Experiences for Nature Systems Simulation

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ABSTRACT: Some Nature Systems, such as River Valley, River Basin and Sea Coastal Zone are at bottom Opened Non-Equilibrium Systems. Permanent penetration of energy/matter flows through the system causes oscillations and thresholds and determines dynamics and evolution of the system. The objective is experience of 2D Simulation for the Nature System - River Basin. For the purpose all spatial Data are presented by some grids of square cells. River basin (or some basins) must be fully included in the grid (matrix). All temporal data should be presented by rows. Matter/energy flows and balances estimation through the 2D system is done by two kinds of Evolution Algorithms – String Genetic Code (SC) and more by Matrix Evolutionary Algorithms. Numerical methods consist on algorithms, which were worked out for matter/energy balance estimation between all cells of grids for any changeable spatial structure of flows and for any sequence of temporal steps. Dynamics and evolution are described by interactions between the following conformed matrixes: Elevation/Bathymetry, Surface Water Content, Soil Resistance, Water Delay, Infiltration, Contamination and others. The system engine consists on two corresponding components: Water Flows and Elevation. The core idea of the models is simulation of water – elevation interactions. External input and influence factors are as follows: precipitation, temperature, sea level changes, any human pressure/impact, tectonic movements and others. Discussed are model uncertainties and verification results.

1 INTRODUCTION

Simulation of river basin dynamics and evolution is necessary for many following applications: River Basin Management, land use policy, water and flood management, pollution monitoring and many others. Computation Algorithms must be suitable for modeling of complex nature systems. The System is characterized by permanent penetration of water/matter/energy flows through boundaries and through the systems (Prigogine, 1984). These flows cause basin evolution (Klenov, 1989) and help to understand evolution laws. The River Basin belongs to Opened Non-Equilibrium Systems. Non-Equilibrium system induces complex processes of self-organization by oscillations and thresholds. The non-stability (oscillations and thresholds) determines and depends on feed backs in the system and is caused by flows of water and sediment through the basin. Water – Elevation interactions are also counteraction between Active forcing factor (Water) and Conservative factor – Elevation. The complexity of the systems is increased by stochastic external stochastic climatic forcing factors. Every System (Nature and Simulated) must be extracted from the Environment by determine of boundaries, of inner processes and exchange with surrounding. River Basin is comparatively easy spatially restricted by the natural boundary – line of watershed. Other Systems may be more complicated: The exclusion of System, including underground water, is complicated by non-conformity of surface water and ground water watersheds. River Basin and nearby Coastal Zone is the other coupled System, extracted from surrounding. The following objectives are as follows: numerical methods for simultaneous mass/balance estimation on 2D River Basin systems for consistent phases of Dynamics/Evolution; reefs and uncertainties for complex system simulation; verification of the River Basin model for the case of Water Flows and Floods assessment.

2 NUMERICAL METHODS

Methods of Nature system simulation should be adequate the system peculiarity. The peculiarity is that spatial system of flows inside the basin is complex and changeable flow structure. In accordance the modeling objects were applied two main simulation methods: Genetic String Coding (SC) and Evolution Matrix (EM) Algorithm (Klenov, 1985, Babovic, 1997) . SC and EM are convenient for various objectives. SC is more suitable for description and calculation of pollution flows through any river net, from point and spatial distributed sources (Klenov 1999, 3). EM is preferable for multi – objective assessment of complex system Dynamics and Evolution. (Klenov 1989, 1998, 1999-2).System identification includes boundaries and input/output exchange through boundaries. Natural elevation boundaries are watersheds. Input output mass/energy exchange consists on precipitation/evaporation Surface Water – groundwater interactions processes is through upper boundary (air): rainfall and evaporation, other is surface water – ground water interactions, surface water outflow. Tectonic movements, Sea level changes and Trend are other inputs for the large basins. Finally, river basins are now by permanent pressure by human activities. The core of SC is coding of River net structure by tracing of each flow through the basin until its mouth (Klenov, 1985, 1999, 3) of elevation matrix and by adding of each numbered flow to string. The SC is intended to determine the order of water/mass balance estimation between all following cells through a basin. Double String consists on Source and Target strings. Each cell is vector of variables (Water, Sediment and Pollution) and parameters. Erosion or sedimentation at each cell depends on sediment balance. Local sedimentation (overfilling) or erosion (over-cutting) is the reason of origin of bottom oscillations and of flow thresholds. The thresholds cause changes of flow of flow structure (pattern). Forming of new String Code (Genotype) is done before the each next calculation step, after the foremost input of precipitation and other forces. SC determines the order of next system state (Phenotype) estimation. SC is in results similar to Evolution Matrix method, but needs for more computer memory. Therefore String Coding was reduced for River Net simulation, for assessment of pollution spread along rivers. The first River Net input is done by direct drawing at the display. The drawn plane structure is then once self-coded to String Code, for following calculation of pollution flows downstream from point and non point sources (Klenov, 1999, 3). The object is urgent assessment, forecasting and warning of pollution disasters (oil spills or toxic wastes) and for support of regional monitoring by co-processing obvious visualization of River Net pollution dynamics. The value of pollution is vividly shown at 2D computer map by own colors for each concentration value. The method of Evolution Matrixes was worked out simultaneously and is used now instead SC. The new principle is operation with Source and Target multi-layer matrixes. The core of the method is usual scanning accompanied by determination of source – target flow direction. Moved water, sediment and pollution is written in determined cell of target matrix. Delayed part of water/matter stay at the source cell.

The EM model of River Basin is a method for water/matter balance estimation for any plane structure of flows (Klenov 1989, 1998). The structure is changeable for following step, and the order of estimation is corresponding with it. Algorithm includes following steps:

1- Beginning scanning of Elevation and Water matrixes $\boldsymbol{A_{i,j}}$, $\boldsymbol{Q_{i,j}}$ $(i = 1, n, j = 1, m)$,

2- choose the most of neighbor slope angles 8 directions, determine of elevation difference between source and target cell,

3- estimation of water flow as aspiration to water level equalization,

4- estimation of Snow Melt, if exceed $1\text{-}2^0$; air temperature estimation of Evaporation as non-linear function on air temperature,

5- estimation of sediment transport capacity as function of slope angle and water lay thickness: $E = aU^bQ^c$, where U-slope angle, Q-water thickness, a, b, c – parameters, which must be optimized by calibration (Makkaveev, 1955), E depends also on soil resistance parameter, what is calculated,

6- the value of water and sediment flows is written to target cell of doubling matrixes ($\boldsymbol{A^1}$, $\boldsymbol{Q^1}$), and is deducted from $\boldsymbol{A}$ and $\boldsymbol{Q}$,

7- scanning continue and when scanning is over, then go to 7,

8- rewriting of source and target matrixes, source water matrix is summarized to target matrix $\boldsymbol{Q}$, matrix $\boldsymbol{Q^1}=0$, Difference matrix $\boldsymbol{D}$ between initial and current elevation is the matrix of summarized elevation change,

9- new spatial or local input of precipitation and human/nature impacts at cells of corresponding matrixes, into basin,

10- non - restricted repeating of 1 – 8 calculation steps.

Initial and boundary data and conditions, concerning the basin are as follows: boundary conditions are prohibition of surface flows through watersheds; transit flows should be excluded in connection with the uncertainties of its assessment; initial surface water content should be filled, because the basin initially is dry; the same is for groundwater level and initial groundwater inputs; cross boundary flows through the basin is to be assessed; initial data includes conform grids of parameters (water delay, infiltration, soil resistance), input data for water depth (thickness) simulation through all points of basin includes precipitation and air temperature.

3 THE MODEL UNCERTAINTIES

There are four following sources of data and methods uncertainties and reefs in the simulation model: elevation data, initial conditions of water matrix, numerical oscillations and parameters.

The first and the main is numerical uncertainty is origin of oscillations in the model. The grid spacing out causes oscillations of high frequency. It is adequate to origin of oscillations and non-stabilities in real non-equilibrium nature systems of any frequency. Origin and location of oscillations and thresholds inside the basin are determined by values and gradients of Energy Potential (Transport Capacity of flows) surface, according the properties of Non-Equilibrium Systems (Prigogine, 1984).These nature phenomenon is widely known in geomorphology and is received by river Valley and River Basin simulation (Klenov, 1985, 1999,1). Other reef is caused by procedure of elevation grid preparation. Experience of simulation shows also necessity for co-processing visual mapping. The multi-layer map is changes without interruption simultaneously simulation. Some operations are worked out to reduce uncertainties.

The second is initial data uncertainty. Elevation of stream bottom does not equal to elevation of cell, because cell elevation is middle for the cell and usually exceed elevation of the stream, which cross a cell. Therefore grid value does not coincide with structure of flows, especially for the bottom of valleys. It means, that elevation along stream do not fall monotonously. The structures of flows, which are build the model by use of elevation grid, do not coincide with real river plane structure. Grid of mean elevations usually uneven exceeds real bottom ones. No one automatic correction warrants, that plane structure of flows and longitude profiles of streams are non-deformed in grid of comparatively low resolution.

The preliminary correction of elevation along streams is necessary until full conformity of modelled structure to real ones. But usually model is able to self-correction by preliminary running, by filling of holes by sediments and by cutting of local height jams along the streams, with permanent rewrite of elevation matrix. Then corrected elevation grid is used as initial, available for simulation. Initial work of the model and hand correction fill the holes and cut shelf. It is done until the structure of model flows coincide with nature structure. Then this state of grid became initial for simulation.

Spatial resolution for basin usually does not ‘feel’ and to distinguish stream, flood plane and terraces. All these geomorphology forms are included to one average cell. It confines assessment of water level and of flood height. This uncertainty may be minimized only by increase of spatial resolution and by increase of grid dimension. The consistent restriction is that modeled basin must be completely included in grid.

The third data uncertainty is that initial water matrix is 'dry'. Some cycles of computation are necessary for filling the water matrix and for forming of river by full penetration of water through the basin and for river matrix filling until middle level of the current season. It is preferably to do for the beginning of year, including snow thickness. Moreover, must to be input a water equivalent of snow for previous part of winter. It makes new uncertainties.

Underground surface water – groundwater interaction must be included for more correct water balance estimation. This estimation is included in the model by use infiltration simulation, but is not discussed here. Apparently, initial conditions for underground water level needs for essentially more time for establish of flows through boundary of grid, because underground basin usually do not coincide with surface water basin. Usually initial filling of the basin by water should be done by numerous preliminary running of the model.

Precipitation input into model is interpreted by the model for the whole basin. But real spatial distribution of precipitation does not coincide with precipitation, measured at gauge stations. Local summer strong storms are randomly distributed in the basin square. Therefore the computed discharge and water level never will fully coincide with observed.

Each cell is summarizing input from neighbor cells, from upstream, slopes and tributaries. For all inputs must be done equal chances. Therefore water/sediments moves from each source to target cell, is written by add on double target matrix. There is no feed back between cells inside temporal step. For each cell inputs and output are random. Some source cells 'do not know' on changes of the target. It results in possible over filling of the target current cell. This overfilling may be, if value of flows is too large. Sediment overfilling leads to sediment jams in valley bottom. This reef might be minimized, if temporal step is less, but almost in the each basin would be points of over filling, nuclear of non-stability, sites of oscillations origin. Physically overfilling may be interpreted as effects of inertia of flows. Such over filling exists in nature for example as cones from tributaries as local over filling.

Finally, the forth group of uncertainties is obviously caused by value of parameters. The rank of parameters includes the following: coefficients of all empirical equations, water delay, soil infiltration, evaporation, snow melt, soil resistance, parameters of solid and liquid contaminants. Some of physical coefficients are distributed and may be changed in time.

Data on soil properties, including evaporation, infiltration, soil resistance strongly depends on its location in the basin and on geological conditions. For example, water delay depends on slope angle, on vegetation, on slope micro-elevation and on land use. Some data for large basin is insufficient. It is very important to calculate the influence of small regional tectonic trends, trends of sea level and air temperature. Numerical possibilities of the model exceed available data. The data for calibration and verification is always un-sufficient.

4 VERIFICATION

The Basin modeling is multi-objective. The unified model may be turned by any size (layer): water level/discharge simulation for any point of basin, soil and stream erosion and sedimentation, sediment thickness (as sediment layer), value or concentration of solid/liquid pollution, elevation, current or summary change of elevation and some layers for computation of surface water- ground water interactions. All these are simulated simultaneously as the unified system. All model sides and interaction depends on Elevation and Water content (climatic factors). Each model layer needs for validation and for parameters verification. River Basin Morphodynamics, Erosion and Sedimentation processes were validated by direct and non direct geomorphology methods (field observation, observation repeat, remote sensing methods, Klenov 1998, 1999a).

The range of model and data uncertainties, concerning surface water flows, may be continued endlessly, but the basic model accuracy must be checked by calibration and verification.

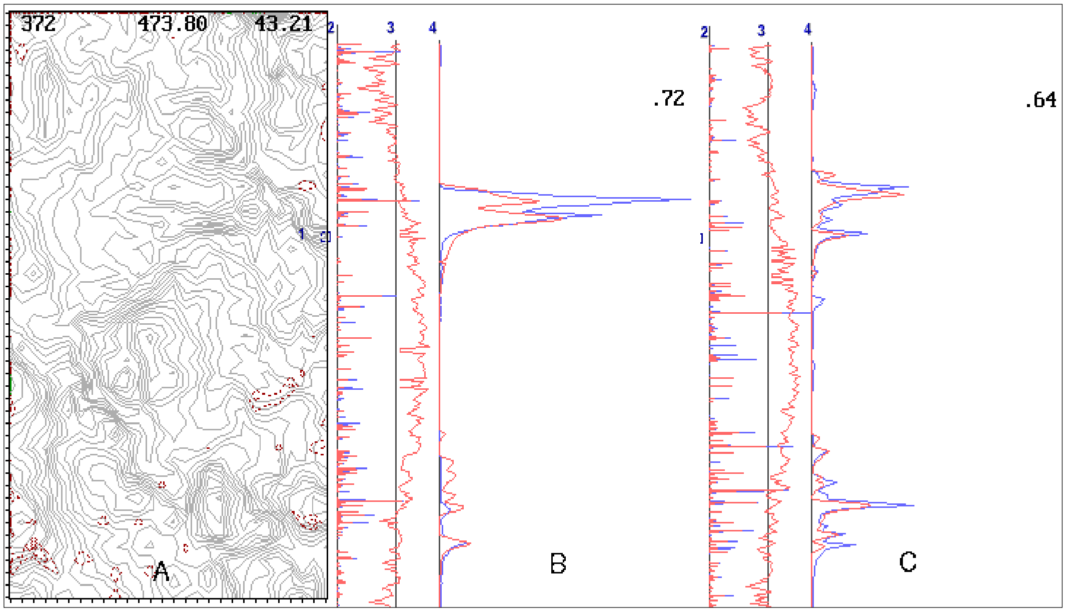

Figure 1. Verification for the River Basin Model, where A – the source computer map, B – verification for 1970 year, C – verification for 1971 year, 1- Gauge station, 2 – daily precipitation, 3 – daily temperature, 4 – computer (red) and observed discharge,

Verification for water flow processes was done by comparison of observed discharge with computed discharge for chosen cells (gauge stations). Daily precipitation and air temperature for 5 years were used for estimation of discharge at output boundary cell of basin. During the run of this rank calibrated parameters did not changed. The modeled basin (1500 km^2) Moscow River upstream. Discharge Gauge-station is in Barsuki. Two precipitation and temperature gauge stations are located on the west and on the east (Gagarin and Mojaisk). 5 years rank is computed at 25 – 30 min (PENTIUM – 200)

Spatial resolution of the elevation and other grids is 1 km. The grid elevations was corrected until distinguish flow structure similarity with nature by comparison with topography map. Vegetation and land use maps were used to initial establish of water delay distributed coefficients and of other distributed and common parameters.

The example for annual calibration is shown at Figures 1 - 2, where is also shown daily precipitation and temperature, observed and simulated discharge in gauge station Barsuki. Results of 5 year calibration were checked by R^2 criteria (Nash, 1970) – which are varied from 0.55 to 0.82 (1975-1979 years). For single year calibration was attained the result $R^2 = 0.931$. Nevertheless it is preferable to use some (5) years for calibration, because calibrated parameters depends on time. Verification was done for 16 other years (before and later then basic period) and are resulted in between 0.35 - 0.85. The analysis of results shows, that the best results was received for cases of single and large snow melt peak. Calibration results for the case of several rather low snow melt peaks are some worse. Finally the verification seems to be satisfactory and valuation will be improved in further

Artificial scenario (Figure 2) differs in 6 day lowering of air temperature during strong rains in august. These conditions resulted in strong simulated summer discharge peak.

The single difference on the previous scenario is simulation of water retention reservoirs building in the Basin (Figure 3). The result is essential mitigation of Flood peaks. The simulation tools enable local or general changes of any matrix of parameters or data.

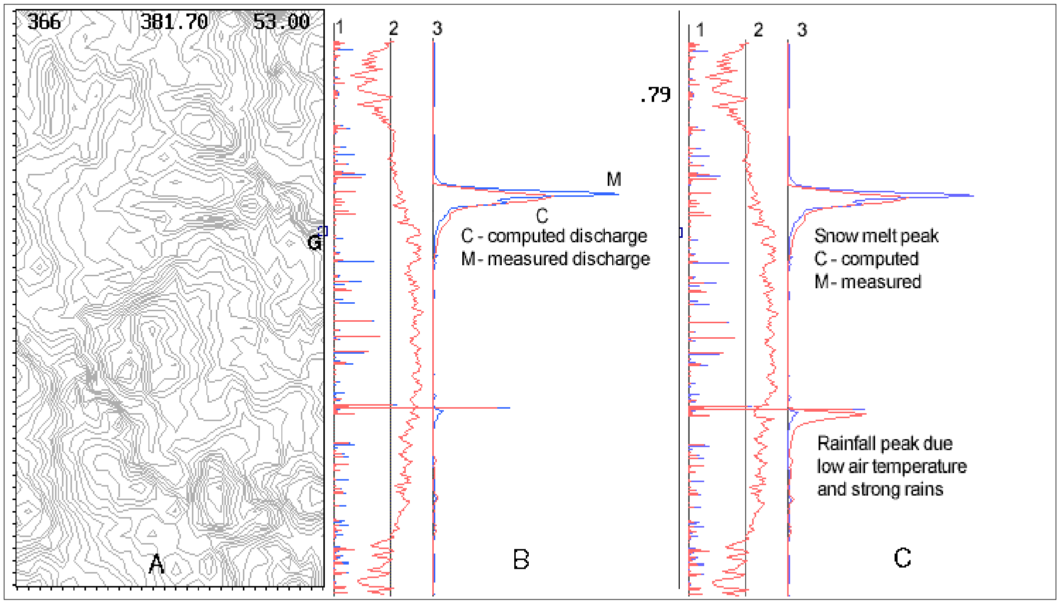

Figure 2. The following model verification (B) and scenario simulation for the same year with artificial lowering of daily temperature for 6 days (C), where A – the Basin, G – the Gauge station, 1 – precipitation, 2 – temperature, 3 – observed (blue) and computed (red) discharge.

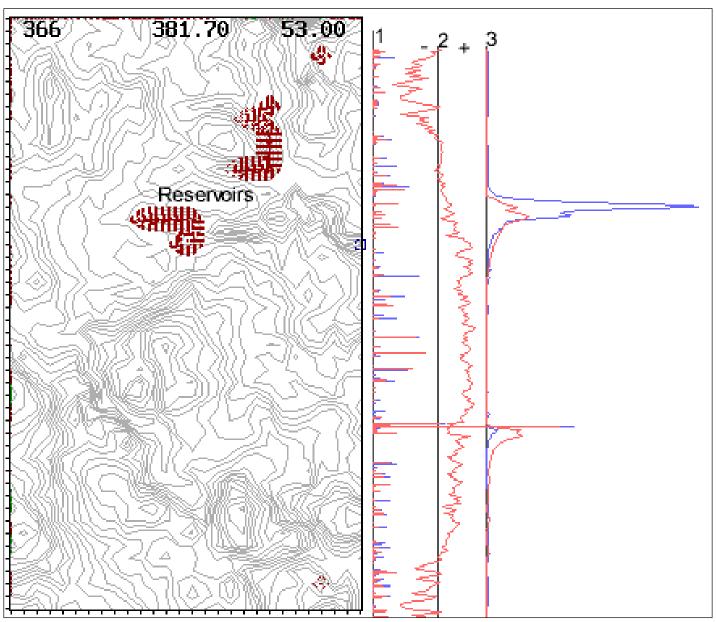

Figure 3. The continue of scenario simulation (Figure 2 – C). Snow melt and Rainfall peaks were mitigated by artificial reservoirs, where: 1 – 3 the same designations as at Figure 2. .Compare the Fig.2 -C with Fig.3 – C show reduction of flood peaks.

The simulation tools enable local or common changes of any matrix or parameter and for any temporal step. The vividly accompaniment by computer maps foster to rapid versatile scenario simulation.

5 CONCLUSIONS

The experience of River Basin simulation as of unified system shows the adequacy of the EM numerical method for the complex opened System. The model behavior is consistent to the prototype behavior.

Simulation of complex Nature System is done with simplified model, where some leading chosen factors are included in. The method of mass/energy balance calculation for opened non equilibrium systems must be adequate the systems properties. With the object of the system River Basin simulation is worked out two numerical methods (Genetic String or Evolution Matrix), where EM method is more appropriate for 2D River Basin simulation.

Numerical uncertainties coincide with non-stabilities in real systems, coincide with the real system uncertainties. Uncertainties of the model due to grid presentation of Elevation are in principle non eliminated. Uncertainties of initial Water Matrix condition can be essentially reduced. Calibration and verification of grid model is facilitated by vividly support by computer co-processing maps and by high speed run for many varied scenarios. Any 'side' or 'layer' of the simultaneous calculation may be shown at the screen for multi-objective applications. In future calibration should be done by usual optimization algorithms by any criteria. Calibration and verification of the Water Matrix was done by parameters optimization and preliminary results in 0.35 – 0.85 by R^2 criteria.

The model of the system do not consist of sub models, it is unified model of complex system, where various sides/layers are indivisible. Some example model applications are following: Flood Management, Land Use decision support, assessment of Pollution Spread, basin Monitoring support. Moreover, the tool is available for various scales: from Small Basin (10 m cell size) to Large River Basin (10 km). Change of scale changes spatial and temporal resolution, due changes of time for water flow through cell. Additional following parameters and forces must be included for Large Basins: any deformations of elevation, oscillations and trends of sea level, altitude and latitude air temperature stratification and necessity to input spatial distributed precipitation. The Large River Basin (RIDEC) model also includes Delta and Coastal Zone (Klenov, 1999b).

The possibilities of long time forecasting for pressure/impact consequences are not hopeless, because divergence of system phase trajectories is pressed by elevation inertia. Every external or internal pressure or impact nevertheless is irreversible. Moreover, numerical experiment shows that system response system on impact strongly depends on site location in the system. It make the task of forecasting extremely complex, with obligatory multiple versatile scenario simulation. Scenario experiences, forming of active images Database but verification is necessary for increasing of model prediction capacity and for Decision Support Systems.

REFERENCES

Ilya Prigogine, Isabella Stengers. "Order out of chaos," Heinemann, London, 1984.

Klenov, V.I.. "Computer Simulation of Geomorphic Systems," *Geomorphologia,* pp.39 –43, 1985.

Klenov, V.I. 1989, "Models simulation the Evolution of Elevation: Analysis, Reconstruction, Forecasting," *Geomorphologia*, 1, pp. 51 – 56, 1989.

Klenov, V.I., "Simulation of Erosion – Accumulation Processes in River Basins," *Proceedings of Abstracts and Papers (on CD –ROM) of the 3rd International Conference on Hydro-science and – Engineering*. Cottbus/Berlin, 1998.

Klenov, V.I. "Simulation of River Basin and Coastal Zone morpho-dynamics and evolution". *Proceedings on IAHR Symposium on River, Coastal and Estuarine Morphodynamics , (on CD-ROM),* Genova, Italy, 1999a.

Klenov, V.I., “River Basin Simulation for Flood forecasting and management,” *Coping with Floods: Lessons Learned from Recent Experience. Proceedings of NATO Advanced Research Workshop.* Malenovice, Czech Republic, 1999b.

Klenov, V.I., “RiverNet Simulation for Emergency Warning”. *XXYIII IAHR Congress. Hydraulic Engineering for sustainable Water Resources Management at the turn of the Millennium. Proceedings. Abstract Volume, Papers on CD-ROM.* Graz, Austria, 1999c.

Makkaveev, N. I., “Ruslo Reki I Erosia v ee basseine,” Moscow, AS USSR, 1955.

Nash, J.E., and Sutcliffe, J.V., “River flow forecasting through conceptual model,” *Journal of Hydrology*, 10, 1970.

Vladan Babovic and Michael B. Abbott, “The evolution of equations from hydraulic data,” *Journal of Hydraulic Research*, vol. 35, 3, pp.397 – 430, 1997.