EXPERT REPORT OF DR. PETER H. GLEICK

Assignment

I was asked by the Natural Resources Defense Council to review Expert Reports submitted by Friant expert witnesses Dr. Charles Burt and Dr. Robert McKusick and to provide my expert opinion relating to how those reports address, or fail to address, the potential for improving water-use efficiency of agricultural and urban users within the Friant Division of the Central Valley Project.

STATEMENT OF QUALIFICATIONS

I have 20 years of professional experience analyzing, assessing, measuring, modeling, and reporting on freshwater issues, with a focus on water-use efficiency. I have a B.S. in Engineering and Applied Science (1978 cum laude and with distinction) from Yale University. I have an M.S. in Energy and Resources (1980) from the University of California, Berkeley. I have a Ph.D. in Energy and Resources (1986) from the University of California, Berkeley. Both of these graduate degrees were given for work on water resources in California. I am a member of the Water Science and Technology Board of the United States National Academy of Sciences. In 2001, I was appointed an Academician of the International Water Academy in Oslo, Norway. In 2003, I was awarded a MacArthur Foundation Fellowship for my work on water conservation science and policy. I currently serve on the California Department of Water Resources Public Advisory Committee for the California Water Plan.

I am a co-founder, and current President, of the Pacific Institute for Studies in Development, Environment, and Security in Oakland, California, created in 1987. The Pacific Institute is a non-profit corporation dedicated to finding solutions to the related problems of regional and global environmental degradation, unsustainable development, and political conflict through interdisciplinary research, policy analysis, and public outreach. We work collaboratively with water users, corporations, environmental and community groups, local, state, and national governments, and international organizations to address water issues.

The Institute has worked on California water issues since its inception in 1987. In 1993, the Institute began comprehensive water conservation and efficiency analysis for the State of California's urban and agricultural sector, including residential, commercial, industrial, and institutional water use, and we published an analysis of this in 1995.[1] I served as a Science Advisory Expert for the CALFED Independent Review Panel on Agricultural Water Conservation Potential in 1998. In 1998, we were contracted by the U.S. Department of the Interior to conduct an independent review of the water-use efficiency analyses of CALFED.[2] In 2003, the Institute published a report on the potential for urban water conservation and efficiency statewide.[3] The results of this work have been adopted in state water planning documents, including the draft 2005 California Water Plan and work of the Planning and Conservation League. Local water agencies and organizations have requested that the Institute expand this work to address local water concerns. In September 2005, the Pacific Institute released a new study with an analysis of a "high efficiency" scenario for California urban and agricultural users to the year 2030.[4]

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[1] Gleick, P., Loh, P., Gomez, S., and Morrison, J. 1995. California Water 2020: A Sustainable Vision. Pacific Institute Report, Pacific Institute for Studies in Development, Environment, and Security. Oakland, California.

[2] Gleick, P.H. and D. Haasz. 1998. "Review of the CALFED Water-Use Efficiency Component Technical Appendix." Report to the United States Department of the Interior, Bureau of Reclamation, Grant No. 8-FG-20-16250. Pacific Institute for Studies in Development, Environment, and Security, Oakland, California (June 1998).

[3] Gleick, P.H. et al. 2003. Waste Not, Want Not: The Potential for Urban Water Conservation in California Pacific Institute Report, Pacific Institute for Studies in Development, Environment, and Security. Oakland, California (hereafter "Waste Not, Want Not").

[4] Gleick, P.H., H. Cooley, D. Groves. 2005. California Water 2030: An Efficient Future. Pacific Institute Report, Pacific Institute for Studies in Development, Environment, and Security. Oakland, California.

SUMMARY OF OPINIONS

This declaration will address one main issue: What is the potential to improve water-use efficiency of current uses of the Friant Division? Water users throughout the State of California have demonstrated the ability to develop and implement creative and collaborative improvements to water-use efficiency within California's highly complex, interconnected water management system. While many other options exist to modify and modernize the water management system in the San Joaquin Valley and Tulare hydrologic regions, and to identify alternative approaches to operating infrastructure and allocating water, I do not address those possibilities here. My analysis is limited to the potential for improving the water-use efficiency and reducing water waste within the Friant Division of the Bureau of Reclamation's Central Valley Project (CVP) (hereafter "the Friant Division").

I conclude that there is substantial untapped potential for urban and agricultural water users served by the Friant Division to reduce wasteful uses of water and improve their water-use efficiency. I disagree with Dr. Burt's implied conclusion that there is no waste of water within the Friant Division because of his opinion that Friant agricultural water users have little or no ability to increase their water-use efficiency. I define "water-use efficiency" as providing the same beneficial use to water users while utilizing less water. Although there is additional potential to cut water use by also changing benefits, goods, and services, such as by withdrawing land from agricultural production, I do not consider this "water-use efficiency." And while such an approach can also produce significant reallocations of water, and may be appropriate in this case, I do not address that issue here.

A substantial fraction of current use by Friant Division water users appears to be unproductive, unnecessary, and therefore wasteful. Friant Division users have not fully implemented water management and efficiency measures used by similarly situated water users that also face potential water shortages. There is evidence that agricultural users in the Friant Division are not as water-efficient as other agricultural water users statewide. Moreover, the oft-stated justification for not pursuing improvements in efficiency in the Friant Division – i.e., that all “on-farm over-irrigation” is already recovered by other users – is wrong for several reasons. Discussion of these conclusions is provided below.

DISCUSSION AND ANALYSIS

A wide range of water-management actions are available to lessen the effect of any reduction of deliveries to Friant contractors from the Madera and Friant-Kern Canals due to San Joaquin River restoration.[5] Two of the specific management responses mentioned by Dr. Kirby are the focus of my Report: 1) reducing diversion and pumping requirements by improving agricultural and urban water-use efficiency; and 2) to a lesser degree, reducing demand by crop shifting, fallowing, and land retirement. A brief discussion of urban efficiency in the District is also included.

Irrigation Efficiency

There are many and varied definitions of “water-use efficiency.” The most important definition, and the most relevant for this case, is the ability to do a specific task or satisfy a specific need, with less water. This can be measured and evaluated at the field, or crop, or household level, or at a larger “basin” level. For example, it has often been noted in the agricultural literature that a farmer may be locally inefficient, but if all the wasted water is then used beneficially elsewhere, the overall “basin” efficiency of use may be higher than the “field” efficiency.[6] I discuss both kinds of efficiency here but focus my analysis on “unproductive and irrecoverable” water losses, where water is not used productively to produce a good or service and becomes unavailable for

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[5] Expert Report of Dr. Kenneth Kirby, pages 24-25.

[6] See, for example, Keller and Keller. 1995, “Effective efficiency: A water use efficiency concept for allocating freshwater resources,” Center for Economic Policy Studies, Winrock International, Arlington, VA.

other uses and users in the Friant Division. Examples include water lost to evaporation from a field or water surface, and water that seeps into groundwater that is not available to another user or is too heavily contaminated for additional use, typically with salt and nitrates. I note that even efficiency improvements that do not reduce unproductive or irrecoverable losses can offer substantial benefits to local users, including reduced costs, improved reliability during droughts, and the possibility of leaving water in rivers and streams for ecological improvement.

Before getting to some of data and quantitative arguments to support my contention that improvements in the efficiency of water use are possible, I would like to note that a recent survey of growers in the San Joaquin Valley, conducted by the Center for Irrigation Technology at California State University, Fresno, very clearly notes that farmers *themselves* understand that they can do more with the water they have, or even reduce current uses. In some ways, this is the clearest evidence of the potential to use water more efficiently – academics can argue about data and methods, but farmers themselves have a strong sense of what is possible in their own fields. In this survey, 436 growers responded to a question "Do you irrigate as efficiently as you think you could." 40% of these growers responded "no" and indeed they offered a list of many dozens of different ways they felt they could improve irrigation efficiency. The very next question on the survey was "What contingency plans do you have in the event of a prolonged drought?" The answer chosen more often than any other was "Improve system efficiency" showing that the potential to do so is not only there, but considered their first choice.[7]

The first, and most important conclusion from C.M. Burt's testimony is that "The physical data show that Friant water is used efficiently for agricultural irrigation" – so efficiently, in facts, that he ascribes a greater than 90% "efficiency rate" to Friant water users.[8]. He uses this conclusion

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[7] Zoldoske, D.F. 2002. "San Joaquin Valley Grower Irrigation Survey." CATI Pub. #021201. Center for Irrigation Technology, California State University, Fresno, California, pp.14-16.

[8] Expert Report of C.M. Burt. "On Friant Service Area: Reasonableness of Surface Water use, Annual Gross Groundwater Pumping Requirement, and Estimated Increased Energy Use Under the Spring Run Scenario by 2025." August 18, 2005, p. 1.

to further conclude with certainty that “any reduction in irrigation water deliveries from the Friant system will result in” a series of adverse impact, including a decline in groundwater levels and loss of cropped area.

There are no accurate measured data to support his conclusion of 90 percent efficiency, but even if there were, both of these critical conclusions are false. As shown below, improvements in irrigation water-use efficiency in the Friant Division are possible, and these improvements will not necessarily lead to adverse impacts on either groundwater levels or farmer well-being as measured by crop area or income.

Irrigation efficiency is defined in many different ways by different experts, growers, and academics. The classic definition for on-farm efficiency that is “generally accepted for water conservation studies in California”[9] is:

$$\text{IE} = \frac{\text{Irrigation water beneficially used x 100}}{\text{Irrigation water diverted or applied}}$$

This particular measure of efficiency is a function of the uniformity of application, and accounts for losses through unproductive evaporation, conveyance losses from channel seepage or pipe leaks, and scheduling and operation losses.[10] According to data contained in Burt’s testimony, 1.8 million acre-feet (MAF) of water was used by the crops to satisfy evapotranspiration (ET) and a total of 2.8 MAF of water was applied (1.6 MAF of surface water and 1.2 MAF of

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[9] Keller, J. 1992. “Implications of Improving Agricultural Water Use Efficiency on Egypt’s Water and Salinity Balances.” Winrock International Institute for Agricultural Development, Water Resources and Irrigation Policy Program. Center for Economic Policy Studies, Discussion Paper No. 6. (July).

[10] Molden, D. 1997. “Accounting for water use and productivity. International Irrigation Management Institute (IIMI). SWIM Paper 1. Colombo, Sri Lanka.

groundwater) on average between 1999-2003. These data imply that the on-farm irrigation efficiency of the Friant Division in 1999-2003 is 65 percent.[11]

Burt, however, defines "Irrigation Efficiency (IE)" as:

$$IE = \frac{\text{Irrigation water beneficially used x 100}}{\text{Irrigation water applied – Change in Aquifer Storage}}$$

Although not clearly explained in his Report, the denominator of Burt's definition takes into account surface water deliveries and net groundwater extraction in an effort to address the question of reuse of water in the basin as a whole. Based on this definition, Burt claims that the "Irrigation Efficiency of the Friant Water is above 90%."[12] While an effort to estimate the broader basin efficiency is appropriate, this conclusion is misleading and unsubstantiated – simply put, this is one equation with two unknowns. While some water overapplied to fields is lost to groundwater and then recaptured and reused productively, this amount has not been adequately or accurately quantified. Thus actual net groundwater extraction is not known and claims of over 90 percent basin irrigation efficiency cannot be substantiated.

Burt's attempt at quantifying net groundwater extraction is similarly incomplete. Burt calculates the net groundwater extraction according to the equation:

$$\text{Net groundwater extraction} = (Et_{irr}) – \text{(Irrigation water deliveries to the service area)}$$

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[11] Expert Report of C.M. Burt. "On Friant Service Area: Reasonableness of Surface Water use, Annual Gross Groundwater Pumping Requirement, and Estimated Increased Energy Use Under the Spring Run Scenario by 2025." August 18, 2005, p. 6 and A-9.

[12] Expert Report of C.M. Burt. "On Friant Service Area: Reasonableness of Surface Water use, Annual Gross Groundwater Pumping Requirement, and Estimated Increased Energy Use Under the Spring Run Scenario by 2025." August 18, 2005, p. A-1.

The above equation is based on rearranging the irrigation efficiency definition (above) and assuming that the irrigation efficiency is 100 percent – again, this is one equation with two unknowns. Net groundwater extraction has not been adequately quantified and claiming otherwise is false and misleading.

Burt further argues that "Friant water is used efficiently for agricultural irrigation…Within the Friant service area, there are fairly extensive areas of groundwater overdraft, and little/no irrigation water leaving the area as surface flow. This indicates that the water that is applied within the service area, even when combined with any natural groundwater supplies, is insufficient." This observation, if true, merely indicates that that demand for water exceeds available reliable supply. It offers no insight into how efficiently the water is being used. Further, it ignores the evidence that some surface water does leave the system as spillwater and return flows.[13] And by considering only water that leaves the area "as surface flow," Dr. Burt ignores the amounts of water that "leave" the Friant Division through groundwater infiltration and evaporation. (See Question 5 below; see also Supplemental Expert Report of Dr. Steve Deverel, pp. 15-16).

Reliance on a narrow definition of efficiency, such as used in Burt, limits the kinds of improvements analyzed. Irrigation terminology is important because inherent to it are value judgments concerning whether the water is being used in a beneficial and reasonable manner. For example, crop evapotranspiration is included as one of the beneficial uses of water in the IE equation. However, as shown below, not all ET is beneficial or reasonable. This assumption thus has the potential to lead to a significant overestimation of the actual efficiency of irrigation water use.

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[13] *See* <u>Feasibility Study for Groundwater Recharge Facilities</u> (Gravelly Ford Water District/Provost & Pritchard, October 2003); Ex. J to Richard Moss Expert Report, <u>Water Resources Investigation of the Kaweah Delta Water Conservation District, Final Report</u> (Fugro West, Inc., December 2003).

These conclusions about irrigation efficiency are supported by the independent statewide review of agricultural irrigation efficiency conducted by CALFED, which notes that irrigation efficiency is a gross measurement that is based on information that is often incomplete and can easily be misinterpreted.[14]

For the purposes of this case, the most critical efficiency issue is the extent to which more water is applied to grow crops than is necessary, and the extent to which excess water can be saved and used beneficially elsewhere. I address five major questions:

1. Is any applied irrigation water lost to unproductive evaporation?
2. Is any applied irrigation water lost to groundwater that is not recovered or used by other Friant Division users?
3. Can the same crops be grown with less water by changing irrigation practices and/or using irrigation technology that is readily available and cost effective?
4. Can different crops be grown that require less water?
5. Is any applied Friant irrigation water recovered and used outside of the Friant service area?

As I show below, the answer to all five of these questions is yes.

Question 1: Is any applied irrigation water lost to unproductive evaporation?

Some of the water used by crops goes to "evapotranspiration (ET)." Simplistic assessments of efficiency potential lump evapotranspiration from agricultural production into a single ET estimate. The problem with the aggregation of evapotranspiration into a simple fixed depletion value is that, in fact, it is comprised of two separate terms: evaporation (E) and transpiration (T).

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[14] Willardson, L.S., R.G. Allen, and H.D. Frederiksen. 1994. "Elimination of Irrigation Efficiencies" Irrigation Planning and Management Measures in Harmony with the Environment. 13th Technical Conference, USCID.

For the purposes of evaluating the potential for improving agricultural water use efficiency, these two terms should be analyzed separately. They represent different processes; they are affected by different actions on the part of growers; and they have different implications for water policy and management. In other words, evaporation and transpiration are distinguishable and separating ET into its component parts would shift the focus to beneficial uses of irrigation water by allowing the user to manipulate and reduce non-beneficial evaporative losses.

Evaporation occurs in several ways, including water loss from soils, from soil surfaces, from crop and weed surfaces, and during irrigation water application as wind drift and direct evaporation. Reductions in evaporation can directly reduce both total applied water and the consumptive use of water. Molden distinguishes between "process" and "non-process" water depletions based on their beneficial use.[15] Process depletion is defined as that amount of water diverted and depleted to produce an intended good, such as water transpired by crops and incorporated into the plant tissue. Non-process depletion is when water is depleted, but not by the process that it was intended for, such as evaporation from soil and free water surfaces and evaporation of spray drift.

It is estimated that the proportion of ET lost to evaporation is not known to within 30 percent of its actual value.[16] While it is difficult to accurately measure unproductive evaporation, it is quite clear that such wasted water exists in all irrigation systems. For example, "most measurements have shown spray evaporation and drift to range from 5 to 20 percent of the water discharged."[17]

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[15] Molden, M. 1997. "Accounting for Water Use and Productivity." System-Wide Initiative for Water Management. International Irrigation Management Institute. Sri Lanka.

[16] Burt, C.M. Professor and Director, Irrigation Training and Research Center, BioResource and Agricultural Engineering Dept. California Polytechnic State Univesity. Personal Communication June 23, 1998.

[17] Council for Agricultural Science and Technology (CAST). 1988. "Effective Use of Water in Irrigated Agriculture." Task Force Report No. 113. (June). Ames, Iowa, pp. 32, and 49-51.

In a series of field-level water balances, Molden found that evaporation losses accounted for 17 percent of total depletion in wheat crops and 30 percent in cotton crops.[18] Hillel estimates that, under surface flood irrigation, 20 to 30 percent of applied water can be lost to evaporation from open water surfaces and transpiration by weeds.[19]

A part of evaporation from surrounding areas reduces transpiration because evaporation reduces available heat energy and increases humidity. Reducing evaporative losses will therefore be partly balanced by increasing transpiration. Lascano and Baumhardt note that in cotton production, using a moisture barrier can reduce soil evaporation by as much as 50 percent. This reduction was accompanied by an increase in crop transpiration and an increase in cotton yield. When these different effects were combined, the overall water-use efficiency (measured as the ratio of crop yield to total evapotranspiration) increased 37 percent.[20] Thus the decreases in soil evaporation and accompanying increases in transpiration are not necessarily additive.[21]

There are a number of different ways to reduce evaporation. It is widely understood that changing irrigation frequency, irrigation method, mulching, shading, and other management approaches can modify evaporation.[22] Unproductive evaporation can be reduced without

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[18] Molden, M. 1997. . "Accounting for Water Use and Productivity." System-Wide Initiative for Water Management. International Irrigation Management Institute. Sri Lanka.

[19] Hillel, D. 1997. "Small-Scale Irrigation for Arid Zones; Principles and Options." FAO Development Series 2. Rome, Italy

[20] Lascano, R.J. and R.L. Baumhardt. 1996. "Effects of Crop Residue on Soil and Plant Water Evaporation in a Dryland Cotton System." Theoretical and Applied Climatology, Vol. 54, pp. 69-84.

[21] Solomon, K.H. and C.M. Burt. 1997. "Irrigation Sagacity: A Performance Parameter for Reasonable and Beneficial Use. ASAE Paper No. 97-2181.

[22] Burt, C.M., Clemmens, A.J., Strelkoff, K.H., Bliesner, R.D., Hardy, L.A., Howell, T.A., Members, ASCE, and D.E. Eisenhauer. 1997. "Irrigation Performance Measures: Efficiency and Uniformity." *Journal of Irrigation and Drainage Engineering*, 123(6):423-442.

adversely affecting crop production, soil quality, or yields. For example, some water is lost to winds immediately during and following field application. Changing irrigation technology has been shown to have a major effect on reducing evaporative wind losses, while maintaining or improving crop yields. Efficient crop maintenance is also important: a well-watered crop with dry soil and plant surfaces (full cover, no weeds) requires less water than a well watered crop with wet soil and plant surfaces and weeds in between plants.

Irrigation methods that introduce water directly into the root zone, such as drip irrigation, without sprinkling the foliage or wetting the entire soil surface minimize deep percolation, surface runoff, and unproductive evaporative loss, while surface application induces depletion by evaporation. Drip irrigation (see Sidebar 1 for details and numbers) offers the additional benefit of keeping the soil surface between the rows of crop plants dry, discouraging the growth of weeds that compete with the crops for nutrients and moisture.[23] Evaporation can also be reduced by improving irrigation timing and providing the crops with water when they need it most. For example, there is a greater potential to reduce ET during the midday when transpiration is reduced and evaporation is at its highest. Improvements in irrigation technology and irrigation management can both decrease evaporative losses.

Hillel, D. 1997. “Small-Scale Irrigation for Arid Zones; Principles and Options.” FAO Development Series 2. Rome, Italy.

Molden, M. 1997. . “Accounting for Water Use and Productivity.” System-Wide Initiative for Water Management. International Irrigation Management Institute. Sri Lanka.

Gallardo, M., Snyder, R.L., Schulbach, K., and L.E. Jackson. 1996. “Crop Growth and Water Use Model for Lettuce.” Journal of Irrigation and Drainage Engineering, 122(6).

[23] Hillel, D. 1997. “Small-Scale Irrigation for Arid Zones; Principles and Options.” FAO Development Series 2. Rome, Italy.

According to Piper and Cappelluci, efficient irrigation systems tend to increase crop yield or decrease crop production inputs, an effect noted by many others as well.[24] Bernardo and Whittlesey reported that the potential for conserving water without greatly affecting producer income runs up to 35 percent for surface irrigation and up to 25 percent under center pivot irrigation.[25] Because a substantial amount of irrigated land in the Friant Division is still irrigated with surface or sprinkler methods (see question 3 below), these results suggest that total crop yields in the Friant Division can be maintained or improved with a smaller input of water; or conversely that crop yields can be significantly boosted with the water currently being used by the agricultural sector. Recent experience with precision irrigation systems in California supports this conclusion (see Sidebar 2, below).

Similarly, much of the irrigation in the High Plains region is now shifting away from inefficient sprinklers toward low-energy precision application (LEPA) sprinkler technology or drip systems. True LEPA systems are considered to be significantly more efficient than flood or gravity systems, or even older sprinklers, with a

Sidebar 1: Precision Irrigation

Precision irrigation systems, such as drip systems, offer the advantage of more precisely controlling the delivery of water to the plants. They can improve irrigation efficiency by reducing applied and/or consumptive water use, as well as increasing crop yield, thereby improving the ratio of water beneficially used by the plant to that of the water applied. Because they don't spread water over the soil surface, precision irrigation systems reduce evaporative losses from standing water – a savings in consumptive use – and reduce runoff and deep percolation losses. Drip delivery, for example, can provide high distribution uniformity, which minimizes the amount of water applied to adequately wet the field and reduces water lost to deep percolation.

Drip systems can improve crop yields by improving transpiration rates. For example, sub-surface drip irrigation reduces water lost to evaporation thereby making more water available for transpiration and increasing yields. With improved yields, efficiency as a measure of water used per ton of crop yield, or yield/total evapotranspiration would increase even if there were little change in amount of water applied.

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[24] Piper, R.A. and A.J. Cappellucci. 1993. "Reductions of Deep Percolation and Drain Water." Journal of Irrigation and Drainage Engineering. Vol. 119, No. 3, pp. 568-576.

[25] Bernardo, D.J. and N.K. Whittlesey. 1989. "Factor Demand in Irrigated Agriculture Under Conditions of Restricted Water Supplies." Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture, Technical Bulletin No. 1765. Washington, D.C.

significant fraction of the gain coming from reduction in immediate wind loss.

Reductions in evaporation can also be achieved by reducing surface water exposure, evaporation from soils, and mis-application of irrigation water. Indeed, the switch from surface flooding/gravity irrigation to sprinklers or precision drip systems is done in part to reduce this unproductive evaporative loss of water (see below in Question 3 below).

Question 2: Is any applied irrigation water lost to groundwater that is not recoverable or usable in Friant?

This question must also be answered affirmatively. Properly accounting for overall "basin" water-use efficiency requires understanding that some water overapplied to fields is lost to groundwater and then recaptured and reused productively. Equally important, however, is the fact that some of the water overapplied to fields is *not* recoverable or recovered. As noted by the Council for Agricultural Science and Technology, some is "lost to saline sinks, to deep sediments from which pumping is not possible, or to other sites from which it cannot be retrieved…An additional problem lies in the fact that it is not always economical to reuse runoff or deep percolation."[26]

Even in agricultural areas with efficient groundwater recharge and strong reuse, a fraction of all excess water applied to fields cannot be extracted. In three different water bank agreements in the Tulare Lake Hydrologic Region, contracts specify that around 10 percent of all water recharged into the groundwater banks must be assumed to be unrecoverable. If this assumption is made for legal agreements, I believe that assuming that 100% of all *unintentionally* recharged groundwater can be recovered is unreasonable.[27]

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[26] Council for Agricultural Science and Technology (CAST). 1988. "Effective Use of Water in Irrigated Agriculture." Task Force Report No. 113. (June). Ames, Iowa, p. 51.

[27] Pinhey, N.A., Spaletta, J.L. and D.L.Brown. 2001. "System-wide Conjunctive Water Management: Lessons from Experience." Natural Heritage Institute (August 2001), pp. 76, 85, 96.

Burt himself notes “Within some of the irrigation districts (e.g., Lindsay-Strathmore and Orange Cove), there are areas with no or little usable groundwater supply.”[28] This supports the conclusion that some of the “on-farm over-irrigation” ends up in groundwater basins that cannot be used due to physical or economic difficulties with extraction, or water-quality problems.

Question 3: Can the same crops be grown with less water by changing irrigation technology that is readily available and cost effective?

There has been a substantial change in irrigation method throughout California over time, permitting increased yields, increased water-use efficiency, and reduced water applied per acre for many crops. Figure 1 shows statewide changes in irrigation method between 1972 and 2001. Surveys, conducted with the assistance of the DWR, show that drip irrigation overall has been increasing at a rapid rate, while surface irrigation has been declining.[29] This trend is likely to continue and could be further accelerated by appropriate policies. Drip irrigation can boost crop yields and production while reducing overall water use. See Sidebar 1.

While insufficient data are available to assess irrigation methods in the Friant Division alone, the statewide survey provides data on irrigation methods practiced in the San Joaquin and Tulare Lake Hydrologic Regions (these are official DWR regional divisions) and gives some indication of patterns in the Friant Division. Figure 2 shows the percent of irrigated land by irrigation method and crop type for the State and for the Tulare Lake and San Joaquin Hydrologic Regions combined in 2001. At a hydrologic region level, the Tulare Lake and San Joaquin regions apply water less efficiently than the state average for all crop types. Surface irrigation is used on 95 percent of field crops in the Tulare and San Joaquin hydrologic regions, compared to 87 percent

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[28] Expert Report of C.M. Burt. “On Friant Service Area: Reasonableness of Surface Water use, Annual Gross Groundwater Pumping Requirement, and Estimated Increased Energy Use Under the Spring Run Scenario by 2025.” August 18, 2005, p. 1.

[29] Orang, Morteza N., Richard L. Snyder, and J. Scott Matyac. 2005. “Survey of Irrigation Methods in California in 2001”. In California Department of Water Resources (DWR). The California Water Plan Update. B160-05, Sacramento, California.

in the State on average. For vineyards, the difference is even greater: 45 percent of vineyards in the Tulare Lake and San Joaquin Hydrologic Regions are irrigated with less-efficient surface methods, compared to only 21 percent in the State as a whole. For orchards and vegetables, the San Joaquin and Tulare Lake regions are slightly less efficient than the state average.

Sidebar 2: Drip Irrigation Water Savings: Selected Case Studies [1]

In Los Banos in Fresno County in the late 1990s, Trecho Farms began using subsurface drip irrigation to grow fresh market and processing tomatoes. Trecho Farms reports that applied water use was reduced by as much as 50 percent from previous gravity/flood systems.

At Hammond Ranch in Firebaugh, Fresno County, the owner established subsurface drip irrigation on 560 acres of cotton, tomatoes, and asparagus. Hammond Ranch reported improvements in yields and reduced water use. Cotton on drip requires 20 percent less water than the region's average (2.1 acre-feet of water per acre, instead of 2.7 acre-feet per acre) and has produced yields approximately 15 percent above the region's average. Yields on asparagus were 50 percent higher than those typical produced using furrow or sprinkler irrigation.

Turlock Fruit Company, also in Firebaugh, started testing subsurface drip systems in the early 1990s on 300 acres of asparagus, 150 acres of melons, and 150 acres of cotton. The company reported that drip irrigation increased yields on these fields by 30 to 40 percent and reduced water use by 20 to 30 percent, as well as eliminating drainage problems. Soil salinity is monitored, and they have seen no increase in soil salinity on drip-irrigated fields.

In the early 1990s, the California Energy Commission (CEC) granted low-interest loans to two California farmers to help cover the costs of converting bell pepper row crops to drip irrigation. In 1993, High Rise Farms near Gilroy installed buried drip irrigation equipment on forty acres, and Underwood Ranches near Oxnard installed buried drip irrigation on fifty acres. Technical assistance and monitoring were provided by the Irrigation Training and Research Center (ITRC) at Cal Poly San Luis Obispo. Both farms found that buried drip irrigation substantially increased pepper yields, decreased water consumption, and greatly improved profits. The average net revenue increase for High Rise Farms was $1,100 per acre per year; the average net revenue increase for Underwood Ranches was $1,900 per acre per year. Applied water use dropped between 16 and 25 percent at Underwood Ranches while yields went up between 10 and 50 percent. Applied water use at High Rise Farms dropped as much as 11 percent while yields went up as much as 56 percent. Initial installation and operation problems often experienced with new systems were successfully addressed and both farms subsequently expanded their drip irrigation systems with their own money. All these cases reported additional savings from reduced fertilizer and a pesticide application.

McKusick surveyed farmers within the Friant Division to determine the percent of crop acreage irrigated by each method.[30] These surveys support the hydrologic region data, indicating that while some water districts have implemented more efficient irrigation methods, the majority of districts are far below the state average. In the Chowchilla Water District, for example, 100 percent of field crops and 50 percent of vineyards and orchards are still irrigated using surface methods. Likewise, in the large Lower Tule River Irrigation District, over 90

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[30] Expert Report of Dr. Robert McKusick on the Economic Impact of Reduced Surface Water Deliveries in the Friant Division of the Central Valley Project. August 22, 2005.

percent of field crops and 75 percent of orchards are irrigated using surface methods, compared to state averages of 87 percent and 62 percent.

These data suggest that if growers in the Friant Division districts improved irrigation technology even up to the current state average, water savings would result. No adequate detailed analysis of the magnitude of these savings has yet been done, but a new report released by the Pacific Institute in September 2005 indicates that more widespread application of existing efficient irrigation systems statewide has the potential to reduce agricultural demands more than 20 percent over current use.[31] Moreover, irrigation efficiency can be significantly improved beyond current state average levels.

It has been demonstrated that precision irrigation has increased overall water-use efficiency in this region. Below I describe a few examples of the rapidly expanding application of precision drip irrigation in California for high-valued vegetable and fruit crops, and increasingly, for row and field crops traditionally considered unsuitable for drip. This rapid expansion has been accompanied by reductions in applied water use, reductions in consumptive water use, and increases in crop yield.

Question 4: Can different crops be grown that require less water?

Discussions of crop switching (i.e., growing different kinds of crops on the same land) have traditionally been excluded from California water policy debates. Yet such changes in cropping patterns over time in California have probably had a greater impact on total agricultural water demand, water quality, and consumptive use than any other factor. As noted by the Council for Agricultural Science and Technology, water savings in agriculture "also can be accomplished by

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[31] Gleick, P.H., H. Cooley, D. Groves. 2005. California Water 2030: An Efficient Future. Pacific Institute Report, Pacific Institute for Studies in Development, Environment, and Security. Oakland, California, pp. 34-36.

replacing water-intensive crops such as alfalfa with crops such as cotton or beans that require less water."[32]

Traditionally, the agricultural community has argued that decisions about these changes should be left completely to the discretion of growers and irrigation districts, even though numerous federal, state, and local policies already in place play an important role in influencing these decisions. We believe that policies aimed at reducing transpiration losses could have very large long-term benefits for the California water balance without adversely affecting farm income, and there is evidence that such changes can improve farm income.[33]

Cropping patterns change over time. There has been a clear trend over the past 20 years in the Friant Division away from grain and field crops toward more profitable (and less water-intensive) vegetables, orchards, and vineyards. Figure 3 shows the historical trends in crops planted in the Friant Division between 1987 and 2004. While total crop area has not changed during this period, significant crop shifting has occurred; field crop acreage has declined by 20 percent, whereas vegetable and vineyard acreages have increased by 11 percent and orchard acreage has increased by 26 percent. Orchards and vineyards now account for over 60 percent of the crop area. There is no reason to believe that this trend will stop, and many reasons to believe it will continue or even accelerate.   These include:

- Growing pressures on water availability, which encourage growers to plant crops with lower water demands, or permanent crops likely to be given higher water priority during droughts;
- Higher profit for food crops, which can be grown productively on California farmland;

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[32] Council for Agricultural Science and Technology (CAST). 1988. "Effective Use of Water in Irrigated Agriculture." Task Force Report No. 113. (June). Ames, Iowa, p. 50.

[33] Gleick, P., Loh, P., Gomez, S., and Morrison, J. 1995. <u>California Water 2020: A Sustainable Vision</u>. Pacific Institute Report, Pacific Institute for Studies in Development, Environment, and Security. Oakland, California.

- The ability to better control evaporative losses using precision irrigation, which is more suited to orchards, vineyards, and row crops than low-valued field and grain crops.

Crop-shifting trends suggest that the potential for water savings may be even greater in the future. Although studies have shown that drip systems apply water more efficiently than surface irrigation for field crops, the adoption of this technology for field crops has been slower than for other crop types.[34] Over 50 percent of orchards and vineyards statewide are irrigated with drip, while less than one percent of field crops are irrigated with drip. Thus as agricultural land in the Friant Division is converted to orchards and vineyards, overall water needs will go down, and the ability to install even more efficient irrigation systems goes up.

Finally, even without changes in the actual crop types planted in California, we expect to see the introduction of new varieties of crops that are more water-efficient or drought-tolerant. Traditional crop genetics and efforts to develop new crop varieties with advanced genetic engineering are likely to permit increasing crop yields with either similar or lower water requirements in the future.

Question 5: Is any applied Friant irrigation water recovered and used outside of the Friant service area?

Some on-farm over-irrigation in the Friant Division seeps into groundwater captured by non-Friant farmers. This water is not beneficially used by the Friant Division. Indeed, Burt notes "Any groundwater that does flow laterally out of the project boundaries is captured by downhill

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[34] Colaizzi, P.D., A.D. Schneider, S.R. Evett, and T.A. Howell. 2004. Comparison of SDI, LEPA, and Spray Irrigation Performance for Grain Sorghum. Transactions of the ASAE, 47(5): 1477-1492.

Kamilov, B., N. Ibragimov, Y. Esanbekov, S. Evett, and L. Heng. 2003. Drip Irrigated Cotton: Irrigation Scheduling Study by Use of Soil Moisture Neutron Probe. International Water and Irrigation, 23(1): 38-41.

Ayars, J.E., C.J. Phene, R.B. Hutmacher, K.R. Davis, R.A. Schoneman, S.S. Vail, and R.M. Mead. 1999. Subsurface Drip Irrigation of Row Crops: A Review of 15 Years of Research at the Water Management Research Laboratory. Agricultural Water Management, 42: 1-27.

farmers and irrigation districts. An example is Alpaugh ID, which depends entirely on well water."[35]

This is a crucial point: first, some groundwater from "on-farm over-irrigation" does indeed leave the boundaries of Friant; and second, such water is recovered and used by farmers (or other water users) who either do not have rights to CVP water, or who are not paying for that water. This is water not beneficially used by Friant. The U.S. Department of the Interior Bureau of Reclamation is sufficiently aware of this problem that it has warned at least one Friant contractor about using Friant water on "spreading" and groundwater recharge that results in "project water" going to places and uses outside of the project purpose.[36]

While some or even most of this water may be used productively by others, the fact that other water users avail themselves of inefficiently used water from the Friant Division via groundwater infiltration that leaves the Friant Division does not render water use *within* the Friant Division more efficient. Nor can it be reasonably assumed that over-irrigation within the Friant Division is an efficient way to provide water to these outlying water users. If the relevant state and federal water authorities established that the provision of water to these outliers is a CVP purpose, then appropriate analyses could be conducted to determine the most efficient manner of water delivery to these water users and the amounts of water necessary to meet their reasonable and beneficial water use needs.

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[35] Expert Report of C.M. Burt. "On Friant Service Area: Reasonableness of Surface Water use, Annual Gross Groundwater Pumping Requirement, and Estimated Increased Energy Use Under the Spring Run Scenario by 2025." August 18, 2005, p. 2.

[36] Patterson, R. 1998. Letter to Ivanhoe Irrigation District: "Interim Renewal Contract Between the United States and Ivanhoe Irrigation District." United States Department of the Interior. MP440, WTR 4.00. (February 11, 1998).

Urban Use in Friant Division

While the majority of water use in the Friant Division supports agricultural irrigation, some of this water also is used to satisfy urban needs, including commercial, industrial, and residential uses. Urban water uses in this region are substantially higher, per person, than other parts of the Central Valley, and California. As has been noted in a comprehensive assessment of the potential for improving urban water use in the state as a whole, total urban needs can be satisfied with about 30 percent less water, simply by applying existing cost-effective water-efficiency technologies.[37]

Data on specific regional urban uses in the parts of the Central Valley and Friant Division service area support the conclusion that comparable, and even greater, water savings are possible here. According to the California Department of Water Resources new draft California Water Plan, current urban use (per person) in the Tulare Lake hydrologic region is around 310 gallons per person per day. Similarly, regional average per capita urban use in the San Joaquin River hydrologic region is around 304 gallons per person per day.[38] These levels are substantially higher than average statewide use. In part, this higher use is the result of the failure of major cities in the region, including Fresno, to meter household water use. Such meters have been shown to reduce urban water use when combined with rate structures that charge based on the volume of use.

It can be argued that urban water use is higher in these regions because of the warmer, drier climate, and larger average garden and lawn size. This is true, but when I correct for this difference and simply look at average indoor residential water use – which is similar to uses

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[37] Gleick, P.H. et al. 2003. Waste Not, Want Not: The Potential for Urban Water Conservation in California Pacific Institute Report, Pacific Institute for Studies in Development, Environment, and Security. Oakland, California (hereafter "Waste Not, Want Not").

[38] California Department of Water Resources. 2005. Draft California Water Plan, Bulletin 160. Volume 3, Chapter 7-4, and 8-5. Sacramento, CA.

throughout the state – the urban areas in this region still use substantially more water per person than the statewide average. Table 1 (below) shows this comparison. As this Table shows, the state average of indoor residential water use is around 85 gpcd, while both San Joaquin and Tulare Lake regions have averages of 100 gpcd or more. The outdoor use in the Tulare Lake region is also substantially higher than the statewide average. More efficient outdoor use would reduce evaporative and other irrecoverable losses.

Table 1

Regional Indoor Residential and Total Residential Water Use (gal. per person per day).[39]

Hydrologic Region	Indoor Residential	Total Residential
Colorado River	251	338
South Lahontan	170	265
Tulare Lake	**118**	**242**
San Joaquin R.	**99**	**220**
South Coast	88	132
North Lahontan	78	133
Sacramento R.	77	177
Central Coast	74	116
North Coast	61	123
San Francisco Bay	46	97
State Average	***85***	***145***

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[39] California Department of Water Resources. 2005. Draft California Water Plan, Bulletin 160. Volume 3. Sacramento, CA.

Compensation

My time spent on this project is billed at a discounted non-profit rate of $190 per hour (from a normal rate of $285 for expert witness, depositions, and legal testimony). My colleague Heather Cooley has provided assistance and analysis under my supervision at a rate of $80 per hour.

Materials Relied Upon to Form my Opinion

In formulating the opinions stated in this expert report, I have considered the materials specifically identified in this report, and listed in Appendix A ("Information Considered").

Dated: 9-17-05

Peter Gleick

Dr. Peter Gleick

Appendix A (“Information Considered”)

Note: Additional information considered is cited in the footnotes above. Most of these are publicly available journal articles from the scientific literature.

Cohen R. and Curtis J. 1998. “Agricultural solutions: Improving Water Quality in California Through Water Conservation and Pesticide Reduction.” Natural Resources Defense Council, New York.

Council for Agricultural Science and Technology (CAST). 1988. “Effective Use of Water in Irrigated Agriculture.” Task Force Report No. 113. (June). Ames, Iowa.

Expert Report of C.M. Burt. “On Friant Service Area: Reasonableness of Surface Water use, Annual Gross Groundwater Pumping Requirement, and Estimated Increased Energy Use Under the Spring Run Scenario by 2025.” August 18, 2005.

Expert Report of Kenneth W. Kirby, Ph.D., *NRDC v. Rodgers, et al.*. E.D. Cal. No. Civ. 88-1658 LKK, August 15, 2005

M. Fidell, P.H. Gleick, A. Wong, 1998. “Converting to Drip Irrigation:Underwood Ranches and High Rise Farms,” in A. Wong et al. (editor). Sustainable Use of Water: California Success Stories. Pacific Institute for Studies in Development, Environment, and Security, Oakland (September 1998), pp. 164-178.

Gleick, P.H., H. Cooley, D. Groves. 2005. California Water 2030: An Efficient Future. Pacific Institute Report, Pacific Institute for Studies in Development, Environment, and Security. Oakland, California.

Gleick, P.H. and D. Haasz. “Review of the CALFED Water-Use Efficiency Component Technical Appendix.” Report to the United States Department of the Interior, Bureau of Reclamation, Grant No. 8-FG-20-16250. Pacific Institute for Studies in Development, Environment, and Security, Oakland, California (June 1998).

Gleick, P., Loh, P., Gomez, S., and Morrison, J. 1995. California Water 2020: A Sustainable Vision. Pacific Institute Report, Pacific Institute for Studies in Development, Environment, and Security. Oakland, California.

Jack Keller. 1992. “Implications of Improving Agricultural Water Use Efficiency on Egypt’s Water and Salinity Balances.” Winrock International Institute for Agricultural Development, Water Resources and Irrigation Policy Program. Center for Economic Policy Studies, Discussion Paper No. 6. (July).

Molden, D. 1997. “Accounting for water use and productivity. International Irrigation Management Institute (IIMI). SWIM Paper 1. Colombo, Sri Lanka.

Orang, M.N., R.L. Snyder, and J.S. Matyac. 2005. “Survey of irrigation methods in California in 2001.” In California Department of Water Resources The California Water Plan Update. Bulletin 160-05, Volume 4 Public Review Draft (May). Sacramento, California.

Patterson, R. 1998. Letter to Ivanhoe Irrigation District: “Interim Renewal Contract Between the United States and Ivanhoe Irrigation District.” United States Department of the Interior. MP440, WTR 4.00. (February 11, 1998).

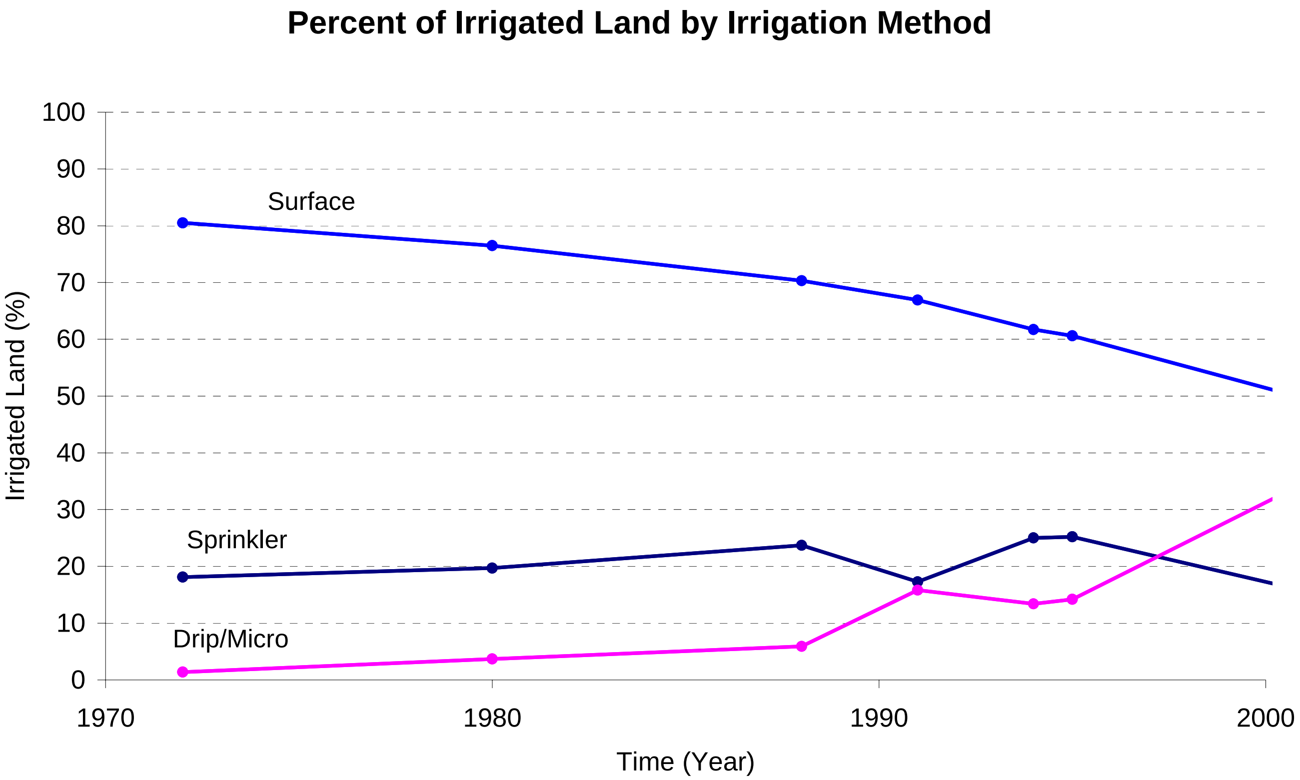
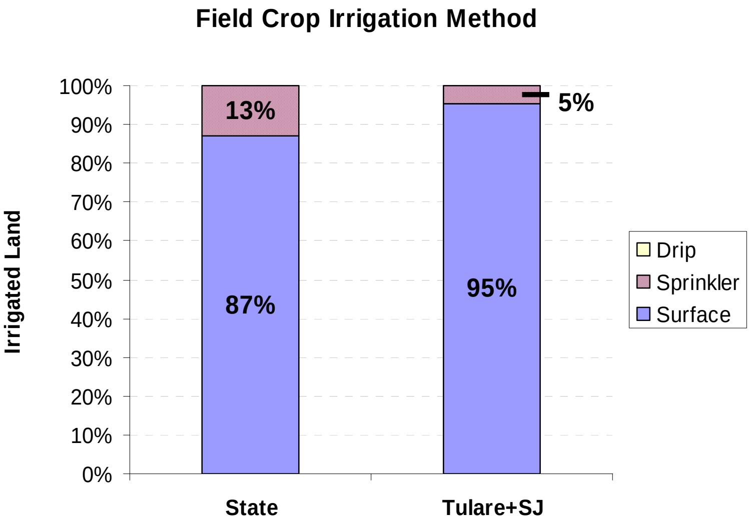


Figure 1: Historical Data on the Percent of Irrigated Land Under Each Irrigation Method Between 1972 and 2001. (Data from California DWR surveys.)



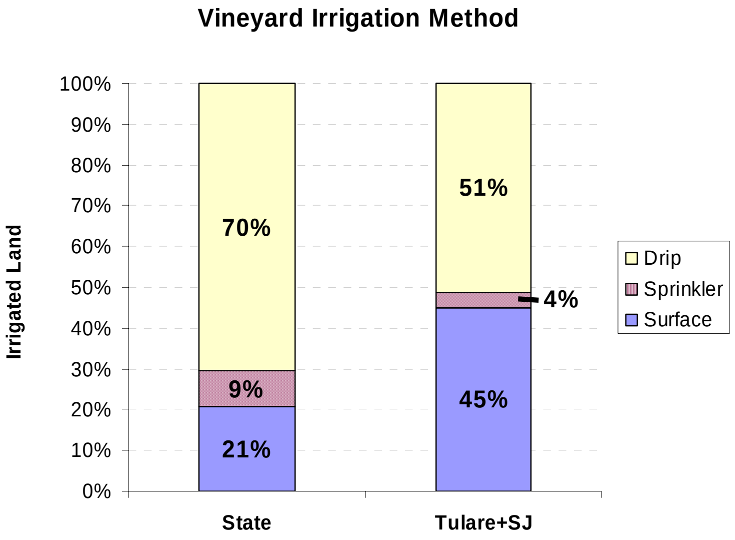


Figure 2: The percent of irrigated land by irrigation method for (a) field crops, (b) vegetable crops, (c) orchards, and (d) vineyards. As noted in the Expert Report, for each of these major crop groups, irrigation in the Tulare and San Joaquin regions uses less efficient technology than is used on average statewide. Statewide data from Orang et al. (2005); data at the hydrologic region from Orang (pers. comm.).

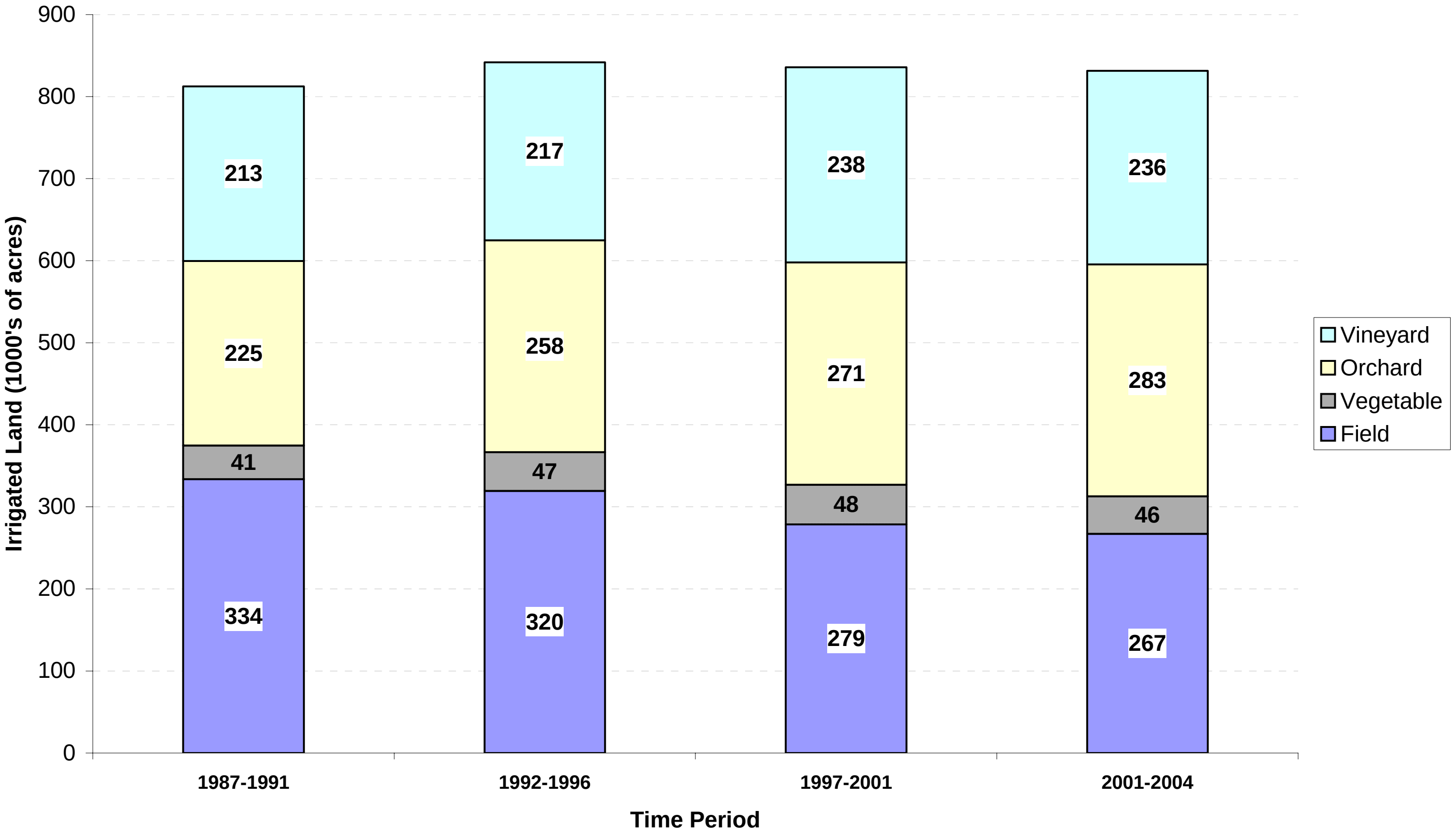


Figure 3: Irrigated acreage in the Friant Division by major crop type between 1987 and 2004. Data from Burt Expert Testimony, Appendix C (2005). Area devoted to orchards and vineyards is growing; field crop area is decreasing.