Economic Rivalry, Irrigation Abstraction, And Partition to Fates

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September 2014

B. Contor and Dr. R. G. Taylor
• 1992
  • 58 hectares
  • Groundwater source
  • Hand lines & wheel lines
  • 70% consumptive-use fraction of field-applied water

• 2014
  • 56 hectares
  • Groundwater source
  • Mostly pivots
  • Mostly 85% consumptive-use fraction of field-applied water
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Is this Improvement?
How do we assess irrigation improvements?

- Consider Irrigator Response
- Close the Water Budget
- Consider Economic Rivalry
- Do the Numbers
Consider Irrigator Response
Supply and Demand

Marginal Cost ($/volume)

Depth (mm)

D2 D1
Consider Irrigator Response
Consider Irrigator Response

Supply and Demand

Marginal Cost ($/volume)

Depth (mm)

S2

shortage

D2

D1

0 200 400 600 800 1000 1200 1400 1600

0 0.2 0.4 0.6 0.8 1 1.2
• 1992
  • 58 hectares
    • 47 hectares barley
    • 12 hectares alfalfa

• 2014
  • 56 hectares – all alfalfa
Close the Water Budget
Transpiration

Evaporation

Surface Runoff

Percolation Below Root Zone
Transpiration

Evaporation

Surface Runoff

Percolation To Non-Usable Aquifers (or unused?)
Take Home Messages:

• It is not complicated
• It MUST be sorted out
- Abstraction (i.e. diversion)
  - Decreased after improvement (case specific)
- Transpiration
  - Increased after improvement (typical)
  - Lost to basin
- Evaporation
  - Increase or decrease?
  - Lost to basin
- Runoff
  - Typically would decrease
  - None in this case
- Percolation
  - Typically would decrease
  - Returns to pumped aquifer
Consider Rivalry
Take Home Messages:
- It is complicated
- It can be sorted out
- It MUST be sorted out
• Rivalry
  • The aquifer is connected to the springs that supply aquaculture

• Therefore: The increase in net consumptive use is **rival** to aquaculture
Do the Numbers
• 1992
  • 617 K m$^3$ pumping
  • 432 K m$^3$ consumptive
  • 0.7 tonne/K m$^3$ pumping (alfalfa)
  • 1.0 tonne/K m$^3$ consumptive (alfalfa)

• 2014
  • 611 K m$^3$ pumping
  • 502 K m$^3$ consumptive
  • 0.9 tonne/K m$^3$ pumping
  • 1.2 tonne/ K m$^3$ consumptive
Is this Improvement?

- 16% increase in consumptive use
- Rival to aquaculture
- 20 – 30% increase in “crop per drop”
Is this Improvement?

- 16% increase in consumptive use
- Rival to aquaculture
- 20 – 30% increase in “crop per drop”

*NOT related to irrigation improvements*
How to assess irrigation improvements:

• Consider Irrigator Response
• Close the Water Budget
• Consider Economic Rivalry
• Do the Numbers
Thank You

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Backup Slides
IRRIGATION DEMAND CALCULATOR:
Spreadsheet Tool for Estimating Economic Demand for
Irrigation Water

University of Idaho
Idaho Water Resources Research Institute

Bryce A. Contor
Garth Taylor
Greg L. Moore

August 2008

Idaho Water Resources Research Institute Technical Report 200803
REFERENCES


Cook, Zena, Joel Hamilton, Leroi Stodick and R. G. Taylor. Spatial Equilibrium of


Spreadsheet Tool: Economic Demand for Irrigation Water
### One-crop Demand per Unit Area (1 Hectare)

<table>
<thead>
<tr>
<th>Column</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>ETm: Evapotranspiration depth at full yield</td>
<td>914 mm</td>
</tr>
<tr>
<td>C3</td>
<td>Im: Irrigation depth at max yield</td>
<td>1328 mm</td>
</tr>
<tr>
<td>D3</td>
<td>Ym: Yield/area at full irrigation</td>
<td>13.5 metric ton/ha</td>
</tr>
<tr>
<td>E3</td>
<td>Yd: Yield/area rainfed (dryland)</td>
<td>3.692560175 metric ton</td>
</tr>
<tr>
<td>F3</td>
<td>Fm: Commodity price at full irrigation, currency units per yield unit</td>
<td>110.00 $/metric ton</td>
</tr>
<tr>
<td>G3</td>
<td>z: Exponent for price relationship (Pc/Pm) = (Y/Ym)^z</td>
<td>0.1</td>
</tr>
<tr>
<td>H3</td>
<td>K: Yield/ET coefficient, yield units/mm</td>
<td>0.014770241</td>
</tr>
<tr>
<td>I3</td>
<td>ETd: Dryland ET = effective precipitation</td>
<td>250 mm</td>
</tr>
<tr>
<td>J3</td>
<td>B: CU fraction of applied irrigation water at full irrigation</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Graph: Willingness to Pay for Irrigation Water**

- **Crop Name**: Name
- **ETm**: 914 mm
- **Im**: 1328 mm
- **Ym**: 13.5 metric ton/ha
- **Yd**: 3.692560175 metric ton
- **Fm**: 110.00 $/metric ton
- **z**: 0.1
- **K**: 0.014770241
- **ETd**: 250 mm
- **B**: 0.5

**Graph: Crop Yield**

- **I**: 500 mm
- **Y**: 9.5 metric ton
- **Pw**: 0.11 currency/m^3
Willingness to Pay for Irrigation Water

Commodity Price/Yield Relationship
(when yield reduction is from water stress)

Crop Yield

Consumptive Use From Irrigation

(1 meter depth = 10,000 m^3 on one hectare)
<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
</table>
| CU fraction of applied irrigation water at full irrigation (this is one definition of irrig.
| Irrigation depth
| Yield/hectare
| Commodity price
| Gross revenue/hectare

<table>
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<tr>
<th>Name</th>
<th>914 mm</th>
<th>1328 mm</th>
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**Willingness to Pay for Irrigation Water**

- **Pw (currency/meter-3) vs. Irrigation depth (I, meters)**
  - (1 meter depth = 10,000 m3 on one hectare)

**Crop Yield**

- **Units/Hectare**
  - **500 mm**
  - **9.5 metric ton**
  - **0.11 currency/m^3**
A = irrigated area, acres
Pwv = Price of water, dollars/acre foot
Pc = Price of crop, dollars/crop unit
a = 1/B
R = Revenue, dollars/acre
Pm = Price of crop at full irrigation, dollars/crop unit
z = price exponent

Relationship between transpired water and dry-matter yield.

The relationship between full-season transpired water and dry-matter yield was described as approximately linear by Doorenbos et al. (1979; see also Allen et al. 2002 (FAO56)). This relationship generally applies to the full-season growth of agronomic crops, across a wide range of crop types and climate regimes. Some imprecision is introduced by considering a harvested portion that is not the entire plant (for instance, harvesting only seeds or fruit) and by combining evaporation with transpiration. However, a linear relationship still generally describes crop yield as a function of evapotranspiration. The relationship terminates at an upper limit of yield and evapotranspiration determined by agronomic characteristics of the crop and site-specific constraints such as soils, solar radiation, temperature and day length. It may be expressed as:

\[(C1) \ Y = K1 \ (ET)\]

Relationship between applied irrigation water and crop yield.

No irrigation system is 100% efficient; if any meaningful quantity of water is delivered to an irrigated parcel, some of it is lost to other fates besides supporting crop evapotranspiration. Empirically and intuitively, we see that as irrigation depth increases, a smaller and smaller fraction is devoted to evapotranspiration and a larger and larger fraction is lost. At some depth of application, additional application of water begins to reduce yield. This is a classic example of decreasing marginal returns to a production input. The consequence is that, while the production function for transpired water is linear, the production function for applied water is non-linear. The first derivative is monotonically decreasing with increased application depth.

Only the rising portion of the production function (first derivative positive) is of interest for economic analysis, since rational producers will never enter the region beyond zero marginal production. For this rising portion of the yield/applied water function:
First derivative is monotonically decreasing with increased application depth.

Only the rising portion of the production function (first derivative positive) is of interest for economic analysis, since rational producers will never enter the region beyond zero marginal production. For this rising portion of the yield/applied water relationship, an elegant production function by Martin et al (1984, 1989) incorporates the linear yield/evapotranspiration relationship of Doorenbos et al (1979) with the consumptive-use fraction considerations described above. It expresses the relationship in terms of dryland and full-irrigation yield characteristics. Equation (C2a) is the original presentation. Equation (C2b) rearranges terms and makes one substitution for convenience:

(C2a) \( Y = Y_d + (Y_m - Y_d) \left[ 1 - \left(1 - I/I_m\right)^{1/B}\right] \)
(C2b) \( Y = Y_m - (Y_m - Y_d) \left(1 - I/I_m\right)^a \)

Relationship between applied water and commodity price.

For some irrigated crops the value of dry matter production is essentially independent of crop yield. For other crops, as water stress reduces yield, quality and therefore commodity price also decline dramatically. As a first approximation, equations (C3a) and (C3b) express commodity price as a function of water-reduced crop yield, though research is needed into the proper functional form of this relationship.

(C3a) \( \frac{P_c}{P_m} = \left(\frac{Y}{Y_m}\right)^z \)
(C3b) \( P_c = P_m \left(\frac{Y}{Y_m}\right)^z \)

Low values of "z" correspond to crops whose value is insensitive to irrigation adequacy, such as pasture and forage. Higher values correspond to crops where quality and price are sensitive to adequacy.

Multiplying Equation (C2) by commodity price to obtain revenue generates a function that expresses revenue as a function of application depth. The first derivative is the marginal production value, which we assume here to be the marginal utility and therefore the economic demand. Contor et al (2008) derived a demand equation that assumed a constant commodity price (i.e. parameter "z" equals zero). However, it is more correct to instead use the yield-dependent price defined by equation (C3b).
Since gross crop revenue is price times yield, per-acre revenue is:

\[(C6) \quad R = P_c \cdot Y\]

By the product rule, the partial derivative of per-acre revenue with respect to irrigation depth is:

\[(C7) \quad \frac{dR}{dI} = P_c \frac{dY}{dI} + Y \left( \frac{dP_c}{dI} \right), \text{ or in other words} \]
\[(C8) \quad \frac{dR}{dI} = \bigg[ \text{Equation (C3b) times Equation (C4)} \bigg] \text{ plus} \]
\[\bigg[ \text{Equation (C2b) times Equation (C5)} \bigg] \]

This can be expressed as:

\[(C9) \quad \frac{dR}{dI} = P_m \left[ \frac{(Y_m - (Y_m - Y_d) (1 - I/I_m)^a)}{Y_m} \right]^z \times \]
\[\left[ \frac{(a/I_m) (Y_m - Y_d) (1 - I/I_m)^{a-1}}{} \right] \times \]
\[\left[ Y_m - (Y_m - Y_d) (1 - (I/I_m))^a \right] \times \]
\[\left[ z \cdot P_m \left[ 1 - (1 - Y_d/Y_m) (1 - I/I_m)^a \right]^{z-1} \right] \times \]
\[\left[ \frac{(a/I_m) (1 - Y_d/Y_m) (1 - I/I_m)^{a-1}}{} \right] \]

Equation (C9) gives the per-acre demand for irrigation water depth for a single crop. For practical use, it requires conditional constraints to avoid indicating negative prices at very high quantities, or negative quantities at very high prices. Further, the application in horizontal summation to obtain aggregate demand requires consideration of total acreage irrigated, for each crop.

Assumptions. The following assumptions are applied to determine acreage by crop:

1. Total irrigated acreage may be less but cannot be more than some fixed total acreage.
2. We assume that the acreage of the highest revenue-per-acre crop is limited by something other than available water, such as:
   a. Agronomic rotation requirements;
   b. Labor;
   c. Management;