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The Convergence of Water Rights, Structural Change, Technology, and Hydrology: A Case Study of New Mexico's Lower Rio Grande

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ABSTRACT

Irrigated areas throughout the western United States are undergoing water rights adjudication. At the same time, agriculture is undergoing significant structural change, including increasing numbers of smaller, lifestyle-based farms. Today's remote-sensing technology makes it possible to accurately estimate evapotranspiration on individual fields and aggregate this information to basin-wide crop consumptive use. The difference between actual and theoretical consumptive use creates the potential for hydrologic deficits if the theoretical levels are adjudicated (e.g., established as rights) and then consumptively used. This article examines the implications of theoretical versus actual consumptive use and includes a case study of New Mexico's Lower Rio Grande region to illustrate the convergence of water rights adjudication and structural changes in agriculture. It also highlights recently introduced technologies for estimating consumptive use and explores the numerous hydrologic risks of adjudication based on theoretical, rather than actual or historic, consumptive use.

I. INTRODUCTION

Approximately 90 percent of water consumed in the arid regions of the western United States is used by irrigated agriculture.[1] The West's

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1. WESTERN WATER POLICY REVIEW ADVISORY COMM'N, WATER IN THE WEST: CHALLENGE FOR THE NEXT CENTURY 2-24 (June 1998), http://bioe.oregonstate.edu/Faculty/

population and economy are growing, diversifying, and creating pressure to transfer water to non-agricultural uses. Water rights are being adjudicated in many basins throughout the West where state-level water managers are seeking to confirm and formalize water resource property rights. Legally defined water rights are essential for well-functioning, efficient water markets in which both wet water, or actually used water, and paper water, or the amount of a water right confirmed on paper, can be transparently bought and sold.[2]

Adjudications usually involve two processes: (1) defining the boundaries of land upon which water rights are attached; and (2) defining the quantity of wet water that can be put to beneficial use by the water rights possessor. These two processes were initiated in 1986 in New Mexico's Lower Rio Grande region with the filing of *Elephant Butte Irrigation District v. State Engineer*, Doña Ana County Cause No. CV-86-848, by the Elephant Butte Irrigation District[3] (EBID). As of 2011, many offers of settlement from the State of New Mexico for water-righted acreages have been made, and some have been accepted; however, the question of the quantity—or duty—of water associated with these lands has not been settled. This duty of water is likely to be controversial because its legal definition will establish water property rights, impact future usage patterns, and affect depletion levels. Thus, it is imperative that correct information for quantities of water actually put to beneficial use in the Lower Rio Grande region is used during the adjudication process.

The duty of water is an old legal concept challenged by new technology that can accurately measure historic and current consumptive use by irrigated agriculture. Defining duty in an irrigated region is further complicated by changing cropping patterns, new irrigation technologies, and structural change in agriculture. Establishment of a base period for beneficial water use can also be a major problem, as recently introduced crops and new technologies can result in greater consumptive use relative to earlier dominant crops and irrigation practices. Therefore, different equity and hydrologic implications of water rights adjudication are raised based on either current or historic consumptive irrigation requirements.

This article explores the convergence of water rights adjudication, structural change in agriculture, technological advances, and regional

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selker/Oregon%20Water%20Policy%20and%20Law%20Website/Report%20of%20the%20WWPRAC/WATER.PDF.

2. MARKETS FOR WATER: POTENTIAL AND PERFORMANCE (K. WILLIAM EASTER, MARK W. ROSEGRANT & ARIEL DINAR, eds., 1998).

3. Brian C. Wilson, N.M. OFFICE OF THE STATE ENG'R & INTERSTATE STREAM COMM'N, 1999–2000 ANNUAL REPORT, at app. A, *available at* http://www.ose.state.nm.us/publications/99-00-annual-report/index.html (last modified Mar. 8, 2001).

hydrology that is occurring in New Mexico's Lower Rio Grande. This convergence likely affects—or soon will affect—other basins. First, the concepts of duty of water, consumptive irrigation requirement, and farm-delivery requirement are defined and related to notions of successful crop production and farmers' objectives. Second, the changing agricultural structure, evolving farmer motivations, crop choices, production practices, and irrigation practices in the Lower Rio Grande and other basins are reviewed and discussed using data available as a result of recent advances in remote-sensing measurement of on-farm water use. Third, New Mexico's Lower Rio Grande region is used as a case study to examine the numerous hydrologic risks of water rights adjudication based on the theoretical, well-watered conditions assumed for commercially-oriented, working farms rather than the distribution of actual consumptive use found using remotely-sensed data.

II. DUTY OF WATER, FARM DELIVERY REQUIREMENTS, AND CONSUMPTIVE IRRIGATION REQUIREMENTS

In 1903, Bureau of Reclamation great Elwood Mead defined the duty of water as "the area of crop which can be matured with a given volume."[4] The 1917 edition of the *Manual of the United States Reclamation Service* used the more common definition, stating that "the duty of water is the quantity required for crop production on a given area, usually during a year or irrigation season. This may be expressed in acre-feet per acre, in acres per second-foot of continuous flow during the season, or in other units or combinations of these."[5] The duty of water includes water consumed through crop evapotranspiration (ET), water that evaporates during the irrigation process and return flows, or the amount of water applied to the crop in excess of evapotranspiration and evaporation.

The duty of water is the quantity of water attached to a specific water right.[6] In newer terminology, a theoretical consumptive irrigation requirement (CIR), which includes both water consumptively used by plants and evaporated from the soil surface, is estimated for a crop. The CIR is then adjusted by application efficiency in order to determine the amount of water that must be diverted onto a farm (e.g., the theoretical farm delivery requirement, or FDR) in order to mature or produce a

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4. ELWOOD MEAD, IRRIGATION INSTITUTIONS 116 (Richard T. Ely ed., 1903).

5. A.P. DAVIS & WILL R. KING, DEP'T OF THE INTERIOR, MANUAL OF THE UNITED STATES RECLAMATION SERVICE 326 (1917).

6. WELLS A. HUTCHINS, USDA, THE NEW MEXICO LAW OF WATER RIGHTS 26 (1955), *available at* http://www.ose.state.nm.us/PDF/Publications/Library/TechnicalReports/TechReport-004.pdf.

ET, CIR & FDR Explained

$ET_c = K_c * ET_o$

ET_c = theoretical evapotranspiration, or water consumptively used by a crop

K_c = crop coefficient, dimensionless number multiplied by reference ET (or ET_o) to estimate a specific crop's theoretical ET (or ET_c)

ET_o = reference ET, usually grass, calculated from climatic data

$CIR = ET_c – Re$

Re = effective rainfall

FDR = CIR/Eff

Eff = on-farm irrigation efficiency, or water consumptively used by a crop / water applied or diverted at the farm gate

FIGURE 1: Relationships between (theoretical) evapotranspiration (ET), consumptive irrigation requirement (CIR), and farm delivery requirement (FDR).

crop.[7] Relationships between ET, CIR, and FDR are illustrated in Figure 1 (above).

Consumptive irrigation requirements are usually established using a crop coefficient method (e.g., Blaney-Criddle or Penman-Montieth), which incorporates climatic variables.[8] Underlying all of these methods is the assumption of standard production and management conditions.

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7. BRIAN C. WILSON & ANTHONY A. LUCERO, N.M. STATE ENG'R OFFICE, WATER USE BY CATEGORIES IN NEW MEXICO COUNTIES AND RIVER BASINS, AND IRRIGATED ACREAGE IN 1995, at 72 (Sept. 1997), *available at* http://www.ose.state.nm.us/PDF/Publications/Library/TechnicalReports/TechReport-049.PDF.

8. Crop coefficient methods of determining the amount of water consumed by plants use a reference surface (usually grass) with a reference evapotranspiration (ET_o). Field crops are distinguished from grass by surface characteristics and have crop coefficients that vary with crop characteristics and climate. Crop coefficient (K_C) is the ratio of the crop ET_C to ET_o. Crop coefficients predict ET_C under standard, well-watered, unlimited conditions. Crop coefficients are derived experimentally. ORSON W. ISRAELSEN & VAUGHN E. HANSEN, IRRIGATION PRINCIPLES AND PRACTICES (Glen E. Stringham ed., 4th ed. 1980); RICHARD G. ALLEN ET AL., FOOD & AGRIC. ORG., IRRIGATION AND DRAINAGE PAPER NO. 56: CROP EVAPOTRANSPIRATION 210 (Feb. 2006), *available at* http://www.kimberly.uidaho.edu/water/fao56/fao56.pdf.

Standard soils, planting, harvesting, and other key crop stage dates, crop varieties, and cultural practices are all assumed in the region for which crop coefficients are developed.[9] Furthermore, crop coefficients used to determine CIRs are based on the assumption that the irrigated crops are healthy, disease-and-insect-free, actively growing, well-watered, and overall well-managed. Thus, estimates of the water required to produce a crop are usually based on near-optimal conditions.[10]

Even before the development of the technology and research methods used to derive modern CIRs and FDRs, western courts had recognized that crop production and on-farm irrigation conditions were factors that should be taken into account in determining the duty of water.[11] For example, water law scholar Wells A. Hutchins[12] cited a 1924 Montana Supreme Court statement that, "In determining the duty of water the court should ascertain the quantity which is essential to irrigate economically but successfully the tract of land to be irrigated."[13] Hutchins also noted an Idaho case that stated, "In offering evidence as to the duty of water, the inquiry is properly directed to the amount of water necessary to be diverted from the stream in order to properly irrigate the land."[14] Notions of what defines successful or proper irrigation conditions and crop production are modernly referred to as well-managed or above-average management and are characteristic of successful farming.[15]

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9. ALLEN ET AL., *supra* note 8, at 87.

10. *Id.* "The standard conditions refer to crops grown in large fields under excellent agronomic and soil water conditions." The authors also state that K_C "represents the upper envelope of crop evapotranspiration and represents conditions where no limitations are placed on crop growth or evapotranspiration due to water shortage, crop density, or disease, weed, insect or salinity pressures."

11. 1 WELLS A. HUTCHINS, USDA, WATER RIGHTS LAWS IN THE NINETEEN WESTERN STATES 506–15 (1971).

12. *Id.*

13. *Allen v. Petrick*, 222 P. 451, 453–54 (Mont. 1924).

14. *Clark v. Hansen*, 206 P. 808, 809 (Idaho 1922).

15. For example, New Mexico cost and return estimates for farms and ranches published by the New Mexico Cooperative Extension Service are for "above average" management conditions. *Cost and Return Estimates for Farms and Ranches 2001–2007*, N.M. STATE UNIV. COOP. EXTENSION SERV., http://costsandreturns.nmsu.edu/ (last visited Mar. 2, 2011).

III. THE STRUCTURE OF AGRICULTURE AND FARMERS' MOTIVATIONS

Currently, the structure of agriculture[16] in the United States is dualistic and will likely become even more so in the future. This dual structure is one in which approximately 5 percent of farms account for almost 75 percent of the value of agricultural output, with the remaining 95 percent of farms responsible for 25 percent of output.[17] A "farm" is defined by the U.S. *Census of Agriculture* as "any place from which $1,000 or more of agricultural products were produced and sold, or normally would have been sold," in a given year.[18] The United States had 2.2 million farms in 2007, with almost 80 percent of farms selling less than $50,000 worth of goods annually.[19] Approximately 55 percent of farm operators do not consider farming to be their principal occupation, and 65 percent of all farms report some off-farm work during the year.[20] For the farm sector as a whole, 80 percent of total farm household income is derived from off-farm employment.[21]

A new farm typology developed by the U.S. Department of Agriculture classifies the 90 percent of U.S. farms with less than $250,000 in annual sales as small farms.[22] This typology further categorizes small farms as limited resource, retirement, residential/lifestyle, and farming occupation operations.[23] Of all U.S. farms, 56 percent are retirement or residential/lifestyle operations and account for 7.3 percent of the value of agricultural production.[24]

These thousands of farms in lower sales categories tend to have chronic negative net farm incomes and most have no intention of earning

16. The structure of agriculture refers to the number and size of farms, ownership and control of resources, and the managerial, technological, and capital organization of farming. RONALD D. KNUTSON, J.B. PENN & WILLIAM T. BOEHM, AGRICULTURAL AND FOOD POLICY (3d ed. 1995).

17. *See* 1 USDA, 2007 CENSUS OF AGRICULTURE: UNITED STATES SUMMARY AND STATE DATA, AC-07-A-51, at 9 tbl.2 (2009), *available at* http://www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf.

18. *Id.* at viii.

19. *See id.* at 7 tbl.1.

20. *See id.*

21. J. MICHAEL HARRIS ET AL., USDA, AGRICULTURAL INCOME AND FINANCE OUTLOOK 3 (Dec. 2008), *available at* http://usda.mannlib.cornell.edu/usda/ers/AIS/2000s/2008/AIS-12-10-2008.pdf.

22. *See* ROBERT A. HOPPE ET AL., USDA, STRUCTURE AND FINANCES OF U.S. FARMS: FAMILY FARM REPORT iii (June 2007), *available at* http://www.ers.usda.gov/publications/eib24/eib24.pdf.

23. *Id.*

24. *See id.*

a living from agricultural production.[25] For many of these people, crop or livestock production is a consumption activity that must be funded with off-farm earnings.[26] For example, residential/lifestyle farms had an average 2004 total *household* income of $96,515 with average annual *farm* losses of $365.[27]

The classic textbook formulation of the theory of the firm[28] holds that farm operators (like operators of other businesses or firms) have the goal of economic efficiency with the specific objective of profit maximization.[29] Thus, managers of these farm firms are economic agents that incorporate information about production inputs and outputs (and the prices of both) into their decision-making processes.[30] Profit-maximization objectives drive decisions about optimal levels and combinations of inputs as well as optimal amounts of outputs. Like other business owners, profit-maximizing farmers want their businesses to survive, and farm incomes must be positive in order to do so.[31] However, the data presented above indicate that for many farms, off-farm earnings subsidize the farming activity. These farm operators are making an economic sacrifice to engage in farming and are using their farms to pursue lifestyle goals rather than farm profits or farm incomes. If these farmers were truly commercially motivated, they would leave agriculture and invest their resources in activities or enterprises with higher returns.[32] The pursuit of higher returns to financial and human capital explains the massive out-migration of people from agriculture to other sectors of the U.S. economy throughout much of the twentieth century. However, recent decades have seen a turnaround migration of people back into rural-residence farming lifestyles, particularly in regions where opportunities exist for off-farm employment.[33] The 2007 U.S. *Census of Agriculture* found a

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25. *See generally id.* at iv.

26. *Id.*

27. *Id.* at 23 tbl.7.

28. "Theory of the Firm" refers to a number of economic theories that describe and predict the nature and behavior of firms (e.g., a business such as a sole proprietorship, a partnership, or a large corporation) that engage in the production and marketing of goods and services. *See* EDWIN MANSFIELD, MICROECONOMICS: THEORY & APPLICATIONS (4th ed. 1982); *see also* JOHN P. DOLL & FRANK ORAZEM, PRODUCTION ECONOMICS: THEORY WITH APPLICATIONS (2d ed. 1984) (examples of firm theory applied to agricultural applications).

29. *See supra* note 28 and accompanying text.

30. *Id.*

31. *Id.*

32. Steven C. Blank, *Is Agriculture a "Way of Life" or a Business?*, 17 CHOICES: THE MAG. OF FOOD, FARM, & RESOURCE ISSUES, June 2002, at 26.

33. *Briefing Rooms: Rural Population and Migration: Trend 2–Nonmetro Population Growth Slows*, USDA, http://www.ers.usda.gov/Briefing/Population/Nonmetro.htm (last updated Feb. 1, 2007).

4 percent increase in the number of U.S. farmers from 2002 to 2007, with most new farms being small, part-time operations.[34]

The U.S. Department of Agriculture reports that small farms account for 61 percent of the land owned by farms.[35] Although production of agricultural commodities may primarily be a lifestyle activity for many small farms, Steven C. Blank, a specialist in agriculture and resource economics, concluded that wealth accumulation through appreciating land values is a business-like objective of even the smallest "hobby" farms.[36] Little information is available regarding the proportion of western water resources controlled by small farms that are operated primarily for lifestyle objectives rather than for commercial, business objectives. However, it is probably safe to assume that lifestyle-oriented irrigated farm operators anticipate future capital gains in both land and water assets because of the closely related nature of land and water in irrigated agricultural areas.

The agricultural structure in New Mexico's Lower Rio Grande region is even more dualistic than the United States overall. In Doña Ana County, where the majority of EBID lands are located, 79 percent of farms have annual sales of less than $25,000, and 63 percent have annual sales of less than $10,000.[37] Even though the U.S. *Census of Agriculture* reports that total irrigated land in Doña Ana County decreased between 1978 and 2007 (from 84,700 to 79,019 acres), the number of irrigated farms more than doubled (from 772 to 1,594) over the same period due to the growing number of very small farms.[38]

Relationships between farm size, irrigation practices, and on-farm irrigation efficiencies in the EBID were examined in previous research by authors Skaggs and Samani.[39] They found that many small farm opera-

34. Andrew Martin, *Farm Living (Subsidized by a Job Elsewhere)*, N.Y. TIMES, Feb. 7, 2009, *available at* http://www.nytimes.com/2009/02/08/business/08feed.html.

35. HOPPE ET AL., *supra* note 22, at iv.

36. Steven C. Blank, *The Business of an Agricultural "Way of Life,"* 20 CHOICES: THE MAG. OF FOOD, FARM, & RESOURCE ISSUES, 161 (2005), *available at* http://www.choicesmagazine.org/2005-2/grabbag/2005-2-13.htm.

37. *See* 1 USDA, 2007 CENSUS OF AGRICULTURE: COUNTY DATA, NEW MEXICO, AC-07-A-31, at 250 tbl.1 (2009), *available at* http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_County_Level/New_Mexico/nmv1.pdf.

38. U.S. DEP'T OF COMMERCE, BUREAU OF THE CENSUS, 1982 CENSUS OF AGRICULTURE: NEW MEXICO STATE AND COUNTY DATA, AC-82-A-31, at 145 tbl.4 (1982), *available at* http://usda.mannlib.cornell.edu/usda/AgCensusImages/1982/01/31/1982-01-31.pdf (comparing 1978 and 1982 farm lands data); USDA, *supra* note 37, at 250 tbl.1, 302 tbl.10 (2007 farm lands data).

39. RHONDA SKAGGS & ZOHRAB SAMANI, COLLEGE OF AGRIC. & HOME ECON. IRRIGATION PRACTICES VS. FARM SIZE: DATA FROM THE ELEPHANT BUTTE IRRIGATION DISTRICT (2005), *available at* http://aces.nmsu.edu/pubs/taskforce/water/WTF_4.pdf. *See also*, Rhonda Skaggs

tors are primarily motivated to minimize the costs or risks of operating their residential/lifestyle farms regardless of the impact on irrigation water productivity, crop yields, or crop revenues.[40] They also found that operators have the key objective of maximizing utility or satisfaction from the small farm lifestyle and irrigation activities.[41] Recreational irrigators tend to spend more time per acre irrigating, employ less-sophisticated irrigation technology, and are characterized by less-intensive irrigation management than operators of business-oriented farms.[42] The authors concluded that non-commercially-oriented irrigators are not motivated to achieve crop yields and "crop per drop" levels attained by business-oriented irrigators and are unlikely to invest in new irrigation infrastructure and efficiency-enhancing technology.[43] The common property nature of delivery ditches serving small, fractioned fields in rural-residential areas provides an additional disincentive for individuals to make investments in irrigation infrastructure as well.[44]

Agricultural economist Steven Blank also distinguished between the types of investments made on "real" farms versus "investment" farms.[45] He noted that some farmers make investments that raise the value of the operation as a "working farm" while owners of investment farms do not.[46] Skaggs and Samani found few instances of "working farm" investments on the small, irrigated EBID farms they studied, supporting the hypothesis that household cost- and risk-minimization and lifestyle objectives are key to small-scale irrigated farm operators' motives.[47] EBID fields belonging to large commercial farms tended to have improved irrigation systems and were often intensively managed and quickly irrigated through modern turnouts. The "working farm" irrigation investments reduced the costs of irrigating, increased water use efficiency, and raised the value of the farm business.[48]

& Zohrab Samani, *Farm Size, Irrigation Practices, and On-Farm Irrigation Efficiency*, 54 Irrigation and Drainage 43 (2005).

40. *See supra* note 39.
41. Id.
42. Id.
43. Id.
44. Id.
45. *See* Blank, *supra* note 36, at 164.
46. *Id.*
47. *See supra* note 39.
48. *Id*.

IV. TECHNOLOGICAL ADVANCEMENTS IN MEASURING ON-FARM WATER USE

As noted above, crop consumptive use, or ET, is responsible for most water depletion in the West.[49] Various methods have been developed for estimating ET, including the popular use of crop coefficients and climatic parameters.[50] ET estimates also can be made using the eddy covariance technique, by soil moisture monitoring, or with lysimeters.[51] These tools and methods provide a small number of point measurements of ET with data collection limited by available financial and human resources. Although point measurements of ET are routinely extrapolated to larger scales, real-world crop growing conditions and field-level variability mean they are uncertain when upscaled to entire basins or irrigation districts.[52] Fortunately, recent advances in remote-sensing technology make it both technically and financially feasible to conduct basin-wide, field-level ET accounting. Remote sensing provides the most advanced and cost-effective approach to estimating crop ET over large areas with diverse field-level conditions and can be scaled-up in order to objectively assess basin-wide depletion.[53]

Techniques for estimating ET using remotely-sensed data have been under development for several years and applied throughout the world.[54] Using methods similar to those applied by Bastiaanssen et al.[55]

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49. *See* WESTERN WATER POLICY REVIEW ADVISORY COMM'N, *supra* note 1.

50. *See supra* note 8 and accompanying text.

51. IRRIGATION PRINCIPLES AND PRACTICES, *supra* note 8; ALLEN ET AL., *supra* note 8. Eddy covariance techniques quantify evapotranspiration from the plant canopy (surface) to the atmosphere through rapid measurement of vertical wind speed, water vapor density, and other variables. Estimates of ET by lysimeters are based on the water budget method, in which tanks are filled with soil in which plants are grown under natural conditions to measure water lost by evaporation and transpiration. Soil moisture monitoring is based on soil water depletion method in which ET under field conditions is determined by measuring the change in soil water over a period of time using sensors or other methods.

52. RICHARD G. ALLEN ET AL., EVAPOTRANSPIRATION FROM A SATELLITE-BASED SURFACE ENERGY BALANCE FOR THE SNAKE PLAIN AQUIFER IN IDAHO (2002), *available at* http://www.waterplan.water.ca.gov/docs/cwpu2005/Vol_4/02-Crop%20Water%20Use/V4PRD6-EvapoSat.pdf.

53. Wim G.M. Bastiaanssen, David J. Molden & Ian W. Makin, *Remote Sensing for Irrigated Agriculture: Examples from Research and Possible Applications*, 46 AGRIC. WATER MGMT. 137 (2000).

54. Wim G.M. Bastiaanssen et al., *A Remote Sensing Surface Energy Balance Algorithm for Land (SEBAL), Part 1: Formulation*, 212-213 J. HYDROLOGY 198 (1998) [hereinafter Bastiaanssen et al., *A Remote Sensing Part 1*]; Wim G.M. Bastiaanssen et al., *A Remote Sensing Surface Energy Balance Algorithm for Land (SEBAL), Part 2: Validation*, 212-213 J. HYDROLOGY 213 (1998) [hereinafter Bastiaanssen et al., *A Remote Sensing Part 2*]; Richard G. Allen et al., *From High Overhead: ET Measurement via Remote Sensing*, SOUTHWEST HYDROLOGY, Jan./Feb. 2008, at 30.

and Allen et al.,[56] the Regional ET Estimation Model (REEM) developed at New Mexico State University for agricultural and riparian vegetation uses satellite data to calculate ET as a residual of the energy balance. Technical details of REEM are presented in Samani et al.[57]

Research on crop consumptive use often focuses on yield-ET relationships and has resulted in theoretical relationships for crop yield as a function of crop ET.[58] The relationship between yield and ET is linear over a wide range of ET for most crops, with both crop water use and crop yield bounded by climatic, agronomic, or environmental limitations largely outside the control of the irrigator.[59] An optimal crop ET is the foundation for an optimal crop yield and is the theoretical (or standard) CIR assumed for irrigated crops that are healthy, disease-and-insect-free, actively growing, non-stressed, well-watered, overall well-managed, and cultivated under "excellent" agronomic and water management conditions.[60] The earlier discussion on the structure of U.S. agriculture and farmers' motivations described the diversity that currently exists in the agricultural sector and emphasized the growing numbers of residential/lifestyle farms throughout the country and New Mexico.[61] This reality leads us to conclude that it is no longer accurate to assume that the majority of farms are commercially oriented or operated by people primarily concerned about farm profits or farm incomes.

Given the weakness of a one-size-fits-all characterization of these farm operators' objectives, it is further unrealistic to assume uniform irrigation conditions and outcomes or a one-size-fits-all water duty, or CIR. Water rights adjudication based on a theoretically optimal CIR, rather than actual CIR, could lead to over-allocation of water resources, groundwater depletion, and failure to meet downstream obligations. Consumptive use on individual parcels of land can now be measured, and ET variability across the broad spectrum of farms can be documented.[62] This information can provide valuable input into adjudication processes, prevent further over allocation of nonexistent water resources,

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55. *See* Bastiaanssen et al., *A Remote Sensing Part 1*, *supra* note 54; Bastiaanssen et al., *A Remote Sensing Part 2*, *supra* note 54.

56. *See* Allen et al., *supra* note 54.

57. Zohrab Samani et al., *Using Remote Sensing to Evaluate the Spatial Variability of Evapotranspiration and Crop Coefficient in the Lower Rio Grande Valley, New Mexico*, IRRIGATION SCIENCE, Nov. 2009, at 93.

58. J. DOORENBOS & A.H. KASSAM, FOOD & AGRIC. ORG. OF THE UNITED NATIONS, YIELD RESPONSE TO WATER: IRRIGATION AND DRAINAGE PAPER NO. 33 (1979), *available at* http://www.fao.org/landandwater/aglw/cropwater/parta.stm.

59. *Id.*

60. *See* ALLEN ET AL., *supra* note 8.

61. *See supra* Part III.

62. *See* Bastiaanssen, Molden & Makin, *supra* note 53.

and help to avoid water capture efforts that could exacerbate existing shortages.[63] The case study of New Mexico's Lower Rio Grande region, presented below, illustrates these issues.

V. CASE STUDY OF NEW MEXICO'S LOWER RIO GRANDE REGION

New Mexico's Lower Rio Grande region is experiencing rapid population growth, development of the rural countryside, and a growing number of small farms.[64] Lifestyle agriculture is widespread in Doña Ana County, evidenced by the large increase in small, irrigated farms over the last 30 years. In 1978, Doña Ana County had only 158 irrigated farms between one and nine acres; in 2007, that number was 950—a 500 percent increase.[65] As noted above, total irrigated acreage in the county shrank between 1978 and 2007. Almost 90 percent of the growth in number of irrigated farms in Doña Ana County was the result of increases in the smallest farm size category, with another 9 percent of the growth occurring in the 10 to 49 acres farm size category.[66] Small irrigated residential/lifestyle farms selling less than $1,000 in agricultural products are not included in the *Census of Agriculture*,[67] meaning census numbers for Doña Ana County underestimate total numbers of small irrigated farms.

Water defines the landscape throughout New Mexico's Lower Rio Grande region and provides an oasis of green in the middle of a dry desert climate. Irrigation in Doña Ana County is a sociocultural phenomenon with a long and rich history that predates the EBID establishment.[68]

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63. *See* Richard G. Allen, Tony Morse & M. Tasumi, *Application of SEBAL for Western US Water Rights Regulation and Planning*, ICID Workshop on Use of Remote Sensing of Crop Evapotranspiration for Large Regions (Sept. 17, 2003), http://www.kimberly.uidaho.edu/water/montpellier/.

64. *See* U.S. DEP'T OF COMMERCE, *supra* note 38; USDA, *supra* note 37; *see also* U.S. Census Bureau, *2010 Census Data: New Mexico*, http://2010.census.gov/2010census/data/index.php (last visited Mar. 22, 2011); Michaela Buenemann & Jack Wright, *Southwest Transformation: Eras of Growth and Land Change in Las Cruces, New Mexico*, 14 SOUTHWESTERN GEOGRAPHER 56, 75–80 (2010).

65. *See* U.S. DEP'T OF COMMERCE, BUREAU OF THE CENSUS, 1978 CENSUS OF AGRICULTURE: NEW MEXICO STATE AND COUNTY DATA, AC-78-A-31, at 195 tbl.3 (1978); USDA, *supra* note 37, at 302 tbl.10.

66. *See id.*

67. WILLIAM IWIG ET AL., NAT'L. AGRIC. STATISTICS SERV., USDA, MULTI-CULTURAL OUTREACH FOR THE 2007 CENSUS OF AGRICULTURE 4 (2009), *available at* http://unstats.un.org/unsd/statcom/statcom_09/seminars/innovation/Innovation%20Seminar/USA-Agri Census.pdf.

68. 1 NEAL W. ACKERLY, IRRIGATION SYSTEMS IN THE MESILLA VALLEY: AN HISTORICAL OVERVIEW (Sept. 1992).

Economic growth and diversification in the region has made it feasible for increasing numbers of residents to maintain or establish ties to irrigated agriculture while deriving household incomes from off-farm sources.

Pecans, alfalfa, and cotton are produced on approximately three-fourths of the EBID's irrigated acreage.[69] Alfalfa and pecans are well-suited to rural-residence or lifestyle agriculture because both can be grown with low-management intensity.[70] Sub-optimal fertility, pest, and water management are all low-intensity and cost-reducing practices for both crops.[71] Pecan management intensity can be further reduced with infrequent pruning, while increased intervals between crop reseedings and reduced numbers of harvests decrease alfalfa management intensity. Crop quality and yields will be reduced as a result of less-intense management; however, with both pecans and alfalfa, the positive oasis and microclimate effects of green vegetation will be maintained even with low levels of management.[72] Cotton is a crop that is more commonly grown by commercial farmers, often as a part of complex multiyear crop rotations involving pest management and allocation of water among crops on the same farm.[73] Cotton acreage in the EBID dropped from almost 70,000 acres in 1953 to 10,500 in 2008; given this trend, cotton acreage could decrease to zero within a few years, while both alfalfa and pecan acreage have increased since the 1950s.[74]

The standard crop coefficient approach for estimating crop ET for New Mexico's Lower Rio Grande results in consumptive-use values of 55.2 acre-inches/acre (4.6 acre-feet/acre) for alfalfa, 51.6 acre-inches/acre (4.3 acre-feet/acre) for pecans, and 36 acre-inches/acre (3.0 acre-feet/acre) for cotton (see Figure 2, below).[75] These ET values are for healthy, disease-and-insect-free, actively growing, well-watered, and well-man-

69. E-mail from Dr. J.P. King, Professor of Civil Eng'g, N.M. State Univ., to author (Mar. 18, 2011) (on file with author).

70. Both are perennial crops that provide a green landscape and some marketable or usable production at even low levels of management intensity (e.g., fertilization, pest management, water management, harvest timeliness, etc.).

71. *Id.*

72. If crop yield is not a landowner's primary objective, a green landscape of either pecan trees or alfalfa can be produced with relatively little management (including irrigation water) input.

73. R. Skaggs, M. Decker & D. VanLeeuwen, N.M. State Univ. Dep't of Agric. Econ. & Agric. Bus., A Survey of Southern New Mexico Chile Producers: Production Practices and Problems 22 (2000).

74. *See* e-mail from Dr. J.P. King, *supra* note 69.

75. Theoretical consumptive-use values for alfalfa, pecans, and cotton were derived using methods outlined in Richard G. Allen et al., Food & Agric. Org. of the United Nations, Crop Evapotranspiration: Guidelines for Computing Crop Water Require-

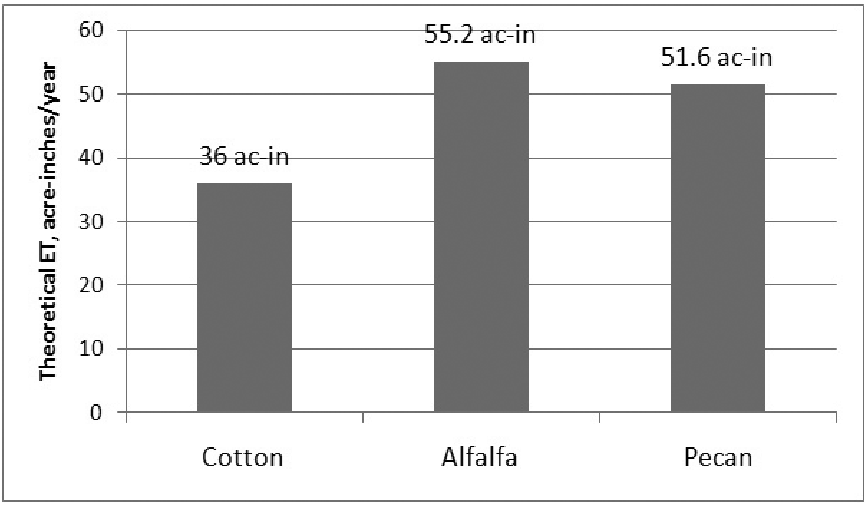

FIGURE 2. Theoretical annual evapotranspiration for cotton, alfalfa, and pecans in New Mexico's Lower Rio Grande, 2002.

aged crops. These theoretical ETs can be adjusted by an average on-farm application efficiency to arrive at a theoretical FDR, or the amount of water required to mature the crops, which includes water not consumptively used by the plant or lost to evaporation. Such theoretical ET values can be the foundation of the water duty awarded to water rights holders, assuming the well-watered and well-managed assumptions are valid and the yields sought by farmers to achieve correspond to the theoretical ET.

The data presented in Figures 3 and 4 (below) are field-level estimates of alfalfa and pecan ET derived using remotely-sensed data and the Regional ET Estimation Model for several hundred fields in the Mesilla Valley portion of New Mexico's Lower Rio Grande region in 2002 (a full allocation year). For both crops, average estimated ET is below the theoretical standard, and ET is highly variable within and across field or orchard sizes.[76] These results show that the majority of farms in the region are producing crops under deficit irrigation conditions as opposed to well-watered conditions. We can further reject the notion that there is a "typical" ET for the two crops by observing the distribution of estimated ET for several hundred alfalfa and pecan fields in 2002 (see Figures 5 and 6, below). Estimated ET for the two crops is normally dis-

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MENTS, IRRIGATION AND DRAINAGE PAPER NO. 56 (1998), *available at* http://www.fao.org/docrep/X0490E/X0490E00.htm.

76. *See infra* Figures 3–4.

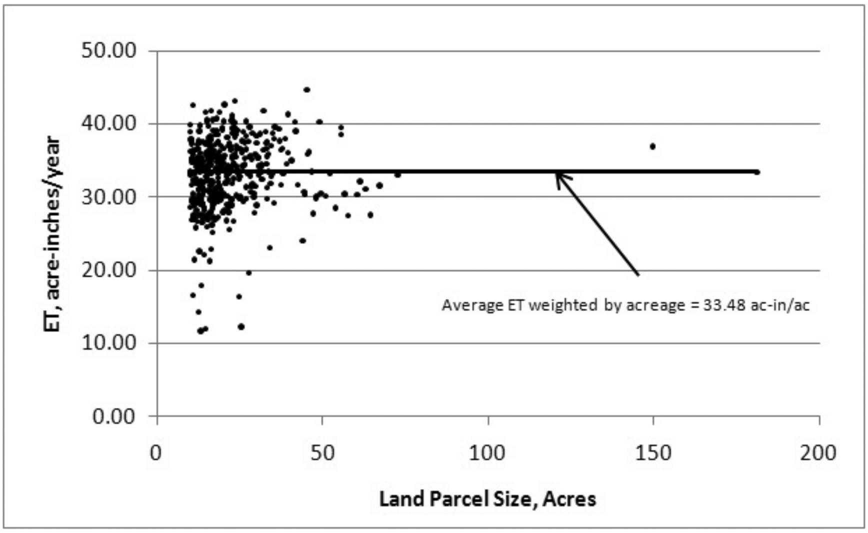

FIGURE 3. Remotely-sensed estimates of annual alfalfa evapotranspiration (acre-inches) for 423 fields (>10 acres) by field size, 2002.

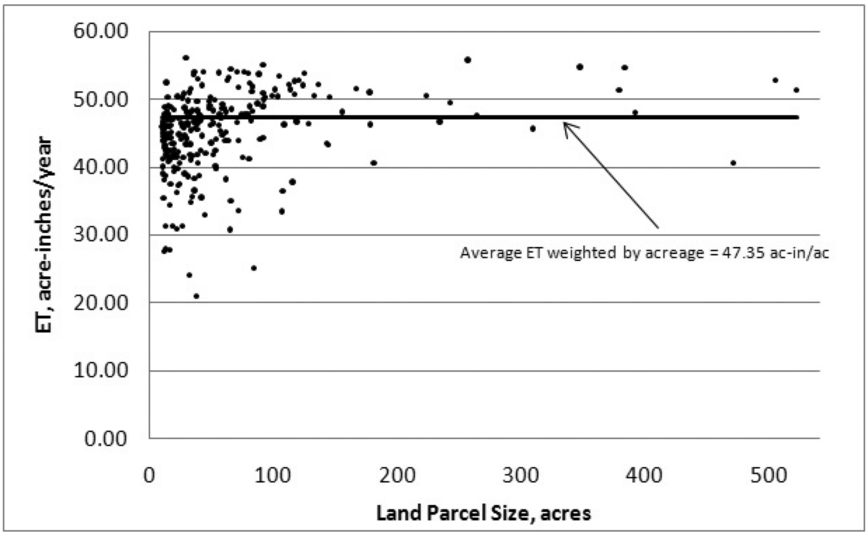

FIGURE 4. Remotely-sensed estimates of mature annual pecan evapotranspiration (acre-inches) for 246 orchards (>10 acres) by orchard size, 2002.

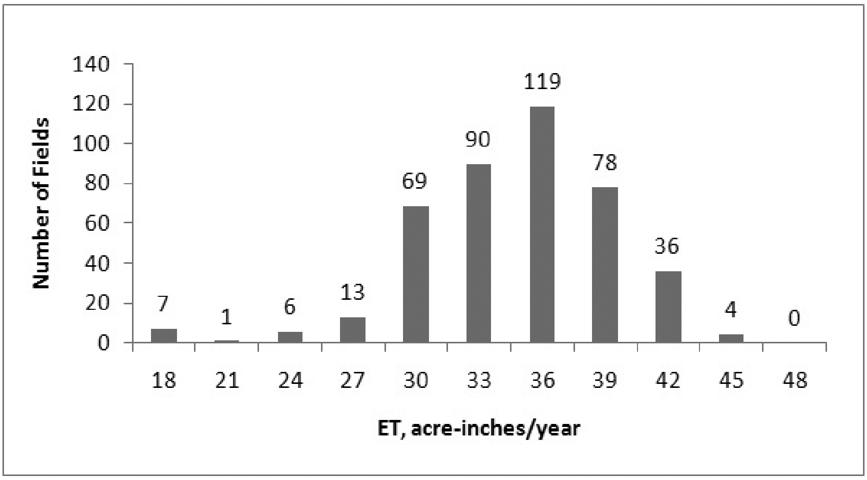

FIGURE 5. Distribution of remotely-sensed estimates of alfalfa annual evapotranspiration (acre-inches) for 423 fields (>10 acres), 2002.

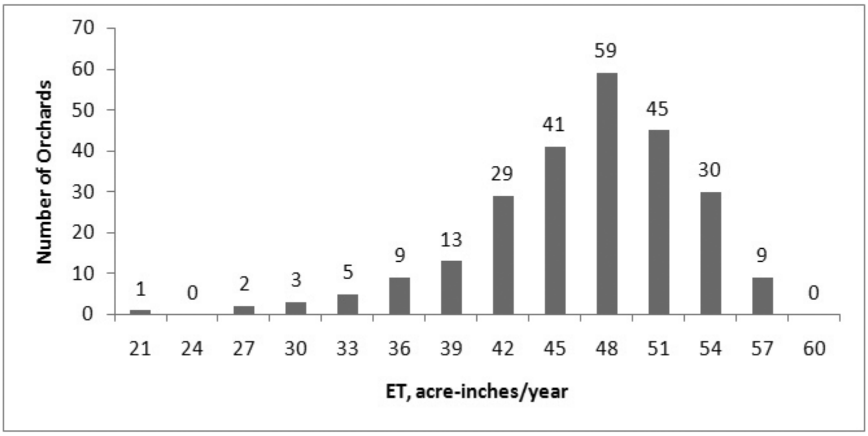

FIGURE 6. Distribution of remotely-sensed estimates of pecan annual evapotranspiration (acre-inches) for 246 mature orchards (>10 acres), 2002.

tributed with the average ET for each crop roughly equal to the most frequently estimated ET found in each crop's distribution.

The results presented in Figures 3 through 6 illustrate the diversity of farms, fields, and farmers throughout the region. This diversity supports the conclusion that assuming a "standard" condition for any crop is extremely unrealistic. Real-world production and management conditions are heterogeneous. Thus, real-world crop water use is highly variable due to several technical factors, including:

- Lack of sufficient groundwater to supplement surface water supplies on individual farms;
- Limited or no access to groundwater of adequate quality on many farms;
- Lack of knowledge of crop water consumptive use and associated benefits of irrigating to meet that demand;
- Inability of the existing canal system to deliver surface water in a timely manner;
- Poor irrigation practices (e.g., non-uniformity of water application) and soil variability;
- Low volume of inflow and poor on-farm water distribution systems;
- Variability in soil physical and chemical properties; and
- Issues related to agronomic practices such as timing of flood irrigations and harvest operations.

Adjudications define the quantity of wet water that can be put to beneficial use by the water rights holder. Adjudications confirm existing rights, or the water that has been put to beneficial use by the water rights holder. In the past, duties of water have been based on theoretical well-watered assumptions; however, actual depletion on individual farms can now be estimated.[77] Advances in technology allow us to demonstrate that depletion varies greatly among farms and that many irrigators are unwilling, uninterested, or unable to achieve "standard" ET values. Numerous technical reasons for this outcome are listed above; however, the underlying reason is the fact that the local structure of agriculture includes a majority of non-commercial lifestyle-oriented farm operators who are not motivated or not able to make "working farm" investments in their irrigation systems.

Adjudication of the Lower Rio Grande has been underway since the mid-1980s with the objective of clarifying both water-righted land areas and water duty.[78] EBID's farm-rate water rights holders (e.g., with at least two acres of land) receive a minimum of 2 acre-feet of surface water per water-righted acre, although they may receive less in drought years.[79] Farm-rate irrigators have the option to purchase additional water if it is available, and in wet years, a full surface water allotment is consid-

77. *See* Allen, Morse & Tasumi, *supra* note 63.

78. *See supra* Part I.

79. LEEANN DEMOUCHE, N.M. STATE UNIV. COLLEGE OF AGRIC. & HOME ECON., COOP. EXTENSION SERV., INTERPRETING THE ELEPHANT BUTTE IRRIGATION DISTRICT FOR WATER USERS 11 (2004), *available at* http://aces.nmsu.edu/pubs/_water/CR590.pdf.

ered to be 3 acre-feet per acre.[80] Some farms do not have access to supplemental groundwater supplies.[81] Although pecans and alfalfa have the *potential* to be very thirsty crops and *can* consumptively use more than 4 acre-feet per acre annually, our research has found that few producers actually achieve ET levels that high. Some producers do use more than 4 acre-feet per acre annually and represent a greater proportion of total acreage than their proportion of the producer population. However, most producers do not—and will not—achieve high consumptive-use levels nor have they achieved them in the past.[82] Continued land fractionalization will result in growing numbers of these producers and their small farms.

In 2006, in response to Texas's claims that New Mexico groundwater pumping was depleting downstream water supplies, the New Mexico Office of the State Engineer issued Draft Active Water Resource Management Regulations for the Lower Rio Grande.[83] The draft regulations proposed that all irrigation FDR in the Lower Rio Grande be limited to 4 acre-feet/acre annually.[84] The draft regulations also stated that groundwater diversions for irrigated lands within the EBID would be limited to the difference between the 4 acre-feet/acre FDR and the surface water allotment.[85] Groundwater pumping for farm irrigation would be subject to the 4 acre-feet/acre total limitation. Assuming an average 75 percent basin-wide, on-farm irrigation efficiency, average CIR would be 3 acre-feet/acre under the proposed regulations.

Leading pecan growers in the region strenuously objected to the state engineer's proposal, claiming they needed 1.5 more acre-feet in order to make a profit.[86] The growers claimed pecan trees have a 4 acre-feet/acre CIR, which, when combined with an average 72 percent basin-wide, on-farm irrigation efficiency for mature orchards, results in a 5.5 acre-feet FDR.[87] In response to the growers' demands, the state engineer entered into an agreement with the New Mexico Pecan Growers Associa-

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80. *Id.* at 15.

81. Telephone interview with Erek Fuchs, Acting Dist. Manager, Dist. 4, Water Rights Div., Water Res. Allocation Program, N.M. Office of the State Eng'r, Las Cruces, N.M. (Apr. 25, 2011) (estimating that 10 percent of farms do not have supplemental groundwater).

82. *See supra* Figures 3–6.

83. N.M. Office of the State Eng'r, Proposed Rules and Regulations Providing for Active Water Resources Administration of the Waters of the Lower Rio Grande Water Master District (June 28, 2006) (unpublished first draft) (on file with author).

84. *Id.* at 37–38.

85. *Id.*

86. Diana M. Alba, *Pecan Farmers Not Nuts About Water Rule,* LAS CRUCES SUN-NEWS, Jan. 3, 2007, *available at* http://wwa.colorado.edu/admin/announcement_files/1315-uploaded/announcement-1315-3349.pdf.

87. *Id.*

tion in February 2008.[88] This agreement stated that specific irrigation water requirements for pecans were appropriate and lawful and that the CIR for mature pecans of 4 acre-feet/acre, with a combined surface water and groundwater FDR of 5.5 acre-feet/acre, would be adjudicated for mature pecan orchards.[89] A state district judge accepted the settlement in August 2008 and announced that the agreement was a major step forward in the adjudication process because a "huge number (of claims) was resolved at the same time."[90] Since August 2008, growers of other crops, as well as non-agricultural water users in the region, have initiated protests against the Office of the State Engineer's pecan settlement demanding equal or higher water duties—an issue that remains unsettled.[91]

Under New Mexico water law, beneficial use provides the measure and the limit of a water right, meaning that users may take only the amount of water they can use for a recognized beneficial use.[92] A blanket adjudication of 5.5 acre-feet/acre, such as that issued by New Mexico's Office of the State Engineer in 2008, makes sweeping conclusions about beneficial use as well as about the pecan producer population and their motivations. However, what *is* beneficial use in agriculture generally or in pecan production specifically? Is it achieving high levels of ET, yields, and economic returns from crop production—thus the demand for 5.5 acre-feet/acre by large-scale, commercially-oriented, working-farm pecan producers? Or is beneficial use the irrigation of a lush, green rural-residential landscape from which little crop or profit is achieved or even expected? In the case of alfalfa, is beneficial use the production of a ton or two of hay, a little grazing by a few head of livestock kept for household consumption, and a green landscape? Or does beneficial use in alfalfa mean achieving yields of 7 to 10 tons per acre in almost as many cuttings? Because of the high correlation between crop ET and crop yield, Figures 3 and 4 illustrate the full range of crop ET, crop yields, and the beneficial use of water in alfalfa and pecans. Yet the New Mexico's Office of the State Engineer's blanket adjudication of a 5.5 acre-feet/acre FDR for mature pecans reflects only the consumptive water use of commercially-oriented pecan growers who intensively manage for yield, income, and profits.

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88. Settlement Agreement, *New Mexico ex rel. Office of the State Eng'r. v. Elephant Butte Irrigation Dist.*, No. CV–96–888, 2008), *available at* http://www.nmpecangrowers.us/Water%20Issue/NMPGFinalSettlementAgreement33108.pdf.

89. *Id.*

90. Diana M. Alba, *Judge OKs Water Deal*, LAS CRUCES SUN-NEWS, Aug. 9, 2008.

91. Diana M. Alba, *Area Farmers Find Strength in Numbers*, LAS CRUCES SUN-NEWS, June 3, 2009.

92. DEMOUCHE, *supra* note 79, at 3.

VI. IMPLICATIONS

Although pecan trees are physiologically capable of consumptively using four or more acre-feet of water, many pecan orchard owners apparently do not have the ability or desire to achieve that CIR and the yields associated with it or to practice the intensive irrigation management and cultural practices required to do so.[93] The non-commercial motivations of these pecan producers are reflected in their management practices, their farm investments, and their crop production outcomes. A minority of larger-acreage, commercially-oriented pecan growers in the study region are consumptively using water at levels above the settlement CIR and contribute strongly to the acreage-weighted average ET shown in Figure 4.[94] Should water policy for all pecan growers be designed around these individuals' production and management practices, resources, investments, objectives, and motivations? While these growers represent a large share of total pecan acreage, they are out-numbered by small-scale, lifestyle-oriented producers.[95] If future trends continue, the number of small, rural-residential, lifestyle, recreational pecan farms will grow at the expense of larger working farms. Thus, adjudication based on the CIR of large-acreage, commercially-oriented producers would be a potentially marketable water windfall for present and future lifestyle-oriented producers who do not irrigate in the manner assumed for water rights holders earning a living from crop production.

If everyone grows their crops under optimal conditions, then establishing a "typical" CIR and FDR is simple. However, farm diversity is reflected in a broad spectrum of water use and irrigation practices. From a hydrologic standpoint, basing water adjudications on theoretical standards is dangerous, particularly when the crop under consideration is a relative newcomer to a basin and has consumptive potential higher than crops previously dominating the region. Using well-watered standards for crops with high water-use capacity increases the potential for over-allocation through adjudication of nonexistent wet water.

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93. Figure 2, *supra* Part V, shows a theoretical annual evapotranspiration for pecans of 51.6 acre-inches. Remotely-sensed estimates of annual pecan evapotranspiration in New Mexico's Lower Rio Grande region presented in Figure 4, *supra* Part V, and Figure 6, *supra* Part V, illustrate the diversity of actual evapotranspiration. The majority of pecan orchards in the region have evapotranspiration levels below 51.6 acre-inches.

94. The acreage-weighted evapotranspiration shown in Figure 4, *supra* Part V, for pecans is greater than the simple (unweighted) average orchard evapotranspiration in the region.

95. Figure 4, *supra* Part V, illustrates the large numbers of small orchards (10–100 acres) present in New Mexico's Lower Rio Grande region relative to the small numbers of orchards (greater than 100 acres).

Current hydrologic balances in the Lower Rio Grande exist because many users are depleting water at levels below the well-watered standards. Granting a property right for additional CIR that has not been depleted in the past could dramatically increase basin-wide depletion if the means and desire to actually deplete arise in the future. Active water markets, along with growing demand for water in non-agricultural uses, could contribute to the additional depletion. It is not difficult to imagine situations in which water rights holders sell the paper for 1 to 2 acre-feet/acre of CIR—water that they have *never* before put to beneficial use. Turning this paper water into wet water will likely increase conflict, and if the wet water is consumed, basin-wide depletion is guaranteed to increase.

Adjudication consistent with long-run average consumptive use would help to avoid the more extreme inequities associated with adjudication based on the needs of the highest water-using producers. This approach to duty determination would also help prevent the negative hydrologic impacts of adjudicating based on the right-hand-side of a consumptive-use distribution.[96]

Western water rights have historically been based on principles of successful or proper irrigation.[97] Notions of success in irrigation were based on crop production that generated income for households largely dependent upon that income for survival. However, times have changed, the number of households that engage in recreational or lifestyle-oriented irrigated agriculture has grown, and the perception of "beneficial use" is also in a state of flux.

VII. CONCLUSIONS

Agriculture in many regions is evolving into a lifestyle or consumptive activity rather than a commercial enterprise. Crops grown on rural-residential farms and the management intensity of those farms reflect household objectives very different from the objectives of commercially-oriented farms. "Well-watered" crop production assumptions are likely to reflect a steadily shrinking share of irrigated farms in regions undergoing land fractionalization and the structural change occurring in New Mexico's Lower Rio Grande region. New technology is providing previously unavailable data for farm-level water use, and water accountability is enhanced as a result of field-level estimates of crop ET.[98] As more information and data become available about the distribution of

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96. Figure 6, *supra* Part V, shows the distribution of annual pecan evapotranspiration in New Mexico's Lower Rio Grande region.

97. *See supra* Part II.

98. *See* Allen, Morse & Tasumi, *supra* note 63.

water use by the same crop in a particular region, adjudicating water duty based on optimal, well-watered assumptions will be indefensible. Such adjudications are inequitable because they can award a water duty that has not been beneficially used in the past. They also transfer wealth to rural-residential farmers producing lifestyle-compatible (and heavy water-using) crops, such as pecans, from commercially-oriented producers of management intensive (and lower water-using) crops, possibly violating prior appropriation or "first in time, first in right" principles.[99]

Hydrologically, adjudication based on theoretical crop water use could result in extreme water deficits, groundwater overdraft, reductions in downstream deliveries, and further divergence between wet and paper water quantities in already over-appropriated basins. However, if there is a steady removal of land from agriculture to other uses in these basins, this hydrologic deficit could be avoided. Continued fractionalization of farmland into small lifestyle-oriented parcels with reduced consumptive use and the discontinuation of off-farm CIR transfers in excess of actual consumptive use would also mitigate the divergence between water actually used and water allocated by way of adjudication. If the number of lifestyle farms continues to increase and more acreage is irrigated as a landscape rather than as a commercial enterprise, fewer farms will achieve optimal consumptive use, causing associated yields and theoretical crop water use to be even more of a rarity than already exists throughout the region. However, a hydrologic catastrophe is possible if unrealistically high water rights are awarded, large numbers of currently deficit-irrigating agricultural water users increase on-farm consumptive use, or if adjudicated CIR in excess of actual consumptive use is transferred to other consumptive uses.

Early on, irrigation planners in the western United States recognized the need to establish standards for the duty of water. Thus, the notion of the amount of water required to mature a crop was created. Even in the early twentieth century, diverse resources, motivations, and abilities of farmers made that standard less than ideal. Now, in the early twenty-first century, field-level consumptive-use data can readily demonstrate the extreme diversity of water use throughout entire basins. Furthermore, analysis of the parcel-level data can and does provide extensive insight into "what if" analyses of alternative adjudication scenarios.

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99. Cotton accounted for approximately 80 percent of irrigated acreage in the EBID in the early 1950s. By the mid-2000s, cotton accounted for approximately one-fourth of the EBID's irrigated acreage. Pecan acreage in the EBID went from approximately 5 percent to 30 percent over the same period. Pecans are a relative newcomer to the region's crop mix. *See* e-mail from Dr. J.P. King, *supra* note 69.

As populations grow throughout the West and competition for water resources increases, water managers will need the best available information in order to plan for the region's water future. Planning based on theoretical assumptions about what constitutes optimal water use in agriculture is not realistic, has the potential to increase conflict, and creates hydrologic risks and uncertainties. To achieve hydrologic sustainability, adjudicated duties should not exceed a basin's historical, long-run average water use across all crops, even if many of the past years' crops were produced under significantly less than well-watered conditions. Long-run water planning and emerging water markets will be best served if adjudicated water rights reflect hydrologic reality rather than the fiction of widespread, optimal, well-watered conditions.

Due to technological advances, we are now able to accurately and cost-effectively estimate the range of actual consumptive use across the broad spectrum of real-world farms, fields, and farmers. Incorporating this information into the water planning and adjudication processes will greatly increase accountability and improve hydrologic sustainability throughout the West. New Mexico's Lower Rio Grande region is an example of the diversity of consumptive-use conditions in the region's two largest crops, both of which are produced across the spectrum of farm sizes and types. This research confirms that changing agricultural structure is reflected in a broad distribution of consumptive use, and that water managers throughout the West should be cautious about the use of theoretical water use assumptions in their assessments of irrigated agriculture.