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Testing the Stability of Coupled Hydrologic and Agricultural Systems to Changes in Climatic and Economic Conditions

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Long-term predictions of the water cycle in a watershed must account for the human factor. Agriculture is by far the largest water user, making up 70% of water use worldwide and over 95% of water use in Montana. Predicting agricultural water use is complicated because farmers make decisions based on climatic conditions, economic conditions, and personal preferences. Coupled models that account for both climate and agricultural economics are necessary to understand and predict the whole water cycle.

The impact of agriculture at the watershed scale is effectively determined by total agricultural area and crop water requirements, and ultimately comes to bear on the flows at the watershed outlet. In many watersheds total agricultural area is declining. As urban areas grow, the market value of agricultural land increases. If the value of a Farmer's land is higher than the expected return from the sale of crops, the land will likely be sold and divided into smaller parcels. This sell-off is influenced by climate conditions, which affect crop yields, and by economic conditions, such as crop prices or input costs. Accounting for these factors at the scale of individual farms is impractical, but at the scale of a watershed the sell-off of parcels could be statistically modeled to capture the overall behavior of the agricultural system. However, the agricultural parcel sizes of a watershed have a complicated distribution that is not easily represented statistically.

We have developed a method for representing agricultural land as a mixture of Gaussian distributions. Because the individual Gaussian distributions are symmetric, they can be propagated through linear models of agricultural economics that calculate the fraction of agricultural land for which market value exceeds expected returns. By assuming that this land is sold and ultimately converted to urban use, we can calibrate this model to reproduce an observed loss of agricultural land area over time. We have applied our model to the Bitterroot River Watershed, which is an ideal case study due to its strong agricultural economy and steady urban growth. We have been able to reproduce observed trends in agricultural land area, including accelerated sell-off during periods of prolonged dry weather. We use calibrated model to estimate the sensitivity of the system to climate scenarios, such as drought, and economic scenarios, such as reduced crop prices. The model is also used for stability analysis – under steady conditions the coupled models converge to an equilibrium point – highlighting potentially unsustainable combinations of climatic and economic conditions. These results further our ability to manage land and water resources in a way that can maintain both healthy agricultural economies and healthy flows in our rivers.