Simulation of Water Behavior Includes Inundation and Flow on its Streambed Based on GeoSpatial Processing Functions

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Publication Date: 27 December 2013


Abstract Many organizations concentrate on water inundation [1] behavior because of its important role in different aspects of people day to day life. Prevalent software solutions to simulate have serious limitations and restrictions which make them difficult for all to be deployed. It makes the things even worse while some leave the process alone and do it with traditional manual methods. To come over the problem a new basic conceptual solution was proposed to use Geo-Spatial functions [2] in combination with traditional strength points; well form hydraulic equations and best proved conceptual algorithm to solve the hydraulic problems. The proposed solution expands a new concept to construct a computation environment [3] within GIS computation environment which simply matches the other Geo-Spatial problems. Nevertheless idea coincides some potential problems include conceptual fitness of real hydraulic environment with available geo-functions, arrangement of geo-functions in algorithm to solve the problem and tuning the geo-spatial functions proportional to problems. In this paper, mentioned points have been covered and results were proposed for a sample study area on a river part, named “Ghare-Chai” which is located in Markazi [4] province. The results’ comparison with measured observations reconfirms the wonderful potential ability of Geo-Spatial functions to solve spatial problems [5].

Keywords Geo-Spatial Functions; Pixel-Agent; Water Inundation; Water Simulation; Streambed

1. Introduction

Simulation of water behaviors is important almost in any organization which faces the water management affairs. It is essentially e.g. for engineering water district department to determine, rivers’ and floodways’ streambed and more important their security risk buffers [6] to avoid settlement of any activities in it.

This idea mainly arises from previous disasters occurred in last decades in different countries (Global Flood Survey, 2013). According to such problems legal restraining decree were issued to avoid settlement and refuse any ownership petition. Since then, Water Engineering department is
responsible to determine streambed security risk buffer and continuous advertisement to report any infringes in those districts.

To determine river or floodway risk buffer, there are so many different instructions and scripts all are based on mathematical hydraulic equations. These equations start by Manning’s roughness coefficient [7] and the ways to define it for a demanded district. These are followed by equations to determine water flow on stream bed. Finally different solutions are proposed to compute water inundation.

Of course water accumulation in upper watershed area has been neglected whereas it is not the main scope of this paper. This is the same for streambed extraction which has been covered in other issues. (Eivazy, 2013).

Regardless of its vast and great applications in several fields, simulation process itself has involved so many experts to get it practical in the context of commercial software. So many mathematical equations have been set to mimic the water behavior but all suffer from common point. In fact development of equations in the context of one practical algorithm is so difficult (Brownlee, 2011).

Nevertheless some pre-developed vector-based solutions are available in commercial market which all has common weak points (Merwade, 2012). Each solution contains just a part of final solution. In addition whereas algorithms have been regulated based on sequential simple vector computation, pre-defined standards should be followed by a user to get the software compute.

Estimation is the other common point in almost every traditional solution. Indeed a user hover the field himself and then decide about critical lines, points and districts. Designated spots then will be critical on computation approximation. In addition users have to determine basic structure of water body themselves. These structures are the backbone of whole process and are deployed sequentially in proceeding process.

On other side, there are plenty of spatial functions are available but are left intact whereas they are not obviously match to real world problems such as water inundation simulation process. According to previous experiences (Eivazy, 2013) which refuse the lateral assumption, geoprocessing functions have wonderful ability to fit real world problem requirements. The most important problem arises from two points; conceptual modeling fitness and specified real world functions.

Except for mentioned problems, their potentials could be easily deployed to automate the process, decreasing the time, decreasing dependencies on users’ actions and human decisions, simplifying the whole process, better data interoperability with other Geo-data sources [8], better visualization and increasing the deployment of results in other applications. In addition conceptual deployment of Geo-Processing functions defines new computation environment which simply match the other Geo-Spatial problems. The left point is the genius to Geo-Spatial function arrangement and tuning [9]. Altogether these actions are efficient steps to construct and develop new full geo-computational environment as the best geo-simulator tool. I hope for!

2. Methodology

2.1. Prevalent Approach

Water behavior simulation has been important since humans decide to settle beside water bodies. While people gain directly from its benefits and base their life on it, water bodies have their own behaviors and sometimes may exceed their normal borders and would hurts its neighbors. However these disasters are not something unexpected. These occur under the direct effect of water bodies’
temporal behaviors. In fact ignoring these temporal phenomena is the main reason to such disasters (CollinsFosu, Eric K. Forkuo, and Mensa Y. Asare, 2012).

Tropical hurricanes and storm surges [10] are among the most important motivations which push the experts to use practical solutions. Using prediction numerical surge model would be the simplest solution. Among the prevalent model such one is used within the Army and Navy community is the Advanced CIRCulation Model. It is a well-known two-dimensional model that vertically integrates shallow water equations and is used to predict surge and of course storm surge heights (C.A. Blain, R.H. Preller, and A.P. Rivera, 2002). Then it would be easy to derive water inundation by exerting previous results to costal DEM model (C.A. Blain, T.C. Massey, J.D. Dykes, and P.G. Posey, 2007) Regardless of their importance and concentrations, (sidereal simulation model e.g. coastal erosion or bathymetric data acquisition) indeed the most important problem arises from their point of view (Neil G. Dickson, Kamran Karimi, and Firas Hamze, 2010).

In River flood simulation process there are excellent reviews of storm sewer modeling (Abbott, M. B., Bathurst, J.C., Cunge, J.A., O'Connell, P.E., and Rasmussen, J., 1986; Akan, 1993; Institute, 2000). All has concentrated on water behavior equations and the approaches to fit the model with observed parameters. Although their fitness or drift is important to water experts but none negotiates on the approach to implement solutions in a predicative, sequential or descriptive Programming Language [11] (Brownlee, 2011; Algorithm Implementation, 2010).

Indeed using numerical algorithms [12] lead to approximated results. Comparison of results with real observation demonstrates considerable amount of errors which can’t be neglected.

Nevertheless some equations guide to such algorithms are practically so difficult to implement (Algorithm Implementation, 2010). Of course difficult and sophisticated algorithms’ implementation, usually cause restrictions in module efficiency. Therefore there would be some software with limited abilities and stiff manual script that should be strongly followed by users. So it would be clear, any deviations won’t be stood by software and result in alarm messages.

Among the commercial software available in trading market, DHI MikeStrom is a good paradigm. It is an engineering professional software package for simulation of flows, water bodies, sediment transport in estuaries, irrigation system and other water bodies. Most of all, it is able to simulate the tidal stormy water bodies and of course water inundation (Mike11, 2011).

While users work with software, first of all should create different mandatory script files according to a rigid format. Script files include structural data e.g. river boundaries, axels, cross sections, and equation parameters. In this software, the most important part of data should be provided manually or under direct stewardship of users. Figure 1 displays the tools are used to digitize and edit stream network.

![Editing Toolbar of Mike11 which is used to Manipulate Stream Network](image)

In such software it has tried to deploy best hydraulic equations but fitness process is done due to users’ test and tries activities.
Figure 2: Mike 11 Cross Section Editor

Figure 2 demonstrates Mike GUI [13] which has been specified for user editing process. Nevertheless, temporal behavior simulation of water bodies via time series is considerable due to its realistic graphical report.

Figure 3: Time Series Editor Toolbar

Figure 3 depicts the tool that handles storm temporal data. Regardless of error volume, bulky data entering and editing can be interpreted as a weak point and make the deployment of software difficult to the users. In addition, to predict water inundation volume, a complete data cycle has to be done, many parameters should be regulated and many editors should be edited. So this process is too time consuming. But the main weak point arises from vector processing method and algorithms’ implementation approaches.

Another good example could be seen in HecRAS. As Mike, HecRAS uses the Saint Venant hydraulic equations. Therefore it is expected that altitude be exactly taken in to account. In the other words, the mentioned equation is so sensitive to DEM deposition and tries to compute accurate results based on
stream cross sections. Nevertheless most of users usually use estimated morphologic parameters to decrease the time and expenses (Firas S.M. SALEH, Agnès DUCHARNE, and Ludovic OUDIN, 2010).

HecRAS is free software which has been developed by US Army Corps of Engineers Hydrologic Engineering Center. It is well known software among water engineer experts mainly because it is free and although because of its abilities. Some users use it alone specially those who do not care about data storage issues. But GIS experts usually use it along with other free module is called GeoRAS.

GeoRAS is although a free pre-developed module has been designed by US Army Corps. The module is added to ArcMap and ArcCatalog environment to form a new hydraulic graphical user interface in general ArcGIS interface.

Starting GeoRAS procedure requires setting input raster data (usually DEM or TIN) according to instruction. Then bulky manual process is begun by the user to create vector data requirements which takes considerable amount of time. Figure 4 displays the input vector data should be set before simulation.

Figure 4: Vector Data Initialization Dialog Box of Geo-RAS

This creates complete hydraulic conceptual model in ArcGIS geodatabase which is essential to water body simulator engine of HecRAS software. Then user has to start digitization of important water body structure depends on his or her water knowledge. Of course digitization should follow instructions too.

Figure 5: Digitization Direction of Water Bodies in Arcmap Environment
For example Figure 5 notes that digitizing should be directional from upstream to downstream. Otherwise you will receive perplex results than can't be interpreted by you. Worst of all, in digitizing process all topological rules should obey by user himself. This makes the process even more confusing and tiresome.

Then mandatory descriptions and parameters of body structure should be introduced by user one by one. After all, data should be exported to HecRAS to compute cross sections and earning the final results. Of course this procedure is user-based and needs user direct advertisement. Finally vector results will be ready to be imported back to geodatabase environment and should be regulated by user to be prepared for presentation (Merwade, 2012).

2.2. Purification of Final Scopes According to Experiences

Therefore, it can be claimed that empirical hydraulic equations, have two major weak points. They neglect morphological details of streambed which deflect the simulation. Although it is tried to fit them to real nature of water bodies using derivation techniques and additional parameters, but they still remain weak are not coincidence with real field observations. In addition these equations are mostly numeric and are not conceptually suitable to be fitted with commercial programming languages. In other words, it is so difficult to envision such equations in the context of software.

But commercial pre-developed software such as Mike and HecRAS use better equations. They are not merely empirical instead they are strongly under the effect of geometrical aspect of water bodies. This makes them more accurate than previous ones. In addition they use specific types of equations which are easier to be implemented in a prevalent predicative programming language.

Nevertheless, there are some problems too. As it was mentioned in part 2.1, hydraulic commercial simulation software is not fully automated. They are strongly dependent on user actions and knowledge. In addition the module process became more difficult to users because they have to exactly follow stiff manual instruction.

Mentioned reasons were good motivations to design and implement new solution to minimize the previous problems.

3. Designing and Implementing

3.1. Planning for Primary Project Requirements and Project Conduction

Whereas phenomena such as rivers have continuous nature are expected to be modeled in raster [14] space. It is obvious stream model conversion to vector, subsequently decrease demanded accuracy. Therefore implementing a GIS functional solution based on grid space, has the high potential of keeping accuracy because it doesn’t change the primary nature of altitude data. (Eivazy, 2013).

The most important data required for GIS solution is DEM. In contrary with traditional approaches which focus on hydraulic descriptions, GIS methods have strong correlation with geometry. According to previous experiences, using contours could be evaluated as a suitable tool to create DEM (Eivazy, 2008). Regardless of GIS based studies that prove the advantages of contour deployment, efficient hydrological software offer the same solution. Figure 6 demonstrates the contour data role in water bodies’ simulation according to water expert research (CollinsFosu, Eric K. Forkuo, and Mensa Y. Asare, 2012).
Therefore a data preparation process [15] was exerted on contour sheet based data, and then TIN was created on each data sheets. Data sheet size TINs, were converted to raster data and finally all data were combined together using mosaic function [16]. Figure 7 display the Markazi province DEM extent.

For the scope of this project, part of DEM which underlies a river named “Ghare chai” was selected and clipped with other spatial function. This part of river was selected because there was some water level measurement and flow meters instruments installed which would help us to give real observation values. Such values would be compared against the simulated parameters and thus could be suitable verifying approach to test the proposed solution.
Next figure displays a river part with its streambed DEM which has been extracted from province DEM. As it mentioned it is simply done due to deployment of a spatial function “Clipping”.

![Part of Streambed and its Axel that was selected](image)

**Figure 8:** Part of Streambed and its Axel that was selected

### 3.2. Defining Raster Spatial Function as the Solution Main Key

According to previous empirical experience, it was decided to use another spatial function as the main platform. This function which is classified in propagation group is so called ‘cost distance’.

From the cell perspective, the objective of the cost functions is to determine the least costly path to reach a source for each cell location in the Analysis window. The least accumulative cost path to a source, the source that allows for the least-cost path, and the least-cost path itself must be determined for each cell.

Cost distance functions apply distance in cost units, not in geographic units. This point is the key point of proposed solution. All cost functions require a source dataset and a cost raster. If the source dataset is a raster, it may contain single or multiple zones. These zones may or may not be connected. The original values assigned to the source locations (raster or feature) are retained. There is no inherent limit to the number of sources in the input raster or feature source data. Here in the study, source is equal to streambed axel. It is painted with blue in Figure 8.

If the source dataset is a feature dataset as in this study, it will be converted internally to a raster at the resolution determined by the environment; if the resolution is not explicitly set there, it will be the same as the input cost raster. If the source data is a raster, the cell size of that raster will be used.

The cost raster, the most important part of solution, can be a single raster and is generally the result of the composite of multiple rasters. Here it is created as the output of some hydraulic equation which will be discussed late. The units assigned to the cost raster here is the some kind of hydraulic energy volume. It is strongly defined relative to the cost assigned to other cells.

The cost values assigned to each cell are per-unit distance measures for the cell. That is, if the cell size is expressed in meters, the cost assigned to the cell is the cost necessary to travel one meter within the cell. If the resolution is 50 meters, the total cost to travel either horizontally or vertically through the cell would be the cost assigned to the cell times the resolution (total cost = cost * 50). To travel diagonally through the cell, the total cost would be 1.414214 times the cost of the cell times the cell resolution [total diagonal cost = 1.414214 (cost * 50)].
To determine the cost for a path to pass through cells to reach a source, the cost surface functions are based on the node/link cell representation used in the graph theory [15]. In the node/link cell representation, each center of a cell is considered a node and each node is connected by multiple links. Every link has impedance associated with it. The impedance is derived from the costs associated with the cells at each end of the link (from the cost surface) and the direction of movement through the cells. If the movement is from a cell to one of the four directly connected neighbors, the cost to move across these links to the neighboring node is one times cell 1 plus cell 2, divided by two.

\[ a_1 = \frac{\text{cost}_1 + \text{cost}_2}{2} \]

Where \( \text{cost}_1 \) is the cost of cell 1, \( \text{cost}_2 \) is the cost of cell 2, and \( a_1 \) is the cost to move from cell 1 to cell 2.

The accumulative cost to move from cell 1 to cell 3 is determined by the following formula:

\[ a_2 = a_1 + \frac{\sqrt{2}}{2} \left( \text{cost}_2 + \text{cost}_3 \right) \]

Where \( \text{cost}_2 \) is the cost of cell 2, \( \text{cost}_3 \) is the cost of cell 3, and \( a_2 \) is the accumulative cost.

If the movement is diagonal, the cost to travel over the link is 1.414214 or the square root (sqrt) of 2 (accounting for the difference in the orthogonal link or the longer distance to travel), times the cost of cell 1 plus the cost of cell 2 divided by two.

\[ a_1 = 1.414214 \left( \frac{\text{cost}_1 + \text{cost}_2}{2} \right) \]

When determining the accumulative cost for diagonal movement from cell 1 to cell 3, the following formula must be used:

\[ a_2 = a_1 + 1.414214 \left( \frac{\text{cost}_2 + \text{cost}_3}{2} \right) \]

A cost path consists of sequentially connected links that provide the route for each cell location to reach a source cell. A cost path distance (or cost distance) from any cell to a source cell is the
The accumulative cost of all links along the path for the cell to reach the source cells. There are many possible paths to reach each source cell, and there are many paths to reach the many source cells. There is one least-cost path. The least-cost path distance from a cell to a source cell is the smallest (or least) cost distance among all cost path distances from the cell to the source cells.

Since the cost distance is based on an iterative allocation, the lowest accumulative cost for each cell to a source is guaranteed. The accumulative values are based on the cost unit specified on the cost surface.

The output back-link raster identifies, for each cell, which cell to move or flow into on its way back to the source that will be least costly to reach. The values range from 0 through 8. The source cells are assigned 0 since they have reached the goal (the source). If the least costly path is to pass from the existing cell location to the lower right diagonal cell, the existing cell will be assigned 2; if traveling directly down or south, the existing cell would receive the value 3, and so forth. The back link is used to reconstruct the least-cost path from every cell of a raster.

Figure 11: Directional Surrounding Values for Each Given Pixel

The cost allocation identifies, for each cell, which source would be the least costly to reach. The values on the output raster would contain the same values assigned to the cells in the input source raster or the values associated with each source location derived from the (in_value_raster).

The cost distance raster tells how much it would cost each cell to return to a source via the least-cost path; the cost allocation raster defines, for each cell, the least costly source to reach; and the cost back link identifies how to return to the source. The cost distance and cost back link rasters must be created before initiating the Cost Path function. As long as the source and the cost rasters do not change, Cost Path can be run as many times as necessary with as many different destinations or combination of destinations (ESRI, 2011).

3.3. Extracting Proper Cause Hydraulic Equations

The next step is to fuse distance function with hydraulic behavior simulators. As long, experts in water engineering field have had great interests to numerical equation simulators. Among these experts, (Abbott, 1998) gives suitable paradigm in context of derivative equations to simulate behavior.

It is possible to neglect the momentum effects because that is small in comparing with gravitational and frictional parameters of flow.

The most important parameters we are looking for is average depth. This equation would be as below:

$$\frac{\partial d}{\partial t} + \frac{\partial [(1 - \beta)ud]}{\partial x} + \frac{\partial [(1 - \beta)vd]}{\partial y} = q_s(x, y, t) - q_i(x, y, t) \quad (1)$$
In above equations, \( d \) is water depth, \( \beta = \frac{\sqrt{A_{\text{b}}}}{A} \) is a detaining ratio which convey the linear ratio of building area to all area related to river cross section, \( u \) and \( v \) are velocity components related to water flow; \( x, y \) are two main directions one is parallel to river path and the other means \( y \) is perpendicular to primary axis, and \( h = d + z \) is the water surface height. Mentioned equations try to simulate temporal behavior of water flow using derivative mathematical approaches. In Raster Environment it is simply done due to derivation definition. It means

\[
f'(x) = \frac{f(x+\Delta x) - f(x)}{\Delta x}
\]

Take equation (4) while the denominator is tended to zero. In raster environment, it would be the sensitivity of spatial function due to small changes in function inputs. Therefore it is simple to execute above functions using two raster dataset. Two other components are

\[
s_{fx} = \frac{n^2uv\sqrt{u^2+v^2}}{d^3}
\]

\[
s_{fy} = \frac{n^2uv\sqrt{u^2+v^2}}{d^3}
\]

These are the friction slopes along the \( x \) and \( y \) directions which are mainly supported by terrain slopes. In other words functions (5) and (6) are used to determine raster datasets pixels. These raster datasets will be used instead of normal slope map. \( q_{x}(x, y, t) \) and \( q_{y}(x, y, t) \) are the rate of water entering and leaving ground surface per unit area, which are expressed as below:

\[
q_{x}(x, y, t) = I(x, y, t) + \sum_{k} Q_{x}(x_{k}, y_{k}, t)\delta(x - x_{k}, y - y_{k})
\]

\[
q_{y}(x, y, t) = \sum_{k} Q_{y}(x_{k}, y_{k}, t)\delta(x - x_{k}, y - y_{k})
\]

Which \( I(x, y, t) \) is the rainfall excess intensity, \( Q_{x}(x_{k}, y_{k}, t) \) the outflow discharge from surcharged river, \( Q_{y}(x_{k}, y_{k}, t) \) the inlet discharges and inlet system, where the outflow discharges and inlet drainages which occur in river canal systems are considered as point sources and sinks in 2D overland flow, and \( \delta \) is the Dirac delta function. In Equation (7) and (8), it is assumed that the influx direction of rainfall effluent is normal to the overland surface and the inlet drainage leaves with practically the overland flow velocity components \( u \) and \( v \) (Abbott, 1998). The unknown parameters include \( d, u \) and \( v \) in Equations (1) to (3) are solved by an alternating direction explicit scheme. The derivation of finite difference equations was depicted in the authors’ earlier studies (Hsu, M.H., Chen, S.H., and Chang, T.J., 2000) which have been specified for manmade canals and urban water discharging systems.
Although such solutions was introduced among the best solution (Ming-Hsi Hsu, Shiuan-Hung Chen, and Tsang-Jung Chan, 2002) which meet the requirements of manmade and natural streambed, regardless of its strength points (slope, temporal behavior) it doesn’t care the altitude. In other words, it has focused on hydraulic behavior instead. Such solution was taken first and was examined via the real control points on streambed. Results depict a great amount of errors which can’t be neglected.

Other equation was examined due to its fusion in pixel agent solution [17] was USACE’s UNET (Barkau, 1985) model which is simple enough to be deployed in pixel solution. It was expected that this model present better results whereas complexity of previous deployed model caused undesired deflection.

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q_l = 0 \quad (9)$$

Where:

- $Q$ = Discharge ($L^3/T$)
- $A$ = Cross Sectional Area ($L^2$)
- $x$ = the distance along the longitudinal axes of the channel or floodplain (L)
- $t$ = Time (T)
- $q_l$ = Lateral inflow per unit length (($L^3/T)/L$)

$$S_f = S_o - \frac{\partial y}{\partial x} - \frac{v \partial v}{g \partial x} - \frac{\partial v}{\partial t} \quad (10)$$

Where:

- $S_o$ = Bottom slope
- $S_f$ = Friction slope
- $V$ = Velocity (L/T)
- $y$ = Flow depth (L)
- $g$ = Acceleration due to gravity ($L/T^2$)

Term a, is the friction slope and reflects the resistance to flow. Term b is the bed slope and reflects the body force from gravity. Term c is the pressure term and reflects the change in depth in the longitudinal direction. Term d is the convective acceleration and reflects both spatial variation of the flow ($\partial Q/\partial x$) and longitudinal change in the cross-section area ($\partial A/\partial x$). Term e is the local acceleration and reflects unsteady flow. Terms b and c combine to give the water-surface slope.

To simplify the problem it is assumed: (1) a horizontal water surface at each cross section normal to the direction of flow, (2) the exchange of momentum between the channel and the floodplain was negligible; (3) the discharge was distributed according to conveyance, i.e.

$$Q_c = \varphi Q \quad (11)$$

Where

$$\varphi = \frac{K_c}{K_c + K_f} \quad (12)$$

$$K = \frac{1}{n} AR_s^2 \quad (13)$$
\[ Q = K \varphi \frac{Q_c}{Q} \]  

(14)

Where:
\[ \varphi = \text{Discharge distribution factor (dimensionless)} \]
\[ Q_c = \text{Flow in channel (L}^3\text{/T)} \]
\[ Q = \text{Total flow (L}^3\text{/T)} \]
\[ K_c = \text{conveyance in the channel (a measure of the carrying capacity of a channel)} \]
\[ K_f = \text{conveyance in the floodplain} \]
\[ n = \text{Manning’s roughness coefficient (dimensionless)} \]
\[ A = \text{Flow area (L}^2\text{)} \]
\[ R = \text{Hydraulic radius (L)} \]

3.4. Fusing Hydraulic Equation with Spatial Function

Therefore according to equations (9-14), first flow is computed along the longitudinal stream axes for each given stream segment. Axes segment length should be equal to pixel size. This part should be done due to approximately bulky vector processing function. The main reason is that all geometrical and a spatial description of streambed should be attached to stream section.

Then, longitudinal stream axes segment is changed to raster based on its flow attribute. It is done by feature to raster spatial function. Up to this point, source dataset which is necessary for cost distance function is ready. Then resistance or cost raster dataset, as the other mandatory input of cost distance function, should be prepared.

This would be designed for both, symmetric river cross section and asymmetric ones. Of course, symmetric ones are easier to implement but not accurate whereas most streambeds are not symmetric.

\[ A = \int_a^b f(x) \, dx \]  

(15)

Where,
“a” is the central point on axis.
“b” is the point far from the axis in direction which is perpendicular to stream flow. In other words, “b” is the coastal point or river, which is marked by water inundation.
\[ A \] is flow area
\[ f(x) \] is the surface function

In equation (15), “b” is unknown and should be solved. To solve it an alternative equation (16) is deployed:

\[ A = \sum_{i=1}^{n} d_i P \]  

(16)

Where,
“d” is depth related to each pixel is computed from subtracting DEM elevation from lowest point in each cross section of streambed
\[ P \] is the pixel size
This mimics the geometrical description of streambed cross section. Sigma process or integrator process is done by cost distance function and $d_1$ is simulated due to cost raster dataset or resistance layer.

To create resistance raster layer, another spatial function was developed whereas there was no suitable spatial function which fully fit desired requirements.

Developed spatial function, calculate reciprocal geometric description of pixels in both sides of longitudinal axes of streambed. To do it, a combination of spatial join, near point, proximity, point in polygon, spatial selection was deployed. Picture below demonstrate the developed spatial algorithm and solution.

![Figure 12: Design Solution in Model Environment](image)

As it is clear in Figure 12, DEM is used in two split but parallel process. In upper line, it is converted to raster [Raster to point] and then a spatial joining process [Spatial Join] is begun to calculate the resistance layer which is important and feed the cost distance function [Cost Distance]. To do it, output of split function [Split Line at Vertices] is taken as entrance of spatial function Join [Spatial Join]. As it is clear its output is processed by a field Calculator function [Calculate Field] is shown in upper right of the Figure 12. This calculation exerts geometrical aspect of streambed and its reciprocal interactions. Then this output is used as entrance for conversion function [Feature to Raster].

In lower part of model, DEM is used for another calculation. First it is converted to raster [Raster to Point (2)] and then altitude point data is joined to stream axes which comes from split line function [Stream_Split_Line]. The spatial join is done due to spatial join function [Spatial Join (2)]. The output is processed to mimic the hydraulic behavior of stream length according to manning’s equations and its proper parameters such as slope, hydraulic radius and other ones. This is done by calculator function [Calculate Field (2)]. Its output create resource raster layer which is another important input of cost distance function. Finally cost function [Cost Distance] takes two raster layers and gives the main output [Output Distance] as the water inundation level. Process is simply done using a given value for input flow water.
4. Results; Presentation and Discussion

Figure 13 shows the result for a given value of 5.7 (water flow) using symmetric streambed equations.

Figure 13: Water Inundation Based on Symmetric Streambed Equations

Figure 14 demonstrates result for the same value using asymmetric streambed equations.

Figure 14: Water Inundation Based On Asymmetric Streambed Equations

To check the result, real depth was measured in 15 different locations of study area at the time of flow measurement.
Figure 15: Displays the Check Points.

Figure 15 Comparison among errors arise from three examined methods, red bars belongs to numeric method, orange one belongs to pixel spatial solution with symmetric streambed and green one represents error of spatial pixel agent solution with asymmetric streambed equation.

Figure 15 demonstrates errors of three examined methods. To compute the errors, real measured depth values have been subtracted from simulated values in three methods. Thus negative errors define that simulated values are much more than real ones.

As it is clear, numeric values depict a great amount of errors which generally have exaggerated depth. Figure 16 compare different method results against the observed values.

Figure 16: Displays That Prevalent Numeric Method

Figure 16 comparisons among values, blue represent spatial agent pixel solution based on symmetric streambed assumption, red belongs the spatial agent pixel solution based on asymmetric streambed, and green displays valued related to prevalent numeric equation method.

Graph 16 displays that prevalent numeric method is to some extent far from real observed values except for one point (that would be by chance). Otherwise proposed spatial pixel agent solutions are
relatively better in comparison. Table 1 shows the calculated total measured errors on 15 check points.

**Table 1: Comparing Standard Deviation Related to each Method**

<table>
<thead>
<tr>
<th>Method</th>
<th>STD_e_se</th>
<th>STD_e_as</th>
<th>STD_e_num</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9.844989</td>
<td>6.620315</td>
<td>16.052305</td>
</tr>
</tbody>
</table>

According to Table 1, proposed spatial pixel agent solution based on asymmetric streambed equation, gives the best result with accuracy equal to 6.62 centimeters. The significant point is where this method released maximum amount of error. As it is clear in Figure 16, this point is located on stream bend. This might be under the effect of neglecting river momentum and its inundation effect.

5. Conclusion

Water engineers have done lots of efforts to optimize stream simulation but most concentrate on mathematical equations. Although optimized math equations had improved reality and fitness of model on real environment but according to experience there is always a significant shift, bios and errors in results which are interpreted as manning’s coefficient problem or some other similar things. Therefore empirical surveying observation is necessary to calibrate the models. In addition, traditional methods include bulky and of course difficult manual process which prohibit the others to use them.

In this research the main idea was to deploy powerful and geo-accurate spatial functions which all are predesigned in GIS software and computation environment. Whereas GIS is general simulator, logically it has not expert tools to be proper enough to simulate the stream inundation behavior. Therefore hydraulic equations were considered and one is selected which was most efficient and easy to be developed using geo-spatial functions.

Fusion of hydraulic equations was done due to specification of geo-spatial functions and of course a specific new spatial function was developed to complete the solution. A plan was designed to arrange geo-functions together to form a new module. This module uses small pixels or agents with almost simple behavior to simulate water inundation. There were two candidates for geometric module equations. Both were developed and along with traditional approach were examined in a streambed part.

Three groups of simulated values were compared against real observed values which indicated the significant amount of fitness in simulated values by developed geo-spatial pixel-agent module. Regardless of improvement of fitness, this module eases the process considerably along with decreasing the time. In the other words, now it is perfectly easy for anyone to use the module with the least requirements.

In addition, combination of geo-spatial functions to solve the mentioned problems depicts the high potential of GIS geo-spatial function to solve any other spatial problems too. Nevertheless, there are some weak points coherent with proposed method which requires more attention. Upcoming water on bends e.g. is among the issues should be covered by more efforts to complete pixel-agent behavior via the better deployment of hydraulic equations. This had not done because implementation of hydraulic equations was not enough simple while one should do it via pre-designed and limited geo-spatial functions. This problem would be solved due to develop new geo-spatial functions which can do more than before.
References


Merwade, Venkatesh. Tutorial on using HEC-GeoRAS with ArcGIS 10 and HEC-RAS Modeling. School of Civil Engineering, Purdue University, 2012.


### Appendix

[1] Whenever water flows in its streambed, it touches its streambed and come up to reach specific point according to streambed cross-section and water flow.

[2] Pre-developed functions such as software module which has been specified to solve or done spatial problem or process. These functions are able to be combined with each other in specific environment (such as ArcGIS Model environment) to do more sophisticated spatial processes.

[3] That is a high level environment same as what offered by different PL but very specific. It contains its operations, procedures and functions but not general. These all have been specified for special scope.

[4] It is a political division in Iran which clearly corresponds to State in USA in some reasons.

[5] Some things such as mathematical problems but difference mainly arise from their geometry dependencies. They are more complex in comparing with math problems whereas there so many aspects should be kept in mind along with its sophisticated geometrical specifications.

[6] It is a buffer which surround the stream main axes and is critical and dangerous because any settlement it this area would result in losses of lives on flood time.

[7] It is a coefficient which defines streambed friction against water flow.

[8] There are some great and powerful Geodatabase which are governed by organizations and are responsible for suitable and standard spatial data sources. For an instance National Cartography Center of Iran, established a great Geodatabase which includes all countries spatial data within.

[9] Each spatial function or procedure has many settings parameter which considerably define the way that function behaves. Fining and regulation of these parameters is called tuning.

[10] Upcoming waves from water bodies such as river or sea.

[11] In such PLs, commands, procedures or functions should be read and then executed one after one in a regular sequence.

[12] Algorithms which just concern about numerical cause model equations. They even behave the geometry as the least importance factor e.g. cross section geometry is replaced by an area volume.

[13] It is abbreviation form of Graphical User Interface.

[14] It is a data model which is proper enough to model continuous natural phenomena. Model is comprised from Small Square that is arranged in regular grid and each has its own specific value.
[15] In this main process, different sub-processes should be done includes, data molding, rasterization, interpolation, cleaning, structuring etc.

[16] It is a spatial function which combines different raster datasets with common spatial coordination system.

[17] Pixel agent is assumed as a small simple object poses the least complicated behaviors and properties. Upcoming solution will be based on combination of such agents. Of course combination of simple agents is able to demonstrate sophisticated behaviors.