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# Cost-Effectiveness of On-Farm Conservation Practices to Protect Playa Lake Hydroperiod in the Texas High Plains

**By**

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Selected Paper Presented at the Southern Agricultural Economics Association Annual Meetings, Dallas, Texas, February 3-6, 2008.

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# Abstract

The Agricultural Policy/Environmental eXtender (APEX) simulation program was modified to simulate cost-effectiveness of on-farm conservation management practices designed to protect hydroperiod length of the unique playa lake ecosystems in the Texas High Plains over a 50-year time horizon. Conservation benefits are measured in terms of reduced cumulative sedimentation levels into the playa, the additional number of wet days in each environmentally critical hydro-period, and the change in average water volume level in each critical hydro-period. Costs are measured as the sum of forgone crop yields and annualized cost to establish and/or maintain the conservation management practice.

## Introduction

The Texas High Plains (THP) is one of the most intensively cultivated regions in North America (Bolen et al. 1989) relying heavily on irrigation from a once abundant supply of groundwater in the Ogallala Aquifer. Playas are a dynamic part of the THP landscape. Their role in the regional ecosystem includes such ecoservices as habitat, flood water containment, and groundwater recharge (Luo et al. 1997). Playas are hydrologically simple watersheds and are the primary wetland in the semi-arid region. As endpoints in their own watersheds, playas are a major source of recharge to the Ogallala Aquifer (Wood and Osterkamp 1984). Sources of playa water are rainfall and irrigation runoff. Due to intensive cultivation in the region, playas remain one of the few natural ecological features. As such, playas are essential to maintain biodiversity of the region (Haukos and Smith 1994).

Many playas have been cultivated to enhance crop production. Traditionally, furrow irrigation relied on playas to catch and store excess runoff (tailwater) to supplement groundwater in irrigation. A limited number of playas are replenished by irrigation runoff, but this runoff can contain chemicals and/or high concentrations of sediment that adversely affect the ecology and function of the playas. Modern technology such as center-pivot sprinklers, LEPA, and drip irrigation has improved the application efficiency of irrigation water and reduced runoff. A second farm practice that reduces runoff is the practice of furrow diking to keep rainfall and applied sprinkler irrigation water in the field. This practice, while logical in field management terms, reduces natural and irrigation runoff into the playa and thus could have a negative ecosystem impact.

Most agricultural producers ignore the impact their production activities have on playa ecosystem integrity because there is no private economic incentive to limit sediment runoff from agricultural fields into playas. As sediment accumulates within a playa over time, the maximum quantity of watershed runoff which can be stored within the playa is decreased and the watershed runoff from natural precipitation and irrigation sources previously stored within the playa is spread over the land surface adjacent to the playa. The spreading of watershed runoff over a larger surface area increases evaporation and seepage losses which shortens playa hydroperiod A decrease in playa hydroperiod reduces the period of time playas can hold water and can adversely affect playa provided environmental values. Thus, privately determined land-use decisions often rob the state of environmental resource values by considering wetland damages to be costless losses. The primary environmental benefit of increased hydroperiod in October through February is increased waterfowl habitat, whereas the primary benefit of increased hydroperiod between May and August is the maintenance of biological diversity.

The heavy reliance of the region on irrigation agriculture makes aquifer recharge another major concern. Nativ (1988) has estimated that playas are the primary source of recharge into the Southern Ogallala Aquifer which occurs through 25,000 playa lakes located within the region. Clearly, playas represent dynamic interactions between humans and the environment. However, the numerous playa ecosystems have deteriorated over time, as a result of human activities in the region (Luo et al. 1997). It is essential that residents of the THP recognize the impact current land use practices have had on playas and the cost and benefit of reducing and/or eliminating the detrimental effects of existing land use practices.

In order to promote long-term sustainability of economic growth in the THP and protect the biological diversity of playas and the region as a whole, the impact of agricultural practices on playas and the costs/benefits of eliminating or modifying detrimental practices must be addressed. The objectives of this study are two-fold. The first is to quantify the impact that current agricultural land use practices have on playa hydroperiod and maximize water storage volume. The second general objective is to estimate the agricultural cost of implementing alternative land management practices designed to increase playa hydroperiod and/or reduce the rate of soil sedimentation into playas.

## Empirical Model

The Agricultural Policy and Environmental Extender (APEX) computer simulation program developed by the USDA was modified to simulate playa response to existing baseline agricultural practices and conservation motivated agricultural practices over a 50 year planning horizon. The APEX Model (Williams et al. 2004) is the multiple field version and an extension of the original U.S.D.A. EPIC (Erosion-Productivity Impact Calculator) computer model. It can be an effective simulation tool for modeling the environmental effect of alternative land use practices in small watersheds. The model enables environmental policy personnel to simulate different land management strategies considering sustainability, erosion (wind, sheet, and channel), economics, water supply and quality, soil quality, plant competition, weather, and pests. The model is capable of simulating management strategies such as irrigation, drainage, furrow diking, buffer strips, terraces, waterways, fertilization, manure management, lagoons, reservoirs, crop rotation and selection, pesticide application, grazing, and tillage. Additionally APEX is capable of simulating climate/CO2 changes and is capable of modeling hundreds of years. Farms/Watersheds can be subdivided into fields, soil types, landscape positions, or other configurations (Williams et al. 2004; Intarapapong and Hite, 2003).

The APEX model was used to simulate the effect of both current and alternative agricultural production practices on playa sedimentation rates and hydroperiod over a 50-year planning period. The conservation benefit of alternative agricultural practices with regard to changes in hydroperiod and sedimentation rates are measured relative to the simulation baseline condition of no on-farm conservation playa conservation practices.  In addition to the hydroperiod and sedimentation rate data, APEX also generates per acre crop yield data for specific land management practice. The biological data provided by APEX is used in conjunction with economic data on production costs and crop revenues to estimate per acre agricultural cost of each alternative conservation practice. Figure 1 provides an overview of the data flow.

The baseline simulations estimate the impact that the current agricultural practices used to produce the four dominant crops grown in the region (cotton, corn, sorghum, and wheat) that account for over 95% of all agricultural acreage (TCES 2005) have on per acre profitability and playa hydroperiod.  The crop simulations are performed for the two most common soil types (silty-clay pullman soil and a coarser sandy amarillo soil) in the THP. The baseline condition for a given set of agricultural practices is derived as the average outcome of one hundred 50-year stochastic weather simulations. APEX’s stochastic weather simulator was used to generate the one-hundred fifty-year simulated daily weather data series.  Daily weather data was generated for precipitation, daily high temperature, daily low temperature, solar radiation, relative humidity, and wind velocity using 86 years of daily weather data collected from the Lubbock Texas Weather station.   Each of the one hundred 50-year simulations was sequentially used in each of the one-hundred APEX stochastic wetland baseline simulations.  In each baseline simulation all model parameters for the wetland watershed were held constant (e.g., soil type, slope, land management practices, etc.), except that a different stochastic weather data series (50 years of daily data for temperature, precipitation, wind, relative humidity, and solar radiation) consistent with current weather conditions for the location of the wetland location were used. The mean and standard deviation value for each wetland quality variable through time was calculated in each simulation year over all one hundred simulations. The estimated mean yearly values and associated standard deviations were used to establish the expected stochastic baseline mean outcome, and confidence interval for the mean outcome, for each measured wetland quality variable tracked over time. The simulated baseline results for playas adjacent to agricultural lands are compared to simulations for playas adjacent to natural range to determine the impact that existing agricultural practices have on playa hydroperiod.

The environmental benefit of each alternative conservation practice considered was determined by comparing the change in the tracked environmental variables over time relative to the expected baseline condition. The effectiveness of each conservation control practice was simulated using the one-hundred fifty-year weather data series used in the baseline to isolate the impact each conservation control practice had on the playa ecosystem. In each 50-year simulation, five critical indicators of playa quality are tracked through time: (1) cumulative volume of sediment deposited into the playa; (2) annual playa water storage volume; (3) number days the playa contains water in each simulation year; (4) the maximum number of days the playa contains water in each simulation year; and (5) the average quantity of water stored in the playa each day the playa contains water in each simulation year. Conservation control practice effectiveness is examined relative to the baseline simulation condition for a given crop, soil type, and slope. The simulated results for two sediment control practices are reported in this paper: (1) establishing buffalo grass filter strips 50 meters wide around the playa, and the (2) use of furrow dikes.

As illustrated in Figure 2 the representative playa watershed encompasses one square mile or 259 hectares (ha). The representative playa is circular with an area of 6.27 ha (15.5 acres) and 1.0 meter deep, average dimensions for a playa in the THP, and is located in the center of the watershed and has an approximate initial storage volume of 63,000 cubic meters. The slope of the representative watershed is 1%, which is characteristic of 95% of the land in the region (USGS 1976). The soil directly underneath the playa is a relatively impermeable Randall clay soil. The remaining watershed soils are either a silty-clay Pullman soil or a coarser sandy Amarillo soil. The choice between the two cropland soils is dependent on the specific APEX simulation. The Pullman and Amarillo soils are the two dominant agricultural soils in the THP.

The representative watershed is divided into 5 distinct areas or fields, the 6.27 ha playa, a 5.23 ha buffalo grass filter strip surrounding the playa and three cropped fields labeled primary field (237.73 ha), marginal field 1 (7.5 ha)and marginal field 2 (7.5 ha). The size of the 5.23 ha buffalo grass filter strip is consistent with the area required to construct a protective 50 meter wide buffalo grass filter strip around the playa. The cropped area within the playa watershed is broken into three areas because APEX treats all areas within a given specified field as homogenous when simulating values for important field variables such as sediment runoff, crop yield, fertilizer leaching, chemical runoff, and soil moisture. Thus, multiple crop fields within the watershed are necessary to control for heterogeneous field characteristics that can arise over time from the effect land use practices have on sediment and water transport. Particularly important to this analysis was the need to control for crop yield differentials that occur as a playa fills with sediment and loses water storage volume, and water historically stored within the playas backs up onto the surrounding agricultural fields. Through an iterative process two marginal fields, labeled marginal field 1 and marginal field 2 were introduced into the representative playa watershed. Marginal field 1 is the inner most field and adjacent to the filter strip as shown in Figure 2. As the playa loses water storage volume do to sedimentation, the runoff water backfills onto marginal field 1 and continues to backfill onto marginal field 1 until marginal field 1 storage volume is exhausted, at which point the stored water begins to spill onto marginal field 2, which surrounds marginal field 1. Without introducing the marginal fields, the backfilled storage water is distributed over all cropland within the watershed and the impact of the backfill water has a negligible effect on crop yields. Thus the marginal fields provide a means to more accurately model the impact of yields losses associated with excessive soil moisture and/or field flooding attributable to lost playa water storage capacity.

In the APEX simulations the sediment and water runoff from cultivated land in the primary field was routed directly through each of the marginal fields and through the filter strip (if buffer filter strips were being used) and then into the playa. APEX developers contributed to the design of the representative watershed illustrated in Figure 2 (Williams 2005).

The APEX simulations required replication of farming practices in the region. Crop budgets prepared by the Texas Cooperative Extension Service (TCES) were used to identify current farm practices, as well as to facilitate the economic analysis of current and proposed production practices. The TCES budgets (2005) were closely followed in formulating the APEX operation schedules for representative crop practices. These operation schedules were then applied, within APEX, to a sample playa watershed representative of an average playa in the THP. Each simulation assumed a center-pivot irrigation system. Annual irrigation rates, as well as all other farming operations and tillage operations were held constant in a given management simulation for a given crop. The economic cost and environmental benefit of each alternative conservation management practice was examined for the four major crops of the THP. Those crops are cotton, corn, sorghum, and wheat. Each APEX simulation tracked the accumulation of sediment into the playa and the resulting losses of playa hydroperiod (measured in days) and storage volume over time for a given management practice.

The cumulative losses of storage volume and hydroperiod over a 50-year planning horizon for a given conservation practice were measured against the appropriate baseline condition of no on-farm conservation practices, to measure environmental benefit of the conservation practice.  The agricultural cost of each sediment control policy is calculated on a per acre whole farm basis.  Control costs are incurred in establishing and maintaining each control practice, yield changes, and land idled by a conservation practice.

## Empirical Results

Because of space limitations only the simulation results for cotton, wheat, and range on Amarillo soil are presented.   The discussion focuses on the hydroperiod simulations for the time period spanning May through August, the critical period for protecting biodiversity.  Prior research by Smith et al. (2007) has found that amphibian richness, a proxy measure for biodiversity, begins to significantly decrease in the THP when summer playa hydroperiod below 75 days.  Three measures of playa quality are used to summarize the impact existing land use practices have on the representative playa wetland over the fifty year simulation period.  The measure consist of the average number days the playa has water in the May-August period in each simulation year, average playa water storage capacity at the end of each simulation year, and the average volume of water stored each wet day.

## Playa Wetland Impacts

Figure 3 summarizes the impact current agricultural land use practices are having on playa hydro period through time. The reported average number of wet days for cotton, wheat, and range are representative of a playa completely surrounded by one of the two agricultural crops or range through time. Range provides the reference frame to determine how the playa would function in the absence of the agricultural land use practices. As shown, a playa adjacent to range on Amarillo soil maintains approximately 94 wet days each year, on average, over the 50 year simulation. In contrast, a playa surrounded by either cotton or wheat, gradually loses wet days through time. Early in the simulation, because runoff is greater from agricultural land than range land, the playa has more wet days on average, but as agriculturally driven sediment begins to fill the playa the average number of wet days for a playa adjacent to either cotton and wheat drops below range. By the end of the 50-year simulation the average number of wet days has decreased by 60% and 25% respectively for cotton and wheat, whereas the average number of wet days remained constant for range over the 50 year simulation.

The rate at which the playa looses wet days through time is a function of how rapidly the playa fills with sediment. As the playa fills with sediment its water storage capacity decreases. As shown in Figure 4, because cotton acreage is very prone to wind and water erosion a playa surrounded by cotton acreage essentially loses storage capacity within 40 years. Because wheat is a denser crop and covers more of the land surface, sediment erosion from wheat fields into the playa is less than for cotton, and the playa maintains about half of its initial water storage capacity at the end of the 50-year simulation.  Given that Range represents the natural condition it is not surprising that a playa adjacent to range has retained over 90% of its initial storage capacity at the end of the simulation.

A similar story is also presented in Figure 5 where the average quantity of stored in the playa each wet day is fairly constant for a playa adjacent to range.  Despite the decrease in average number of wet days per year over time for cotton and wheat, the average volume of water stored per wet day also decrease over time for playas adjacent to these two crops. Clearly agricultural land use practices are impacting the quality of playa wetlands.

Figures 6 and 7 respectively summarize the effectiveness of using a 50 meter wide buffer filter strip to protect the number of playa wet days and water storage capacity for playas adjacent to cotton grown on Amarillo soil.  Over the 50-year simulation the buffalo grass filter strips reduce the rate at which wet days are lost by about 10%, and extend the number of years that the playa maintains some storage capacity by about 20%.

Furrow diking is becoming a common agricultural practice in the THP because it reduces irrigation and natural precipitation runoff loses and enhances crop yield by increasing the amount of soil moisture available to the crop. Figures 8, 9, and 10 respectively summarize the impact that field diking has on playa wet days, water storage capacity, and the stored water level per wet day for cotton grown on Amarillo soil.  The diking simulations are presented just for the diking practice and in combination with the use of buffer filter strips.  In Figures 8, 9, and 10 the average simulation labeled “No Diking or Buffer” is simply the cotton baseline simulation respectively reported Figures 3, 4, and 5.   Field diking, by itself, is slightly more effective than installing 50 meter buffers to reduce the number of wet days lost (Figure 8) and in retarding the rate playa storage capacity is lost (Figure 9). When field diking and buffers are used in combination the reduction in playa wet days and water storage capacity is further reduced. Thus, furrow dikes strongly compliment the effectiveness of buffer strips in reducing sediment runoff into playas. However, as illustrated in Figure 10, furrow dikes to little to enhance the level of water stored per wet day because the dikes prevent field water runoff into the playa.

## On-farm Economic Impacts

As shown in Table 1 government crop support programs significantly affect the costs of installing buffer filter strips to reduce agriculturally produced sediment runoff into playa wetlands. Under the current program in the THP buffer strips earn the same rental rate as Conservation Reserve Program (CRP) acreage which is $40/acre/year for Amarillo soil, and $38/acre/year on Pullman soil. The NRCS managed EQUIP program currently pays 50% costs ($32.50 per acre) of FAS estimated establishment (Underwood 2007). Annual maintenance cost on established buffer acreage is $5 per acre (Underwood 2007). Under current policy producers lose base payments on acres bid into buffer strips, but recover base and associated payments when the land is returned to crop production. The temporary loss of base payments (direct payments and counter cyclical payments) provides strong disincentive to bid land in buffer strips.

As shown in Table 1, both cotton and wheat producers would bid land into buffer filter strips under current market conditions on both Amarillo and Pullman soils if they did not temporarily lose their base payments. Moreover, given currently depressed market price levels, they would be better off putting their land in buffer strips even without the rental payment as long as they did not lose their base payments. However, when producers must forfeit their base payments the opportunity cost of buffer strips is too great even with the rental payment for all producers except wheat producers producing on Pullman soil.  The lower yield on Pullman soil relative to the more productive Amarillo soil generate low wheat gross revenues, even with base payments, and the per acre buffer strip rental payment exceeds the buffer strip opportunity cost.

Furrow diking is not employed on wheat fields and thus no adoption cost entries are reported in the furrow diking columns for winter wheat.  A producer growing cotton and using furrow diking would be better off financially if he adopted established buffer strips and was not required to temporarily forfeit his base payments.  Moreover, the producer would be better off without the rental rate payment.  However, when the base payments are temporarily forfeited the producer is worse off even when the buffer rental payment is paid. As shown in Table 1 it is extremely costly to provide a large enough incentive to encourage a producer who furrow dikes and does not use buffers, to install buffer strips and end the practice of furrow diking.  The additional cost results from the fact that furrow diking increased the simulated average cotton crop yields by about 30 pounds of lint per acre.

## Conclusions

Wetland management is a challenging task for economists.  As playa hydro-period is reduced both water fowl habitat and biodiversity is lost within a playa ecosystem.  This study marks the first known effort to simulate how depressional wetland hydroperiod is impacted by agricultural land-use practices using APEX as the modeling tool.  As an incentive for agricultural producer cooperation, the economic results provide policy makers with a cost framework on which to structure compliance incentive contracts, should that be the preferred conservation management strategy.  However, the volatility of agricultural prices limits the ability of policy makers and farm producers to develop long-range, cost-effective, farm management plans.

Increasing global competition in agricultural markets also restricts the planning capability of the decision-making parties. It is unclear how current market conditions and global trade environments will affect future agricultural production in the THP. Crop price changes will shift the private marginal benefit curve for agricultural producers. Price sensitivity of compliance cost needs to be investigated.

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Table 1. Annual per acre Buffer Filter Strip Cost by Crop, Price Scenario, and Soil Type

| | | Amarillo Soil | | | Pullman Soil | | |
|---|---|---|---|---|---|---|---|
| Price Scenario | Crop | Base[1] to Buffer | Diking to Buffer and Dike | Diking to Buffer no Dike | Base[1] to Buffer | Diking to Buffer with Dike | Diking to Buffer no Dike |
| Market Price & LDP | Cotton | 25.95 | 17.34 | -383.73 | 105.17 | 39.91 | -472.93 |
| Market Price & All GP | Cotton | -128.07 | -142.64 | -821.70 | -15.45 | -111.37 | -950.91 |
| Market Price & LDP | Winter Wheat | 25.95 | | | 17.34 | | |
| Market Price & All GP | Winter Wheat | -128.07 | | | -142.64 | | |

Note: LDP designates the loan deficiency payment, and All GP designates all applicable government programs (loan deficiency payment, direct payments, and counter cyclical payments). A positive per acre value implies there is a net benefit of adopting a given practice and a negative value implies there is a net cost. Under current rental rates buffer strips earn the same rental rate as CRP: $40/ac/yr for Amarillo soil, and $38/ac/yr for Pullman Soil. These rental rates are not reflected in the per acre cost estimates.

[1] Base is the agricultural land use practice that uses neither buffer filter strips or furrow diking.

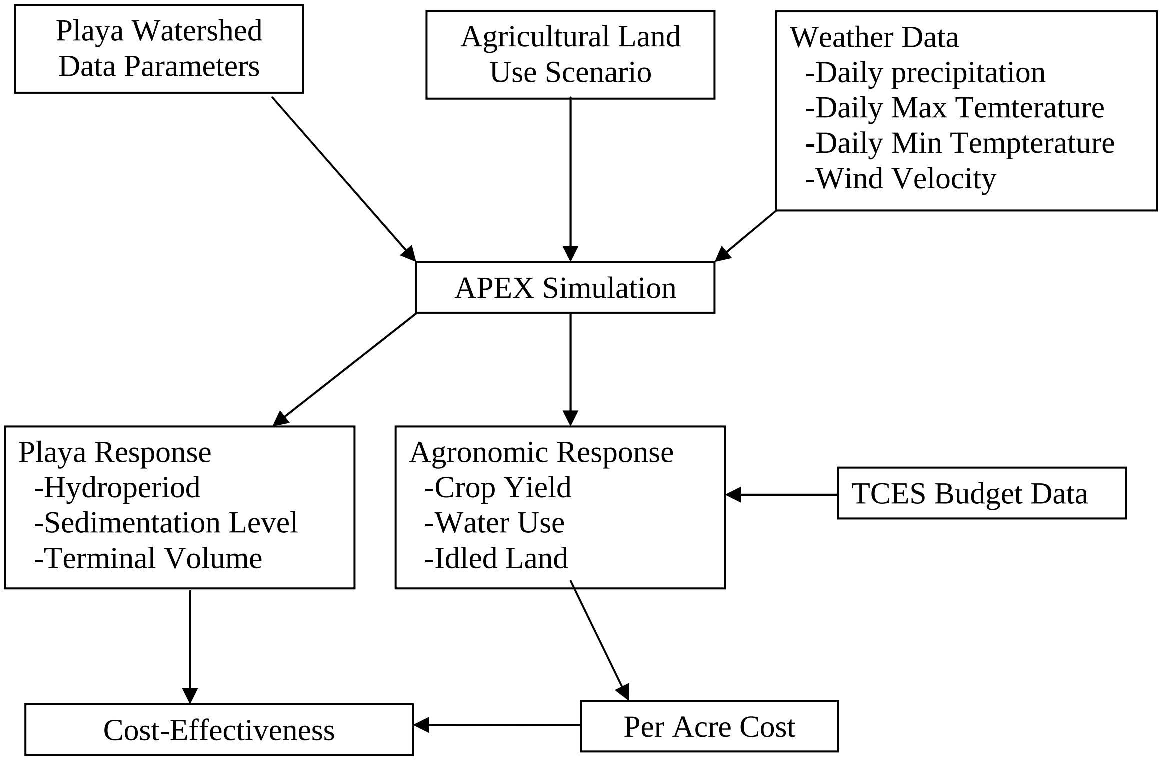

Figure 1: Flow Chart of Economic and Biological Data Use and Management Practice Analysis

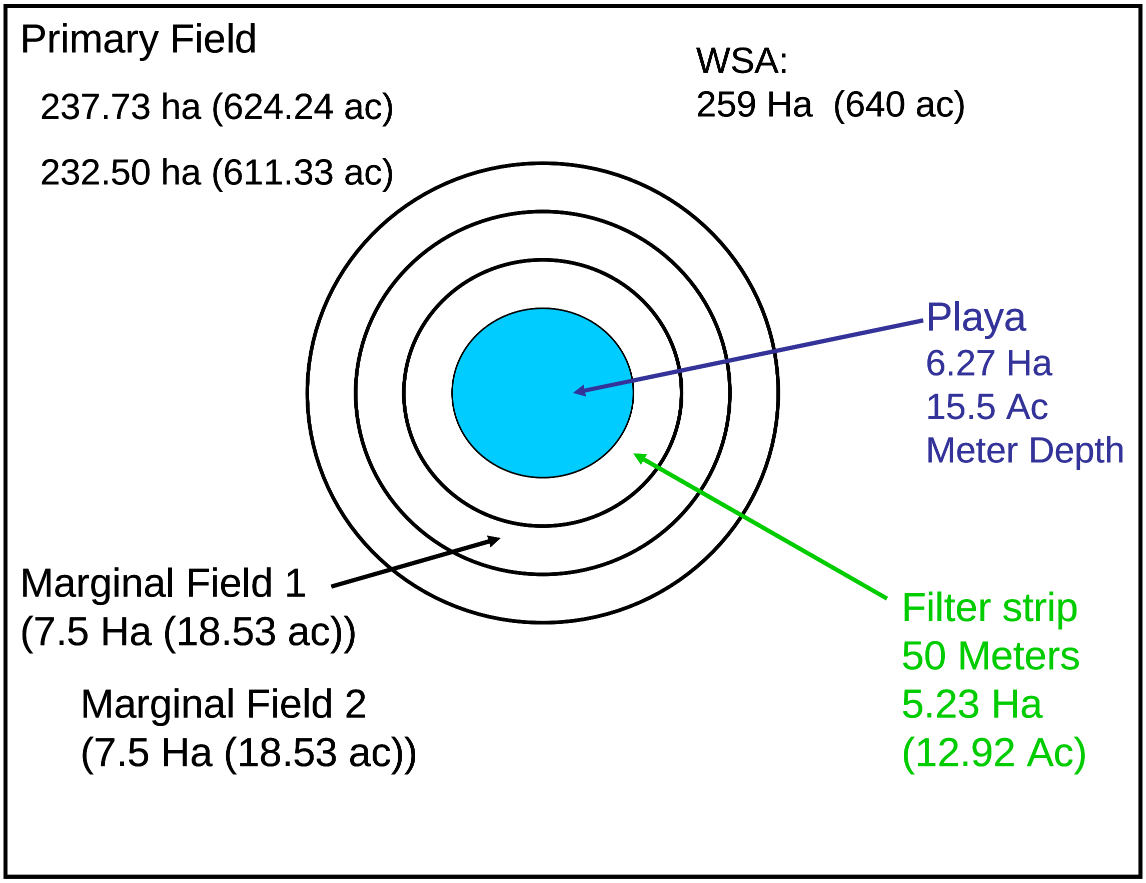

Figure 2. Representative playa watershed design

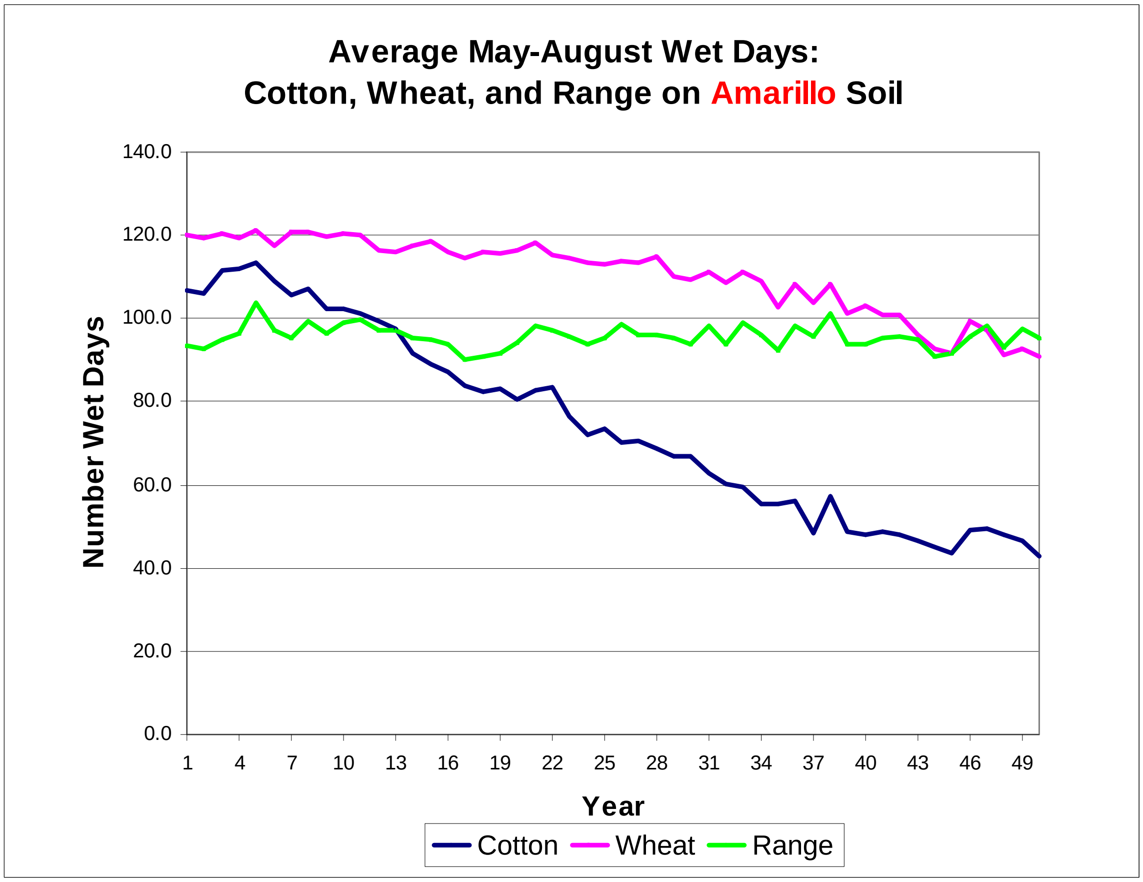

Figure 3: Average Number Playa Wet Days in May through August for Cotton, Wheat, and Range on Amarillo Soil.

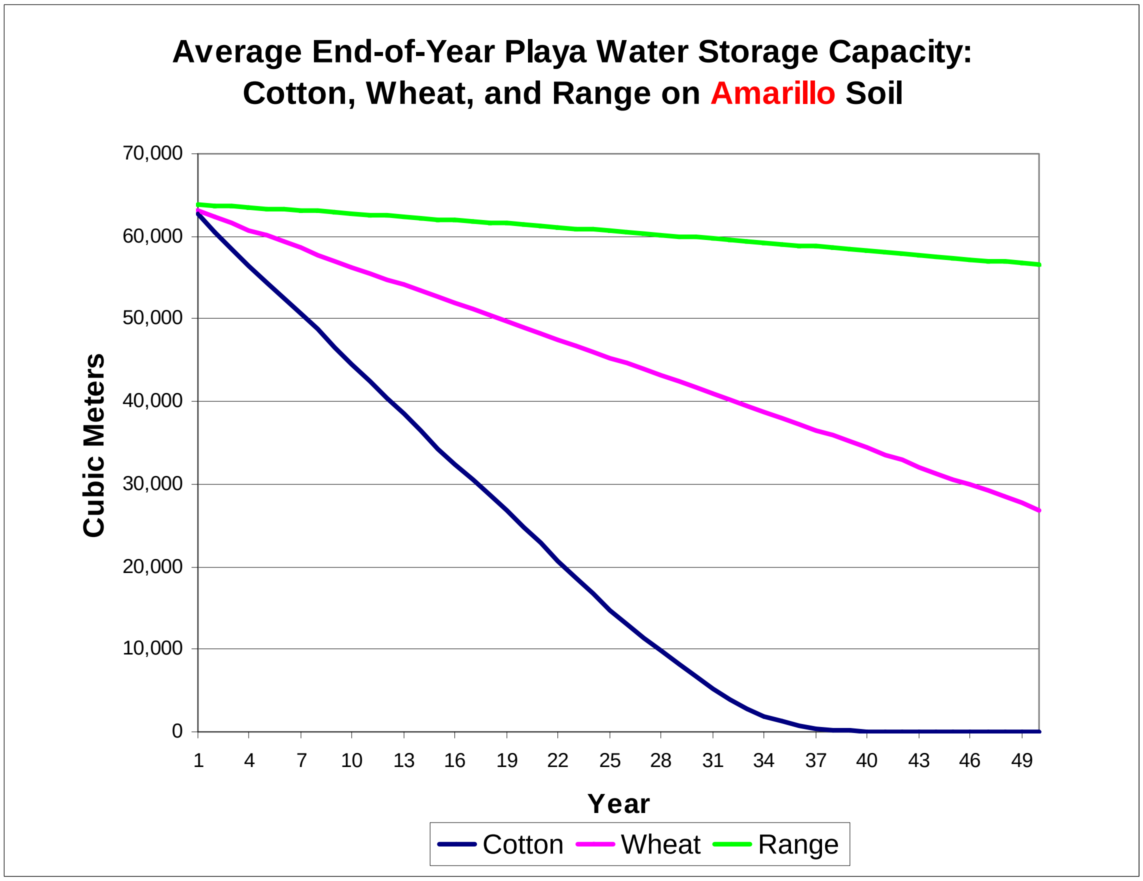

Figure 4: Average End of Year Playa Water Storage Capacity for Cotton, Wheat, and Range on Amarillo Soil

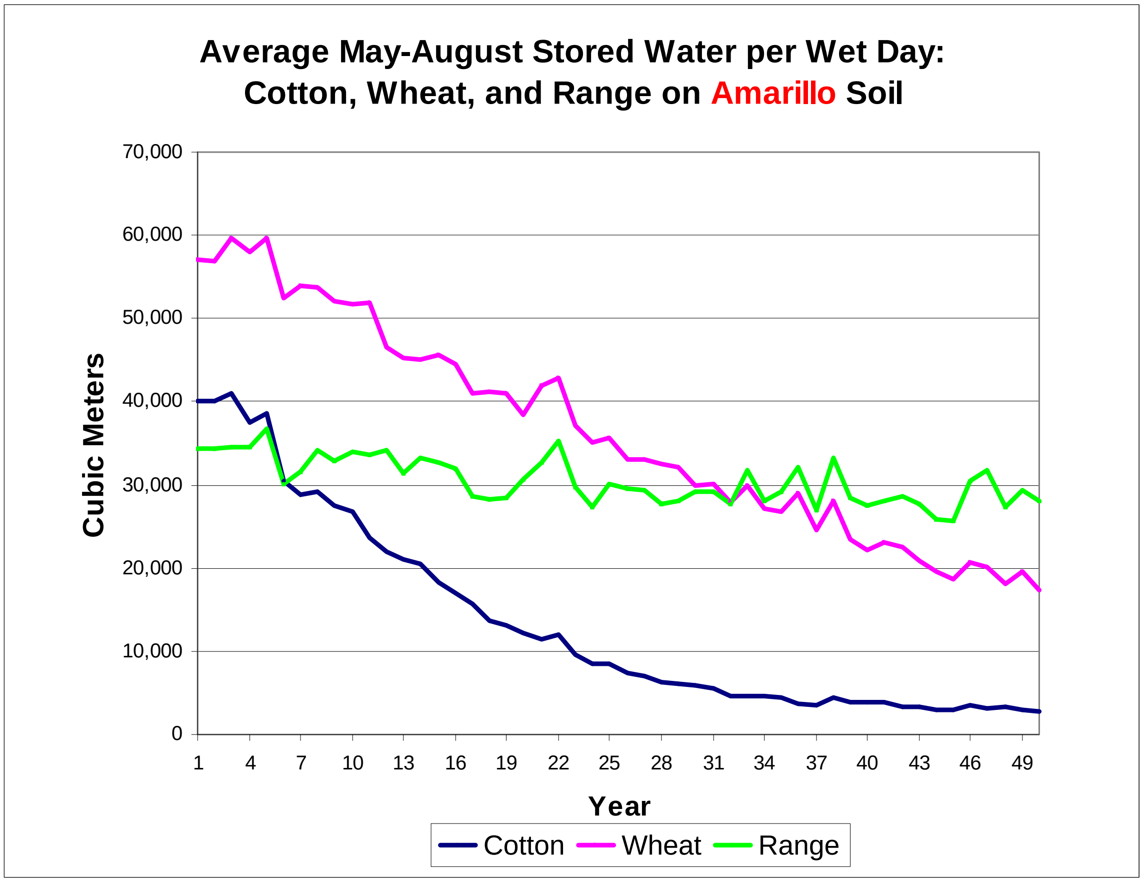

Figure 5: Average Volume Stored Water per Playa Wet Day in May through August for Cotton, Wheat, and Range on Amarillo Soil

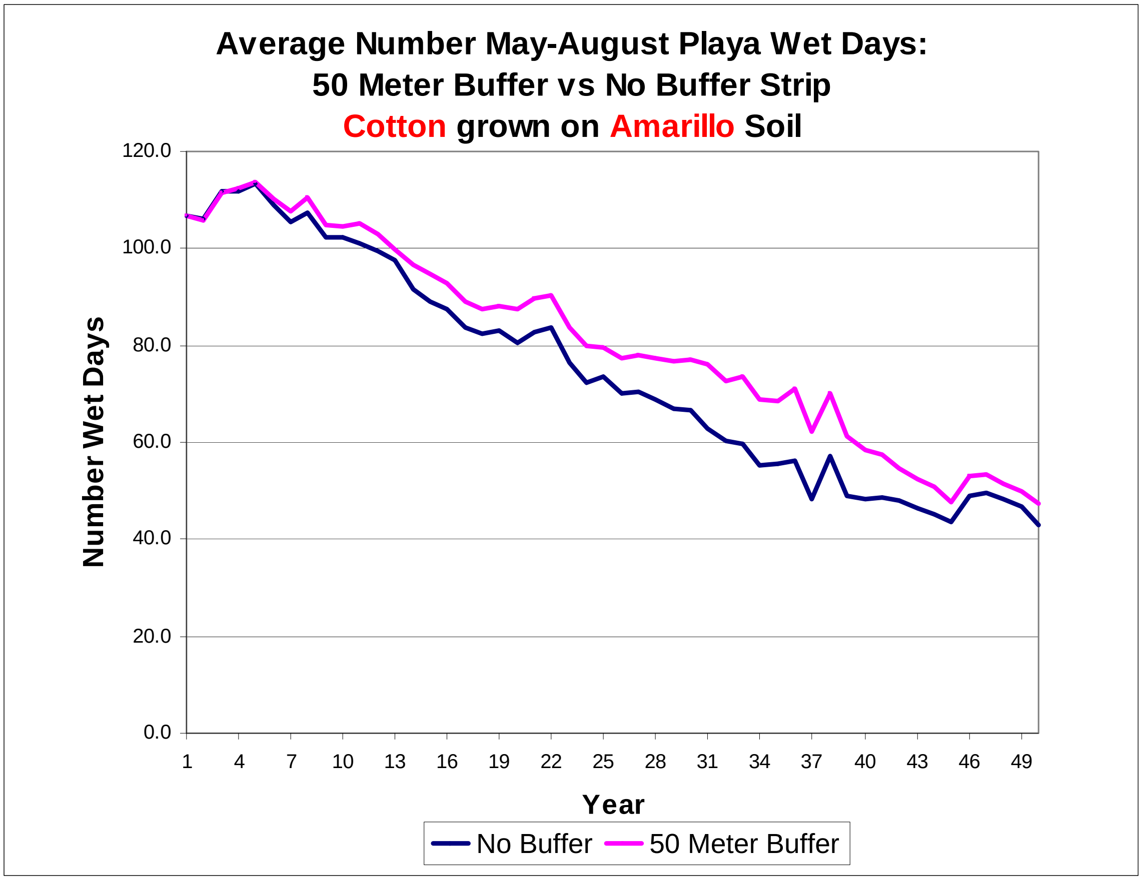

Figure 6: Average Number Playa Wet Days in May through August for Cotton Grown on Amarillo Soil with and without a 50 meter Protective Buffer Filter Strip.

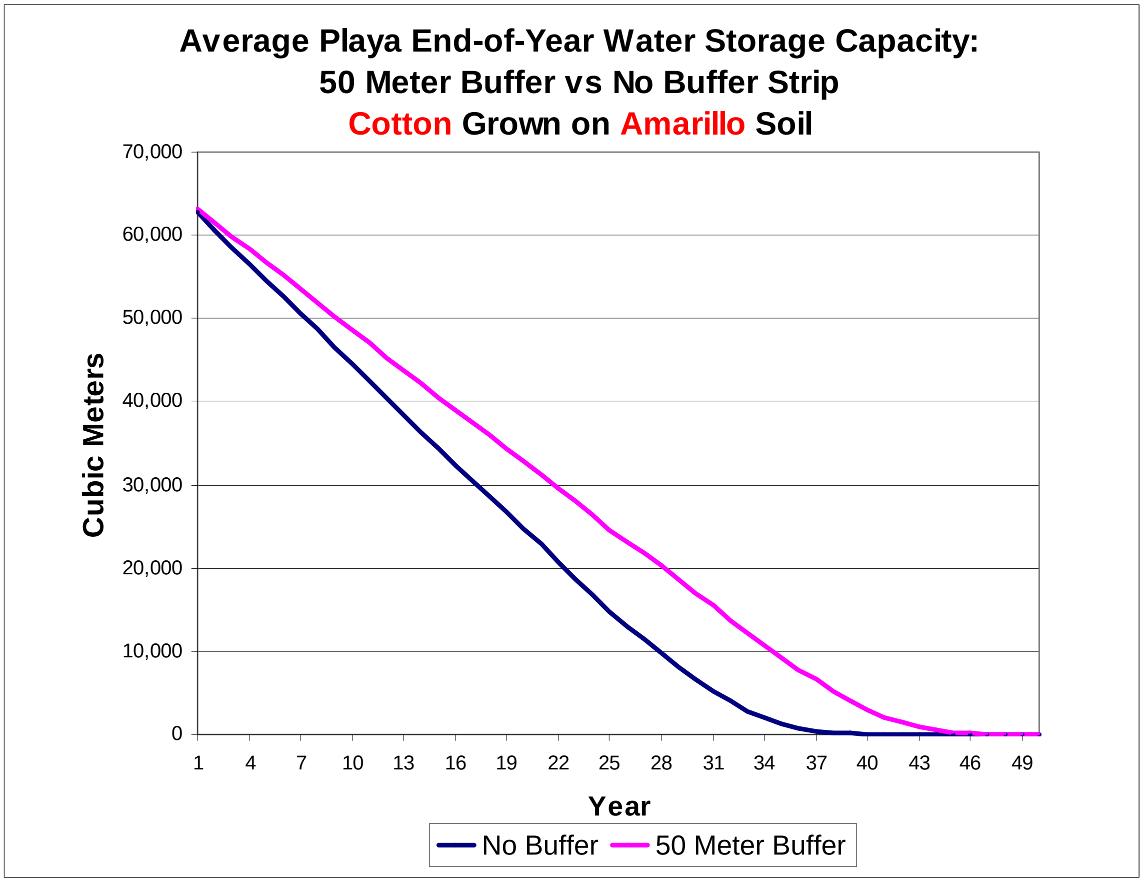

Figure 7: Average Playa End of Year Water Storage Volume for Cotton grown on Amarillo Soil with and without a 50 meter Protective Buffer Filter Strip.

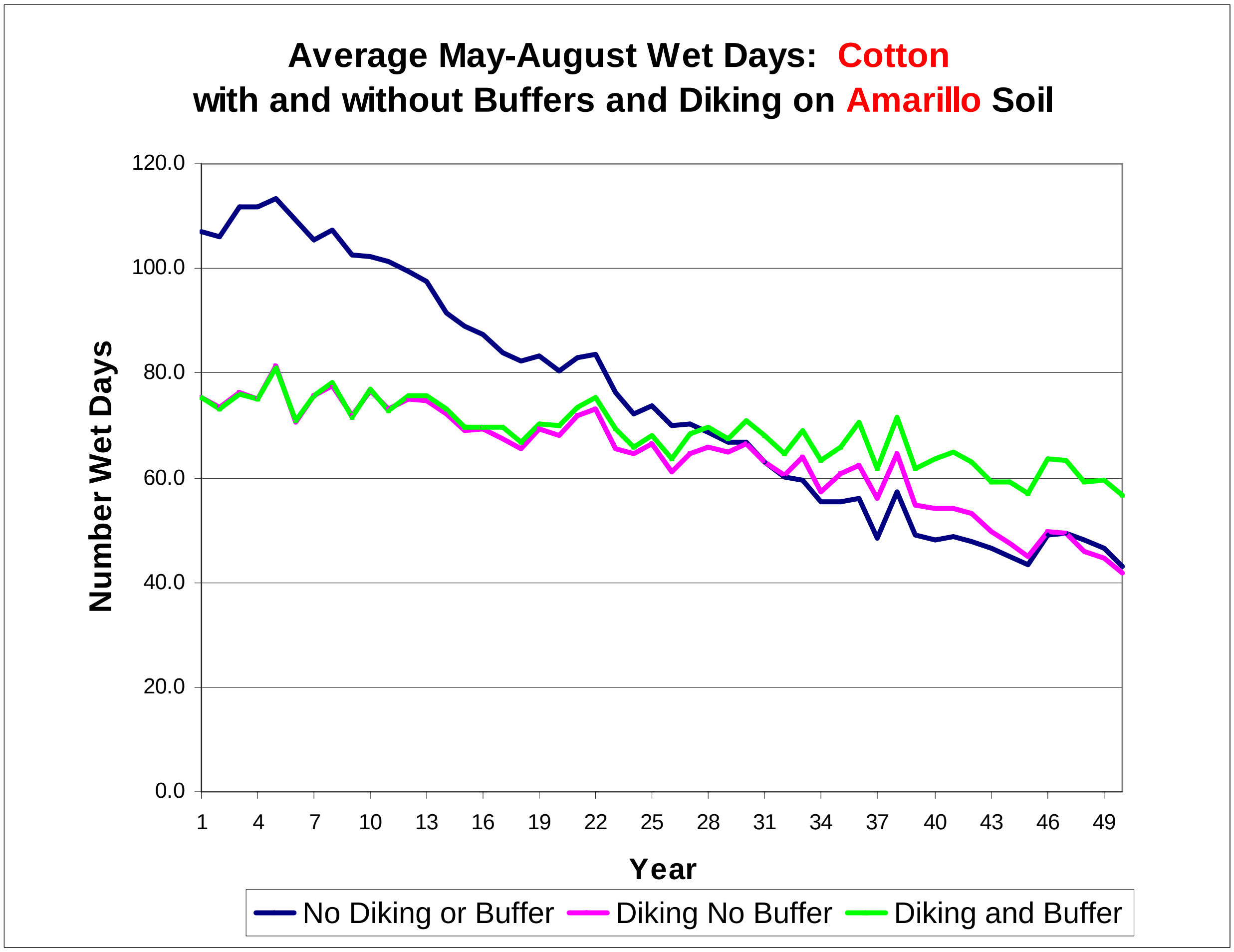

Figure 8: Average Number Playa Wet Days in May through August for Cotton Grown on Amarillo Soil with Alternative Control Practices

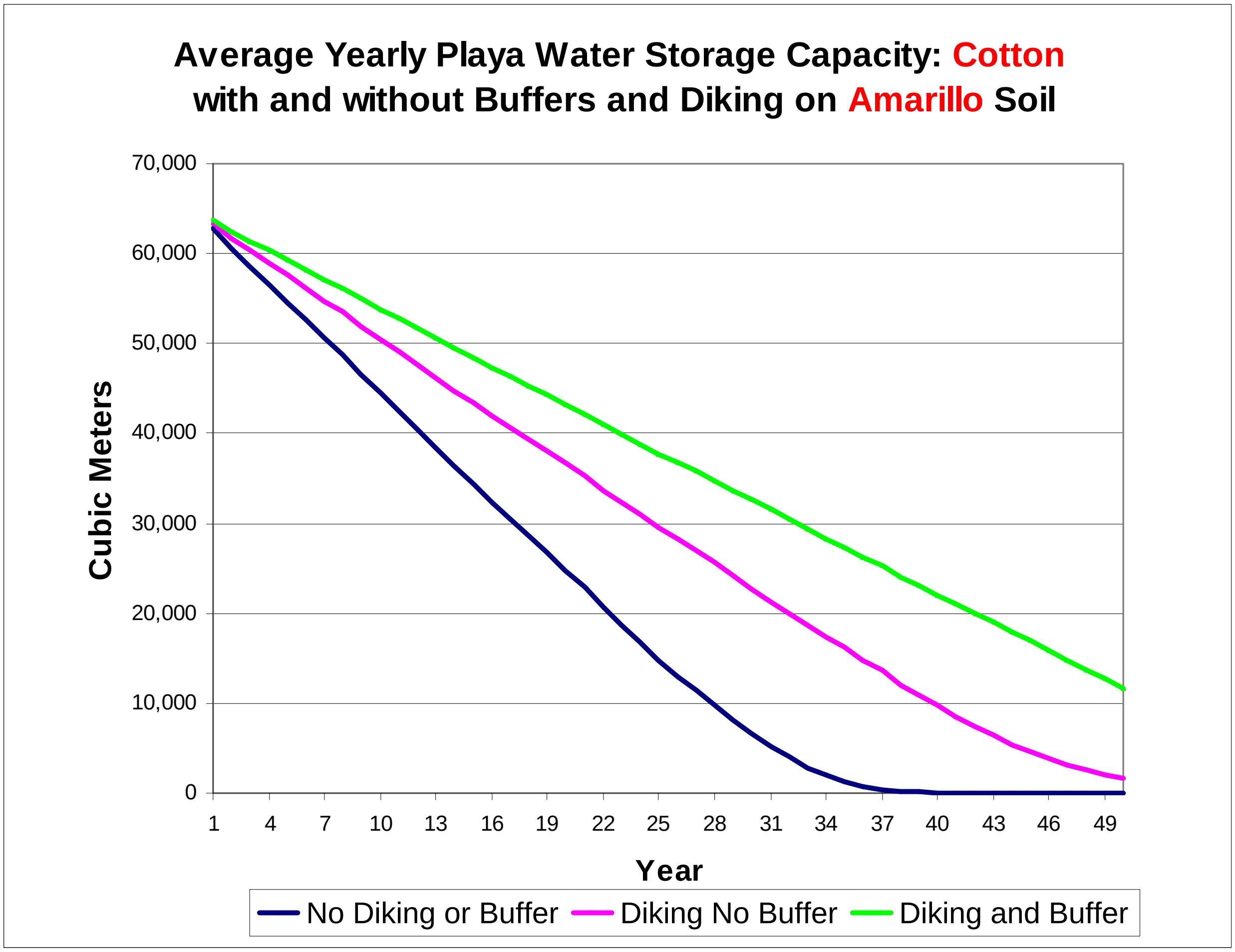

Figure 9: Average Playa End of Year Water Storage Volume for Cotton Grown on Amarillo Soil with Alternative Control Practices

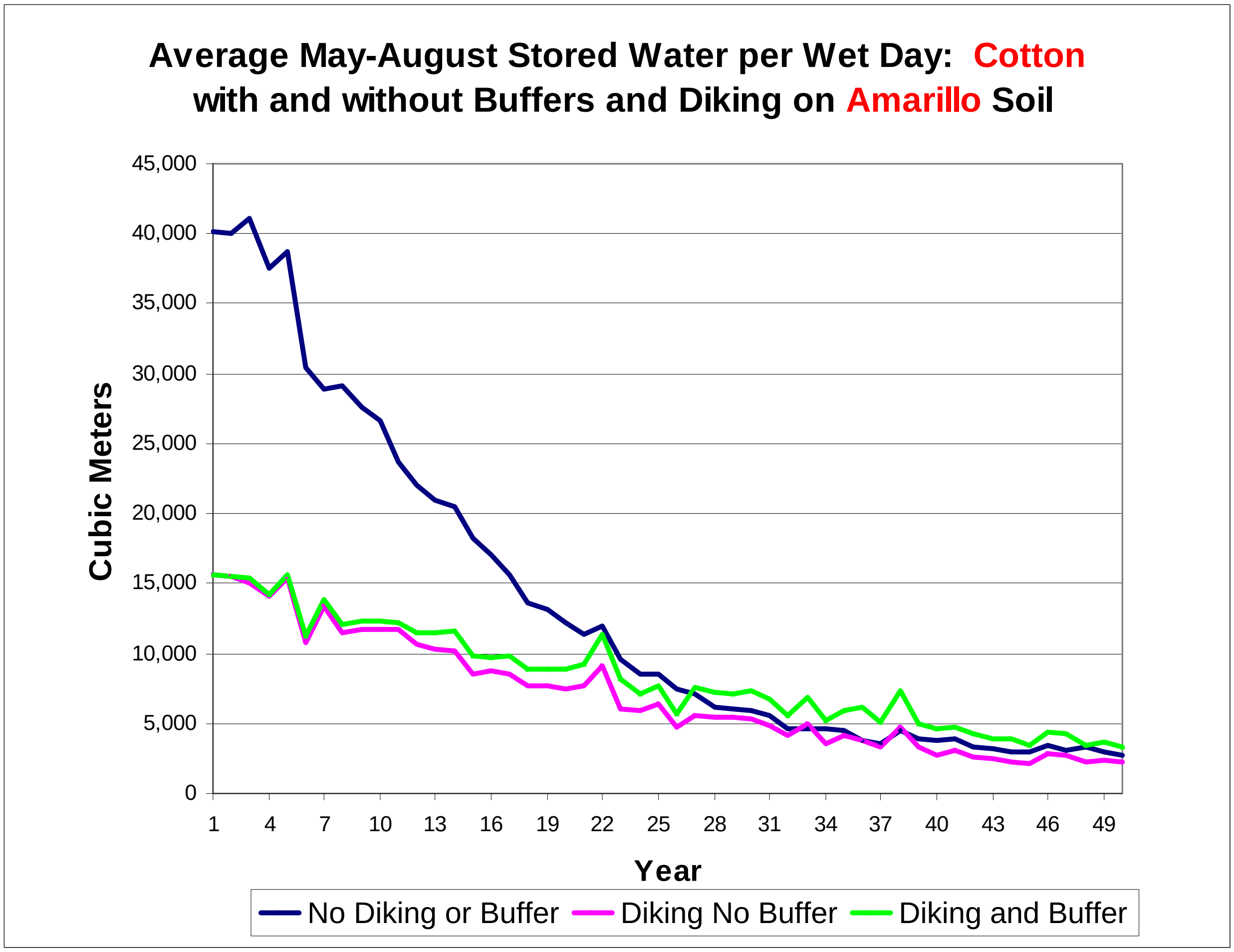

Figure 10: Average Volume Stored Water per Playa Wet Day in May through August for Cotton Grown on Amarillo Soil with Alternative Control Practices