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# Cellular automata algorithm for simulation of surface flows in large plains

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**Abstract**

A hydrological model based in the cellular automata paradigm, capable to handle extended geographical domains discretized in a large number of cells is presented. The automata simulates the natural surface water flow by tracking local water stocks, book-keeping precipitation, infiltration, evapotranspiration, and intercellular flows. The flow resistance is represented with a relaxation local parameter, which takes different values for the watercourses and the terrain. Likewise, an infiltration function regulates the downward movement of water. The model was tested in the Santa Catalina Creek Basin (158 km$^2$, centre Buenos Aires Province in Argentina), showing excellent performance in reproducing the effect of various rainfall scenarios.


*Keywords:* Cellular automata; Surface flow; Hydrological models; Flooding

## 1. Introduction

Simulations of surface flow in landscape models play an important driving role in floodplain management. Although considerable efforts have been spent in creating adequate models for various landscapes, still there is not a universal code that can be easily adapted for a wide range of applications. Therefore, substantial efforts are required to calibrate the existing models to the specifics of each landscape and the goals of each study.

In general, hydrologic models are part of more complicated modeling structures, therefore requiring simple algorithms to run within the framework of the entire ecological scenario. Consequently, some details should be sacrificed in order to make the numerical calculation feasible. An important trade-off in hydrologic models is the coarser spatial and temporal resolution that should be employed (kilometers and days), in contrast to small scale flows (meters and seconds).

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**Nomenclature**

| | |
|---|---|
| $h(x,y)$ | average vertical coordinate of spatial cell $(x,y)$ |
| $w(x,y)$ | water level in cell $(x,y)$ |
| $W_i^{\text{old}}$ | current water level of the *i*-cell |
| $H$ | equilibrium surface water height |
| $W$ | water volume of a partition divided by the unit-cell area |
| $w_i^{\text{drain}}$ | drained water level of the *i*-cell |
| $w_i^{\text{new}}$ | calculated water level of the *i*-cell |
| $\alpha_{\text{terrain}}$ | flow resistance relaxion parameter |
| $\alpha_{\text{river}}$ | flow resistance in the river cells |
| $I_n(x,y)$ | infiltrated water level in cell $(x,y)$ after $n$ steps |
| $I_0(x,y)$ | bias infiltration of cell $(x,y)$ |
| $\beta$ | soil saturation coefficient |

Presently, it is still not known what process representation should be included in a floodplain inundation model to achieve given levels of predictive ability. Ultimately, the best model will be the simplest one that provides relevant information while reasonably fitting the available data.

Any software tool aimed to tackle the mentioned problems should be designed taking into account that ultimately it will be used together with a set of other applications. Accordingly, generic input and output data formats should be used in order to enable the flexible management of information. The object-oriented methodology provides efficient solutions to these problems, supporting the implementation of reusable models and flexible data structures. In the fifties Ulam and Von Neumann [2] conceived the idea of an ingenious mathematical tool called cellular automata. They realized that certain complex phenomena might be simulated as assemblies of finite cells, which interact according to a small number of simple rules based on heuristic considerations. The interaction rules, generally applied to the immediate neighbors, may or may not bear a resemblance to the actual physical laws governing the phenomena at hand. However, for fluids, it was found that the statistical averages tend to the solution of the partial differential equations known to govern the situation – typically, the Navier–Stokes equation [10]. More recently, numerical simulations of sand piles have shown that complex systems amenable to representation by cellular automata, exhibit certain regularities in their global behavior, thus rising hope that quantitative laws might be formulated to encompass disparate phenomena: earthquakes, stock markets, weather, biological systems and fluids.

With the spreading of the software agent paradigm [9] as a by-product of the object orientation programming [7] new tools to tackle collective phenomena became available to the simulation community. Complex processes can be simulated as an assembly of finite entities that interact according to simple rules based on heuristic considerations [3].

In this article, a novel perspective in the modeling of surface flows in large plains, based on virtual landscapes created using cellular automata, is presented. The model is able to provide the evolution of the flow variables by tracking local water stocks, book-keeping precipitation, infiltration, evapotranspiration, and intercellular flows. Thus, while retaining the basic philosophy underlying cellular automata, a realistic model of surface flows is obtained, offering a useful tool for the modeling of floodings in plains.

## 2. The AQUA automata

The precipitations are stored in terrain depressions, forming shallow ponds and marshes. On sloping terrain this storage is generally negligible, but the amount of water accumulated in the local depressions of flat areas might substantially exceed the other terms of the water balance equation. The water exceeding the storage capacity of the depressions moves on the surface very slowly as sheet flow. Infiltration and evaporation is gen-