SIMULATED FILTRATION POND TO REMOVE *ESCHERICHIA COLI* FROM IRRIGATION WATER

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Abstract

The United States Food and Drug Administration's (FDA) proposed water rules to implement the Food Safety Modernization Act (FSMA) could leave some growers, especially those who rely on an irrigation system based on recycled water, unable to irrigate fresh produce with their irrigation water, especially those who rely on an irrigation system based on recycled water. Irrigation water could be treated with chlorine, ozone, or other product to reduce the bacterial load in the water; however, at present not one of these options has been approved by the Environmental Protection Agency for treating irrigation water. In an attempt to reduce the number of bacteria present in irrigation water entering a farm, a simulated filter pond was constructed using gravel, sand, and silt-loam soil. The filter pond sought to utilize in part what occurs naturally with the filtration of water through the soil profile. This natural process provides clean water in wells and aquifers. The simulated pond reduced the *Escherichia coli* load in water by 95% with a flow rate of 3.9 gal/h/yd^2. In order to increase the water productivity of the simulated filter pond, most of the dirt was removed; subsequently the *E. coli* filtration rate went to 55% and 46%, with flow rates of 12.9 gal/h/yd^2 and 17.6 gal/h/yd^2, respectively.

Background

The Food Safety Modernization Act, signed into law in January 2011, is the first major federal reevaluation of food safety since 1938. It charges the FDA with ensuring the safety of the U.S. food supply by acting preventively rather than reactively to foodborne illness outbreaks. One of the new regulations the FDA has proposed is an agricultural water standard that limits the amount of *E. coli* present in any water applied to the harvestable parts of fresh produce crops that are often consumed raw. According to the proposed rule, water for fresh fruit or vegetable production must not exceed 235 Colony Forming Units (CFU) per 100 mL and must not exceed 126 CFU/100 mL in a five-sample rolling geometric mean. The proposed rule allows either CFU or Most Probable Number (MPN) testing, "as appropriate" (FDA, 2013b). In this paper, we use CFU/100 mL as the units of the standard under the proposed rule, and we use MPN/100 mL as the units of our estimates of generic *E. coli* density in water, consistent with the method used for generic *E. coli.*

The proposed regulations would require that growers with surface irrigation water sources must test their water weekly. If either quantitative standard is exceeded, growers "must immediately discontinue use of that source of agricultural water and/or its distribution system for these uses and take specified follow-up actions. Follow-up actions include making changes to the system and re-testing, or treating the water" (FDA, 2013a).

This proposed agricultural water rule would likely apply broadly to growers in Eastern Oregon and Western Idaho who get their irrigation water from gravity systems that rely on recycling runoff water to provide enough of this scarce resource to all growers within the system. Excess water coming off of one field is caught in a drainage ditch and is fed to other fields or captured into a lower drain, carrying runoff sediment, nutrients, and bacteria with it. In turn, this water is frequently commingled with supply water in a design that ensures adequate quantity of flow. This leads to a buildup of *E. coli* and nutrients in the water delivered to subsequent fields that receive water that has already been used on a higher field. Water may be reused up to seven or eight times before being discharged into drain ditch or a river.

E. coli from surface deposits of manure do not routinely contaminate aquifers. Water from wells generally, and certainly in the Treasure Valley, have very low bacteria counts. The fact that clean water exists underground in spite of contamination above ground from corrals, pastures, and fields fertilized with manure shows that there is some combination of 1) limited survival of *E. coli* in soil and 2) natural filtration processes exist between the surface soil and the aquifers. Limited survival and natural filtration are broadly recognized in the literature, as we discuss below.

Research by Mankin et al. (2007) suggests that different soil types both absorb and release bacteria at different rates due to their structure. Mankin et al. found that silt-loam had both high absorption rate of *E. coli* and a high rate of retention when later rinsed, suggesting that silt-loam is effective in filtering *E. coli*. Mosaddeghi et al. (2009) found that soil type and structure played a pivotal role in the preferential flow of water, and thus the rate of soil infiltration by bacteria. They theorized that in fine-textured soils the water films may connect via larger spaces in the soil, effectively transporting bacteria.

To explore the possibility of a viable but cost effective method for *E. coli* removal, we investigated how water might be filtered through subsequent layers of soil, sand, and gravel. Since macropores can channel bacteria through soil (Mosaddeghi et al. 2009, Beven and German 1982), a soil-and-sand filter would need to be relatively homogenous to filter out bacteria. The World Health Organization has recommended designs of sand filters used for filtering contaminated water for human consumption (Huisman and Wood 1974). We built a simulated filtration pond and tested it for the possibility of partially reducing water *E. coli* content in growers' irrigation water to the levels acceptable in FDA's proposed rules.

Materials and Methods

A galvanized 300 gallon 8ft x 3ft x 2ft (1,136 L 2.4m x 0.9m x 0.6 m) stock water tank was used to simulate a filtration pond. An outlet plug on the side of the stock tank 4 inches (100 mm) from the bottom was a standard element of this commercially obtained product. Mimicking other filter designs, the bottom 8 inches (200 mm) of the tank were filled with 2-inch gravel for drainage. The gravel was covered with two layers of gray landscape fabric (Landmaster Commercial Weed Control Fabric, Professional Grade, Waco, TX). Four inches of sand for filtration were placed on top of the landscape fabric. The sand layer became 3 5/16 (8.5 cm) thick once it was flooded with water. Four inches (100 mm) of Owyhee silt-loam soil (34% sand, 66% silt) were added on top of the sand to provide filtration for silt-sized particles such as *E. coli* (Figure 1).

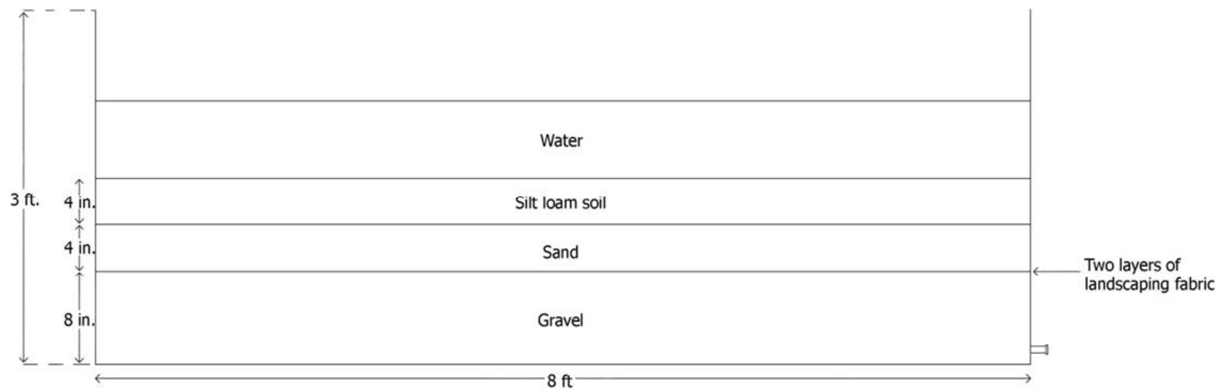

Figure 1. Schematic showing the layers of the simulated filtration pond. Oregon State University Malheur Experiment Station, 2013.

An assembly of PVC piping was attached to the manufactured outlet (Figure 2). This assembly was built upward such that the outlet valve was above the soil layer, reducing the pressure gradient from the surface of the water to the height of the outlet of the tank. The reduced pressure drop (4 ¾ inches (120 mm) from the top of the water in the tank and the level of water at the outflow) was intended to maintain a saturated system regardless of flow rate to avoid letting air in and to avoid water pressure developing paths of preferential water flow through the silt-loam and sand layers of the filter.

Figure 2 – Photograph showing the outlet of the simulated filtration pond constructed at Oregon State University Malheur Experiment Station, 2013.

The tank was filled continually with ditch water supplied via a length of 2-inch layflat hose with a gate valve starting on 23 August 2013. The rate of water flow entering the tank was matched to the rate of flow exiting the tank by manual operation of the gate valve. The flow rate was allowed to stabilize over 24 hours before any samples were taken. To increase the *E. coli* present in the irrigation water, surface irrigation was intentionally applied across a pasture upstream and recaptured in a lower irrigation ditch prior to intake of the 2 inch layflat hose. Water flow rates and amounts were not recorded except during measurement cycles.

Inflow and outflow water samples were collected every hour or half hour subject to constraints on irrigation water availability. At the same times that water samples were taken, water flow rates out of the tank were recorded. Samples and flow rate measurements were taken on August 27th, September 3rd and September 10th. Water samples were kept refrigerated and were transported the same day to Western Laboratories, Parma, ID, where *E. coli* count was estimated using a Most Probable Number (MPN) *IDEXX Colilert® +Quanti-Tray/2000®* (IDEXX Laboratories, Westbrook, ME).

After the flow rate was measured at 8.7 gallons/hour (32.9 liters/hour) during the first test on August 27th, in an attempt to increase the water flow, most of the soil was removed on September 2nd leaving a soil layer 1 3/8 in (35 mm) thick. Inflow and outflow water samples were taken again on September 3rd and September 10th.

Results

The first set of 2 samples taken on August 27th 2013 showed a mean of 1483 MPN of *E. coli* per 100 ml in the source water and 77 MPN/100ml in the water passing through the simulated filtration pond, an average reduction of 95% (table 1). The flow rate through the filter was measured at 8.7 gallons/hour (32.9 liters/hour).

Table 1 – Partial purification of irrigation water using a simulated filtration pond comparing *E. coli* counts in irrigation ditch inflow water and filtered output water, Oregon State University Malheur Experiment Station, August 27, 2013.

Sample	**Inflow, *E. Coli***	**Outflow, *E. coli***	**Reduction**	**Tank flow rate**	**Flow rate per area**
	MPN/100 ml		**%**	gal/h	gal/h/yd^2
1	1553	69		8.604	3.9
2	1414	86		8.772	3.9
Average	**1483**	**77**	**94.8**	**8.688**	**3.9**

Samples taken on September 3rd 2013 showed 456 MPN/100ml in the source water and 206 MPN/100ml in the filtered water, a reduction of 52% (table 2). The flow rate was measured at of 28.8 gallons/hour (109 liters/hour) or 12.9 gal/h/yd^2 of tank surface area.

Table 2 - Partial purification of irrigation water using a simulated filtration pond comparing E. coli counts in the irrigation ditch inflow water and filtered output water, Oregon State University Malheur Experiment Station, September 3, 2013.

Sample	**Inflow, *E. Coli***	**Outflow, *E. coli***	**Reduction**	**Tank flow rate**	**Flow rate per area**
	MPN/100 ml		**%**	gal/h	gal/h/yd^2
1	411	308		27.3	12.3
2	649	167		28.2	12.7
3	308	137		31.2	14.0
4	461	210		28.2	12.7
Average	**457**	**205**	**55.1**	**28.8**	**12.9**

Samples taken on September 10th 2013 showed 167 MPN/100ml in the source water and 90 MPN/100ml in the filtered water, a reduction of 46% (table 3). The flow rate was measured at 39.3 gallons/hour (149 liters/hour) or 17.6 gal/h/yd^2 of tank surface area.

Table 3 - Partial purification of irrigation water using a simulated filtration pond comparing *E. coli* counts in irrigation ditch inflow water and filtered output water, Oregon State University Malheur Experiment Station, September 10, 2013.

Sample	**Inflow, *E. Coli***	**Outflow, *E. coli***	**Reduction**	**Tank flow rate**	**Flow rate per area**
	MPN/100 ml		**%**	gal/h	gal/h/yd^2
1	186	86		37.6	16.9
2	148	91		34.8	15.6
3	213	93		34.8	15.6
4	122	91		50.2	22.5
Average	**167**	**90**	**46.1**	**39.3**	**17.6**

Discussion

Despite efforts to maintain consistent conditions, the *E. coli* in the surface irrigation water varied greatly by day. *E. coli* numbers were consistently lower in the filtered water filtered than in the irrigation ditch water source. Well over 90% of the *E. coli* was filtered out with the presence of a four-inch silt-loam soil layer, but at the cost of flow rate (Table 1). The proposed regulation suggests that agricultural irrigation water only need be less than 235 CFUs of *E. coli* per 100ml of water, so the additional filtration provided by 4 inches of silt loam which provided concentrations less than half of this value might not be needed and thus unnecessarily sacrificing flow through the filter. The units of most probable number (MPN per 100ml of water) are an estimate of CFU per 100ml of water. With a much shallower soil layer, the simulated filtration pond still kept the *E. coli* levels below the FDA's proposed agricultural water rules of 235 MPN/100ml in all but one sample (Sample 1 on Sept. 2nd), and increased flow rates by over three-fold.

According to Mankin et al. (2009), sand has a lower *E. coli* adsorption and retention rate than silt-loam soil. This suggests that a filter containing only sand and gravel would have limited effectiveness in filtering *E. coli*. However, the water in a gravity delivery system carries sediment with it, perhaps contributing to the effectiveness of a filter containing only sand and gravel by depositing soil on the surface of the sand filter. It is important to note that the slow sand filtration described by Huisman and Wood (1974) relies on a low flow rate, development of an undisturbed bio-film atop the filter to trap and kill bacteria, and a microbial community living underneath the bio-film to digest the resultant organic debris, completing the purification process. The integrity of the bio-film relies on a low flow across the film, so a biofilm method may not be effective for a high flow rate scenario, such as agricultural water purification.

Growers in this region might experiment with filtration ponds without soil layers. Sediment in the water would gradually fill the pores in the sand, creating an effective *E. coli* filter. The sand contained 2 percent silt at the end of the experiment. For further research, we suggest varying the composition of the filter. Different soil compositions may have different filtering capacities.

Perhaps a mat of small plants on a thin layer of soil might increase filtration; however, the roots of the plants could eventually establish routes for *E. coli* to bypass the filter. More investigation into the dynamics and materials of pond or even thin layer filtration of *E. coli* is needed to establish possible viable designs for field use.

Although filtration might be more efficient with sand on top of the silt, the practical reality is that the operation of a filtration pond on a farm in Malheur County would result in the continual deposit of silty soil into the pond. The pond would eventually need to be maintained by partial removal of the accumulated soil.

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