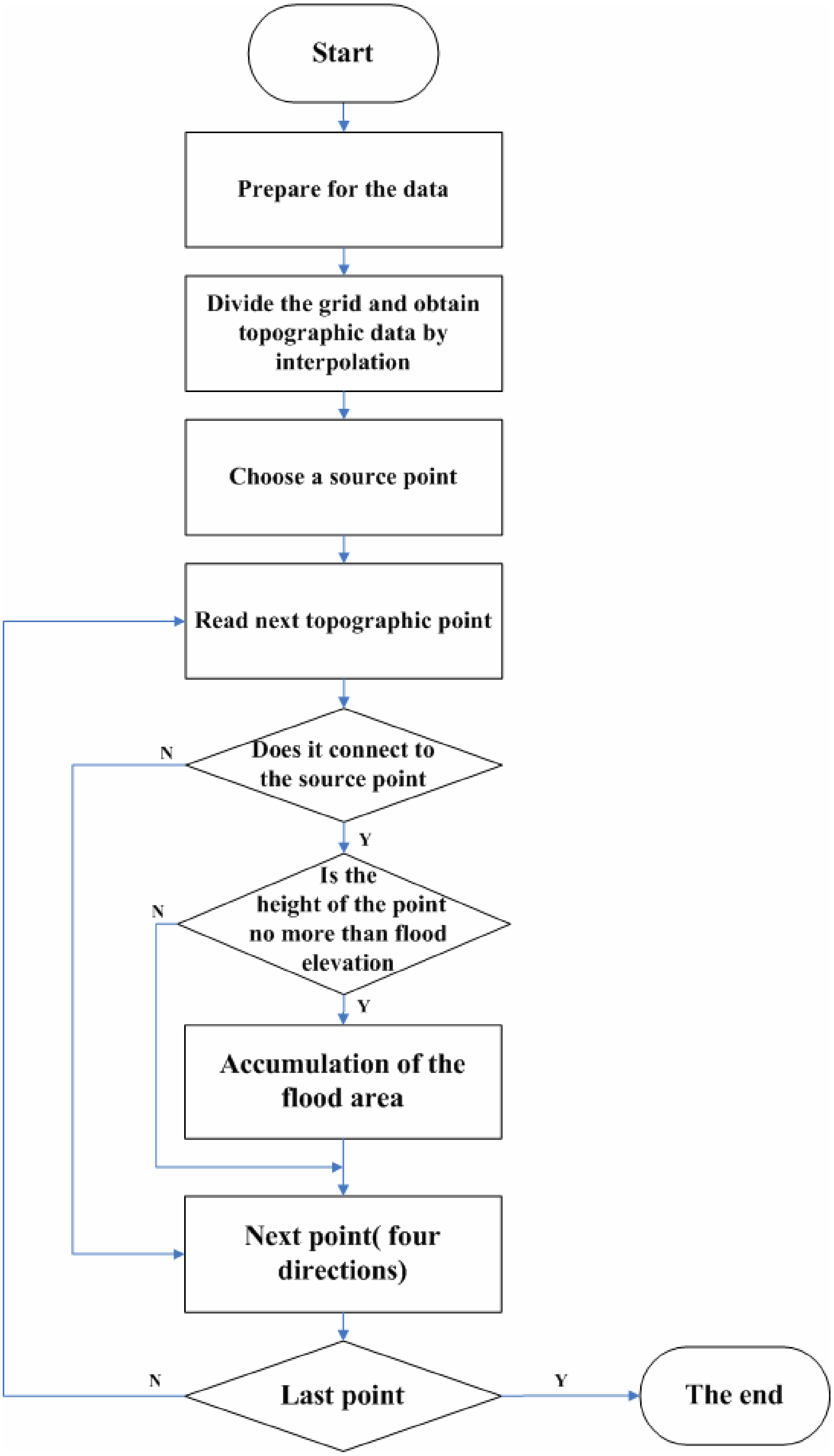
Utilizing the available topographical data near the dam, we can get a 3-dimensional graph by Matlab. It is depicted below:



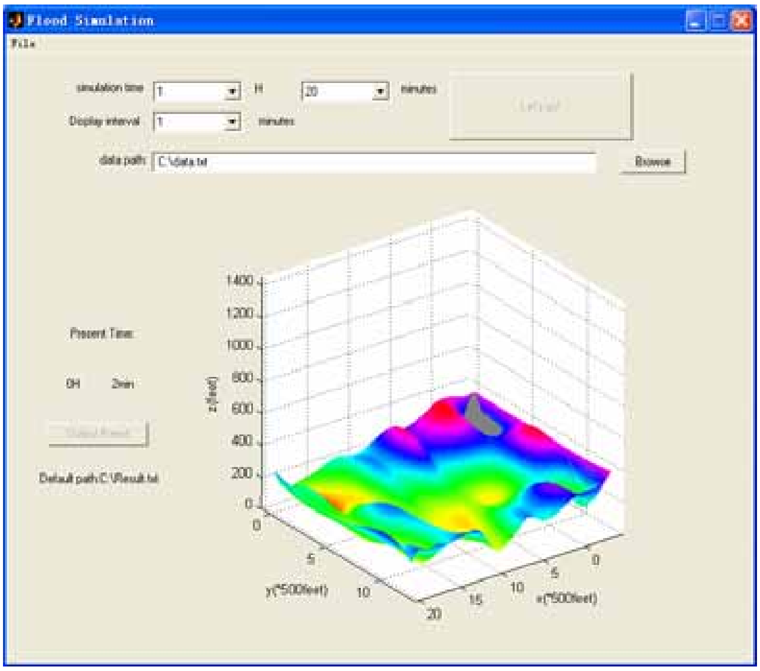
3-D topographical map near the dam

Then, go step-by-step with the following flow chart: After starting and inputting carefully prepared data, we divide the grid and obtain topographical data by interpolation. Then we choose a source point and read the next topographical point. Our next step is to check whether this point connects to the source point. If the answer is no, we can just go on searching an unvisited point in four directions to this point and if it is not the last point, we should read it and ask ourselves the same question again. Otherwise, we should go a step further and find out whether the height of the point is less than or equal to flood elevation, if it satisfies the condition, we can boldly add it to our current flood area, then go on searching an unvisited point. If it does not satisfy the condition, then we just skip it and go on searching an unvisited point. If it is not the last point, we should read it and apply the same criteria again. At last, if we get to the last point, then the algorithm should be terminated.

Till now we could see the rightness and rationality of the algorithm.


Start
Prepare for the data
Divide the grid and obtain topographic data by interpolation
Choose a source point
Read next topographic point
Does it connect to the source point
N
Y
Is the height of the point no more than flood elevation
N
Y
Accumulation of the flood area
Next point(four directions)
Last point
N
Y
The end

Eventually, we write a Matlab program in conformity with the above flow chart, and will come to a flood simulation interface:



simulation time 1 H 20 minutes

Display interval 1 minutes

data path: C:\data.txt

Present Time:

0H 2min

Default path:C:\Result.txt

Simulation interface

Now, just put in the simulation time and display interval, you will get a crystal clear look as to how the flood area looks like and its ongoing process. (The grey part in the graph is the current flood area).

Testing and Results

1. Detailed testing of the flooding at the intersection of Saluda River and Rawls Creek

Employing the already-known formula of the discharge attenuation factor:

$$\alpha = \left| \frac{2\pi}{r^2} \left(\frac{L_0 d_0 B}{V_w} \right) \left[\zeta - \left(\frac{N-M}{2} \right)^{½} \right] \right|$$

The steady equilibrium flow depth

$$\mathrm{d}_0 = 1.0813\mathrm{m}$$

The breach-outflow hydrograph volume

$$V_w = S_{area} * \Delta h = 202 * 10^6 * 18.3 m^3 = 3.7 * 10^9 m^3$$

Here, S_{area} is the area of Lake Murray and Δh is the height drop of the lake surface due to the flooding.

From our data
(“Engineering of Hydraulics and Hydrology”, www.topozone.com and www.terrafly.com)

$S_0 = 0.005$

Substituting these data into the above formula, we can get $\alpha = 0.0012$

And, as we know $Q_0 = 0.0443 g^{0.5} V_w^{0.367} H_w^{1.40} = 26353 m^3/s$ **and**

$$\frac{Q}{Q_o} = \exp\{-\alpha * \frac{X}{L_0}\}$$

Reducing them, we obtain $Q = 25881 m^3/s$ **(When** $x = 3.229 km$ **)**

Here x is the distance between the intersection of Saluda River and Rawls Creek and the dam.

Utilizing $Q = f(h)$**, we get the value of h,** $h = 32.48m = 106.56\,feet$

Here $Q = \frac{\sqrt{i}}{n} \frac{((b+mh)h)^{5/3}}{(b+2h\sqrt{1+m^2})^{2/3}}$ $i = S_0 = 0.005$ **(approximation)**

$m = 1.5$ $\theta = 33.69^o$

$n = 0.035$ **(suited to stony, grassy plain)**

2. Minute discussion about whether the inundation would reach S.C. Capitol

The method is very similar to that used to calculate the above question.
$x = 18.166 km$
Here x is the distance between Metro Columbia and the dam.
First, we will take the general area of Columbia into consideration.
From our data
(“Engineering of Hydraulics and Hydrology”, www.topozone.com and www.terrafly.com)

$S_0 = 0.005$ $h = 150\,feet$ **Then** $Q = 23785 m^3/s$

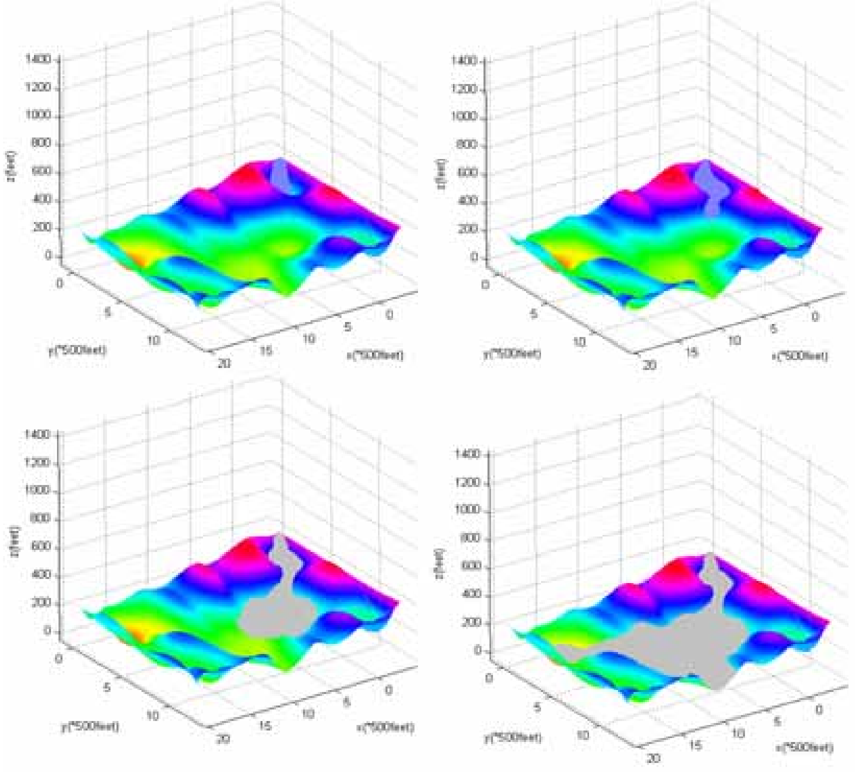
Next, we ponder over S.C. Capitol in particular (which is on a hill overlooking the Congaree River with height about 300 feet).
From our data
(“Engineering of Hydraulics and Hydrology”, www.topozone.com and www.terrafly.com)

$S_0 = 0.0001$ $h = 270\,feet$ **Then** $Q = 156.5 m^3/s$

3. Computer simulation result

Since the whole model is already fully and soundly developed, the next objective is to simulate the local inundation situation using the application interface we have discussed before.

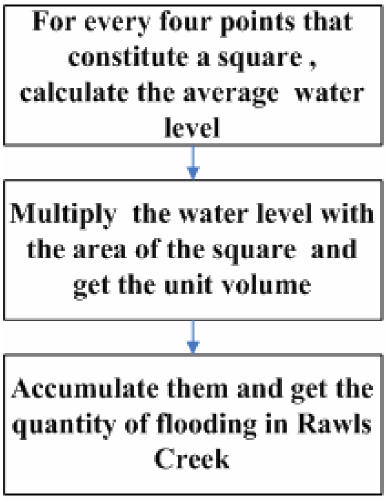
Selecting 50*50 points along Saluda River district, inputting their positional data, the following graph (a 500*500 grid) will be yielded:



Ongoing process of the flood

(Ordinate axis demonstrates the water level)

Choose the points neighboring Rawls Creek and in the reach of the flood, go through the following flow chart:



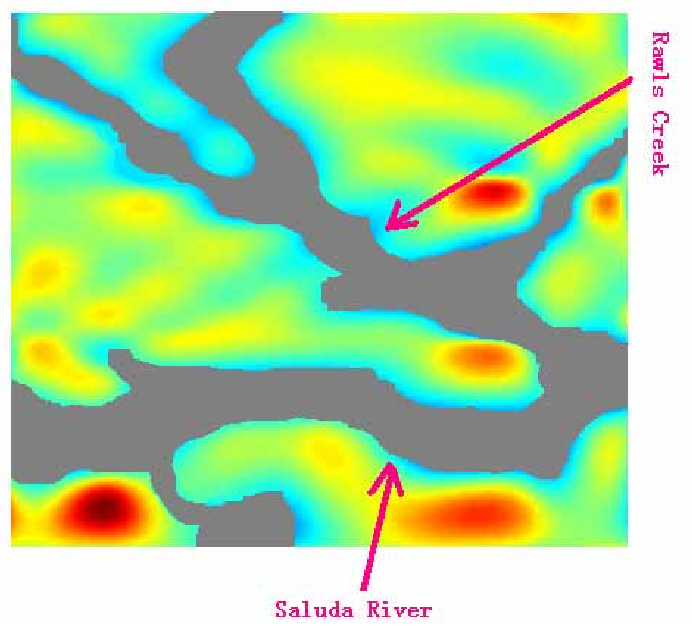
For every four points that constitute a square , calculate the average water level

Multiply the water level with the area of the square and get the unit volume

Accumulate them and get the quantity of flooding in Rawls Creek

Flow chart to calculate flooding in Rawls Creek

We can see that flood in Rawls Creek will flow back around 6400m -- 6500 m, and the quantity of flooding will be about 1800000 m^3 -- 2000000 m^3.



Part of the flooding situation at a certain time

Also, it is easy to detect that the flood area (the grey part) is enlarging by the minute and flood can finally reach Metro Columbia within about 5 to 6 hours. However, please note that this is not very accurate due to the incompetence of the computer to handle large load of data needed for a long floodway, but it is also worth indicating that in places not too far away from the dam, the simulation is rather precise.

Conclusions

1. Extension of flooding at intersection of Saluda River and Lake Murray

According to our testing results, $h = 32.48m = 106.56\, feet$

And that is the distance between the Creek surface and its bed.

Subtracting the steady equilibrium flow depth $d_0 = 1.0813\text{m}$ **we will get an idea that water level has risen** 31.3987m **or** $103.01\, feet$.

Without enough precise data on hand, we can not compute the very slope that Rawls Creek may have. Moreover, it is very difficult for us to know its width as it has a bearing on the local topographical situation, which is extremely

complicated. Thus, the relevant flooding occurring in Rawls Creek from the dam failure and its extension back are hard to determine.

2. S.C. Capitol will escape the flood

Based on testing results,

$$h = 270\,feet \qquad Q = 156.5m^3/s = 5527\,feet^3/s$$

$$h = 150\,feet \qquad Q = 23785m^3/s = 8.4*10^5\ feet^3/s$$

From our collected data, we find that the Saluda River average $Q = 1237\,feet^3/s$ (Near Columbia), the relative difference of Q for S.C. Capitol is not very large, and considering the high altitude of S.C. Capitol (resting on a hill about 300 feet in height), it will luckily be safe from the flood.

However, our analysis also points out that most of the Columbia District will be flooded, due to its low height and enormous Q (with $Q = 8.4*10^5\ feet^3/s$ in contrast to the 100-year flood elevation $3.4*10^5\ feet^3/s$). The Simulation Model likewise depicts the catastrophe.

Sensitivity Analysis

We have to point out that our result may be influenced by many factors. To demonstrate it more thoroughly, please look at the following formula:

$$Q = \frac{\sqrt{i}}{n}\frac{((b+mh)h)^{5/3}}{(b+2h\sqrt{1+m^2})^{2/3}} = 25881m^3/s$$

Let us change the value of m, n and i and get a rough idea how h (flow elevation calculated from the bed of Saluda River at the intersection with Rawls Creek) changes accordingly.

m is determined by the local soil texture

n is decided by the roughness of Saluda River course

i is ruled by topography

We make m range from 1.4 to 1.6, n range from 0.030 to 0.040, and i range from 0.0045 to 0.0055, here are some of the outputs:

Sensitivity analysis table

m	n	i	h(m)
1.5	0.035	0.005	32.48
1.5	0.035	0.0045	33.21
1.5	0.035	0.0055	31.83

1.5	0.030	0.005	30.42
1.5	0.040	0.005	34.37
1.4	0.035	0.005	33.26
1.6	0.035	0.005	31.78

It is easy to see that n and i have stronger influence than m on the value of h. And now, we will try to explore why this is the actual case.

m, n have direct relationships with the local environment, while i, the slope, not only relates to the local condition, but also, the very condition near the dam, so the influence is somewhat indirect.

Strengths and Weaknesses of the Models

Strengths of the Models

Robustness: **We derive our model from basic relationships in mechanics and limit our use of assumptions. In every case where an assumption is required, we verify it with evidence and reasoning that illustrate why the assumption is cogent.**

Grounded in theory and research: **We construct our model based on both theory and research.**

Ease of use: **We create a user-friendly computer program with a graphical interface that allows anyone with a basic knowledge of computers to input the required data and get the expected result.**

Adaptability: We validate the model for stability, sensitivity, and realism, and find that small changes in initial conditions do not cause drastic changes in the end result.

Weaknesses of the Models

Incompleteness of data required: We can not get the precise topographical map of the area discussed in our model and the exact materials concerning Rawls Creek, some of the data we use have to be inferred, and corresponding errors may be incurred.

Limitation of consideration: **There are parameters that we do not incorporate in our model, such as the interaction of Saluda River and**

neighboring rivers, and they may influence the eventual result.

Future Work

1. Careful rethinking

In discussing about the water flow in Saluda River aroused by the dam breach, we suppose that whole load of water flow goes into the river. However, it is not the case in reality. Much of the water runs off in all directions and can be absorbed throughout its journey, determined by the topographical conditions of the drainage area, which is very elusive.

It is a shortcoming in our work, but we can improve through computer simulation by lessening the distance between each grid point, thus having a clearer picture of the flooding process.

2. Test the model in real life

Breaching incident in Jian, Jiangxi Province, P.R. China

A dam in Jian was breached on June, 26th, 1992, with vertical sliding about 3.6m. A coal mine 1700m downriver from it was submerged whereas a chemical plant 4856m away survived the catastrophe. Altogether a district on the order of $7.34*10^6m^2$ was inundated. (From data "1997 Bound volume of Supervision of Hydraulics Engineering")

Our collected data show that the reservoir formed by the dam had an area of around $5.14km^2$. The initial river level was 0.8m, with bankfull width about 3.8m and slope 0.1 approximately.

Based on our model work, we can deduce that at 1700m, the discharge flow is $108.6m^3/s$, and the water level is 2.6m, so it is apparent that this district will be flooded. And also, we can find that at 4856m, the discharge flow is $10.25m^3/s$, and the water level is 1.0m, thus it gives a good explanation why flood influence is rather insignificant.

After careful analysis, the flood area is calculated to be $7.38*10^6m^2$, which is very near the available data $7.34*10^6m^2$.

3. Try to decrease the losses

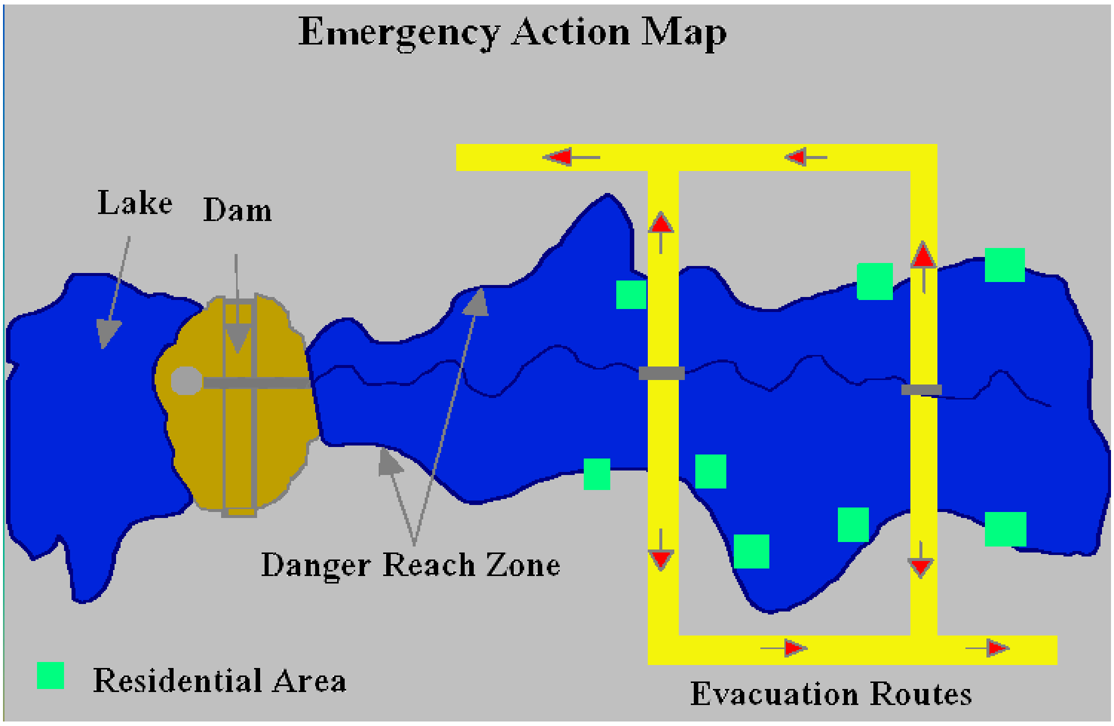
The purpose of the Emergency Action Plan (EAP) is to safeguard lives and secondarily to reduce property damage in the event that a dam would fail. To carry out this mission, the EAP should contain: 1. Monitor the dam periodically

and during flood warnings issued by the National Weather Service; 2. Notify Emergency Operation Center of a potential dam failure; and 3. Warn and evacuate the isolated residences at risk.

Possible actions to be taken in the event of dam breach:

Imminent Overtopping by Flood Waters: 1. Open drain or flood gates to maximum capacity; 2. Place sand bags along the dam crest to increase freeboard; 3. Place riprap or sandbags in damaged areas of dam; 4. Provide erosion protection on downstream slope by placing riprap or other appropriate materials; 5. Divert flood waters around dam if possible.

Erosion of Dam by Seepage through the Embankment or Foundation: 1. Plug the seepage with appropriate material; 2. Lower the reservoir level until the flow decreases to a non-erosive velocity or stops leaking; 3. Place a sand and gravel filter over the seepage exit area to minimize loss of embankment soils; 4. Continue lowering the reservoir level until the seepage stops or is controlled. Refill reservoir to normal levels only after seepage is repaired.



Emergency Action Map

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