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# A CASE ANALYSIS OF STREAM FLOW FORECASTS WITH REFERENCE TO FERTILIZING MOUNTAIN HAY MEADOWS

James J. Jacobs and Larry J. Held*

A major portion of annual streamflow in mountain and intermountain regions of the west comes from mountain snowpack and can be quite variable from year to year. For irrigators relying on direct streamflows (no water storage), the consequences of variable water supplies can be quite adverse. Water supply outlook reports (based primarily on mountain snowpack) are issued each year by the Soil Conservation Service and National Weather Service to predict several months in advance, the expected volume of streamflow over the following six-month period of peak flow (April-September).

Mountain valley ranchers producing irrigated hay frequently rely on direct streamflow for their irrigation water supply. In years when irrigation water is below normal, several water management options are available. One option entails spreading the limited supply of water over the entire meadow acreage (fewer acre-inches per acre), with the result of realizing lower hay yields. Another alternative involves depriving water from a certain portion of the meadow acreage and concentrating the limited supply on a smaller acreage (more acre-inches per acre). The latter alternative in fact has been observed in actual practice and suggested as one for consideration. For example, Kearl (p.8) has noted that...

> "farm and ranch operators with restricted or partial water supplies should be encouraged to use fertilizer and concentrate water on their most productive land to maximize production. In general fewer acres properly fertilized and irrigated will produce more total crop than will a larger acreage which is stinted on irrigation water"....

This implies that in conjunction with improved water management, hay production can also be increased with more effective management of nitrogen fertilizer (Jacobs *et al.*; Koch). To the extent a producer expects below normal streamflow in the upcoming year, thus inducing him to deprive water from some of his meadow--it follows that similar adjustments can be considered in applying fertilizer. Specifically, a grower might consider not fertilizing those portions of a meadow which could be deprived of irrigation water, with the idea that benefits of nitrogen fertilizer would essentially go unrealized in that particular year.

## Purpose

The purpose of this paper is to examine the potential value of using annual streamflow forecasts for managing variable water supplies--with special reference to adapting annual fertilizer usage to expected quantities of irrigation water for an example mountain valley hay meadow. As described in greater detail below, a Bayesian structure will be used to evaluate the benefits of adapting annual fertilizer decisions to streamflow forecasts. Bayesian decision models have been widely used and shown to be effective for examining the value of forecast information in a variety of applied agricultural settings, including estimating the value of: weather forecasts (Doll); predicting crop disease (Carlson); forecasting frost (Baquet *et al.*); and projecting prices (Eidman *et al.*; Bullock and Logan; and Chiang *et al.*).

The remainder of the paper is organized as follows. Streamflow data will be initially presented to develop prior probabilities of different states of water flow (low, medium and high), as well as posterior probabilities (indicating the probability that water flow will be in a specific state - given a particular forecast). Next, financial outcomes for different water flow states and fertilizer strategies will be developed for an example Wyoming mountain valley hay meadow. Finally, using the above financial outcomes, expected values of alternative strategies will be derived with (1) prior probabilities (associated with decisions based on average conditions) and (2) posterior probabilities (associated with decisions based on outlook information).

## Annual Streamflows and Forecasts

The target area for analysis is the upper Wind River near Dubois, Wyoming - providing irrigation water for mountain valley hay meadows at elevations exceeding 7,000 feet. Data for peak streamflow volume (April-September) were obtained for a 37-year period (1949-1985), along with corresponding February 1 streamflow forecasts (USGS and USDA-SCS). As shown in Table 1, annual streamflow data and February 1 forecasts are initially assembled in chronological order (unsorted cases) and then ranked in ascending order of low to high runoff years (sorted cases). This ranking allows a division of the 37-year set into three states of water flow (low, medium and high).

In order to place a similar number of cases (years) in each of the three categories, the low runoff state is developed by grouping the 12 of 37 years having the lowest runoff (ranging from 42,000-88,000 ac. ft.). Similarly, the high runoff state is derived by grouping the 12 of 37 years having the highest runoff (ranging from 119,000-170,000 ac. ft.). This leaves the remaining 13 of 37 years (ranging from 92,000-114,000) falling within the medium water state. This division results in similar, although not identical prior probabilities of low (.324), medium (.352) and high (.324) states of streamflow. The average annual streamflow over the 37-year period is 104,500 acre feet. The low runoff state as defined in Table 1 (≤90,000 ac. ft.) reflects <86% of average streamflow, while the high runoff state (≥117,000 ac. ft.) is ≥112% of average, and the medium runoff state (91,000-116,000 ac. ft.) is between 87-111% of average. With reference to the five SCS classifications of streamflow shown below, the low runoff state ($W_L$) conforms closely to the Below to Much Below Average categories, while the high runoff state ($W_H$) is consistent with the Above to Much Above Average categories.

| Item | Much Below Average | Below Average | Near Average | Above Average | Much Above Average |
|---|---|---|---|---|---|
| SCS % of Avg. | <70% | 70-90% | 90-110% | 110-130% | >130% |

In addition to showing actual streamflows in ascending order over the 37-year period, Table 1 also contains corresponding February 1 forecasts, thus providing a basis for deriving posterior probabilities. Posterior probabilities, reflecting the probability of realizing a particular state of runoff given a specific forecast [P(W/F)], are computed with Bayes Theorem in a sequence illustrated in Table 2 (Halter and Dean). Initially, the performance records of water supply forecasts are evaluated in the context of conditional probabilities (Table 1, Part B), showing the odds of obtaining a particular forecast reading, given a specific state of water runoff [P(F/W)]. For example, conditional probabilities of receiving low, medium and high level forecasts--given the actual occurrence of a low runoff state, are shown in Table 2 to be ($P(F_L/W_L)$ = .75; $P(F_M/W_L)$ = .25; and $P(F_H/W_L)$ = 0.

As the next step, joint probabilities are developed (Table 2, Part C) as the product of unconditional priors [P(W)] and conditional probabilities [P(F/W)]. Summation of joint probabilities for a given forecast reading, yields marginal probabilities [P(F)] indicating the probability of obtaining a particular forecast reading (low, medium, high). It is shown that the probability of obtaining medium level forecasts is the greatest [$P(F_M)$ = .486], followed by low level [$P(F_L)$ = .271] and high level [$P(F_H)$ = .243] forecasts. This information is then consolidated into Bayes formula to derive respective posterior probabilities (Table 2, Part D).

Posterior probabilities in Table 2, indicate that incurring a high runoff year is a virtual certainty given a high level forecast, and the likelihood of realizing a low runoff year is also high given a low level forecast (.897). In these two cases, SCS streamflow outlook information is substantially superior to prior historical information when developing expectations for high runoff [$P(W_H/F_H)$ = <u>1.0</u> vs. $P(W_H)$ = <u>.324</u>)] and low runoff [$P(W_L/F_L)$ = <u>.897</u> vs. $P(W_L)$ = .324)]. Although realizing a medium state of streamflow (given a medium level forecast) is somewhat less certain [$P(W_M/F_M)$ = .666], it still represents considerable improvement in knowledge compared to only using prior information [$P(W_M)$ = .324].

## <u>Example Hay Meadow and Net Returns</u>

To evaluate some potential economic benefits of using annual streamflow forecasts at the firm level, an example 600-acre mountain hay meadow is developed for a case analysis. As illustrated below, the 600-acre meadow is divided into three sections (A:100 acres, B:100 acres and C:400 acres) where Sections A and B are assumed to be potentially at risk of being deprived of water in selected years.

| State of Water Flow & Prob. | | Meadow Section | Water Status |
|---|---|---|---|
| | | A:100 acres at risk | DEPRIVED OF WATER |
| $W_L$ (Low streamflow) | .324 | B:100 acres at risk | DEPRIVED OF WATER |
| | | C:400 acres not at risk | Always Adequate Water |
| | | A:100 acres at risk | DEPRIVED OF WATER |
| $W_M$ (Med streamflow) | .352 | B:100 acres at risk | Adequate Water |
| | | C:400 acres not at risk | Always Adequate Water |
| | | A:100 acres at risk | Adequate Water |
| $W_H$ (High streamflow) | .324 | B:100 acres at risk | Adequate Water |
| | | C:400 acres not at risk | Always Adequate Water |

Specifically, adequate water is assumed to be available for the entire 600 acres (including the 200 acres at risk), only in years of high runoff ($W_H$). Conversely, in years of low runoff ($W_L$) the 200 acres at risk (both Sections A and B) are deprived of water with limited water concentrated on the remaining 400 acres (Section C). In medium runoff years ($W_M$) only 100 acres (Section A) are deprived, and water is concentrated on the remaining 500 acres (Sections B and C). As shown below, an average of 16.7% of the 600-acre meadow is deprived of water over time given prior probabilities of low (.324), medium (.352) and high (.324) runoff states.

| Average % Impacted Acreage | $W_L$ (Low Flow) | | $W_M$ (Medium Flow | | $W_H$ (High Flow) | |
|---|---|---|---|---|---|---|
| | Prob. | Deprived Acres Ratio | Prob. | Deprived Acres Ratio | Prob. | Deprived Acres Ratio |

$$16.7\% = [(.324) \cdot (200/600)] + [(.352) \cdot (100/600)] + [(.324) \cdot (0/600)]$$

For purposes of this analysis, hay production is assumed to be a function of two factors, availability of adequate irrigation water and the application of nitrogen fertilizer. If one or both sections of the meadow are deprived of water there is presumably no hay production or yield response to nitrogen and as a result potential loss of fertilizer.1/ Therefore, the decision becomes one of choosing whether to apply fertilizer to one or both of the impacted meadow sections (A and B) given the risk of inadequate irrigation water.

Table 3 shows expected financial outcomes from alternative strategies of not fertilizing (0 acres), fertilizing half (100 acres) or fertilizing all of the 200 acres at risk--given the three possible states of streamflow ($W_L$, $W_M$ and $W_H$). The financial outcomes in this analysis are expressed as hay revenue over fertilizer cost (ROFC). Hay revenue is based on expected hay yield times its net price. The base yield for unfertilized irrigated native hay is 1.26 ton/acre, compared to 2.67 ton/acre resulting from 120 lbs. of actual N. The net price for hay is assumed to decrease with higher yields, in consideration of an $8/ton added harvest cost. Nitrogen is assumed to be purchased and applied for $36.60/acre in this example.

Table 3 shows that the consequences of incurring a year of "low" streamflow ($W_L$) are increasingly more "severe" moving from fertilizing none of the impacted acres ($0) to fertilizing all of the acres at risk (-$7,320), since in the first case, there is no fertilizer cost incurred with zero production. Conversely, the consequences of having a "high" runoff year become increasingly more "favorable" moving from fertilizing 0% ($15,120) to 100% ($18,846) of the impacted meadow acres, since increased profitability from higher yields are captured over more acres.

## Expected Values of Alternative Fertilizer Decisions

Given the financial consequences (ROFC) described above, optimum fertilizer strategies for the impacted meadow acreage are examined with respect to two approaches for maximizing expected ROFC: (1) a nonadaptive fixed policy of choosing a fertilizer strategy based solely on prior information and average type of conditions versus (2) an adaptive policy of adjusting fertilizer usage with regard to streamflow outlook.

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1/ It is assumed that fertilizer applied to a hay meadow deprived of water results in zero production with no response to nitrogen in the year of application. What is not well known at this point is the extent of nitrogen carryover to increase yield response in future years. Although carryover effects of nitrogen are generally thought to be minimal compared to other nutrients such as phosphorus, there is reason to believe that carryover could be more pronounced under drier conditions of water-deprived meadows, depending in part on the type of nitrogen material. To the extent that some nitrogen carryover could occur, the value of using streamflow outlook for annual adjustments of fertilization could be diminished to some extent.

Table 4 shows the expected values of ROFC for the three strategies (fertilize 0%, 50% and 100% of impacted acres) derived as weighted averages with unconditional prior probabilities. Fertilizing 50% of the impacted acreage (i.e. 100 acres) is found to yield the highest expected ROFC ($7,634), which is only slightly more than expected ROFC from fertilizing none of the impacted acreage ($7,560). Fertilizing all 200 acres of impacted meadow results in the lowest expected ROFC ($5,763) which is substantially below the other alternatives.

Table 5 shows the same financial outcomes (ROFC) from the three selected fertilizer strategies (by state of streamflow)--weighted in this case by conditional posterior probabilities associated with a particular forecast prediction. In this setting, the optimal fertilizer strategy (yielding maximum expected ROFC) is now found to be dependent upon the nature of the streamflow forecast. In terms of the optimal percentage of acreage to be fertilized--a low forecast dictates fertilizing none of the impacted meadow (Max. EV = $779), a medium forecast favors fertilizing 50% of the 200 at-risk acres (Max. EV = $8,501), while a high streamflow forecast suggests fertilizing all 200 acres (Max. EV = $18,846). In addition, the expected value of following an adaptive fertilizer policy with respect to streamflow outlook can be readily derived by weighting the value of the optimal actions associated with each forecast, by respective forecast frequencies.

$$\underset{\$8{,}922}{\underline{\text{EV of Adaptive Fertilization}}} = \left[\underset{(.271)}{\underline{P({}^{F}L)}} \cdot \underset{(\$779)}{\underline{\text{Max. EV (Given } {}^{F}L)}}\right] + \left[\underset{(.486)}{\underline{P({}^{F}M)}} \cdot \underset{(\$8{,}501)}{\underline{\text{Max. EV (Given } {}^{F}M)}}\right] + \left[\underset{(.243)}{\underline{P({}^{F}H)}} \cdot \underset{(\$18{,}846)}{\underline{\text{Max. EV (Given } {}^{F}H)}}\right]$$

From Table 4, the optimal strategy using only prior information is fertilizing 50% of the impacted acreage over time, yielding an expected ROFC = $7,634. The value of using streamflow outlook for adjusting annual fertilizer usage can be considered as the difference between the expected value of adaptive fertilization ($8,922) versus the expected value of the best non-adaptive policy ($7,634), which in this case amounts to an annual benefit of $1,288 or $6.44 per acre. In addition, a maximum value of using streamflow forecasts can be derived by comparing the expected ROFC of the worst non-adaptive policy shown in Table 4 (i.e. $5,763 from fertilizing all of the impacted acreage) to the expected ROFC from adaptive fertilization ($8,922). In this case the annual value of forecast information is shown to be even more pronounced, amounting to $3,159 or $15.80/acre.

## Conclusions

Streamflow forecasts issued by the SCS for the upper Wind River near Dubois, Wyoming are shown to be very effective for increasing the accuracy of streamflow expectations as compared to relying only on long-term historical frequencies. There appears to be a marked potential for increased economic benefit in using such forecasts for adaptive fertilizer decisions and perhaps many other applications as well. However, to the extent results shown here are situation specific, additional analysis of forecasts and streamflows for other situations and regions of the mountain west are necessary for drawing more generalized conclusions.

Table 1. Annual Forecasted (Feb. 1) and Actual Ensuing Six-Month(Apr-Sept.) Flows of Water in the Wind River Near Dubois (1949-1985) Which are Ranked in Chronological Order (Unsorted Cases) and Ascending Order (Sorted Cases) for Purposes of Deriving Three "Water Flow" States (Low, Medium, High) and Associated Prior Probabilities.

| Case | (1) Year | (2) Unsorted Cases a/ 6 Mo. (Apr.-Sept) Flow Feb. 1 Forecast | (3) Actual | (4) Year | (5) Sorted Cases b/ 6 Mo. (Apr.-Sept. Flow) Feb. 1 Forecast | (6) Actual | (7) Water Flow States and Associated Prior Probabilities c/ |
|---|---|---|---|---|---|---|---|
| | | ---1,000 ac. ft.--- | | | ---1,000 ac. ft.--- | | |
| 1 | 1949 | 105 | 93 | 1977 | 65 | 42 | |
| 2 | 1950 | 133 | 127 | 1961 | 77 | 60 | $W_L$ |
| 3 | 1951 | 133 | 170 | 1960 | 85 | 61 | |
| 4 | 1952 | 102 | 94 | 1955 | 68 | 66 | Low Water |
| 5 | 1953 | 102 | 92 | 1973 | 80 | 72 | (≤ 90,000 ac. ft) |
| 6 | 1954 | 104 | 105 | 1981 | 89 | 74 | |
| 7 | 1955 | 68 | 66 | 1958 | 83 | 75 | |
| 8 | 1956 | 141 | 146 | 1969 | 107 | 75 | $P(W_L)=12/37(.324)$ |
| 9 | 1957 | 92 | 114 | 1966 | 78 | 80 | |
| 10 | 1958 | 83 | 75 | 1985 | 90 | 80 | |
| 11 | 1959 | 98 | 88 | 1979 | 112 | 85 | |
| 12 | 1960 | 85 | 61 | 1959 | 98 | 88 | |
| 13 | 1961 | 77 | 60 | 1953 | 102 | 92 | |
| 14 | 1962 | 106 | 108 | 1949 | 105 | 93 | $W_M$ |
| 15 | 1963 | 76 | 98 | 1952 | 102 | 94 | |
| 16 | 1964 | 91 | 113 | 1970 | 109 | 94 | Medium Water |
| 17 | 1965 | 132 | 153 | 1968 | 91 | 96 | (91-116,000 ac. ft.) |
| 18 | 1966 | 78 | 80 | 1980 | 98 | 96 | |
| 19 | 1967 | 96 | 129 | 1963 | 76 | 98 | |
| 20 | 1968 | 91 | 96 | 1954 | 104 | 105 | $P(W_M)=13/37(.352)$ |
| 21 | 1969 | 107 | 75 | 1983 | 95 | 107 | |
| 22 | 1070 | 109 | 94 | 1962 | 106 | 108 | |
| 23 | 1971 | 136 | 144 | 1984 | 104 | 111 | |
| 24 | 1972 | 131 | 150 | 1964 | 91 | 113 | |
| 25 | 1973 | 80 | 72 | 1957 | 92 | 114 | |
| 26 | 1974 | 110 | 137 | 1978 | 152 | 119 | |
| 27 | 1975 | 100 | 126 | 1975 | 100 | 126 | $W_H$ |
| 28 | 1976 | 130 | 146 | 1950 | 133 | 127 | |
| 29 | 1977 | 65 | 42 | 1967 | 96 | 129 | High Water |
| 30 | 1978 | 152 | 119 | 1974 | 110 | 137 | (≥ 117,000 ac.ft.) |
| 31 | 1979 | 112 | 85 | 1982 | 120 | 140 | |
| 32 | 1980 | 98 | 96 | 1971 | 136 | 144 | $P(W_H)=12/37(.324)$ |
| 33 | 1981 | 89 | 74 | 1976 | 130 | 146 | |
| 34 | 1982 | 120 | 140 | 1956 | 141 | 146 | |
| 35 | 1983 | 95 | 107 | 1972 | 131 | 150 | |
| 36 | 1984 | 104 | 111 | 1965 | 132 | 153 | |
| 37 | 1985 | 90 | 80 | 1951 | 133 | 170 | |

a/ Actual flows are based on data from United States Geological Survey. Forecasted flows are from United States Department of Agriculture, SCS.

b/ Sorting partial streamflow data by ascending order is done to facilitate dividing the 37-year set into three states representing (1) low water runoff (≤ 90,000 acre feet); (2) medium water runoff (91,000-116,000 acre feet; and (3) high water runoff (≥ 117,000 acre feet).

c/ The low runoff state is defined to be ≤ 90,000 acre feet, which is derived as the average of the upper limit observation for the low state (88,000) and lower limit observation of the medium state (92,000). Similarly, the high runoff state is defined to be ≥ 117,000 acre feet, which is derived as the average of the upper limit observation of the medium state (114,000) and lower limit observation of the high streamflow state (119,000). Falling between these two extremes, the medium state is then defined by flows ranging from 91,000-116,000 acre feet.

Table 2. Derivation of Posterior Probabilities [P(W/F)] Indicating the Probability of Realizing a Particular State of Water Flow (Low, Medium, High)--Given a Particular Forecast Reading (Low, Medium, High).

[A] - - - - - - - - - Unconditional Prior Probabilities - - - - - - - - -

| States of Water Flow | P(W) |
|---|---|
| $W_L$ | .324 |
| $W_M$ | .352 |
| $W_H$ | .324 |

[B] - - - - - - - - - - - Conditional Probabilities[a] - - - - - - - - - -

P(F/W)

| States of Water Flow | Forecast Reading $F_L$ | $F_M$ | $F_H$ |
|---|---|---|---|
| $W_L$ | .75 | .25 | 0 |
| $W_M$ | .08 | .92 | 0 |
| $W_H$ | 0 | .25 | .75 |

[C] - - - - - - - - - - - - Joint Probabilities - - - - - - - - - - - -

P(W) · P(F/W)

| States of Water Flow | Forecast Reading $F_L$ | $F_M$ | $F_H$ |
|---|---|---|---|
| $W_L$ | .243 | .081 | 0 |
| $W_M$ | .028 | .324 | 0 |
| $W_H$ | 0 | .081 | .243 |
| P(F) = | .271 | .486 | .243 |

[D] - - - - - - - - - - Posterior Probabilities - - - - - - - - - - - -

$$P(W/F) = \frac{P(W) \cdot P(F/W)}{P(F)}$$

| States of Water Flow | Forecast Reading $F_L$ | $F_M$ | $F_H$ |
|---|---|---|---|
| $W_L$ | .897 | .167 | 0 |
| $W_M$ | .103 | .666 | 0 |
| $W_H$ | 0 | .167 | 1.000 |

a/ Conditional probabilities estimates are obtained by observing the frequency of low, medium and high level forecasts for the 12 selected years in the low water ($W_L$) state shown in Table 1. For example, there were no forecasts predicting runoff to be >117,000 acre feet when actual streamflow was in the low water state ($L_W$ ≤90,000 ac. ft.) and hence, $P(F_H/W_L) = 0$. Similarly, in 3 of 12 years of low runoff ($W_L$), the forecast predicted runoff within the 91,000-116,000 acre feet medium runoff range (i.e. 107,000 in 1969; 112,000 in 1979; and 98,000 in 1959), thus yielding $P(F_M/W_L) = .25$. In the remaining 9 of 12 years, the forecast correctly predicted runoff to be ≤90,000 acre feet so that $P(F_L/W_L) = .75$. Conditional probabilities for Medium ($W_M$) and High ($W_H$) water runoff states are developed in a similar manner.

Table 3. Return Over Fertilizer Cost (ROFC) Resulting from Low, Medium and High States of Water ($W_L$, $W_M$, $W_H$) and Percentage of the Impacted Meadow Which is Fertilized (0%, 50%, 100%).

| State of Water Flow and Prior Prob.[a] | Impacted Meadow Sections | Revenue: Yield[b] | Revenue: Net Price[c] | Revenue: Total | Fertilizer Cost[d] | ROFC: Individual Mead. Sec. | ROFC: Total (Sec. A+B) |
|---|---|---|---|---|---|---|---|
| | | ton/ac | $/ton | ($) | ($) | ($) | ($) |
| - - - - - Fertilize 0% of Impacted Meadow - - - - - | | | | | | | |
| $W_L$-Low (.324) | A (100 ac) | 0 | -- | 0 | -- | 0 | |
| | B (100 ac) | 0 | -- | 0 | -- | 0 | 0 |
| $W_M$-Med (.352) | A (100 ac) | 0 | -- | 0 | -- | 0 | |
| | B (100 ac) | 1.26 | 60 | 7,560 | -- | 7,560 | 7,560 |
| $W_H$-High (.324) | A (100 ac) | 1.26 | 60 | 7,560 | -- | 7,560 | |
| | B (100 ac) | 1.26 | 60 | 7,560 | -- | 7,560 | 15,120 |
| - - - - - Fertilize 50% of Impacted Meadow - - - - - | | | | | | | |
| $W_L$-Low (.324) | A (100 ac) | 0 | -- | 0 | -- | 0 | |
| | B (100 ac) | 0 | -- | 0 | -3,660 | -3,660 | -3,660 |
| $W_M$-Med. (.352) | A (100 ac) | 0 | -- | 0 | -- | 0 | |
| | B (100 ac) | 2.67 | 49 | 13,083 | -3,660 | 9,423 | 9,423 |
| $W_H$-High (.324) | A (100 ac) | 1.26 | 60 | 7,560 | -- | 7,560 | |
| | B (100 ac) | 2.67 | 49 | 13,083 | -3,660 | 9,423 | 16,983 |
| - - - - - - Fertilize 100% of Impacted Meadow - - - - - | | | | | | | |
| $W_L$-Low (.324) | A (100 ac) | 0 | -- | 0 | -3,660 | -3,660 | |
| | B (100 ac) | 0 | -- | 0 | -3,660 | -3,660 | -7,320 |
| $W_M$-Med. (.352) | A (100 ac) | 0 | -- | 0 | -3,660 | -3,660 | |
| | B (100 ac) | 2.67 | 49 | 13,083 | -3,660 | 9,423 | 5,763 |
| $W_H$-High (.324) | A (100 ac) | 2.67 | 49 | 13,083 | -3,660 | 9,423 | |
| | B (100 ac) | 2.67 | 49 | 13,083 | -3,660 | 9,423 | 18,846 |

a/ It is assumed that in years of low water flow ($W_L$), all of the 200 impacted acreages (in the 600 acre meadow) are abandoned; and in years of medium flow ($W_M$), 50% (100 ac) of the 200 impacted acreage is abandoned. In years of high flow ($W_H$) sufficient water is assumed to be available for all 200 impacted acres (in addition to the other 400 unimpacted acres).

b/ Yield of 1.26 ton/acre is unfertilized yield for native meadow hay and 2.67 ton/acre results from applying 120 lbs. of N. (Jacobs, et. al. p.5).

c/ Net price of $60/ton for unfertilized hay is based on a 5-year (1982-86) acreage hay price (Wyo. Agric. Stat.). Net price of $49/ton reflects an $8/ton added harvest cost on the additional 1.41 tons (2.67 - 1.26) of hay (Jacobs, et. al. p.9).

d/ Fertilizer cost includes a $3.00/acre application charge and $33.60/acre charge (120# X 28¢/lb) for granular ammonium nitrate (Wyo. Agric. Stat.).

Table 4. Expected Values of Alternative Fertilizer Decisions - Given Only Prior Information

| DECISION ACT: Percentage of Impacted Acreage Fertilized | Actual State of Water Flow | Prior Probability | ROFC ($) | Expected Value ($) |
|---|---|---|---|---|
| | $W_L$ - Low | .324 | 0 | |
| 1) Fertilize 0% | $W_M$ - Med | .352 | 7,560 | 7,560 |
| | $W_H$ - High | .324 | 15,120 | |
| | $W_L$ - Low | .324 | -3,660 | |
| 2) Fertilize 50% | $W_M$ - Med | .352 | 9,423 | 7,634* |
| | $W_H$ - High | .324 | 16,983 | |
| | $W_L$ - Low | .324 | -7,320 | |
| 3) Fertilize 100% | $W_M$ - Med | .352 | 5,763 | 5,763 |
| | $W_H$ - High | .324 | 18,846 | |

* Maximum Expected Value.

Table 5. Expected Values of Alternative Fertilizer Decisions - Given Additional Outlook Information of Low, Medium or High Water Runoff Forecasts.

| DECISION ACT: Percentage of Impacted Acreage Fertilized | Actual State of Water Flow | Posterior Probability | ROFC ($) | Expected Value ($) |
|---|---|---|---|---|
| [A] | Low Water Runoff Forecast: $P(^{F}L) = .271$ | | | |
| | $W_L$ - Low | .897 | 0 | |
| (1) Fertilize 0% | $W_M$ - Med | .103 | 7,560 | 779* |
| | $W_H$ - High | 0 | 15,120 | |
| | $W_L$ - Low | .897 | -3,660 | |
| (2) Fertilize 50% | $W_M$ - Med | .103 | 9,423 | -2,312 |
| | $W_H$ - High | 0 | 16,983 | |
| | $W_L$ - Low | .897 | -7,320 | |
| (3) Fertilize 100% | $W_M$ - Med | .103 | 5,763 | -5,972 |
| | $W_H$ - High | 0 | 18,846 | |
| [B] | Medium Water Runoff Forecast: $P(^{F}M) = .486$ | | | |
| | $W_L$ - Low | .167 | 0 | |
| (1) Fertilize 0% | $W_M$ - Med | .666 | 7,560 | 7,560 |
| | $W_H$ - High | .167 | 15,120 | |
| | $W_L$ - Low | .167 | -3,660 | |
| (2) Fertilize 50% | $W_M$ - Med | .666 | 9,423 | 8,501* |
| | $W_H$ - High | .167 | 16,983 | |
| | $W_L$ - Low | .167 | -7,320 | |
| (3) Fertilize 100% | $W_M$ - Med | .666 | 5,763 | 5,763 |
| | $W_H$ - High | .167 | 18,846 | |
| [C] | High Water Runoff Forecast: $P(^{F}H) = .243$ | | | |
| | $W_L$ - Low | 0 | 0 | |
| (1) Fertilize 0% | $W_M$ - Med | 0 | 7,560 | 15,120 |
| | $W_H$ - High | 1.000 | 15,120 | |
| | $W_L$ - Low | 0 | -3,660 | |
| (2) Fertilize 50% | $W_M$ - Med | 0 | 9,423 | 16,983 |
| | $W_H$ - High | 1.000 | 16,983 | |
| | $W_L$ - Low | 0 | -7,320 | |
| (3) Fertilize 100% | $W_M$ - Med | 0 | 5,763 | 18,846* |
| | $W_H$ - High | 1.000 | 18,846 | |

* Maximum Expected Value.

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# RESPONSE OF PACIFIC NORTHWEST IRRIGATED AGRICULTURE TO RISING ENERGY COSTS

Moeketsi Majoro, Linda May, and Norman K. Whittlesey

## INTRODUCTION

Throughout western irrigated agriculture a large amount of energy is used for pumping and applying irrigation water. This paper examines how the Pacific Northwest (PNW) irrigated sector would respond in the short run (3-4 years) to rising electricity prices. In this region all irrigation pumping is accomplished with electricity. The analysis provides estimates of the elasticity of short-run demand for electricity in irrigated agriculture and examines the effects of electricity cost increases on factor use and farm income.

## METHODS AND BACKGROUND

### Scope

The study area contains all pump irrigated agricultural land in Washington, Oregon, Idaho and Western Montana. Lands that depend upon gravity flow water supplies and application methods are obviously excluded. Also excluded is a small portion of total regional pumping energy that is within USBR projects and totally insulated from energy price changes due to long-term power supply arrangements. The analysis is based on the assumption that no changes in technology can occur in the short run. However, all managerial adjustments within the limits of current technologies are considered.

More than 8 million acres of the PNW are under irrigation. Some 3.6 million acres (44 percent) are irrigated using gravity systems. Of the 4.6 million acres irrigated with sprinkler methods, almost two thirds (63 percent) are irrigated using a combination of side roll, wheel lines and hand move sprinklers, followed by center pivot (32 percent) and solid set (5 percent). In terms of total acres irrigated, side roll and its related systems provide water to 35 percent of the region's irrigated land, while center pivot and solid set systems supply 18 percent and 3 percent, respectively. The region was divided into 13 agricultural production areas (APA's) for this analysis as shown in Figure 1. APA's are groupings of counties with similar agricultural production characteristics.

### Procedure

The response to changing electricity prices was examined using mathematical programming. Estimates of electricity demand were based on the behavioral assumption that farmers seek to maximize profits and will respond to changes in relative factor prices by adjusting farm input combinations. A linear programming model was used to determine the profit maximizing input combination for farm types representative of farming practices and conditions in the various APA's. The model maximized the net return to land, management and investment in existing irrigation systems. The fixed costs of irrigation systems were not deducted from crop net revenue.

A scaled-down version of the SPAW-IRRIG simulator model developed by Bernardo and Whittlesey was employed. The actual model configuration was initially developed by Whittlesey, Hamilton, and Halverson. In summary, the farm model considered the following options for each crop. Limited water application was permitted down to about 65 percent of full net irrigation requirements (NIR). Within each of five NIR levels, at least five levels of irrigation efficiency were possible by changing the inputs of irrigation labor and management. Crop yields and production costs were varied according to the