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Climate Change and Adaptation in Irrigated Agriculture - A Case Study of the Yakima River

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CLIMATE CHANGE AND ADAPTATION IN IRRIGATED AGRICULTURE─A CASE STUDY OF THE YAKIMA RIVER

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Using a case study of the Yakima River Valley in Washington State, we show that relatively simple tools originally developed to forecast the impact of the El Niño phenomenon on water supplies to irrigated agriculture also can be used to estimate impacts during climate change. The significantly shifted probability distribution of water shortages in irrigated agriculture during climate change can be used to estimate the impact on agriculture in a region. The more permanent nature of changes in the temperature and precipitation regime associated with climate change means that risk management options also take a more permanent form (such as changes in crops and cultivars, and adding storage).

Total agricultural production in the Yakima Basin, including low-valued crops and livestock, is worth about $1.3 billion and annual net cash return (roughly, net farm income) is about $310 million. The key irrigation season water supply concept for the Yakima is Total Water Supply Available (TWSA), which is computed as the estimated unregulated flow of the river, plus accumulated stored water on April 1, plus estimated irrigation return flow, less remaining storage on September 30. In years with low irrigation season flows, the sum of all users' entitlements exceeds TWSA, leading to a deficit in available flow. The deficit is resolved by proportionately reducing (prorationing) water allocations to the more junior irrigators, whose entitlements therefore are considered to be "proratable." The total annual value of high-valued crops in the Yakima Basin is about $750 million at the farm gate, of which junior growers appear to grow about two-thirds. Senior users are considered to be "non-proratable" and generally receive their full allocation, regardless of drought.

Earlier analysis (Scott et al. 2004) performed with the CROPSYST model (Stöckle and Nelson 1996) in the Yakima valley showed that most crops have an S-shaped relationship between water availability and yield during El Niño-associated drought. Growing weather (mainly temperature regime) matters far less for yield than does the amount of irrigation water available (see Figure 1). Figure 1 shows these relationships for sweet corn for a simple 2˚ C global warming and two different levels of atmospheric concentration of carbon dioxide. The baseline yields and plus-2˚ C yields are virtually the same at all levels of water availability for either level of carbon dioxide, but levels of water availability below about 80% of normal rapidly reduce yields.

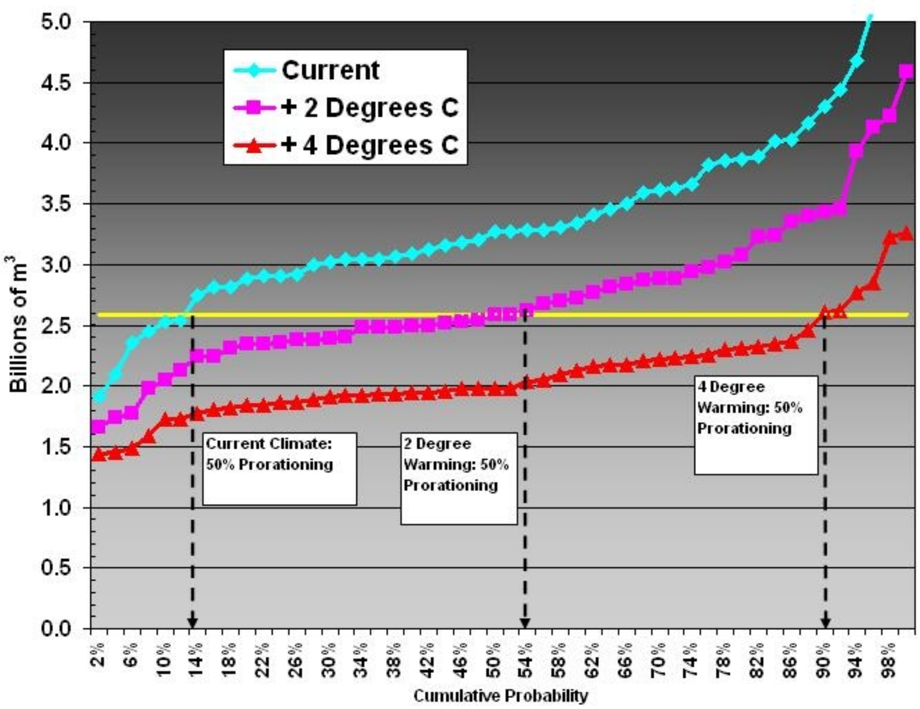

Figure 1. Effect of 2˚ C Climate Warming, CO_2 Atmospheric Concentration, and Water Availability on the Mean Yield of Sweet Corn for 40 Simulations with the CROPSYST model, with Yakima Valley Soils and Crop Management.

Climate warming has similar effects on water availability and crop growth as recent El Niño episodes. Calculations for TWSA have been done for a number of future climate scenarios, both using downscaled transient (time-dependent) General Circulation Model (GCM) scenarios results and simple increases in average temperatures. These mid-21st century simulations, as calculated by the Distributed Hydrologic Supply and Vegetation Model (DHSVM) (Wigmosta et al. 2002), show that climate warming substantially reduces the seasonal TWSA, even though annual runoff is similar to current climate. This is because with warmer temperatures, the mountain snowpack in the Yakima basin is smaller and melts off as much as two months earlier. Storage in the basin is not adequate to capture the additional winter flow, so that the unregulated flow portion of TWSA is smaller than under current climate, and storage does not grow to compensate. As shown in Figure 2, with the current climate, severe prorationing of about 50% or more occurs roughly 14% of the time; with 2º C warming, about 54% of the time, and with 4º C warming, almost 92% of the time. The latter is equivalent to an almost continuous drought under today's conditions.

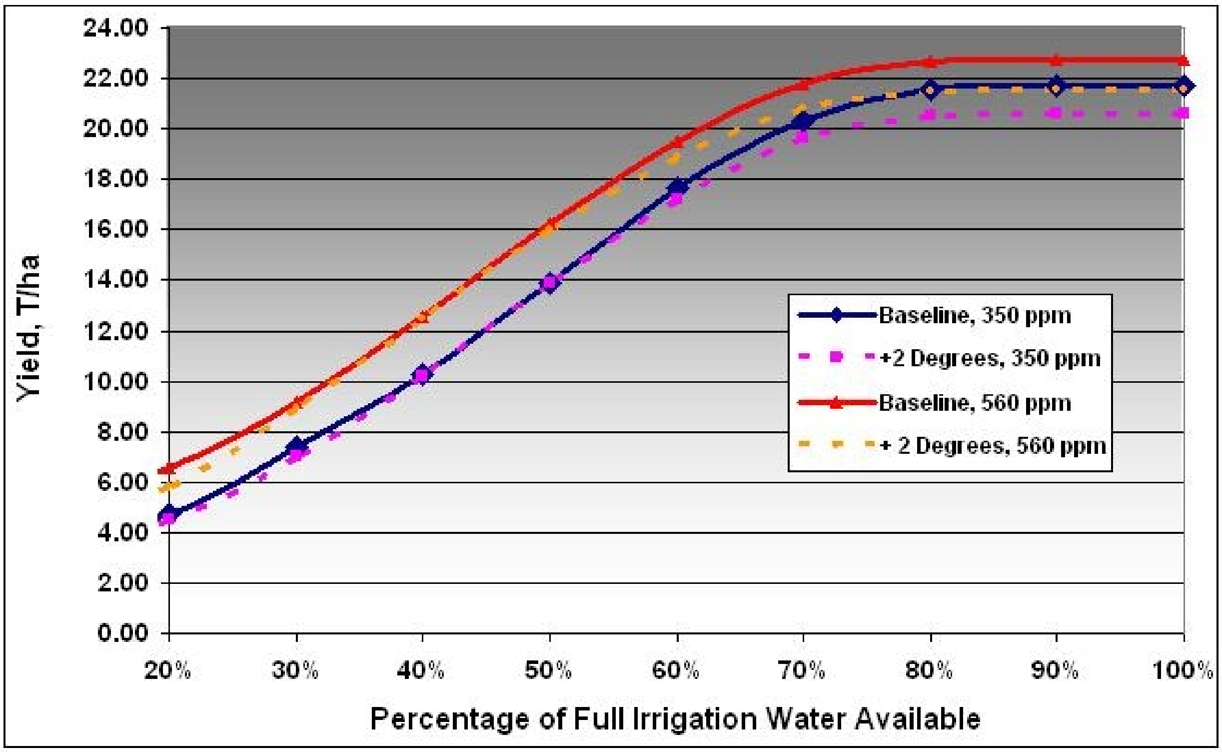

Figure 2. Effect of Climate Warming of 2˚ C and 4˚ C on Total Water Supply Available and Prorationing of Water in the Yakima Valley for Average April 1 Reservoir Fill and 8.5 m^3 (300 cfs) Minimum Instream Flow.

Periodic drought in the Yakima Valley can be quite costly to irrigated agriculture. For example, in the water year October 2000-September 2001 (which was not an El Niño year), some water users experienced the most stringent water prorationing on record, and crop losses reportedly were in the range of $100 million. Table 1 shows the potential impact of various water shortfalls on crop value among the major irrigation divisions of the Yakima Valley. The table is based on CROPSYST yield curves for the major Yakima Valley crops similar to Figure 1, on the distribution of crops and junior (proratable) water users among the major irrigation divisions of the Yakima Valley, and on average crop prices for the last ten years,.

Table 1. Effect of Reduced Water Availability in Current Climate for Yakima Valley Crop Value at Average Prices.

Estimated Crop Value in Million $ When Water Availability to Junior Users is									
Division	100%	90%	80%	70%	60%	50%	40%	30%	20%
Roza	$188	$187	$178	$162	$141	$119	$98	$80	$69
Wapato	$177	$177	$172	$165	$155	$144	$133	$123	$117
Kittitas	$24	$23	$22	$20	$18	$15	$12	$9	$7
Sunnyside	$184	$184	$181	$176	$170	$164	$158	$152	$149
Tieton	$93	$93	$91	$89	$85	$81	$78	$75	$73
Kennewick	$14	$14	$14	$13	$12	$11	$10	$9	$9
Total	$680	$677	$659	$624	$581	$534	$489	$448	$424

A number of water storage options have been proposed to deal with drought and would be more valuable under climate change. The most ambitious of the proposed storage projects is Black Rock, which would add about 617 million m^3 (500,000 acre-feet [ac-ft]) of Columbia River water to the lower Yakima (mainly the Roza and Sunnyside Divisions) to supplement the Yakima's current 1.4 billion m^3 (1.1 million ac-ft) of storage, at a cost currently estimated at $1.9 billion. For perspective, economic losses in the Yakima Valley reportedly have been about $100 million in a drought year such as 2001. Under current circumstances, the expected annual fisheries benefits and periodic drought relief benefits may be large enough to justify the expenditure. However, since drought damage has been only occasional, environmental consequences of new projects uncertain, and the price tag beyond the reach of all but the federal government, no projects have been built.

Table 2 shows the approximate impact of different levels of prorationing on value of Yakima Valley crop production for normal climate years, El Niño years, all of current climate (including normal, El Niño, and La Niña years), and a future climate with 2˚ C average warming. The corresponding expected values of climate-related yield losses are shown at the bottom of the table, derived by applying the loss in crop value at a given level of water availability times the probability of that level of water availability occurring. For example, in normal years there is a about a 9% probability that TWSA will be less than or equal to 2.9 billion m^3 (2.3 million ac-ft) (80% water availability for proratable water users). The crop loss associated with that level of water supply is $21 million = ($680-$659 million), and the estimated value is applied to the segment in the cumulative probability function between 90% and 80% water availability, so that the marginal probability is calculated as 20% = (29%-9%), and the probability-weighted value for the segment $4.2 million. The expected value is simply the sum of the values of the individual segments. The normal and El Niño climate TWSA calculations were done for the water years 1926-1994, using reconstructed unregulated flows and estimated historical values for April 1 and September 30 reservoir contents and return flows. The Current Climate and 2˚ Warming scenarios of TWSA shown in the table were calculated from modeled unregulated flows for 50 years of record, and were standardized on April 1 and September 30 reservoir content corresponding to long-term average values of 919 million m^3 (745, 000 ac-ft) and 480 million m^3 (389,000 ac-ft), respectively. Return flows were standardized at 413 million m^3 (335,000 ac-ft). The individual modeled current climate scenario TWSAs depart somewhat from their estimated historical values, and therefore produce a slightly different cumulative probability function. However, the differences are mostly at the high-flow end, where crop losses are small to begin with. There is almost no impact on the expected value of crop losses.

Table 2. Loss of Yakima Crop Production Associated with Low Water Supplies with Various Levels of Prorationing

	TWSA and Crop Value Corresponding to Percentage of Full Water Availability to Proratable Water Users										
	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
TWSA (10^6 m^3)	3221	3050	2879	2707	2536	2365	2193	2022	1851	1679	1508
Crop Value (10^6)$	$680	$677	$659	$624	$581	$534	$489	$448	$424	$421	$420
Cumulative Probability that TWSA is Less than Value Above:											
Normal Years	31%	29%	9%	3%	<2%	<2%	<2%	<2%	<2%	<2%	<2%
El Nino Years	75%	65%	60%	50%	35%	25%	10%	5%	<2%	<2%	<2%
Current Climate	50%	38%	20%	14%	12%	8%	6%	4%	2%	<2%	<2%
2 ° C Warming	82%	80%	70%	60%	48%	26%	14%	10%	8%	4%	2%
Expected Annual Value of Crop Losses Due to Insufficient Water (Million$)											
Normal	$8.16										
El Nino	$83.58										
Current Climate	$28.38										
2 Degrees Warming	$104.06										

The expected values of crop losses that could be prevented by additional storage may be compared to that portion of the costs of new storage that might reasonably be attributed to the water provide in the lower Yakima River. We compare a storage project modeled loosely on the proposed Black Rock project that would add up to 617 million m^3 (500,000 ac-ft) of water to the lower Yakima River (Washington Infrastructure Services, Inc. and Benton County Sustainable Development 2002). Although the actual picture is far more complicated, for purposes of this analysis it is assumed that

- the storage project costs $1.9 billion (present value) for 2.1 billion m^3 (1.7 million ac-ft) of total water storage, 617 million of which would be available to supplement the Lower Yakima irrigation districts
- even with climate change, water flows in the Columbia River are not materially affected by the withdrawal
- pumped storage and other benefits (such as fish supplementation flows and recreation pay for all annual operating costs and the aspects of the project that do not involve supplementing irrigation flows) are equal to about $35 million (Washington Infrastructure Service's mid-range estimate $28 million power benefits and $7 million other)

- the project would be paid for by a federal government loan at 3% per annum, with the bonds retired in 50 years. The farm sector would bear a portion of the costs commensurate with the total project costs, less non-farm benefits

Using these assumptions, the annualized costs of the project (at 3% for 50 years) would be approximately $73 million. Net costs to the farm sector (net of non-farm benefits) would be $38 million. Under current climate, the costs of the project are in the range of one-third higher than the expected benefits of $28 million.

However, benefits of storage appear to become more certain with warming. Repeating the above analysis with 2º C warming shows an expected benefit to agriculture greater than the total annualized costs of the project ($104 million benefit in Table 2 vs. $73 million annualized costs). It is not clear what the impacts of warming would be on such factors as anadromous fish and recreation. Although more Yakima water could be devoted to instream flow supplementation in the Lower Yakima with the project, for example, the lower snowpack in the Cascade mountains might mean that some tributaries upstream might no longer sustain salmon or resident fish. On the other hand, Yakima flow supplementation may actually become more critical to salmon survival as a result. In addition, water may be less available from the Columbia River to operate the project with climate warming.

Some other potentially important factors have not been taken into account in this preliminary analysis. The demand for water has been assumed to be roughly constant at the higher average temperatures associated with climate warming. Higher water demands would be favorable for more storage. While it might seem that water demands would be higher with warmer temperatures, CROPSYST analyses do not necessarily bear this out on a seasonal basis because crops also mature more quickly and need not be watered as long. Second, the cause of climate warming is assumed to be an increase in the atmospheric concentration of carbon dioxide, which acts both to increase the growth rate of many crops and to increase the efficiency with which the plant uses water. Both of these factors offset the negative effects of warming to some degree and would reduce the agricultural benefits of storage. Third, the analysis reported in this paper does not account for crop switching, water trading, and other attempts to reduce the impact of water shortages. These would also reduce the net benefits of additional storage. Finally, while preliminary analysis has been done of the impacts of reduced farm production on the rest of the economy in the basin, this has not yet included the effects of increased storage.

Conclusions

Additional water storage sometimes has been suggested as a method for reducing the negative effects of climate change on agriculture. This paper has used analysis tools hitherto focused on the effects of drought under current climate to assess the benefits of one frequently-discussed storage project on the Yakima River. The specific preliminary analysis presented in this paper suggests that supplementing the water supply of the Yakima River may create net agricultural benefits due to the likely greater certainty of water shortages with warmer climate, whereas the current expected agricultural benefits do not appear to be large enough. While a more complete analysis of climate change may change these conclusions, it is evident that the tools used may be useful in helping determine whether water storage is a valuable option to deal with climate change in the Yakima Valley. The same tools may also prove valuable in screening options for other river basins.

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