Components of Irrigation Water Budget Related Sprinkler Application

Irrigation Application Method Conversion

Because rates of irrigation diversion and of groundwater recharge incidental to irrigation are both dependent upon irrigation application method, we developed a descriptive statistical model of the temporal conversion from surface application (flood and sub-irrigation) to sprinkler application. No detailed data on conversion from surface to sprinkler application methods have been compiled for the Henry’s Fork watershed, but data based on examination of aerial photographs and satellite images have been published for other areas in southeastern Idaho (Contor 2004). We assumed that the temporal patterns of irrigation application conversion in the Henry’s Fork were similar to those quantified by Contor (2004), and thus we fit statistical models to Contor’s (2004) data. In general, this temporal pattern is one in which no land was irrigated with sprinklers prior to the 1960s, and the fraction of land under sprinkler irrigation increased continuously over time to its current value of about 90% (Figure 1).

![Figure 1. Data from Contor (2004).](image)

Because this data set consisted of only six data points, we used an information-theoretic approach rather than data exploration to determine the best descriptive model (Burnham and Anderson 2002). The response variable was the fraction of irrigated agricultural land under sprinkler irrigation in a given year, which is denoted by \( p(t) \). We proposed three candidate models of the form

\[
p(t) = \frac{1}{1 + \exp(-a - bf(t) - \varepsilon)}
\]

where \( f(t) \) is a strictly increasing function of year \( t \), \( a \) and \( b \) are coefficients to be estimated statistically (\( b > 0 \) for the case in which \( p(t) \) increases with \( t \)), and \( \varepsilon \) is a random, normally distributed error variable with mean zero. In general, Equation (1) describes a sigmoidal dependence of \( p \) on \( t \) in
which \( p(t) \to 0 \) for \( t \) sufficiently small and \( p(t) \to 1 \) as \( t \) becomes large. Equation (1) is algebraically equivalent to

\[
\log_e \left( \frac{p(t)}{1 - p(t)} \right) = a + bf(t) + \varepsilon,
\]

so that the statistical estimation can be performed by linear regression of \( \log_e \left( \frac{p(t)}{1 - p(t)} \right) \) versus \( f(t) \), which yields unbiased coefficient estimates and diagnostic statistics provided that the residuals \( \varepsilon \) are normally distributed.

The three models consisted were defined by specifying three choices for \( f(t) \). The two choices for \( f(t) \) were \( f(t) = t, f(t) = \log_e(t - 1969) \), and \( f(t) = \log_e(t - 1978) \) When \( f(t) = t \), equation (1) is a logistic function in which \( p(t) \to 0 \) only the limit as \( t \to -\infty \). When \( f(t) = \log_e(t - 1969) \), equation (1) becomes a rational function in \( t \) in which \( p(t) = 0 \) in the year 1969. We chose 1969 because the earliest irrigation method conversion project in the study area of which we are aware was the conversion of the Trail Creek irrigation system from a traditional canal-and-flood system to a pipeline-and-sprinkler system. This project began in the late 1960s and was completed by the early 1970s. The third choice forces \( p(t) = 0 \) in the year 1978. Even though we know that the Trail Creek project began in the late 1960s, Contor’s (2004) data suggest that conversion progressed very rapidly over a short period of time in the 1980s. The choice of 1978 assumes that essentially no land was in sprinkler irrigation prior to the first year of our model time frame, which is 1979. Proposal of these three models allowed us to use the standard logistic function as a “null” model to which to compare the hypotheses that the fraction of land under sprinkler irrigation was essentially zero prior to 1970 or 1979, respectively.

The AICc analysis showed that there was essentially no evidence for the null model (Table 1). The model in which \( f(t) = \log_e(t - 1978) \) had 90% of the model weight, suggesting that the fraction of land in sprinkler irrigation was very small prior to 1979. Thus, we chose this as our best descriptive model of conversion from surface to sprinkler irrigation application methods. The predictive equation is

\[
p(t) = \frac{1}{1 + \exp(1.79 - 1.17\log_e(t - 1978))} = \frac{(t - 1978)^{1.17}}{(t - 1978)^{1.17} + 5.99}, \tag{3}
\]

where \( t \) is in years (Figure 1). Adjusted \( R^2 \) for this model was 90.8%. A normal probability plot showed that the residuals from this model were normally distributed (Figure 2). A plot of the three fitted models clearly shows that models 1 and 2 overestimate the observed values in the 1970s and underestimate them in the last decade, resulting in a systematic bias between predicted and observed values. The selected best model predicts a value of 89% of land in sprinkler irrigation in 2011, consistent with our field observations.
Table 1. Results of model comparison for temporal conversion of irrigation methods to sprinkler application.

<table>
<thead>
<tr>
<th>Model</th>
<th>$f(t)$</th>
<th>Number of parameters</th>
<th>$\Delta AIC$</th>
<th>$AIC_C$ weight</th>
<th>Evidence ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>$\log_e(t - 1978)$</td>
<td>3</td>
<td>0</td>
<td>0.90</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>$\log_e(t - 1969)$</td>
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<td>4.89</td>
<td>0.08</td>
<td>11.3</td>
</tr>
<tr>
<td>1</td>
<td>$t$</td>
<td>3</td>
<td>7.31</td>
<td>0.02</td>
<td>45.0</td>
</tr>
</tbody>
</table>

Figure 2. Normal probability plot of residuals from the model given by equation (3).

Figure 3. Observed (Contor 2004) and predicted fraction of land in sprinkler irrigation.
Estimation of evaporative loss from sprinkler application

Over the past 60 years, a large body of research has been devoted to estimating evaporative loss from irrigation sprinklers. Loss estimates reported in the literature vary widely, from less than 1% to over 45% (Kohl et al. 1987). Losses depend on temperature of both the air and applied water, humidity, wind, physical characteristics of the droplets, and whether the losses are calculated for a single sprinkler or over an entire field irrigated by more than one sprinkler (Frost and Schwalen 1955, Lorenzini 2002, Lorenzini 2004, Tarjeulo et al. 2000, Yazar 1984). Generally, estimated losses due to drift and evaporation are larger under conditions of low humidity, high temperature, high winds, and smaller droplet sizes. Losses aggregated over fields are much lower than those measured for individual sprinklers. Reported loss rates also depend on the definition used to define loss and the methods used to quantify loss (Kohl et al. 1987).

Using changes in isotopic composition between the source water and that collected in catch cans distributed across an irrigated field, Kohl et al. (1987) estimated evaporative losses at less than 1.5% of applied water, consistent with theoretical analyses and laboratory studies. They concluded that most studies greatly overestimate the fraction of evaporative loss because of measurement error and definitions that include other sources of loss. Thompson et al. (1997) provided a careful accounting of all losses associated with sprinkler irrigation application, based on a controlled, field-scale experiment performed over the course of an entire day under irrigation conditions typical of those used on-farm. Canopy evaporation, transpiration, and soil evaporation were greater under sprinkler irrigation than in the control fields (no irrigation), but because irrigation reduced transpiration, the net increase in consumptive use of water over the course of the day was only 2.4% for spray irrigation and 5.8% for impact sprinklers. Less than 1% of consumptive use was attributable to droplet evaporation between the nozzle and the plant or soil surface. The “Actual ET” values calculated and provided by Allen and Robison (2007) for irrigated crops in Idaho account for all sources of evapotranspiration associated with irrigation once the water is applied to the crops. Thus, the only component absent from their figures is loss due to drift and/or evaporation between the nozzle and the plant/soil surface.

Based on the literature, I have chosen to use 2% of water applied by sprinkler irrigation as the evaporative/drift loss due to sprinkler application of irrigation water. This is consistent with the 1.6-2.6% figures calculated by Weaver (2009) for evaporation loss associated with spray washing of gravel in Rexburg, ID, within the Henry’s Fork study area. Thus, in the revised water budget calculations and in the Teton Valley groundwater-surface water model, the amount of water delivered (after conveyance losses) to fields is multiplied by the sprinkler fraction predicted by equation (3) to estimate the fraction applied by sprinklers, and that amount is multiplied by 2% to compute sprinkler evaporative loss.

References


