SUSTAINABLE CONSERVATION

ON-FARM INFRASTRUCTURE NEEDS ASSESSMENT AND COSTS TO IMPLEMENT GROUNDWATER RECHARGE USING FLOOD FLOWS ON CROPLAND

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

1. Introduction

Sustainable Conservation retained Summers Engineering to conduct a study of the on-farm infrastructure that would be needed to implement flooding of crop land for groundwater recharge. The study sets forth assumptions and constraints for typical farms in the Kings River Basin and evaluates the resulting infrastructure needs and costs. Evaluations include flood depths of 6-inches, 12-inches and 24-inches and farm sizes ranging from 10 to 160 acres. Farm sizes greater than 160 acres were assumed to have redundant irrigation systems and therefore the cost per acre would be approximately the same as those identified for a 160 acre farm. Costs include annualized capital costs for system improvements and operating costs. System improvements would be to enlarge existing pipelines and lift pumps or install new facilities to deliver the flood water from a nearby irrigation district ditch or floodway and distribute the water on-farm. For flood depths above 12-inches it would be necessary to construct permanent earth berms to contain the flood water. Operating costs would be for soil preparation, irrigation labor, pumping energy and temporary border checks.

The general term “border irrigation system” is used to identify the type of irrigation systems that might accommodate flooding of crop land for groundwater recharge. Border irrigation systems are typically used for general agronomic irrigation of crops. In this report border irrigation systems include square basins, contour basins, contour checks, border checks, and furrows,

A critical assumption in the evaluations is the duration of time a grower could permit the crop to be flooded without interfering with cultural practices. It was assumed that no more than half of the farm acreage would be flooded at a given time and the desired flood depth should be achieved in 10 days or less. Irrigation systems that could not achieve the desired flood depth within this time period would need to be enlarged. Greater flood depths would require more time to infiltrate after the diversion ended. For instance, at an infiltration rate of 3-inches per day it would take 2 days for 6-inches of flood water to drain and it would take 8 days for 24-inches of water to drain. If the total time for flooding and drainage is limited to 10 days, the volume of recharge would be the same for either depth since the rate of recharge is constrained by daily soil infiltration rate, not by depth of water. This seemed counter to the intent of the study, so it was assumed infiltration time following flooding would be more for greater depths. A typical existing smaller capacity system could achieve a 6-inch flood depth in 10 days or less and drain for 2 more days. Infiltration would begin on the first day and continue until the field was drained and the total recharge would be 36-inches (12 days x 3-inches per day). A larger capacity system could achieve a 24-inch flood depth in 10 days or less and drain for 8 more days. Again the infiltration would begin on the first day and continue until the field was drained and the total recharge would be 54-inches (18 days x 3-inches per day).

The criteria presented in Chapter 2 include basic assumptions about farming systems as well as calculated capacities and limitations of infrastructure to achieve intended flood recharge goals. It also identifies limitations for certain crop types in terms of soil preparation and field types in terms of the infrastructure that might be available or possible to use.

Typical on-farm system layouts are presented in Chapter 3 for some of the different farm sizes considered. These layouts were used to determine material quantities for the cost estimates presented in Chapter 4.

2. Assumptions and Constraints

Following are the assumptions and constraints used to determine infrastructure requirements for crop land flooding for recharge and the associated cost estimates presented in subsequent chapters. Assumptions about typical on-farm irrigation systems needed to spread flood water were used to determine hydraulic capacities of existing systems and size requirements for enlarged systems. Operational assumptions were used to determine how much flood water could be recharged per acre of crop land at various flood depths and the frequency the flood water would be available. Assumptions about the topography of typical farms were used to determine requirements for containing flood waters on crop land and developing cost estimates for containment systems such as border checks and permanent earth berms. Qualitative constraints regarding soil preparation and feasibility for certain farms are also included.

<u>Border Irrigation System</u>

- Average distance from irrigation district ditch or floodway is ¼-mile.
- Typical size of existing turnout gate & pipelines is 15”.
- Farms larger than 160 acres have more than one turnout gate.
- Lift pump(s) needed to irrigate half of the farm (see Figures 1 through 3).
- No more than half of farm will be flooded at a time.
- Irrigation valves on half of farm could be opened simultaneously or flooding could be rotated through checks.
- Recharge rates vary from about 2” per day on heavier soils in the western part of the Kings River Basin to 9” per day or more on the sandy soils in the eastern areas of the Basin. Average recharge rate considering winter climate and soil variations is 3” per day.
- System should be capable of achieving flood depth within 10 days or less to minimize disruption of cultural practices.
- Flooding of land would continue for 10 days regardless of initial fill time.
- Greater flood depths will take longer to drain and will lengthen disruption of cultural practices.
- An average of 3 flooding cycles can be completed in 2½ months or less in years that flood water is available. A flooding cycle includes two turns, one for each half of the farm. One turn includes 10 days of flooding, the time needed to drain the flood depth at an infiltration rate of 3” per day, 2 days of drying, and at least 6 days of the field being accessible for cultural practices.

- On average flood water is available 1 of every 3 years based on Kings River records that indicate significant volumes of flood water left the service area in 21 of the past 60 years, from 1955 through 2014.
- Maximum on-farm distribution pipeline size is 24”. The physical space needed for trenching and stringing larger pipe sizes is typically not available and costs for larger pipe sizes are disproportionately higher.
- New or replacement irrigation systems are PVC pipe with a recommended dimension ratio (DR) of 51 and are in accordance with Natural Resources Conservation Service (NRCS) standards.
- Equipment for temporary systems would be rented for 3 months.

Containment Berms

- Most existing border irrigation systems can achieve 6” flood depth.
- 12” flood depth can be achieved using a ridger to build temporary border checks each flood season without importing soil.
- 24” flood depth requires major modifications:
    - Permanent berms
    - Imported soil for berm construction
    - 24” top width, 2:1 slopes, compacted soil
    - 12’ wide crowned farm roads for interior berms
    - Remove outside rows of permanent crops for space
    - Shorten rows to allow farm equipment to turn around inside berm
- 20 acre maximum within border checks.

Soil Preparation

- Ripping in 2 directions not feasible for permanent crops.
- Rip in dry soil to 24” depth.
- Crops that can be ripped
    - Fallow fields
    - Row
    - Walnuts (middle of rows)
- Crops not typically ripped
    - Almond trees
    - Pistachio trees
    - Fruit trees
    - Vines
    - Alfalfa (can be done between plantings every 4 to 5 years)
- Ripping can be done without damaging most drip & sprinkler systems.
- Additional application of gypsum in fall/winter can be used instead of ripping, cost is approximately equal to ripping.

Other

- Economy of scale is insignificant for farms larger than 160 acres.
- Many old vineyards using drip systems have not been leveled and cannot be flooded due to irregular topography.
- Existing drip system main lines may interfere with installation or replacement of border irrigation systems.
- Farms that were replanted in permanent crops often had border irrigation systems removed and new drip or sprinkler systems installed.

3. Typical On-Farm Systems

Following are schematic maps of typical on-farm systems for 40, 80 and 160 acre farms. Pipelines, irrigation valves, lift pumps, containment berms and farm roads are identified.

Canals owned by the large irrigation districts in the Kings Basin provide gravity water service to most of the lands in their service areas. Occasionally the topography is such that a lift pump is needed to irrigate a farm in these districts, but not typically. In other regions of the Kings Basin where private ditch companies deliver surface water to growers, the need for lift pumps to irrigate all or a portion of a farm is more prevalent. Also, growers that would divert flood water directly from a river or floodway would most likely need lift pumps because those waterways are drainage channels which are lower than the surrounding lands. Although there may be exceptions to these observations, it was assumed that roughly half the acreage in the region could be irrigated by gravity and a lift pump(s) would be needed to irrigate the other half.

Figure 1

TYPICAL 40 ACRE FARM

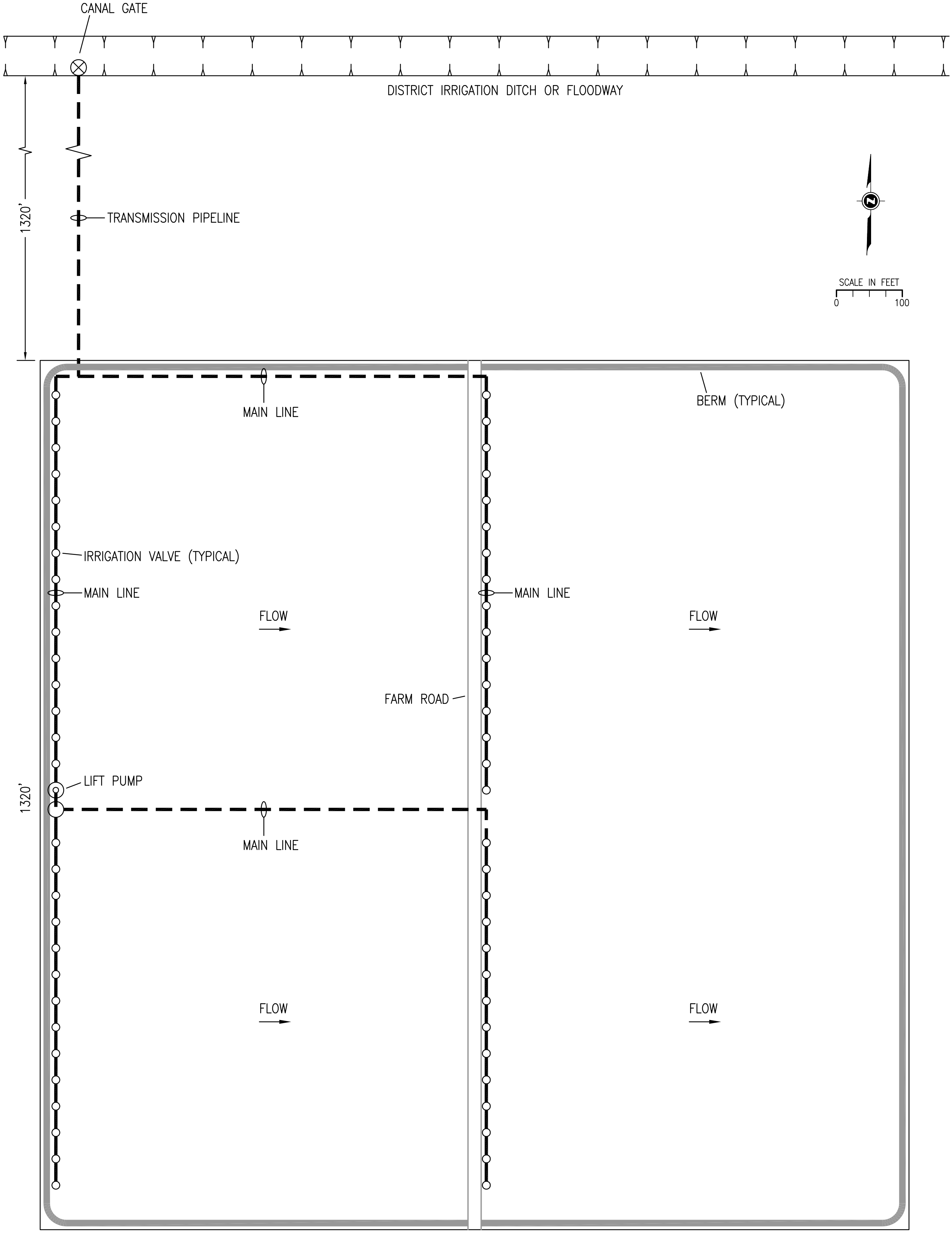


Figure 2

TYPICAL 80 ACRE FARM

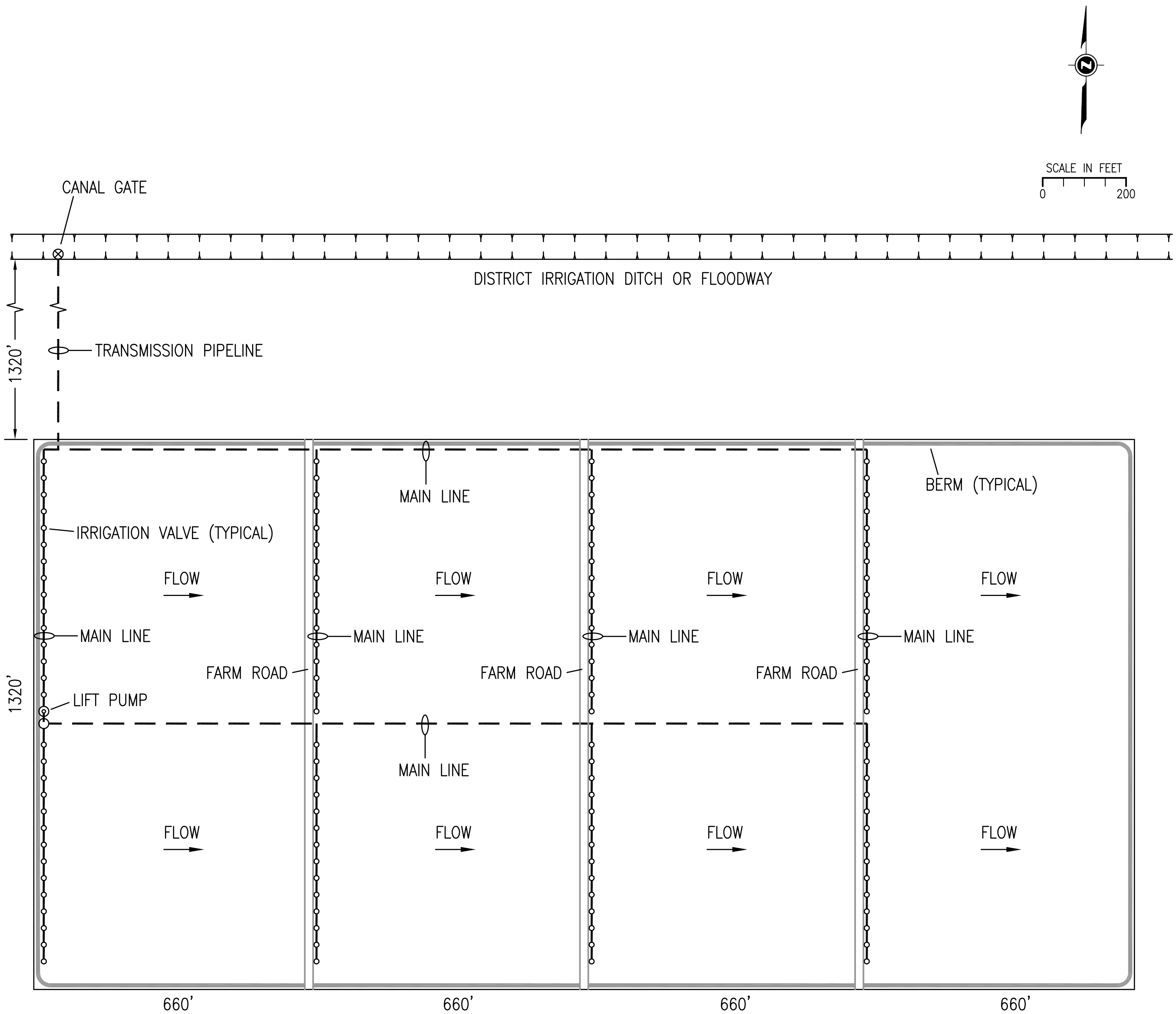
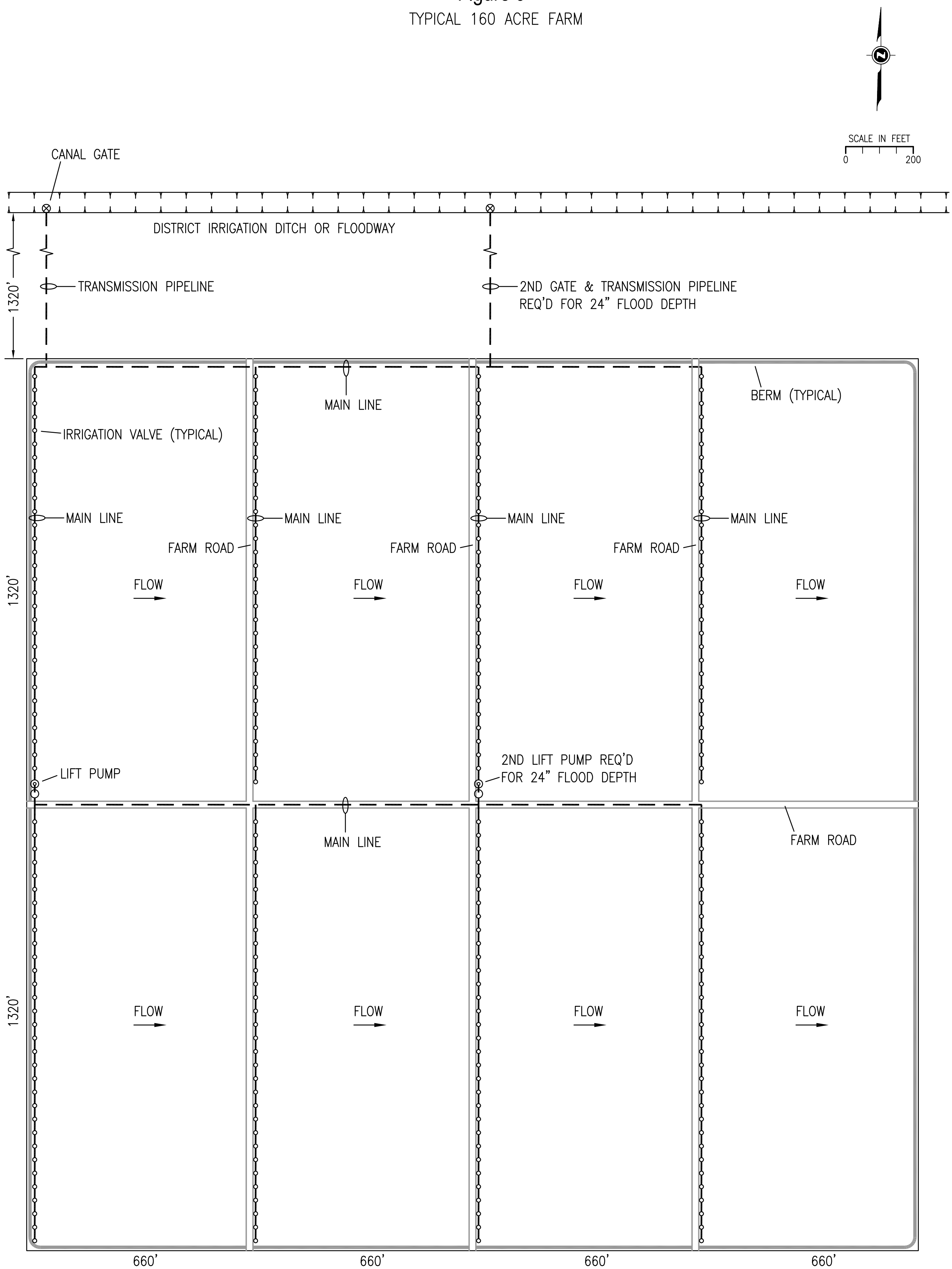


Figure 3

TYPICAL 160 ACRE FARM



4. Costs

Costs were determined based on the assumptions and constraints identified in Chapter 2. Shallow flood depths can be achieved on smaller farms with existing border irrigation systems, provided those systems still exist. To achieve greater flood depths on larger acreage farms would require larger border irrigation systems than might typically be in place, so there would be capital costs. If existing systems are in place but inadequate for the desired flood depth, there would be added capital costs to remove the old system versus a farm that has no existing border irrigation system. Regardless of the infrastructure available there would be operating costs for additional irrigator labor, lift pump energy, temporary border checks and soil preparation. The capital and operating costs were estimated for farm acreages ranging from 10 to 160 acres with or without existing flood irrigation systems. Capital costs were annualized at 4% interest over a 20 year term. As noted in Chapter 2, achieving a 24-inch flood depth would require permanent earthen berms to contain the flood water and space would be needed inside the berms for farm equipment to turn around at the ends of the rows. Permanent crops would have to be removed to allow space for the berms and turn around areas. The capital cost to remove permanent crops was estimated at $5000 per acre and the present worth value for future revenue losses was estimated at $25,000 per acre (total present worth value of $30,000 per acre). Total annual costs per acre are summarized in the following tables and accompanying graphs. Total costs per acre-foot were also determined based on the annual cost per acre divided by the average annual recharge. Based on historic Kings River flood releases out of the service area since 1955, flood water would be available for recharge an average of 1 in 3 years and it was assumed three (3) each 10 day cycles of farm flooding could be achieved on each half of a farm in each year flood water is available.

Costs were also estimated for using temporary pumps and surface pipe to flood farm land. The temporary facilities would be rented only in years when flood water was available so capital costs would be minimized. To achieve 24-inches of flood depth there would still be capital costs for constructing permanent berms, raising farm roads and removing permanent crops at the borders of the field to provide space, but most other costs would be operational. Soil preparation would be done every year in anticipation of flood water being available, but equipment and labor cost for irrigating would only occur in the years flood water was actually diverted. Temporary pumps would be powered by diesel engines so there would be fuel costs versus energy costs for permanent pumps.

Tables 2 and 5 are example cost estimates for permanent and temporary infrastructure, respectively, that would be needed to achieve a 12-inch flood depth on a 160 acre farm.

Table 1

Permanent Infrastructure & Operating Costs for Farms with Existing Border Irrigation Systems

Flood Depth	Farm Acreage	Infrastructure Costs ($)	Annualized Infrastructure Costs ($/ac)	Annual Operating Costs ($/ac)	Total Annual Costs ($/ac)	Average Annual diversion (ac-ft)	Total Cost ($/ac-ft)
6"	10	0	0	114	114	30	38
	20	0	0	99	99	60	33
	40	0	0	99	99	120	33
	80	340,000	313	99	412	240	137
	160	748,000	344	99	443	480	148
12"	10	0	0	121	121	35	35
	20	0	0	105	105	70	30
	40	196,000	361	104	465	140	133
	80	434,000	399	104	504	280	144
	160	748,000	344	104	448	560	128
24"	10	109,000	802	116	918	45	204
	20	181,000	666	101	767	90	170
	40	526,000	968	101	1,068	180	237
	80	1,093,000	1,005	101	1,106	360	246
	160	2,169,000	997	101	1,098	720	244

Figure 4

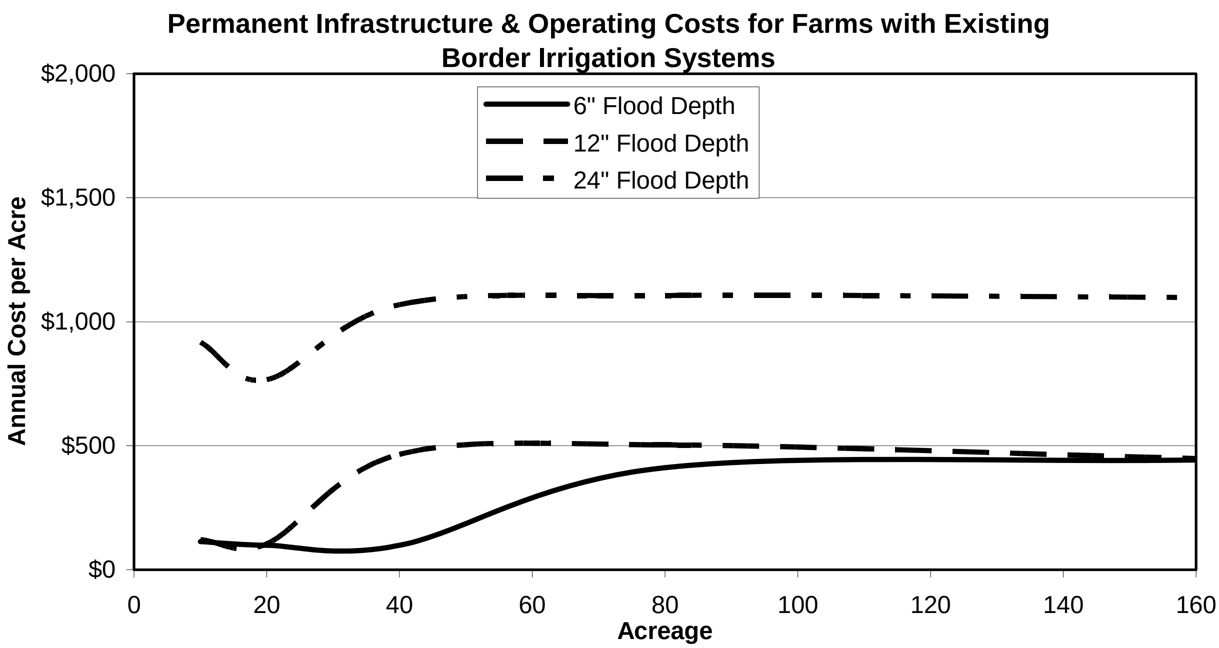


Figure 5

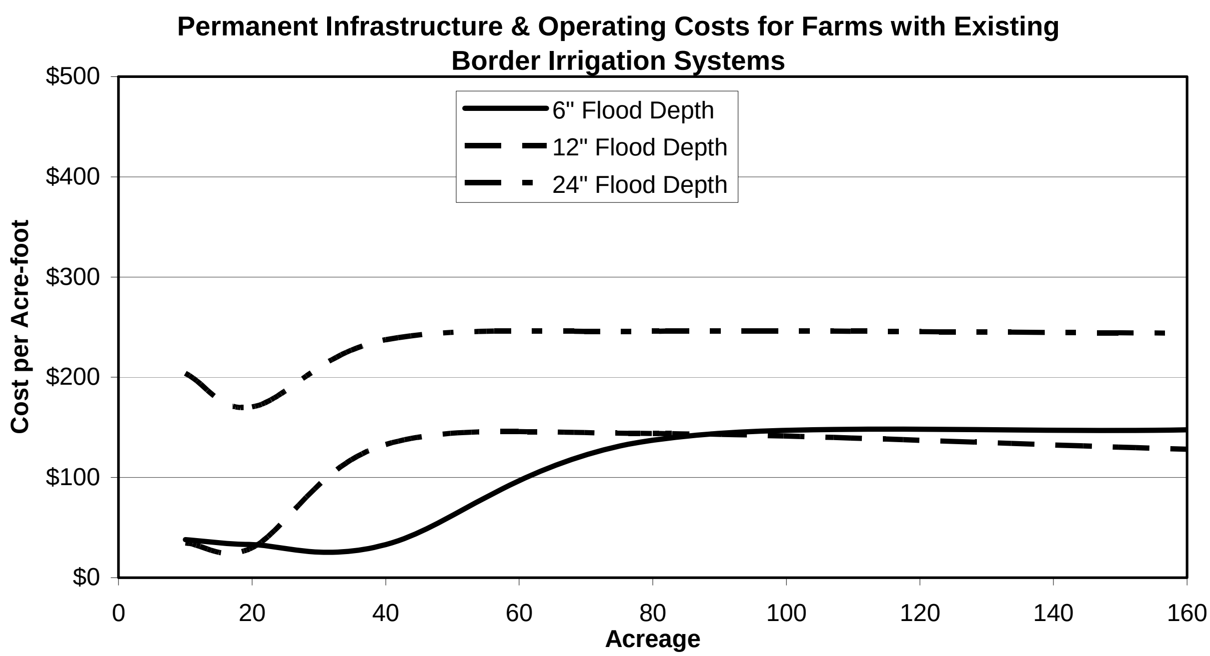


Table 2

Example Cost Estimate

12" Flood Depth, 160 acre Farm with Existing Border Irrigation System

Item	Description	Amount	
	Infrastructure Costs		
1.	Remove existing irrigation system	$79,500	
2.	Furnish and Install (F&I) 24" canal gate	$3,500	
3.	F&I 24" PVC pipe	$509,000	
4.	F&I Irrigation valves	$86,500	
5.	F&I 13 cfs lift pump	$25,000	
6.	F&I Lift pump stands	$20,000	
7.	F&I Electrical service & control panel	$25,000	
	Total Infrastructure Cost	$748,500	
	Capital Recovery Factor (4%, 20 yrs)	0.07358	
	Annualized Infrastructure Cost	$55,075	
		$344	per acre
	Operating Costs		
8.	Build temporary berms 2 times per year	$2,400	
9.	Lift pump power	$2,150	
10.	Irrigator labor	$7,200	
	Operating Cost per Flood Year	$11,750	
	Annualized Operating Cost (flood water 1 in 3 years)	$3,917	
11.	Annual ripping or gypsum application	$12,800	
	Total Annual Operating Cost	$16,717	
		$104	per acre
	Total Annual Cost	$71,791	
		$448	per acre

Table 3

Permanent Infrastructure & Operating Costs for Farms without Existing Border Irrigation Systems

Flood Depth	Farm Acreage	Infrastructure Costs ($)	Annualized Infrastructure Costs ($/ac)	Annual Operating Costs ($/ac)	Total Annual Costs ($/ac)	Average Annual diversion (ac-ft)	Total Cost ($/ac-ft)
6"	10	73,000	537	114	651	30	217
	20	88,000	324	99	423	60	141
	40	138,000	254	99	353	120	118
	80	287,000	264	99	363	240	121
	160	669,000	308	99	406	480	135
12"	10	73,000	537	121	658	35	188
	20	88,000	324	105	428	70	122
	40	170,000	313	104	417	140	119
	80	381,000	350	104	455	280	130
	160	669,000	308	104	412	560	118
24"	10	182,000	1,339	116	1,455	45	323
	20	280,000	1,030	101	1,131	90	251
	40	552,000	1,015	101	1,116	180	248
	80	1,040,000	957	101	1,057	360	235
	160	2,090,000	961	101	1,062	720	236

Figure 6

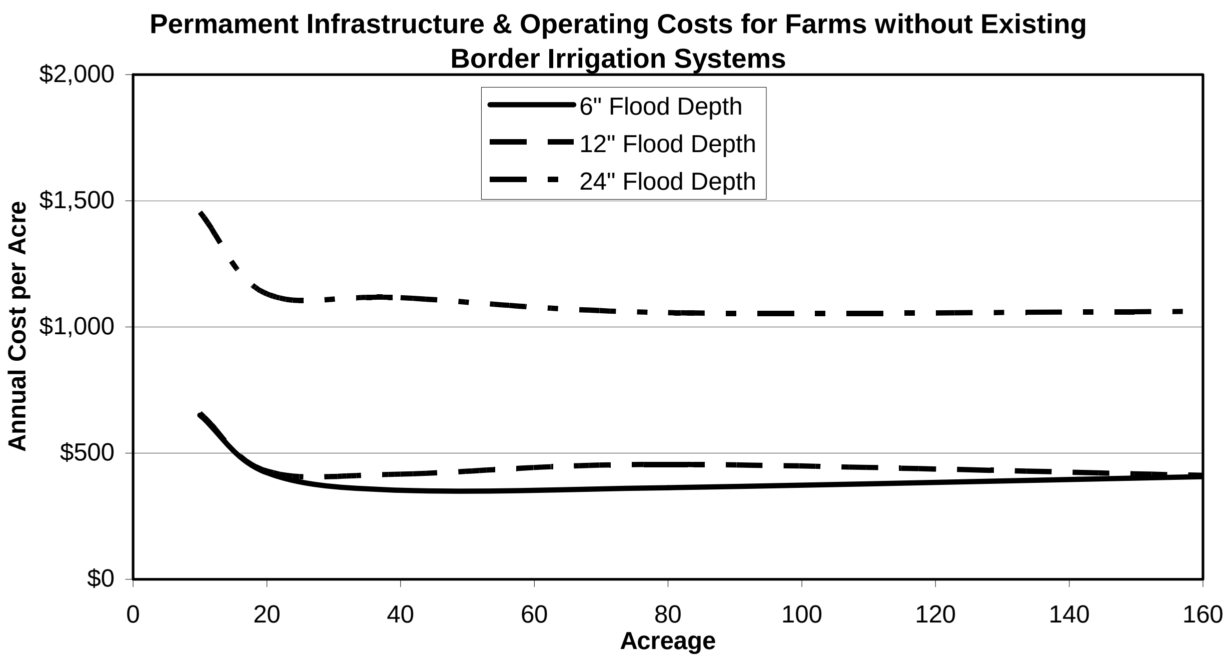


Figure 7

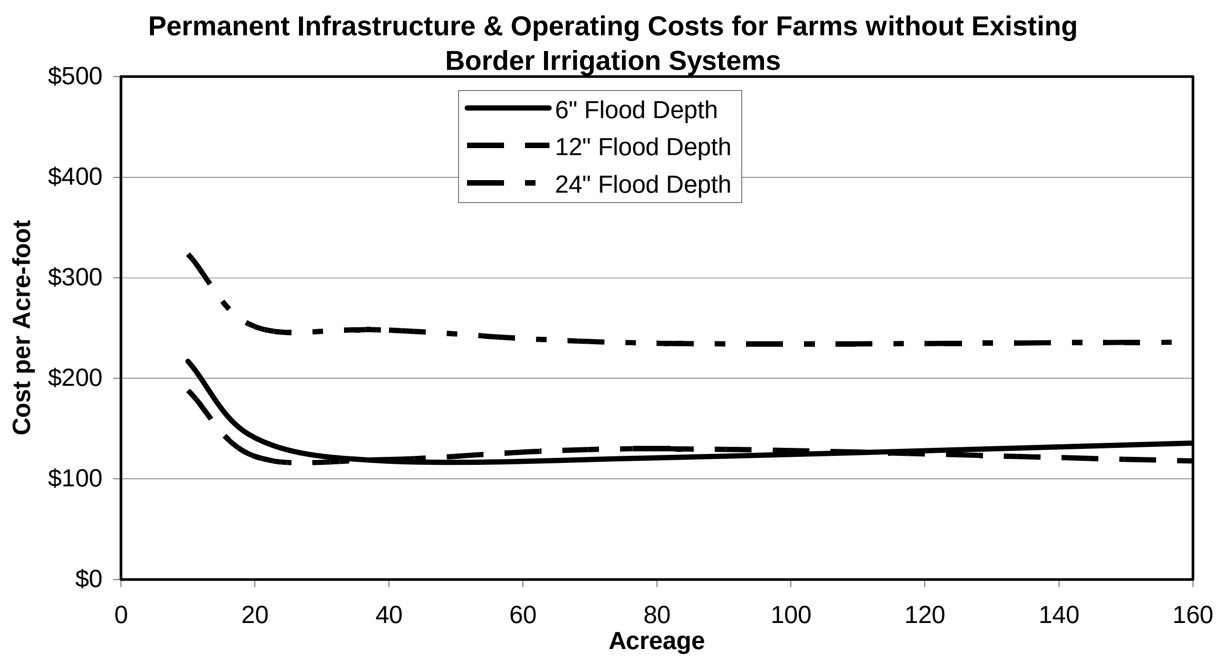


Table 4

Temporary Infrastructure & Operating Costs

Flood Depth	Farm Acreage	Infrastructure Costs ($)	Annualized Infrastructure Costs ($/ac)	Annual Operating Costs ($/ac)	Total Annual Costs ($/ac)	Average Annual diversion (ac-ft)	Total Cost ($/ac-ft)
6"	10	10,000	333	1,070	1,403	30	468
	20	12,000	200	575	775	60	258
	40	16,000	133	335	468	120	156
	80	29,000	121	335	456	240	152
	160	59,000	123	335	458	480	153
12"	10	10,000	333	1,077	1,410	35	403
	20	12,000	200	580	780	70	223
	40	18,000	150	338	488	140	139
	80	29,000	121	340	461	280	132
	160	59,000	123	340	463	560	132
24"	10	119,000	1,135	1,403	2,539	45	564
	20	180,000	818	775	1,593	90	354
	40	346,000	740	468	1,209	180	269
	80	691,000	846	468	1,208	360	268
	160	1,365,000	724	458	1,181	720	263

Figure 8

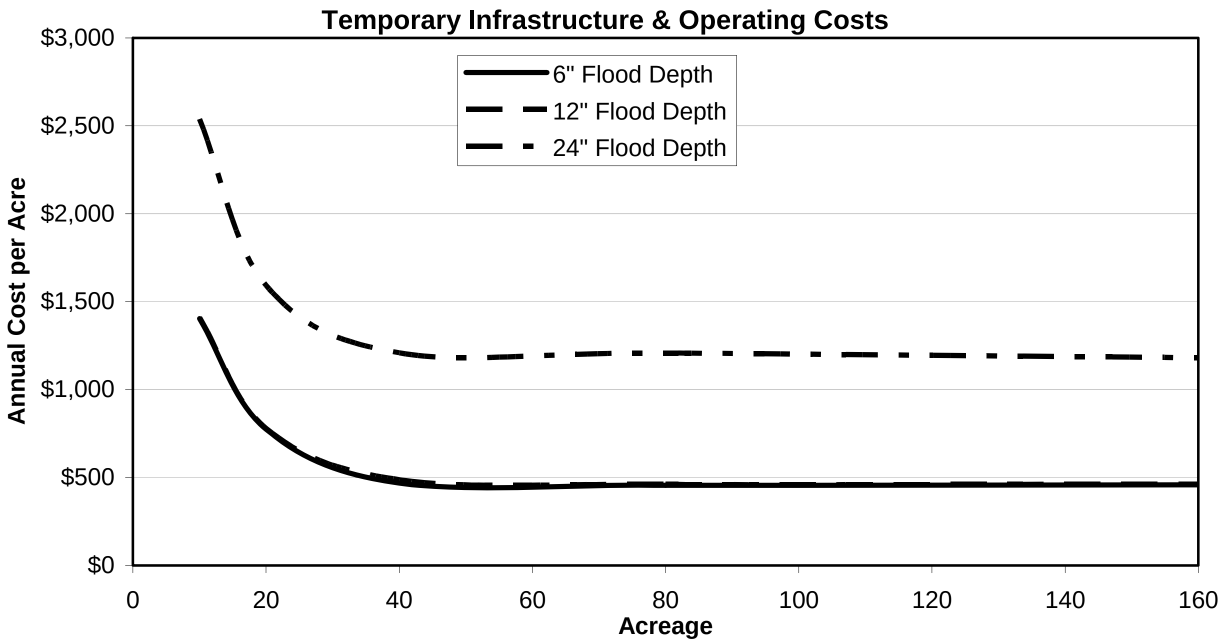


Figure 9

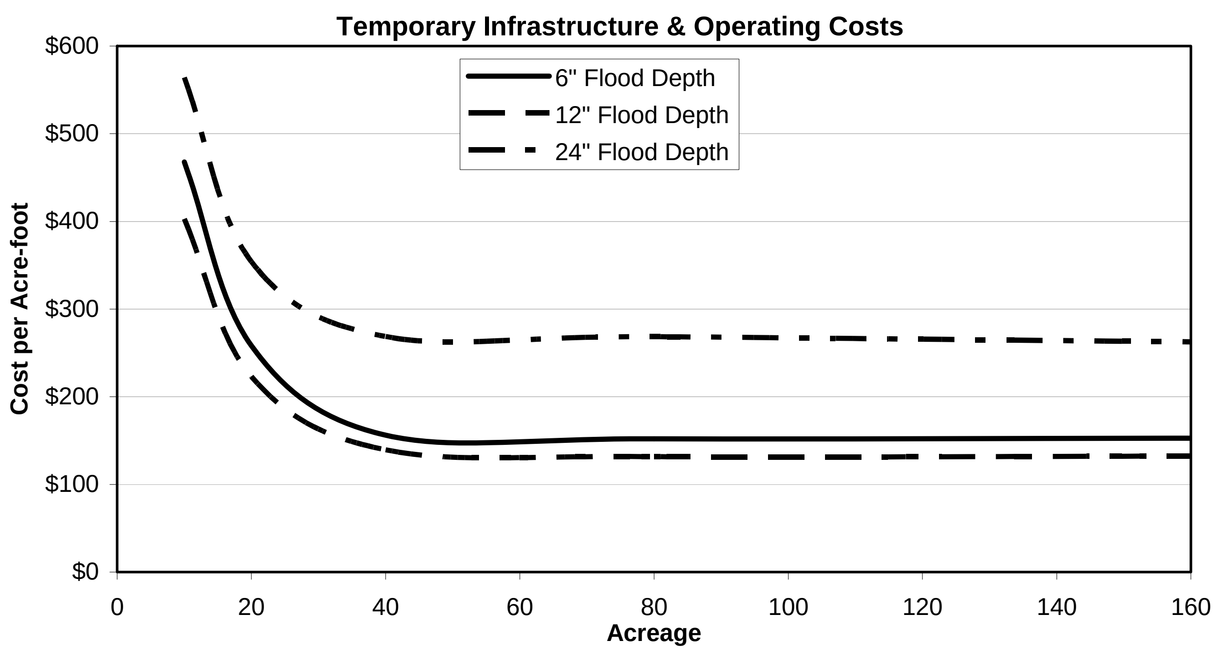


Table 5

Example Cost Estimate

12" Flood Depth, 160 acre Farm with Temporary Border Irrigation System

Item	Description	Amount	
	Infrastructure Rental Costs		
1.	Surface pipe	$35,000	
2.	Lift pumps	$24,000	
	Total Infrastructure Cost per Flood Year	$59,000	
	Annualized Infrastructure Cost (flood water 1 in 3 years)	$19,667	
		$123	per acre
	Operating Costs		
3.	Build temporary berms 2 times per year	$2,400	
4.	Fuel for pump operation	$115,200	
5.	Irrigator labor	$7,200	
	Operating Cost per Flood Year	$124,800	
	Annualized Operating Cost (flood water 1 in 3 years)	$41,600	
6.	Annual ripping or gypsum application	$12,800	
	Total Annual Operating Cost	$54,400	
		$340	per acre
	Total Annual Cost	$74,067	
		$463	per acre

5. Conclusions

Permanent Infrastructure

As can be seen in the figures, costs may be optimal for 20 to 40 acre farms with existing border irrigation systems because the infrastructure needs are minor under the criteria set forth. Recharge flooding would be prohibitively expensive for very small farms of less than 20 acres that do not have an existing border irrigation system (see Figures 6 & 7). Farms of 80 acres or more would need enlarged or new border irrigation systems to achieve the desired flood depths within 10 days. The capacity of existing turnout gates and pipelines would not be sufficient to achieve even a 6-inch flood depth in 10 days on farms of 80 acres or more.

The estimated costs are comparable for 6-inch and 12-inch flood depths, ranging from about $360 to $505 per acre annually and $120 to $150 per acre-foot for farms of 80 acres and above with or without existing border irrigation systems. Flooding to 6-inches deep would be less expensive because border checks would not be needed and the system capacity could be less than is needed for a 12-inch flood depth.

Achieving a 24-inch flood depth would be considerably more costly than for 6-inch and 12-inch depths because of the imported soil and earthwork necessary to construct permanent berms and raised farm roads, removal and shortening of permanent crop rows to provide space for perimeter berms, and the associated loss of crop production and revenue. Pipelines and pumps would need to be considerably larger than they would for a typical irrigation (only) system. Farms larger than 80 acres would need more than one turnout gate or a large (30-inch+) gate and transmission pipeline to achieve a 24-inch flood depth in 10 days or less. Estimated costs range from about $1,055 to $1,105 per acre annually and $235 to $245 per acre-foot for 80 acres and above with or without existing border irrigation systems.

Temporary Infrastructure

Capital costs for permanent infrastructure were amortized over an assumed useful life of 20 years, so a grower would essentially be paying for the system every year even though flood water would not be available some years. Kings River records indicate flood water left the service area in 23 of the last 60 years. In two of those years the volumes released were insignificant. Therefore, a factor of 1/3rd was used to annualize the cost of temporary infrastructure. This reduction should provide a cost advantage for using temporary versus permanent infrastructure. However, rental costs even on an annualized basis are still considerable and the fuel costs to operate diesel pumps continuously while flood water is being diverted are much greater than the assumed energy costs to operate permanent electric pumps. Part of the reason the pumping costs are so much greater is that all water would have to be pumped from the ditch or floodway into a temporary surface pipeline. At least a portion of the surface pipeline would be above the ditch level and it would typically have a smaller diameter than a permanent buried pipeline. Therefore, a surface pipeline could not operate without the head pressure provided by a temporary lift pump. With a permanent irrigation system all of the buried transmission pipeline from the ditch to the farm would be below the ditch level and it is assumed some of the farm land would be below the ditch level so it could be flooded by gravity. The size of temporary surface pipelines is generally limited to 10-inch or 12-inch diameter. While it may be possible to rent larger sizes of high density polyethylene pipe, it is not widely available. Therefore, it is assumed that multiple temporary pumps and surface pipelines would be needed to provide enough capacity to achieve the desired flood depth. This is typically less cost effective than operating one or two larger pumps and pipelines.

The estimated costs are nearly equal for 6-inch and 12-inch flood depths, ranging from about $455 to $465 per acre annually and $130 to $155 per acre-foot for 80 acres and above. Flooding to 6-inches deep would be slightly less expensive because border checks would not be needed and the system capacity could be less compared to a 12-inch flood depth. The cost per acre-foot is actually less for a 12-inch flood depth than for a 6-inch depth because a greater volume of recharge could be achieved at nearly the same cost.

Achieving a 24-inch flood depth would be considerably more costly than for 6-inch and 12-inch depths because of the imported soil and earthwork necessary to construct permanent berms and raised farm roads, and the removal and shortening of permanent crop rows to provide space for perimeter berms. Estimated costs range from about $1,180 to $1,210 per acre annually and $265 to $270 per acre-foot for 80 acres and above.

Augmenting Existing Infrastructure with Temporary Infrastructure

There could be cost savings for farms that have existing border irrigation systems and elect to augment their systems with temporary pumps and surface pipelines versus installing a new enlarged system or using a temporary system to deliver all the flood water. The cost savings would be achieved by using smaller temporary pumps at lower flow rates thereby reducing pump rental costs and fuel consumption. The acreage thresholds at which temporary systems would be needed to augment existing systems would be the same. A 40 acre farm with an existing border irrigation system could achieve a 6-inch flood depth in less than 10 days without a temporary system, but would need a temporary pump and surface pipelines to achieve 12-inch or 24-inch flood depths in less than 10 days. Farms of 80 acres and above with existing border irrigation systems would also need to augment their systems with temporary systems to achieve 6-inch, 12-inch, and 24-inch flood depths.

Final Considerations

Under the assumed criteria set forth in Chapter 2, the range of costs for installation and operation of permanent infrastructure is slightly less than renting pumps and surface pipelines during years that flood water is available. It should be noted that permanent infrastructure would have additional value because it could also be used for regular irrigation. The capital and operating costs that are presented herein for farms of 80 acres or more would be a significant portion of a typical farm budget and may not be attractive to many growers. Water costs of $120 to $150 per acre-foot might be competitive in the western areas of the Kings River Basin where water supplies have become scarce. However, those costs are only for recharge and there would be an additional cost for the grower to later pump the water for irrigation. Also, well level recovery versus recharge would not be one to one. Applying flood water in spring would provide some of the annual water demand of the crops so there would be a benefit of reduced irrigation demands.

Research for this report included a brief interview with Terranova Ranch which has been experimenting with farm flooding for a number of years. With their existing infrastructure, which includes previously constructed pipelines, Terranova was able to implement a program in 2011 at very little cost. More than 3,000 acre-feet were diverted at a cost of $38 per acre-foot. The flooding was done on wine grapes and open ground and the only improvement needed was to build border checks at the ends of the vine rows and within every few rows, or temporarily installing rice checks on the open ground. Flood depths were between 6-inches and 12-inches. Most notable is that the ground was kept flooded as much as possible from January through at least June. To allow for this Terranova completed their pruning earlier than normal. The vines appeared yellow during the latter part of flooding, but returned to their normal color about two weeks after the flooding stopped. Terranova observed modest increases in well levels. One of the greatest benefits they noted was an improvement in the soils for the next few years due to the leaching that occurred with higher quality flood water.

A proactive grower such as Terranova with good existing infrastructure might be able to implement farm flooding much more cost effectively than the estimates presented herein. However, Terranova's methods would not have met the criteria set forth in Chapter 2 because they had to stay out of their fields for several months. Most growers in the Kings River Basin would not be willing to disrupt their farming operations to that extent even if it lowered the costs.

For growers that already have most of the needed infrastructure in place and who might be interested in flooding blocks of land for relatively short durations (as set forth in Chapter 2), it is recommended that no more than a 12-inch flood depth be used. Greater flood depths that require building permanent berms and raised roads and removing permanent crops for the space needed would be expensive, unattractive to most growers, and generally not a practical approach. Also, at the assumed average recharge rate of 3-inches per day, a field flooded to 24-inches deep would take 8 days to drain and another few days to dry out. This means the grower would be kept out of his field for 20+ days, including the time needed to fill the checks.

Farm flooding at depths of 12-inches or less would be feasible for farms of 20 acres or more in the Kings River Basin, provided growers were willing to adjust their cultural practices. With enough participation there could be significant benefits in terms of groundwater recharge, attenuation of flood flows and conservation of flood water. Growers that would have to make a large capital outlay for infrastructure improvements probably would not participate unless they were compensated through grants or the sale of flood easements. Growers that have adequate infrastructure in place and that want a proactive role in managing regional water supplies and flooding might choose to participate with little or no compensation.