Name of model: HydroMan

1. Purpose

We present a simple spatially-explicit model that couples human and hydrological processes to explore the reciprocal relationships between shallow water tables and land cover decisions in flat agricultural landscapes. Our model, called HydroMan, represents the main hydrological processes that influence land-water relationships: planting decisions, rain, infiltration, evaporation, transpiration, and surface and groundwater flows.

2. Entities, state variables, and scales

The landscape is modeled after the Salado A Basin, a part of the Río de la Plata hydrographic system, in the Argentine Pampas, a flat agricultural area possessing strong climate variability. The landscape is represented as a square grid, with the size of lattice determined by the user, depending on the scenario chosen. The default size of each cell is one hectare (100 m x 100 m), but the size can be adjusted by the user. Each cell has a unique absolute elevation, which is determined by the scenario and expressed in meters above sea level. The absolute depth of the soil is the same for all cells: -100 m.

The soil of cells is divided into four separate zones: groundwater, capillary, upper, and root zones and is assumed to have three pore sizes. The small pores are assumed to be always saturated, but their water is unavailable for flow or evapotranspiration due to surface tension (matrix potential). The large pores are assumed to be always empty because of gravitational force, unless located in the groundwater zone, where they are fully saturated. Medium pores can show different degrees of saturation due to infiltration, evapotranspiration, or water transfers between horizons due to changes in the groundwater levels. The proportion of small, medium and large pores in the soil is set by the user.

The soil horizons are dynamic and their depths change as roots grow and groundwater flows horizontally and vertically. Other variables track water content in each horizon. In the groundwater zone, the large and medium pores are fully saturated. Soil in this zone is devoid of oxygen, so any portion of plant roots that reach into this zone will die. The capillary zone is the soil directly above the groundwater zone; for the typical soil type of the study region (i.e., sandy loam Mollisol), this was set as the 0.8 meters above the top of the groundwater zone. Its medium pores remain fully saturated, due to capillary action that draws water from the groundwater zone. Plants can draw water from this zone. The root zone is the top horizon. It is any part of the soil column above the capillary zone into which the plant's roots grow. At a minimum, the root zone is assumed to be 0.3 m in depth, limited by available soil column above the capillary zone, whether roots occupy that space or not, to represent the greater influence of evaporation close to the soil surface. Plants can draw water from the medium pores in the root zone for transpiration. The upper zone is any soil column between the capillary and root zones, to account for water that may be stored in the soil. This water will be available for transpiration as the root grows and expands the root zone into the upper zone, or will add to the groundwater as the water table rises into the upper zone. Water may also pond on the surface of cells, in addition to being stored in the soil.

Boundary conditions can be set to be open, where cells at the edge of the domain maintain a constant groundwater head during groundwater flow, or can be set to be closed, assuming that the landscape acts as a self-contained basin and no water can flow in or out through the edges.

Each cell of the landscape can have one of seven different land cover options throughout a year: pasture, maize, a cover crop of minimal economic value, wheat, regular soybean, short-cycle soybean, and fallow (no crop). Sowing decisions during a simulation determine the land cover at any point during a year for each cell. Each land cover type has unique daily values for water need for transpiration (Kcb, the basal crop coefficient) and rooting depth and critical growing periods when partial unmet water need directly affects. Soybean, maize, wheat and cover crops were assumed to be able to tolerate only seven consecutive days (it can be adjusted by the user between 0 and 10 days) without any water before dying, whereas pasture is more resilient and will never fully die once sown.

3. Process overview and scheduling

The model represents planting and growing seasons in Argentina (May 1 to April 30 in the Southern Hemisphere). Users determine the number of years in a simulation. One iteration represents one day, during which the processes outlined in Figure 1 below may occur. Daily precipitation values can be set using typical values for dry, average, or wet years, or historical data for a period of up to thirty years. Daily values for plant growth and evapotranspiration are typical values by land cover and day of the year.

Sowing decisions can be set by a few different ways. Farmers can plant the same crop on cells every year, cycle through different types of crop rotations, or make adaptive decisions that respond to the depth to the groundwater at key dates during a growing period. The procedure that farmers follow for adaptive decision making is in Figure 2 below. Regardless of how sowing decisions are made, the days when farmers sow crops are different for each land cover.

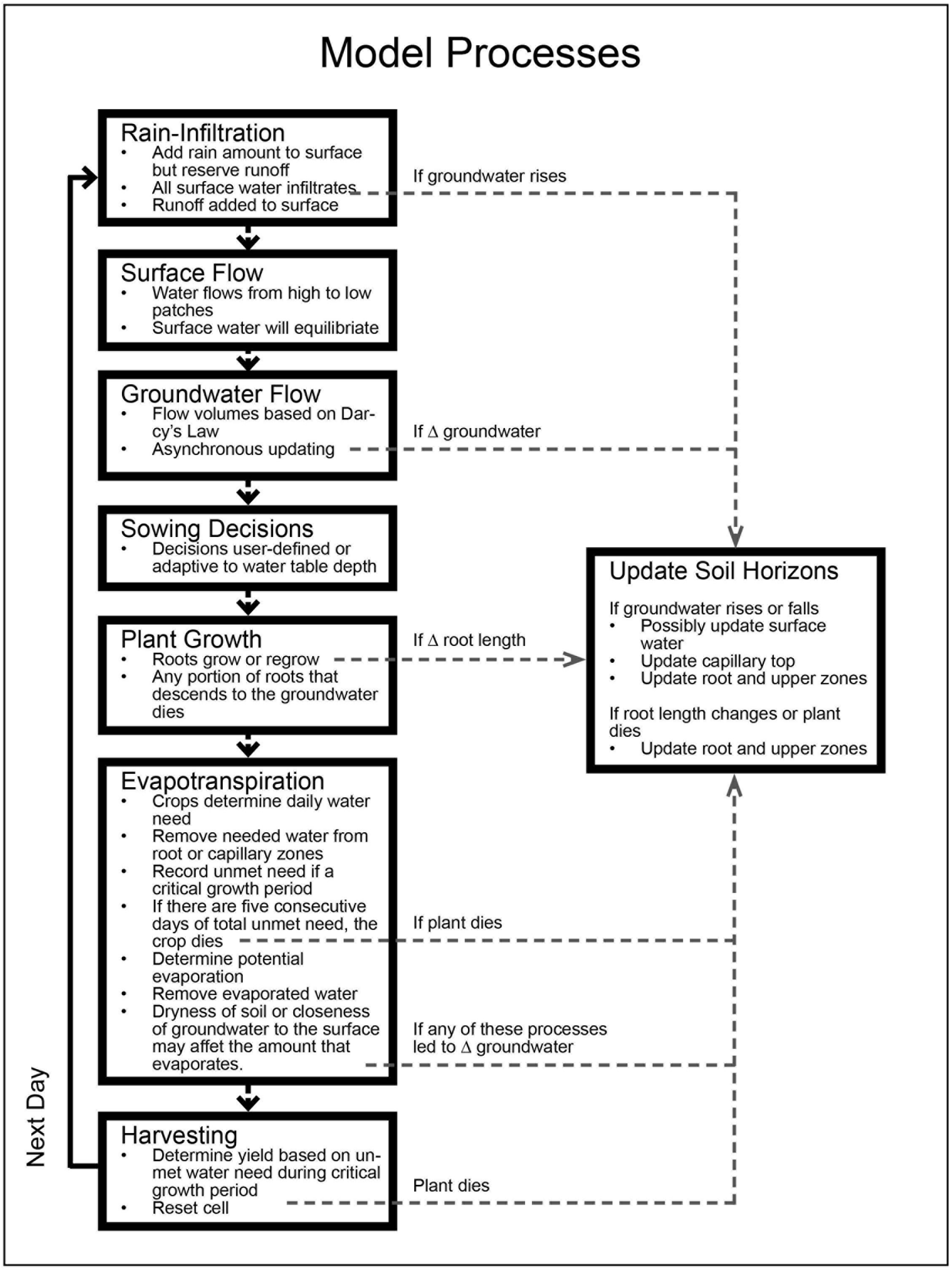

Figure 1: Processes represented by Hydroman and order of events in a given simulation

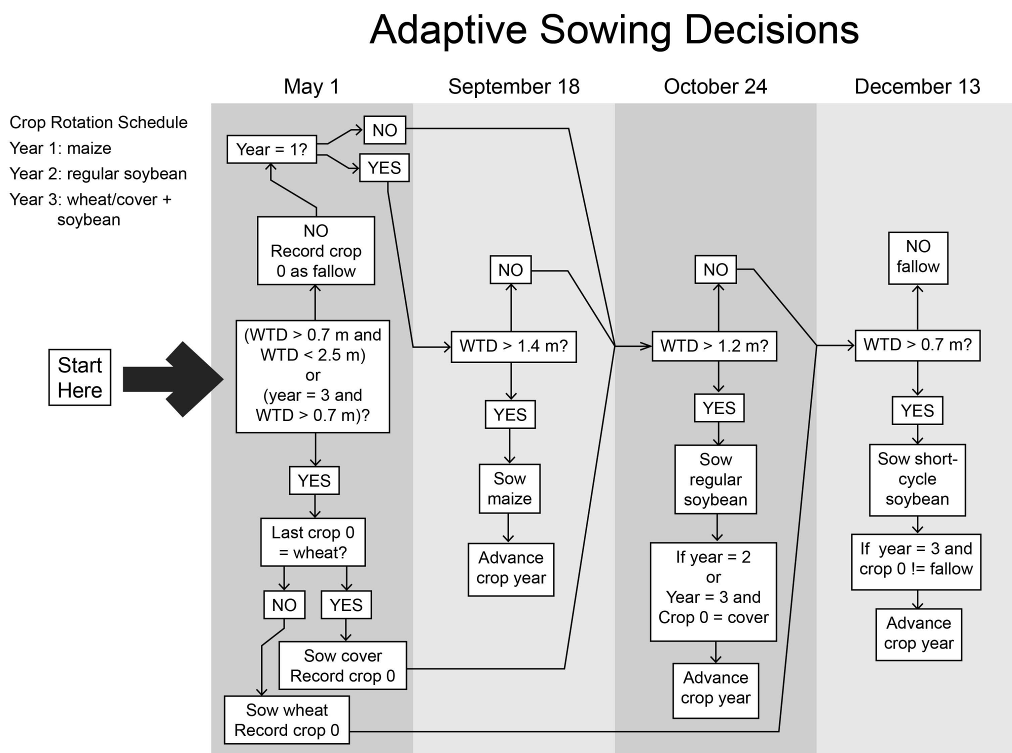

Figure 2: Adaptive sowing strategy

4. Design concepts

Basic principles. HydroMan seeks to provide insights about the interactions between climate, sowing decisions, and groundwater levels. The model is informed by existing groundwater models and studies about the agronomical practices of farmers. Empirical data from Pehuajo, in the Salado A Basin of Argentina, informed the model creation and allowed validation of hydrology and crop yields. The goal for the model was to develop policy recommendations about adaptive water management and agricultural production that can help minimize flooding and losses for farmers.

Emergence. While climate remains the main driver of water table depth, decisions on crops can influence water levels in different climate conditions. The timing of crops' critical periods relative to climate proved essential in both keeping water levels below the surface and in ensuring higher crop yields. Cells update their soil horizons and water content in response to evapotranspiration from crops and water flows from hydraulic differences.

Adaptation. In certain scenarios, farmers make planting decisions in response to water table depths, rather than strictly rotating crops or planting the same thing (see Figure 2).

Objectives. Success is represented in the ability to plant a crop.

Learning. This version of the model does not have any mechanism for learning, but will in the future.

Prediction. Prediction is assumed in the adaptive rules, when planting decisions are made based on water table depths at specific times of the year.

Sensing. Farmers only sense environmental factors when using adaptive plating decisions. Cells detect to the groundwater heads of neighboring cells and use that information to exchange water to simulate groundwater and surface water flow.

Interaction. Cells exchange water with each other as part of the groundwater and surface water flows.

Stochasticity. The only randomness in the model is the order with which cells exchange water when there is groundwater flow. The effect of this is negligible, since cells are shuffled every time water is exchanged throughout a simulation.

Collectives. There are no collectives in this model version.

Observation. Every iteration, cells export data related to sowing history and land cover (numbers of years each crop was planted, root length, unmet water need, and the yield for each crop), groundwater level, surface water height, soil horizons, amounts of water in each zone, and other water accounting measures (e.g., the amount of evapotranspiration)

5. Initialization

The initialization depends on the scenario. It can represent either a stylized landscape with a user-determined size and a uniform slope or an imported landscape with specific elevations for cells. Users set the initial groundwater level, which determines the initial water horizons (see Section 2). Other attributes, including saturation of medium pores, are set by the user.

6. Input data

Daily climate (rain amount, potential evapotranspiration) and land cover values (water need, root length, and potential root regrowth) are loaded from external files. Some scenarios also import from files the size, elevation and initial land covers of the landscape.

7. Submodels

See Section 4 for the order of events of the submodels.

Update soil horizons: If the groundwater level rises or falls, root length changes, or plants die, then the model will check to see if soil horizons need to be updated. This entails computing the top and bottom levels of each zone and transferring water between the zones.

Rain infiltration: Adds the daily rain amounts to the surface of cells, except for a portion that will be added later as runoff. All surface water attempts to infiltrate. If pores are full in the top zones, then water can make its way down to the groundwater zone. Runoff is then added to the surfaces of cells.

Surface flow: Each iteration, water flows from a high hydraulic head to a low hydraulic head. Since iterations are one day in length, surface water is assumed to reach an equilibrium level by the end of a day.

Groundwater flow: Cells exchange water with each other asynchronously. Flow volumes are based on Darcy's Law.

Sowing decisions: See Section 3, Figure 2.

Plant growth: Roots grow or regrow, depending on the daily values of their corresponding land covers. Any portion of the roots that reaches into the groundwater zone dies.

Evapotranspiration: Cells determine their daily water need based on a daily value corresponding to its land cover. This daily water need is removed from the root zone or from the capillary zone if the roots reach it. Cells will record any daily unmet water need if the plant is in a critical growth period (i.e., when adequate water for transpiration affects yield). All covers with the exception of pasture die if there have been seven days of total unmet water need. Cells will determine potential evaporation based on the daily potential evapotranspiration value and the amount transpired that day. Water will evaporate at higher rates when the soil contains more water. If the groundwater is close to the surface, water evaporates at higher rates.

Harvesting: At the end of a growing season for a land cover, the cells will determine the yield based on any unmet water demand during critical growth periods and then reset the cell to start a new cropping cycle.