Optimizing Flood Irrigation to Flush Accumulated Salts through Zonal Flooding

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Problem Statement

In arid and semi-arid areas, efficient irrigation is defined as providing sufficient water for crop health, while minimizing water flow past the root zone. While this approach has clear benefits for water conservation, it necessarily leads to salt accumulation within the root zone. One approach to remediating salinization is to flood-irrigate fields periodically to drive salts to subsurface drains. To achieve efficient water use including flood irrigation periods, it is desirable to minimize the amount of water used for salt removal. In this study, we present a simple analysis that can help to design a zonal approach to flooding, which could greatly reduce water use compared to uniform flooding over an entire field.

Conclusions

With increasing pressure on water resources around the world, there is growing recognition of the need to balance efficient water use with maintenance of soil quality, in particular as it relates to salinization. The standard approach to treating salt accumulation is through periodic flushing. An accepted alternative is zonal flooding, where water is "swept" from the region farthest from the drain towards the drain. We consider these two approaches and a third approach, for which the flood area is decreased by removing areas close to the drain through time. Both zonal effects realize significant water savings. But, the decreasing zonal flush also reduces subsurface mixing, which may be advantageous if the salt (or other contaminant) is heterogeneously distributed.

Methods

We consider a rectangular domain bounded below by an impermeable boundary (Figure 1). We assume that there is a repeating series of horizontal drains, allowing for consideration of one half of the region between drains with zero flux vertical symmetry boundaries. We further assume that the system can be modeled using a sequence of steady state, saturated flow models because we expect that travel time through the vadose zone will be short compared to transport through the saturated zone and transport will be dominated by advection for the relatively high Infiltration rates used for flushing. The steady state flow model is written in MATLAB.

Previously, we showed laboratory dye tracer results that confirmed the pattern of water movement through the subsurface under full surface ponding (Figure 2). In this study, we examine the flow paths and associated travel times of particles released at the ground surface to a subsurface drain as a function of the pattern and timing of flooding. By comparing both the flow patterns and the particle residence times, we compare the efficacy of full surface flooding and two zonal flooding approaches.

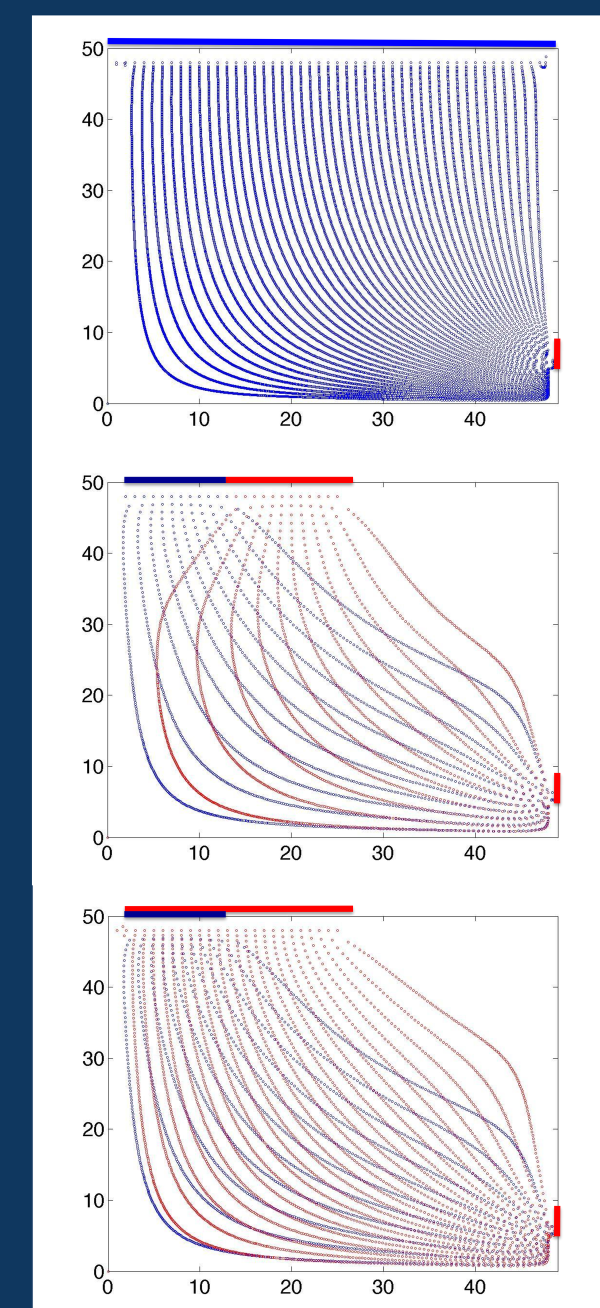

Fig. 1: Flow lines for: (top) full flooding; (middle) isolated non overlapping patch flooding; and (bottom) overlapping zonal flooding. The flooded area is shown on the top boundary as thick colored lines; the drain is a red line on the right boundary.

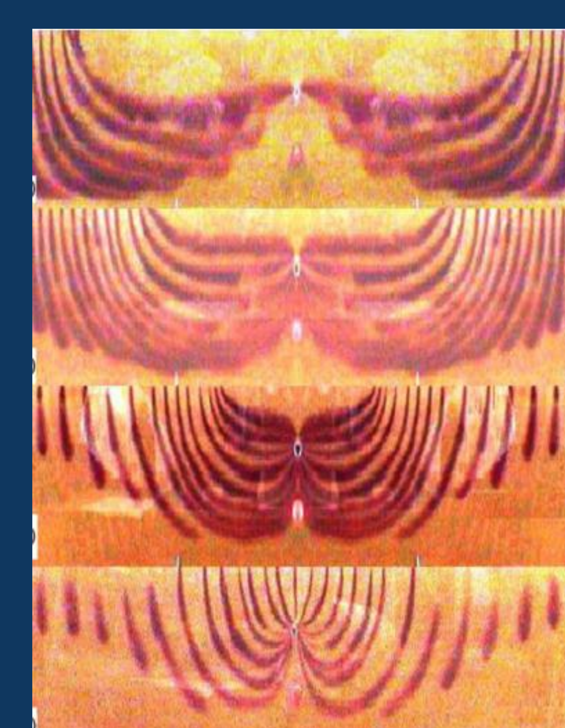

Fig. 2: Flow lines shown by dye tracer experiments in a laboratory sand tank to visualize water flow to a drain in response to 25% (top), 50%, 75% and full (bottom) flooding.

Results

The standard approach is full flooding of the surface (Fig. 1, top). Non overlapping flood areas lead to considerable overlap of flow lines, indicating significant flood-induced mixing. Overlapping flooded areas show less mixing, but more than full flooding. This could be important if the salt (or other contaminant) is not uniformly distributed in the subsurface, leading to spreading of the contaminant due to flooding.

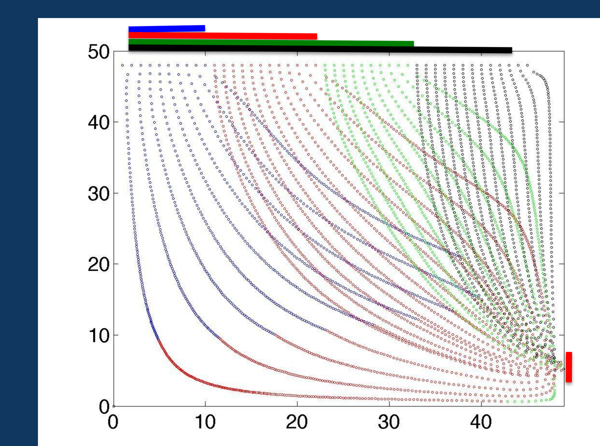

Fig. 3: Flow paths associated with zonal flooding: the initial flooded area is ¼ of the total area, located farthest from the drain. The flooded area increases through time. Each zone is flooded for ¼ of the time required to flush the subsurface using the full flooding approach.

The standard zonal flooding approach begins with a small area far from the drain and sequentially increase the flooded area. The flow paths associated with this sequence of zonal floods show a high degree of overlap (Figure 2). But, the area is completely flushed with 22% less water compared with full flooding.

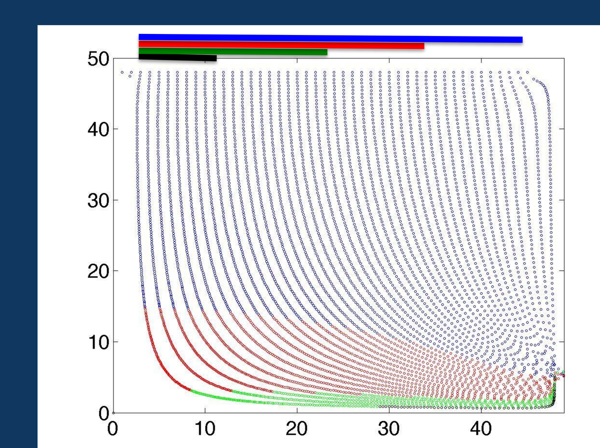

Fig. 4: Flow paths associated with zonal flooding: the initial flooded area is the total area, which is flooded for ¼ of the time required to flush the subsurface using the full flooding approach. The flush area is decreased, sequentially removing areas located closest to the drain. The reduced areas are flooded for 2%, 2%, and 31% of the full flush time.

We also examined zonal flooding beginning with full flooding and sequentially removing flooded areas closest to the drain. This approach maintained the particle tracks of full flooding almost exactly, minimizing the potential for mixing. This approach achieved full flushing with only 46% of the water used for full flooding.

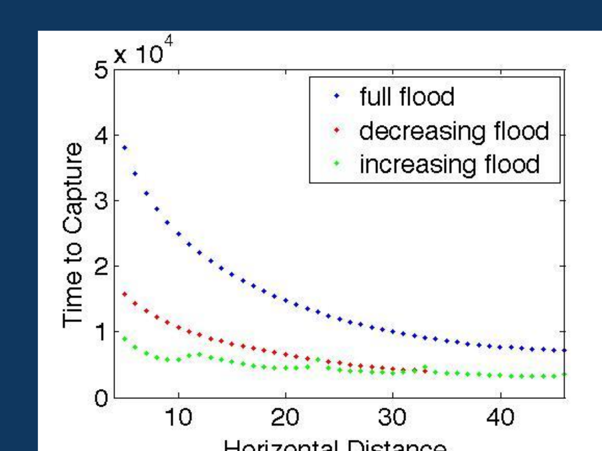

Fig. 5: Residence of particles released just below the ground surface at varying distances from the well for the three flooding scenarios examined.

Comparing the residence time of particles for the three approaches (full flooding, increasing flood area, and decreasing flood area) shows that the standard zonal approach leads to most rapid flushing. However, the performance difference between the zonal flooding approaches is small, so if there are other reasons to prefer reduced mixing in the subsurface, then the decreasing flooding approach may be preferred.

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