An Evaluation of Potential Riparian Irrigation Expansion with Uncertain Water Supplies*

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Abstract

Methods are presented for projecting potential irrigation expansion in a river basin, estimating probabilities of having adequate water supplies for expanded irrigation, and determining the effects of supply shortages on economic feasibility. Results from applying the procedure to a river basin indicate potential for significant expansion as well as supply shortages with expansion.

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Introduction

Irrigation in the humid eastern and southern states of the U.S. has greatly expanded in recent years. In these areas, irrigation supplements rainfall and thereby increases and stabilizes net returns from crop production. The economic feasibility of irrigation depends on the relationship between costs and returns. An economically feasible irrigation investment is one that has a positive net present value (NPV). The NPV is the present value of returns from irrigation minus the present value of all irrigation investment and operating costs. The NPV of the investment varies due to uncertainty about variables such as output prices, yield responses to irrigation, inflation rates, and input costs.

In some areas such as in eastern Virginia, groundwater may be inadequate for irrigation. In these areas, alternative sources such as catch ponds or riparian water bodies must be used (Taylor *et al.*). Using water from riparian sources adds another source of uncertainty to the economic feasibility of irrigation. Streamflow levels may fluctuate widely over the season and from one year to the next depending largely on rainfall. If many farmers decide to irrigate from a river or stream, streamflow levels may not be adequate to supply all irrigation needs in every year.

A mechanism is needed to allocate water among competing users. In many states such as Virginia, water allocation is governed by the riparian doctrine. This doctrine holds that those owning property that physically adjoins a water body have the right to make "reasonable use" of its water. The definition of "reasonable use" depends on the facts of each case; however, such use must not injure the rights of other riparian users (Cox *et al.*). Conflicts regarding water use would likely have to be settled in the courts.

Potential riparian irrigation expansion is of interest to policymakers because of concern that this expansion will cause demand to exceed supplies in some or all years. If supplies are limiting, the riparian doctrine may be too cumbersome and uncertain to effectively allocate water to irrigators. Other more explicit and systematic means for allocating water rights may be required. On the other hand, if supplies are adequate, conflicts are unlikely to arise, and the riparian doctrine may be an effective, low-cost means for water allocation (Cox *et al.*). Information on the economic potential for riparian irrigation expansion and the frequency and severity of water conflicts with expansion is needed to evaluate the adequacy of the riparian doctrine for allocating water.

The purpose of this paper is to present and illustrate methods which can be used to do the following: 1) quantify the economic potential for riparian irrigation expansion when each irrigator is assured of unlimited water supplies; 2) determine the probability of having adequate water supplies on each day of the irrigation season; and 3) evaluate the economic consequences to irrigators of water supply shortages. The methods could be applied to other river basins by by planners and policymakers to evaluate the need for changes in the way water is allocated or for other constraints on the total amount of water used for irrigation. The information from applying these methods would also be useful to farmers, extension personnel, and others concerned with potential irrigation investments.

Previous Work

Robertson *et al.* presented a framework for determining the NPV of an irrigation investment. Boggess and Amerling; Gill; and Bosch *et al.* extended the framework to consider the effects of uncertain yield responses, output prices, energy costs, and demands for irrigation water on the feasibility of an irrigation investment. Palmer *et al.* examined the impacts of varying water supplies on the feasibility of the irrigation investment. In their analysis, the farmer could partially control the supply of water by varying the size of a farm storage pond used for irrigating. In the context of this paper, the irrigator has no control over supply since the source is riparian. The important decision variable is whether to construct an irrigation system given the uncertainty of water supplies as well as price and yield response uncertainty over the system's life. Water supplies for an individual irrigator are uncertain because streamflow levels vary and because the amount of water that will be used by other irrigators is uncertain.

Taylor *et al.* and Vellidis have presented methods for determining potential irrigation expansion in a river basin when irrigation yield responses and prices are known. The methods used here do not assume that prices or yield responses are know. These methods can also be used to consider the effects on yields and net returns of reduced water availability.

Procedure

The methods are illustrated with an application to the Pamunkey River basin located in eastern Virginia, which is a basin where about 3300 acres are currently irrigated and where irrigation is growing in importance (Vellidis). Corn is chosen as the crop considered for irrigation because of its importance in the study area and because of the availability of a calibrated crop model for estimating the effects of moisture stress on corn growth and yield.

The first step in the procedure is to determine the amount of land economically feasible for irrigation with unlimited water supplies. Second, the effects of irrigation expansion on water supplies are estimated. Third, the effects of water supply shortages on irrigation feasibility are evaluated.

Economic feasibility of irrigation

Irrigation feasibility is determined by physical, legal, and economic considerations. Physically, the land must be capable of being adequately drained, not too steeply sloped, and not in use for permanent development. Vellidis subdivided the study area into 27-acre cells and eliminated those cells on which irrigation was not physically feasible. Cells eliminated as nonirrigable were: 1) those bisected by four-lane highways, railroads, or major power lines; 2) cells with slope greater than 10%; 3) cells in which water bodies made up at least 25% of the area; 4) cells in which 25% or more of the area consisted of permanently developed land; and 5) forested cells. This database is used to select land that is physically feasible for irrigation.

Only land that is part of a continuous legal tract bordering the water source has riparian water rights according to the riparian doctrine followed in Virginia (Cox *et al.*). The analysis does not consider the legal riparian status of lands because cells in the database are not classified according to whether they are part of a riparian tract. However, much of the study area is characterized by large riparian tracts extending a mile or more from the river. As will be shown, the results indicate that most lands which are economically feasible for irrigation are less than one mile distant from the river. These factors serve to minimize potential distortions caused by not considering the legal characteristics of land tracts.

The economic suitability of lands for irrigation depends on input and output prices as well as individual characteristics of each site. Each site is classified according to horizontal and vertical distance from the water source, the soil's plant available water-holding capacity (AWC), drainage requirements, and weather patterns. All cells are grouped into one of three AWC classes: two, four, and six inches of AWC in the top 30 inch profile. Weather data for a given site is taken from one of two weather stations, Ashland and Walkerton, depending on which is closer. Historical records for 1973-1984 are used to provide data on random weather variability.

A Map Analysis Package (MAP) (Tomlin) is used to aggregate physically suitable cells that are adjacent to one another into clumps. The per acre cost of an irrigation system depends on its size. The aggregation into clumps allows the system with the lowest per acre cost for the given area to be selected. Each clump is assumed to be physically homogeneous. The AWC, weather station, and drainage status used for the clump is that which predominates among cells in the clump. The horizontal distance from the clump to the riparian source is set equal to the minimum horizontal distance found among any cell in the clump. The vertical distance of the clump from the riparian source is set equal to the maximum vertical distance found among any cell in the clump. Clumps may include cells owned by two or more landowners. The ownership question is not considered because ownership of individual cells in the database is not known. The aggregation procedure is further discussed in Vellidis.

The equations used to compute the NPV of the investment are not shown due to limited space. They state that the NPV of the investment is equal to the present value of the after-tax net income produced by the investment over its life plus the present value of any tax benefits associated with owning a system, plus the present value of the system's salvage value, minus the initial investment cost. Costs are assumed to inflate at 4% per year, while output prices inflate at 3% per year. An after-tax discount rate of 11%, which includes an inflation factor of 4%, is used to discount returns and costs to the present.

Two sources of risk which contribute to the uncertainty of an investment's NPV are considered in this analysis: variable yield responses and variable output prices. A distribution of output prices is used that reflects anticipated output price variability. A long-run forecast price of $2.30 per bushel is used and random deviations from this price mean are generated based on variations in the average September price at Richmond observed over the period 1969-1984 (Bosch *et al.*).[1] The distribution contains 16 equally likely prices of which the minimum, mean, and maximum are $1.91, $2.30, and $2.90, respectively.

A corn growth and yield simulator, CRPSM (Hill *et al.*), is used to determine the yield response to irrigation and the demand for irrigation water under variable weather conditions. The model uses soil AWC, daily temperatures, rainfall, and irrigation data to determine the growth and yield of corn. The model was calibrated for Virginia growing conditions by statistically estimating parameters of the yield prediction equation (Bosch *et al.*). The estimation was done with weather, soils, irrigation, and yield data from irrigation trials over several years at three experiment stations in Virginia. The model is used with 1973-1984 weather data and each AWC to generate a set of yield responses to irrigation and annual irrigation amounts for each clump on which irrigation is physically feasible.

A FORTRAN program, ECONFEAS, is used to evaluate the economic feasibility of irrigating potential sites. Traveling gun and fixed and towable center pivot systems are considered for each potential site. Design models developed by Taylor *et al.* are used to estimate physical capacity and costs of each system as a function of field size, vertical distance, and horizontal distance from the stream. Center pivots are not allowed to exceed 300 acres and traveling gun systems cannot exceed 85 acres. More than one system may be included if clump size exceeds allowable system size. Systems are assumed to last 15 years.

The physical characteristics of a given clump are read and the irrigation system with the lowest investment cost is selected for that clump. Fixed annual ownership costs and tax-deductible depreciation benefits are calculated for each year of the system's life and discounted to the present as is the after-tax salvage value of the system. The present value of the system's cost equals the purchase cost plus the present value of annual ownership costs minus the present value of tax benefits of ownership minus the present value of salvage.

As the benefits of irrigation are uncertain, each system is simulated for 50 lifetimes and a present value of after-tax benefits is calculated for each lifetime. The after-tax benefits of a given year of a given lifetime are calculated as follows: A yield response from irrigation and irrigation application amount are randomly selected from the 12 responses and application amounts generated by CRPSM over the period, 1973-1984, for the AWC and weather pattern characterizing that clump. An output price is selected randomly from the uniform distribution of output prices, inflated to the year of the system's life in which it occurs, and multiplied by the yield increase to get a gross return from irrigation. This return is reduced by the additional production costs of irrigation (primarily for added fertilizer and seed) as well as variable pumping costs associated with the selected irrigation application amount, and variable harvest and drying costs. Finally, taxes are subtracted from net income and the after-tax net income for the year is discounted to the present. The procedure assumes that output prices and yield responses are independent.[2]

The expected present value of after-tax benefits is calculated from the 50 present values. If the expected present value of benefits exceeds the present value of the system's cost, the expected NPV is positive and the clump is economically feasible for irrigation. The procedure is repeated for each clump and the total economically feasible acreage computed.

Effects of irrigation expansion on streamflow

The model CRPSM is used to predict daily per acre irrigation amounts required by irrigation systems characterized by each weather pattern and AWC over the period, 1973-1984. These daily amounts are multiplied by the number of feasible acres in each weather pattern and AWC category, and aggregate demand for each day is calculated. Daily streamflow records obtained from the Hydrologic Information Storage and Retrieved System (HISARS) and measured at mile 12 of the Pamunkey River between 1973 and 1984 are used to provide an estimate of water available for irrigation. There are nearly 48 miles of river from which irrigation occurs below this station; however, in periods of low flow, which are of most interest to this study, the downstream tributaries of the Pamunkey are not likely to contribute greatly to the river flow (Vellidis).

Projected daily demand is compared with daily streamflow to determine the probability and extent of shortages. A simple example illustrates the procedure. Data indicate that on June 9, 1975 the streamflow would provide about 4160 acre inches of water for irrigation. The model CRPSM indicates that, with irrigation expanded to its maximum economic potential there are 16,245 acres which would require irrigation given the weather patterns on and before that date and the distribution of soil AWC's. Dividing the 4,160 acre inches by 16,245 acres yields irrigation supplies of .256 inches per acre for that date.

Effects of water supply risk on irrigation profitability

The riparian doctrine does not provide guidelines for allocating water among riparian users when shortages arise. The doctrine simply states that users must make *reasonable use* of water, that is, use which does not injure the rights of other riparian users (Cox *et al.*). The assumption made here is that total water available in the stream is divided equally among all economically feasible and/or currently irrigated crop acres.

CRPSM is used to search for an expected profit-maximizing irrigation strategy given the actual per acre amount of water available each day over the period 1973-1984. The yield responses to irrigation and irrigation amounts obtained with the expected profit-maximizing strategy are used by the program, ECONFEAS, to project irrigation expansion with the restricted supplies.

Results

A total of 17,348 acres is projected to be economically feasible including current irrigation, assuming that water supplies are not limiting. Of this total, about 3,329 acres are currently irrigated (Vellidis). About 7% of the acreage is on two-inch AWC soil and 93% is on four-inch AWC soil. Approximately 41% of the total lies in the area covered by the Ashland weather station and 59% is in the Walkerton station area. Only one feasible system is more than one mile from the water source (5600 feet).

Table 1 shows the probabilities that per acre supplies will exceed projected per acre demand for each day of the irrigation season with 17,348 acres under irrigation. The period shown, April 26 through August 1, encompasses the days on which the crop model, CRPSM, shows that an irrigation could be required for 1973 through 1984 weather conditions, assuming that the crop is always planted on April 10 and the initial soil profile is always saturated. Days on which irrigation is required are determined from the expected profit-maximizing irrigation schedule derived for the 1973-1984 period. Per acre demand is set at .3125 inches on any day when an irrigation is required, which, assuming 80% efficiency, means .25 net inches are applied to the soil per day of irrigation.

Of the entire 98-day period, 52 days have less than 100% probability of having adequate supplies. On 9 days there is only a .67 probability of adequate supplies. The minimum streamflows give some indication of the extent of potential problems. For example, on days such as July 31 the minimum per acre supply is only about one third of the assumed requirement of .3125 inches. The obvious conclusion, based on the methods used in this study, is that irrigation expansion in the Pamunkey River basin could lead to significant water shortages in some years.

The final question concerns the economic impact of these potential shortages. Daily supplies are divided equally among all currently irrigated and potentially irrigable acres and the feasibility of each system is recalculated with the restricted supplies. The economic impact is measured as a

Table 1. Minimum Water Supply Available per Acre and Probability that Water Supply Will Meet or Exceed Water Demand for Each Day of the Irrigation Season[a]

MO	DAY	PROB	MIN (in/ac)	MO	DAY	PROB	MIN (in/ac)	MO	DAY	PROB	MIN (in/ac)
APR	26	1.00	79.97	MAY	29	1.00	0.59	JUL	1	0.67	0.18
APR	27	1.00	8.96	MAY	30	1.00	0.52	JUL	2	0.83	0.18
APR	28	1.00	8.29	MAY	31	0.92	0.31	JUL	3	0.83	0.16
APR	29	1.00	7.48	JUN	1	1.00	0.72	JUL	4	0.75	0.16
APR	30	1.00	7.77	JUN	2	1.00	0.32	JUL	5	0.75	0.16
MAY	1	1.00	1.70	JUN	3	0.92	0.29	JUL	6	0.75	0.18
MAY	2	1.00	5.41	JUN	4	1.00	0.43	JUL	7	0.75	0.18
MAY	3	1.00	7.69	JUN	5	1.00	0.38	JUL	8	0.83	0.17
MAY	4	1.00	5.45	JUN	6	1.00	0.59	JUL	9	0.92	0.18
MAY	5	1.00	4.56	JUN	7	1.00	0.33	JUL	10	0.83	0.20
MAY	6	1.00	4.17	JUN	8	0.83	0.26	JUL	11	0.92	0.25
MAY	7	1.00	3.96	JUN	9	0.92	0.26	JUL	12	0.83	0.23
MAY	8	1.00	3.75	JUN	10	1.00	0.39	JUL	13	0.83	0.24
MAY	9	1.00	7.94	JUN	11	1.00	0.41	JUL	14	0.92	0.31
MAY	10	1.00	8.40	JUN	12	1.00	0.38	JUL	15	0.92	0.23
MAY	11	1.00	7.62	JUN	13	1.00	0.34	JUL	16	0.83	0.19
MAY	12	1.00	6.86	JUN	14	0.92	0.21	JUL	17	0.75	0.24
MAY	13	1.00	9.69	JUN	15	0.92	0.21	JUL	18	0.75	0.21
MAY	14	1.00	5.63	JUN	16	0.83	0.21	JUL	19	0.67	0.17
MAY	15	1.00	0.90	JUN	17	0.83	0.18	JUL	20	0.92	0.15
MAY	16	1.00	0.36	JUN	18	0.75	0.17	JUL	21	0.67	0.14
MAY	17	1.00	0.35	JUN	19	0.92	0.17	JUL	22	0.67	0.14
MAY	18	1.00	0.36	JUN	20	0.75	0.16	JUL	23	0.75	0.18
MAY	19	1.00	0.53	JUN	21	0.75	0.20	JUL	24	0.75	0.15
MAY	20	1.00	0.51	JUN	22	0.92	0.22	JUL	25	0.92	0.18
MAY	21	0.92	0.29	JUN	23	0.75	0.21	JUL	26	1.00	0.37
MAY	22	0.92	0.28	JUN	24	0.75	0.20	JUL	27	1.00	0.39
MAY	23	1.00	0.65	JUN	25	0.67	0.16	JUL	28	0.92	0.22
MAY	24	1.00	0.63	JUN	26	0.67	0.15	JUL	29	0.92	0.14
MAY	25	1.00	0.66	JUN	27	0.67	0.14	JUL	30	0.92	0.13
MAY	26	1.00	0.68	JUN	28	0.75	0.13	JUL	31	0.92	0.11
MAY	27	1.00	0.75	JUN	29	0.67	0.13	AUG	1	1.00	0.34
MAY	28	1.00	0.77	JUN	30	0.67	0.12				

[a] Minimum water supply is the lowest amount of water available per acre requiring irrigation on a given day for the years 1973 through 1984. Water supply estimates are based on 12 years, 1973-1984, of streamflow data from the Pamunkey River. The probability expresses as a decimal fraction the number of years out of 12 that per acre supply falls above the assumed daily irrigation requirement of .3125 of an inch on a given day.

decline in per acre NPV of each feasible system after water availability is restricted. The average reduction in NPV for all feasible systems is about $46 per acre or about 14% of the NPV with unrestricted water. The NPV reductions are quite variable with a standard deviation of $47. The smallest and largest per acre reductions in NPV are $8.22 and $212.67. The large reductions occur on the less prevalent 2-inch AWC soils which are more drought prone. When only the more predominant 4-inch soils are considered, the largest reduction in NPV is $79. Another cause of variation in the amount of loss is the predominant weather pattern. Sites characterized by temperature and rainfall data from the Walkerton station have lower losses than do sites for which Ashland data is used. Historical weather data from the Ashland station has more rainfall variability and more prolonged dry spells than does Walkerton, thus increasing losses from reduced water availability.

The results show that with restrictions the total of currently irrigated and potentially irrigable acres falls from 17,348 acres to 17,159 acres, a decline of about 1%. Two reasons for the relatively small decline are: 1) the water shortages only occur in some years; and 2) the irrigation scheduling strategy is altered to reflect the reduced supplies. Generally, the optimal strategy calls for starting irrigation at a lower soil water depletion level when supplies are restricted. The irrigator compensates somewhat for the reduced daily streamflow supplies by keeping more moisture stored in the soil.

Conclusions

A method has been presented for projecting potential expansion of irrigation from riparian sources and for comparing the increased demand brought about by this expansion with available streamflow supplies. The methods are applied to the Pamunkey River basin in Virginia. Results indicate the possibility for a nearly five-fold expansion of irrigation from current levels in this basin. Such expansion would lead to water shortages in some years, reduce the returns from irrigation, and likely result in water use conflicts. If such expansion occurs, the riparian doctrine may not be an efficient means for allocating water and resolving water use conflicts in the Pamunkey River basin.

Additional research is needed on at least two questions. First, the effects of imposing minimum streamflow requirements on supplies of water for irrigation and potential irrigation expansion should be evaluated. The need for minimum requirements to protect the esthetic and biological qualities of the stream is recognized (State Water Control Board); however, minimum inflow requirements have not been set in Virginia. If a minimum were set, irrigation supplies would be significantly reduced in some years, thus reducing yields and the profitability of irrigation.

Second, the effects of alternative means of allocating water should be investigated. One alternative which policymakers have is to continue with the riparian doctrine. In that case they may have to deal with frequent conflicts in water shortage situations. A second alternative would be an administrative mechanism by which a limited number of permits to irrigate would be granted. In this case, rules would have to be established for deciding who gets the permits. Other allocation alternatives should also be identified and evaluated.

Footnotes

[1] Two Virginia grain marketing experts estimated that the most likely harvest price for corn in eastern Virginia over the next three to five years is $2.30.

[2] This assumption appears to be reasonable in Virginia as marketing experts indicate the correlation between prices and yields to be very low.

References

Boggess, W. G., and C. B. Amerling. "A Bioeconomic Simulation Analysis of Irrigation Investments." *So. J Agr. Econ.* 15(1983): 85-91.

Bosch, D. J., D. B. Taylor, and B. B. Ross. "Economic Feasibility of Irrigation from Riparian Water Sources." Paper presented at 1987 Southern Agricultural Economics Association Meetings Feb. 1-4, Nashville, Tennessee.

Cox, W. E., L. A. Shabman, S. S. Batie, and J. W. Looney. "Virginia's Water Resources: Policy and Management Issues." Paper developed in the Departments of Agricultural Economics and Civil Engineering, Virginia Polytechnic Institute and State University, Blacksburg, 1981.

Gill, E. E. "A Net Present Value Approach Under Uncertainty for Making the Irrigation Investment Decision in Central Minnesota." Unpublished Plan B Project Paper, Department of Agricultural and Applied Economics, University of Minnesota, 1984.

Hill, R. W., R. J. Hanks, and J. L. Wright. "Crop Yield Models Adapted to Irrigation Scheduling Programs." Research Report 99, Utah Agricultural Experiment Station, Utah State University, Logan, 1982.

Hydrologic Information Storage and Retrieval System. Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg, 1986.

Palmer, W. L., B. J. Barfield, and C. T. Haan. "Sizing Farm Reservoirs for Supplemental Irrigation of Corn. Part II: Economic Analysis." *Trans. Amer. Soc. Agr. Eng.* 25(1982): 377-380.

Robertson, J.D., W. N. Musser, and B. V. Tew. "Lease Versus Purchase of a Center-Pivot Irrigation System: A Georgia Example." *So. J. Agr. Econ.* 14(1982): 37-42.

State Water Control Board. "Memorandum: Summary of Transactions for State Water Plan Advisory Committee." Richmond, Virginia, November 28, 1986.

Taylor, D. B., B. B. Ross, G. Vellidis, and A. B. Lanier. "Assessing the Feasibility and Potential Expansion of Large Scale Riparian Irrigation in Virginia." Bulletin 146, Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg, 1985.

Tomlin, C. D. "The Map Analysis Package." Unpublished Manuscript, School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut, 1980.

Vellidis, G. "A Method for Assessing the Feasibility of Riparian-Based Irrigation Systems." Unpublished M.S. Thesis, Department of Agricultural Engineering, Virginia Polytechnic Institute and State University, Blacksburg, 1985.