Solano Irrigation District
Water Supply Shortage Risk Assessment

Prepared for

Solano Irrigation District

June 2015

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Executive Summary

Prompted primarily by obvious, rapidly changing cropping patterns and irrigation practices in its service area, particularly the rapid expansion of almonds and walnuts, Solano Irrigation District initiated a 2-phase analysis to assess the adequacy of its water supplies. The initial phase was simply to quantify historical agricultural water demands. The second phase involved development of a district water balance as a means of characterizing on-farm and SID distribution system efficiencies, developing projections of future agricultural water demands, and comparing SID's available water supplies to the sum of SID's projected future agricultural water demands and urban water supply obligations. The period of analysis is 2015 through 2059.

Projecting SID's future agricultural water demands is inherently uncertain because those demands depend on a variety of policy, behavioral (economic) and climatological factors that are impossible to predict reliably. This uncertainty was addressed by developing future water demands for seven different scenarios, each representing a unique combination of possible future policy, behavioral and climatological conditions. Specifically, the scenarios were developed according to assumptions made to describe possible future SID cropping patterns, on-farm and SID distribution system efficiencies, permanent crop water use intensity, climate change and urban water supply obligations as summarized Table ES-1. Table ES-1 does not include information for Scenarios 5 and 6 that are described in the body of this report. These two scenarios are identical to Scenario 4 except that they include slightly increased water demands associated with possible future climate change. The increases attributable to possible future climate change are small relative to other factors affecting water demands and they are highly uncertain, so they are not presented in this Executive Summary.

Table ES-1. Future Water Demand Scenario Assumptions Summary

	Assumed Conditions				
		Efficiency			
Scenario	**Cropping Pattern**	**On-Farm**	**System**	**Actual ET_{aw} Of Permanent Crops, inches**	**Climate Change**
1	Current	70%	87%	23.2 (Historical Average)	No
2	Current	70%	92%	23.2 (Historical Average)	No
3	Increased	78%	87%	27.2 (Historical 75th Percentile)	No
4	Increased	78%	92%	27.2 (Historical 75th Percentile)	No
4 (2024)[1]	Increased	78%	92%	27.2 (Historical 75th Percentile)	No

[1]Scenario 4 (2024) has Urban Demand increased from existing quantities to the quantities provided for beginning in 2024 according to existing contracts.

The assessment reveals that under all future water demand scenarios, SID's water demands (agricultural and urban) significantly exceed its 141,000 acre-foot (AF) contractual entitlement. Even if groundwater is used at recent historical levels, significant surface water shortages are forecast to occur. The results of the analysis are summarized in Table ES-2 (which also does not include Scenarios 5 and 6 for the reasons explained above), which shows that projected future average annual shortages will range between approximately 7,000 AF and 27,000 AF depending on the demand scenario. The exception is Scenario 2 for which supplies and demands are estimated to be more or less in balance, on average. However, Scenario 2 is regarded as an unlikely future demand scenario.

The frequencies and related magnitudes of shortages projected to occur under the seven scenarios are presented in Figure ES-1. The frequencies (or probability, or risk) and associated magnitudes of projected future water supply shortages are illustrated in Figure ES-1. The figure indicates that under Scenario 1 (essentially representing a continuation of existing conditions) water shortages will occur in about 50 percent of years and be as large as 30,000 AF, or about 17 percent of the total agricultural and urban water demand. The average annual shortage for Scenario 1 is about 7,000 AF. Scenario 2 represents a possible future condition where SID demands do not increase but SID implements conservation measures to reduce spills by 9,000 AF per year, essentially increasing available supplies by that amount. Consequently, Scenario 2 shortages are estimated to be infrequent and modest; however, as noted above, Scenario 2 is regarded as an unlikely future demand scenario. For all other scenarios, projected shortages significantly exceed those for Scenario 2, with shortages occurring between 53 percent (Scenario 4) and 96 percent (Scenario 4 (2024)) of the years and with maximum annual shortage volumes ranging between approximately 37,000 AF and 60,000 AF. (Note that Figure ES-1 also does not include Scenarios 5 and 6 for the reasons explained above.)

The results of this analysis may not be immediately intuitive because SID has never experienced a surface water shortage in its 56 years of operation. This apparent discrepancy is explained primarily by the assumption that the future conditions used to describe the various scenarios presently exist. In reality, SID is evolving toward these future conditions. Thus, while future shortages are likely to occur, exactly when they will begin is uncertain depending on SID actions, the rate at which on-farm practices and climate change occur and on weather conditions. Avoiding the projected shortages will require that additional water supplies including groundwater be developed, or that water demands be reduced, or some combination of the two. Whether sufficient additional groundwater could be developed sustainably remains a question.

Recommendations stemming from this analysis are as follows:

1) SID should develop and implement a policy for allocating available surface water supplies. A wide variety of options exist for doing this.

2) SID should not wait until water shortages occur to implement conservation measures, but should at a minimum identify the most cost-effective conservation projects and pursue grant and other funding to implement those projects.

3) There is some degree of uncertainty associated with the SID water balance results due primarily to data limitations. SID should assess the sources of uncertainty and identify measurement and recordkeeping improvements that could be implemented to improve data quality and the associated reliability of the water balance. In particular, SID should take measures to more accurately quantify groundwater pumping in the district

Table ES-2. Summary of Average Annual Water Shortage Assessment Results for 2015 through 2059

Future Water Demands Scenario	Ag Demand (at heads of SID laterals)	Surface Water Supply (Reclamation Contract)	Surface Water Supply Minus Ag Demand	Urban Demand	Surface Water Supply Minus Ag and Urban Demand	Groundwater Supply (Total Avg. District + Private)	Total Water Supplies Minus Total Demands (Negatives Equal Unmet Demand)
Scenario 1	138,333	141,000	2,667	18,976	-16,310	9,000	-7,310
Scenario 2	130,815	141,000	10,185	18,976	-8,792	9,000	208
Scenario 3	150,497	141,000	-9,497	18,976	-28,474	9,000	-19,474
Scenario 4	142,318	141,000	-1,318	18,976	-20,294	9,000	-11,294
Scenario 4 (2024 Urban)	142,318	141,000	-1,318	34,929	-36,247	9,000	-27,247

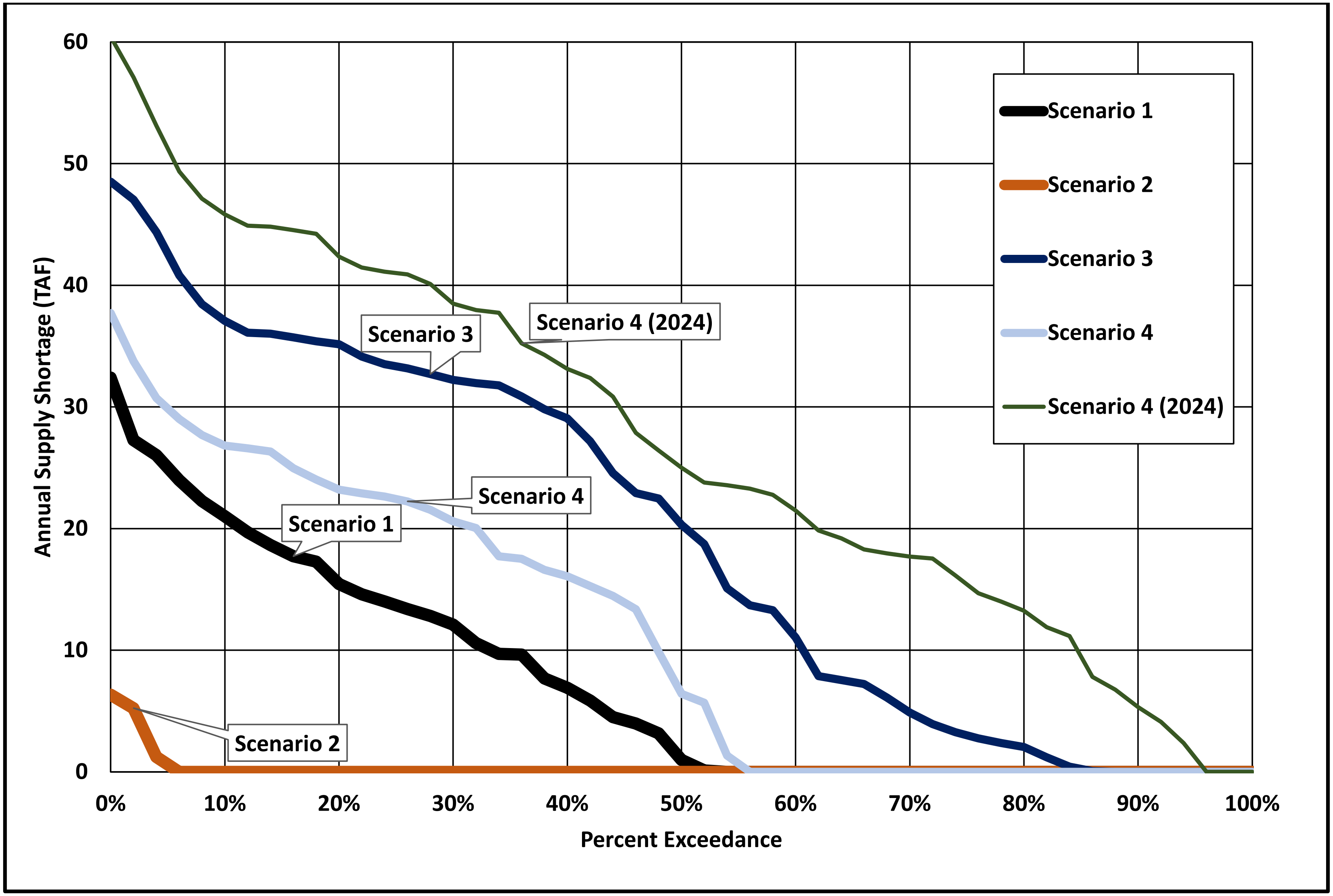

Figure ES-1. Frequency of Projected Future Annual Shortage Equaling or Exceeding the Volumes Indicated

4) SID's surface water allocation and pricing policies have direct implication to groundwater use and management. Particularly in view of the recently enacted Sustainable Groundwater Management Act, SID should undertake investigations to define the limits of sustainable groundwater management in SID and in the Solano Subbasin as a whole (working in collaboration with neighboring local agencies). Such investigations would provide the basis for a comprehensive conjunctive water use program that ensures a high level of water supply reliability and long-term sustainability.

5) The factors posing the greatest uncertainty to SID's future agricultural water supply are associated with cropping and management decisions made by its growers. Therefore, SID should track changes in on-farm conditions to provide a basis for anticipating changes in water demands (as well as in customer service preferences). By comparison, the potential effects of climate change on future agricultural demands appear to be modest.

6) SID should not increase its urban water supply obligations without first defining a regime of sustainable conjunctive water management. The outcome of this effort could be that SID cannot assign more water to urban entities without unacceptably jeopardizing the reliability of its agricultural water supplies, or that provisions should be incorporated into urban water supply agreements that give priority to agricultural water supply under certain conditions.

Introduction

Solano Irrigation District (SID or District) has a fixed contractual entitlement of 141,000 acre-feet (AF) per year of surface water from the federal Solano Project operated by the United States Bureau of Reclamation (Reclamation). Most of the entitlement is used to meet irrigation water demands within the District and some has been dedicated to nearby cities. Over time, municipal water demands have increased as cities have grown. Some of this urban growth has occurred within SID resulting in a reduction of irrigated area and agricultural water demands. Given the general trends of increasing urban water demands and declining agricultural demands, SID has tended to accommodate requests by the cities for additional water without rigorous technical analysis.

However, within SID, permanent tree crops, notably almonds and walnuts, increasingly have been displacing annual crops and pastures. This trend is not unique to SID, but is occurring throughout California's Central Valley. In fact, statewide, almond acreage has increased 65% over the past 10 years, from 620,000 acres to 1,020,000 acres (National Agricultural Statistics Service, 2005 and 2015). Because of the ongoing expansion of tree crops within SID, and because almonds and walnuts are relatively high water use crops, the District felt the need to establish a technical basis to guide its water allocation policy in order to ensure that the District reserves sufficient supplies to meet future agricultural water demands.

An important underlying policy principle is that SID's current and future agricultural water demands should be met with sufficient reliability to ensure that groundwater supplies within the district are managed sustainably. As of January 1, 2015, the Sustainable Groundwater Management Act (SGMA) requires that certain groundwater basins in California be managed sustainably, generally meaning (among other conditions) that groundwater levels cannot decline over the long term (although they are expected to fluctuate over wet and dry hydrologic cycles). SID overlies the Solano Groundwater Basin, which is subject to SGMA, underscoring the importance of SID having a well-founded surface water allocation policy.

SID undertook its water allocation policy analysis in phases. The initial phase was simply to quantify historical agricultural water demands, involving characterizing historical cropping within the district, estimating the total amount of water used by each crop and the portion of use satisfied by irrigation, and summing water demands across crops to estimate district-wide crop water requirements. The results of the Phase 1 analysis were presented to the SID Board of Directors on March 18, 2014 at which time the Board authorized staff to proceed with a second phase of the analysis. The second phase involved development of a district water balance as a means of characterizing on-farm and SID distribution system efficiencies, developing projections of future agricultural water demands under a range of different development scenarios, and comparing SID's available water supplies to the sum of SID's projected future water demands and urban water supply obligations. The Phase 2 analysis is described in this report and is generally referred to as the Shortage Risk Assessment (Assessment).

Objectives

The primary objective of the Assessment is to establish a technical basis for the District's water allocation policy. Secondary objectives of the water balance prepared for the Assessment are to provide essential information for completing the District's System Optimization Review and to support a wide range of SID water management initiatives.

Methodology

The reliability of SID's agricultural water supplies was assessed by comparing projected future water demands to available supplies on an annual basis. The assumption was made that SID's future water supplies, particularly its 141,000 AF per year contractual entitlement from Reclamation, will not change in the future. Consequently, the Assessment focused primarily on estimating future water demands (although the reliability of SID's contractual entitlement could be evaluated as part of refining this analysis). Estimating future demands involved developing an historical district water balance to characterize on-farm and system performance, developing a range of future water demand scenarios and assessing the reliability of future water supplies through a water shortage analysis. The methodologies used for each of the elements are described below.

Water Balance

Recognizing that agricultural water demands depend not just on crop types and weather conditions, but also on the efficiency of on-farm water application and SID's distribution system, a district water balance was developed for recent historical conditions to determine these characteristics on a district-wide, aggregate basis. The water balance was also used to quantify groundwater recharge within SID and as a basis for estimating potential on-farm and district water conservation.

A water balance accounts for all water entering and leaving a 3-dimensional volume over a defined period of time. For a water balance to yield meaningful results, its spatial and temporal boundaries must be clearly and strategically defined, and all flows across the defined boundaries and any changes in water storage within the boundaries must be accounted for during the selected period of analysis. This generally includes surface water, groundwater, rainfall, and exchanges with the underlying groundwater system via pumping and deep percolation.

The water balance structure developed for SID is shown in Figure 1. It includes three accounting centers and associated flow paths. The water balance was completed for 1991 through 2014, on an annual time step for 1991 through 2003 and on a monthly time step for 2004 through 2014. This period was selected because it includes a range of wet to dry hydrologic conditions and because SID's cropping and operational records are sufficiently reliable. The water balance was not developed for earlier years because operational records are less reliable and on-farm and system conditions prior to 1991 are less representative of current conditions. The water balance was completed for the full year (as opposed to for the crop growing season only) in order to account for winter precipitation stored in the root zone and used by crops or percolating beyond the root zone to become groundwater recharge. Natural flows into SID from adjoining watersheds were not included in the balance because those flows generally do not contribute to SID's agricultural water supplies and they are difficult to estimate.

As presented in the Results section, the water balance was used to characterize on-farm and SID distribution system efficiency, to quantify groundwater recharge within SID and to quantify potential future water conservation. Development of the water balance, including discussion of available data and the techniques used for calculating and estimating each flow path are described in a separate report: Solano Irrigation District Water Balance Description and Results (2015).

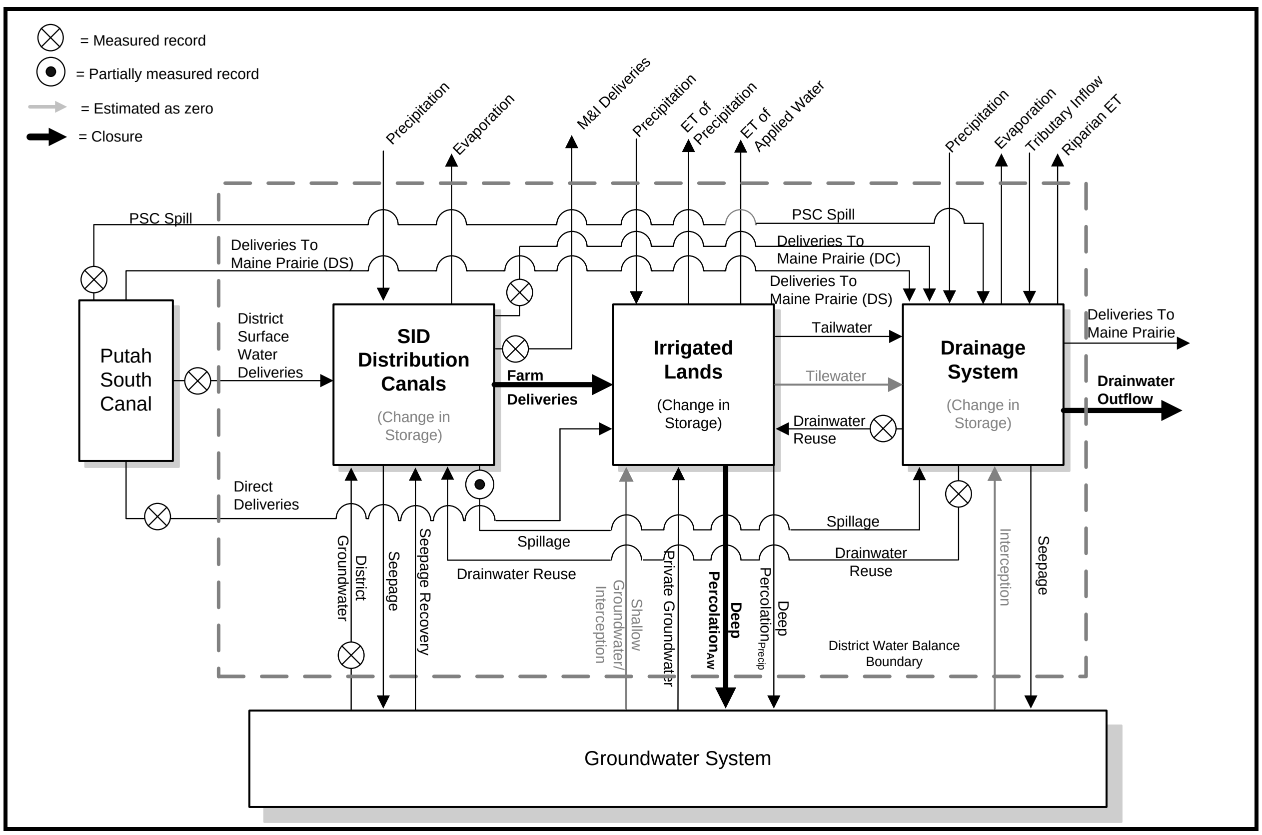

Figure 1. SID Water Balance Structure

Future Water Demand Scenarios

Projecting SID's future agricultural water demands is inherently uncertain because those demands depend on a variety of policy, behavioral (economic) and climatological factors that are impossible to predict reliably. This uncertainty was addressed by developing future water demands for seven different scenarios, each representing a unique combination of possible future policy, behavioral and climatological conditions. Specifically, the scenarios were developed according to assumptions made to describe possible future SID cropping patterns, on-farm and SID distribution system efficiencies, permanent crop water use intensity, climate change and urban water supply obligations. The seven scenarios and associated assumptions are described in the Results section.

Shortage Analysis

For each scenario, its projected water demands were compared to assumed future water supplies, including SID's contractual surface water entitlement and groundwater. The analysis was made for a 45-year period from 2015 through to 2059, on an annual time step. For each year, the sum of projected agricultural water demands and SID's contractual urban water supply obligations are subtracted from the available supplies. If supplies equal or exceed demands, then no shortage occurs and any surplus is carried over to become part of the next year's available supplies. This approach is consistent with SID's contract with Reclamation, which allows unused water in any year to be carried over to the subsequent year (or years), except that any SID carryover is zeroed out if Lake Berryessa spills[1]. Alternatively, if demands exceed supplies, this represents a water shortage that in reality would have to be made up by reducing water demands (temporary fallowing, for example) or increasing water supplies, or some combination of the two.

As noted above, it was assumed that SID's 141,000 AF per year contractual entitlement from Reclamation remains available into the future. Further, it was assumed that future groundwater use would be similar to recent historical use determined from the water balance, although the supply-demand spreadsheet model allows the user to specify any quantity of groundwater use desired.

Results

Results for the water balance (as they pertain to this analysis), the future water demand scenarios and the shortage analysis are presented in the following sections.

Water Balance

The SID water balance analysis provides a platform for comprehensive assessment of historical water use in the district and for identifying water management improvement opportunities. For the Water Shortage Assessment, the water balance was used to assess historical on-farm and distribution system efficiencies, to assess the potential to conserve water and to quantify groundwater recharge. Each of these factors is described in the following sections.

[1] Lake Berryessa operations were not simulated for this analysis, so any loss of SID carryover due to the reservoir spilling is not represented. However, Lake Berryessa rarely spills, so this limitation is not considered to have a significant effect on estimated water supplies or the results of the Assessment.

On-farm and Distribution System Efficiencies

A Consumptive Use Fraction (CUF) was calculated for the Irrigated Lands accounting center as the ratio of evapotranspiration of applied water (ET_{aw}) to the sum of farm deliveries, direct deliveries, private pumping and drainwater reuse. The CUF essentially represents the efficiency of on-farm water application. The CUF varied from 59 to 77 percent, and averaged 69 percent from 2004 through 2014. This period within the full 1991 through 2014 water balance period is regarded as being most the most reliable indicator of existing on-farm efficiency. For purposes of the Assessment, existing on-farm efficiency was assumed to be 70 percent.

For the SID Distribution Canals, delivery efficiency was computed as the ratio of the Farm Deliveries to the sum of District Surface Water Deliveries from the Putah South Canal (into SID lateral headings), District Groundwater, Drainwater Reuse and Seepage Recovery. This performance indicator varied from 82 percent to 91 percent and averaged 87 percent over the 1991 through 2014 period for the months representing the irrigation season. The average value was used to represent existing system efficiency.

Conservation Assessment

Based on the water balance results, the potential to conserve water through improvements to the District distribution system should focus on spillage reduction rather than seepage reduction. This is because spillage flows into drains that flow out of SID whereas seepage contributes to groundwater recharge within SID and may be recovered by pumping. Additionally, most of the distribution system is either lined or pipelined and the areas that remain unlined are areas where seepage has been observed to be relatively low. Average annual spillage of about 10,500 AF has been reduced to about 9,500 AF in recent years due to the installation and availability of SCADA. Based on professional judgment, it was estimated that strategic, system-wide application of SCADA, possibly in conjunction with regulating reservoirs, would allow SID to reduce spillage to 1,000 AF annually.

On-farm conservation potential was expressed in terms of increased on-farm application efficiency relative to existing conditions. Based on professional judgment, it was assumed that on-farm efficiency could be increased from the existing district-wide average of 70 percent to 78 percent. This increase is generally associated with the ongoing rapid conversion from surface irrigation to pressurized irrigation, particularly the adoption of drip and micro-sprinkler systems for permanent crop irrigation. This trend is expected to continue as more permanent crops are planted within SID.

Net Groundwater Recharge

SID overlies the Solano Subbasin (Subbasin 5-21.66) of the Sacramento Valley Groundwater Basin as defined by the Department of Water Resources (DWR, 2003). In the context of supply reliability, understanding net recharge to the subbasin resulting from SID and landowner activities is important because it helps to assess the extent to which forecast surface water supply shortages might be offset by increased groundwater pumping on a sustainable basis.

Losses from SID, primarily deep percolation of applied surface water and seepage from District canals, serve as primary sources of recharge to the subbasin, which is considered to have generally stable groundwater levels in the long-term (SCWA, 2014). Groundwater elevation contours indicate that groundwater flows generally eastward toward the Sacramento River. During the irrigation season, the District recharges an average of about 51,000 AF, including 25,000 AF from deep percolation of precipitation (annually), 15,500 AF from deep percolation of applied water and 10,200 AF of seepage from the distribution and drainage systems. The District and private landowners pumped an average of 15,800 AF from 1991 through 2014, averaging about 9,000 AF annually over the last 11 years. Thus, historically, annual net groundwater recharge due to SID and landowners operations is about 35,500 AF each year. During the study period, net recharge varied from a low of 9,100 AF in 1992 (a dry year) to a high of about 63,600 acre-feet in 1998 (a wet year) (Figure 2). The majority of the variation in net recharge is associated with variability in precipitation from year to year.

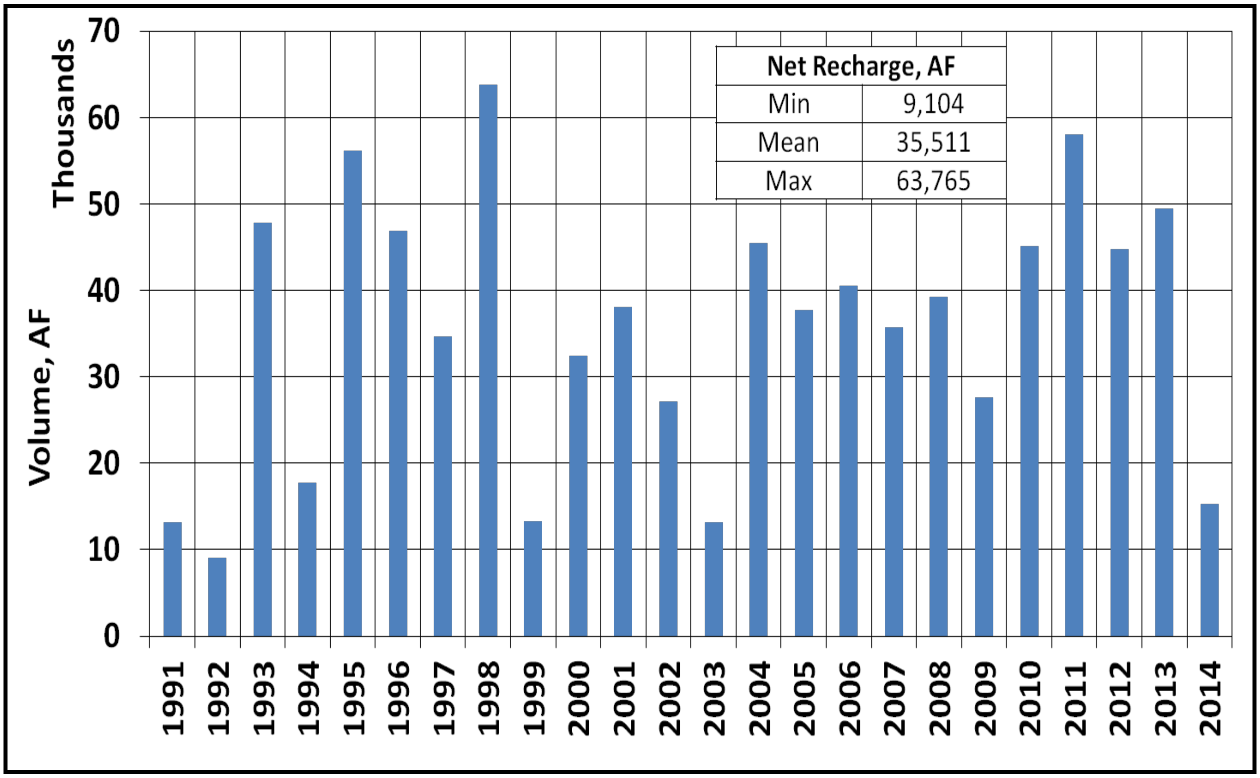

Figure 2. Net Groundwater Recharge

Future Demand Scenarios

As previously described, seven scenarios were developed to represent a range in future water demands to be used in evaluating future water supply shortages. Each scenario is formed by a unique combination of assumptions regarding future cropping patterns, on-farm and system efficiency and different possible future cropping patterns, on-farm and SID distribution system efficiencies, permanent crop water use intensity, climate change and urban water supply obligations. The seven scenarios are described in the following sections. The different sets of assumptions defining the scenarios are summarized in Table 1.

All scenarios assume that SID's future urban water supply obligations will remain as they presently are under existing water supply contracts, except that Scenario 4 is also evaluated assuming that urban demands increase in 2024 to the quantities provided for in existing contracts.

Table 1. Future Water Demand Scenario Assumptions Summary

Scenario	Assumed Conditions				
	Cropping Pattern	Efficiency		Actual ET_{aw} Of Permanent Crops, inches	Climate Change
		On-Farm	System		
1	Current	70%	87%	23.2 (Historical Average)	No
2	Current	70%	92%	23.2 (Historical Average)	No
3	Increased	78%	87%	27.2 (Historical 75th Percentile)	No
4	Increased	78%	92%	27.2 (Historical 75^{th} Percentile)	No
5	Increased	78%	92%	27.2 (Historical 75^{th} Percentile)	Low
6	Increased	78%	92%	27.2 (Historical 75^{th} Percentile)	High
4 (2024)[1]	Increased	78%	92%	27.2 (Historical 75^{th} Percentile)	No

[1]Scenario 4 (2024) has Urban Demand increased from existing quantities to the quantities provided for beginning in 2024 according to existing contracts.

The demand projections for all scenarios are based on historical weather conditions for 1970 through 2014, reflecting the global assumption that future climate conditions will be like recent historical conditions. The exception is that under Scenarios 5 and 6, demands are factored up according to published information to reflect the effects of climate change on crop ET. Minimum, average and maximum reference evapotranspiration (ET_o) and precipitation for the analysis period are presented in Table 2, illustrating that the period includes a wide range of weather conditions.

Table 2. Reference ET (ET_o) and Precipitation during the 1970 through 2014 Period of Analysis

Statistic	ET_o (in)	Precipitation (in)
Minimum	47.8	4.7
Average	56.7	18.1
Maximum	63.0	37.4

Scenario 1

Scenario 1 essentially represents no change from existing conditions. The “Current” cropping pattern represents existing conditions in SID with approximately 42,000 acres under irrigation. This is based on SID’s 2014 cropping records plus new orchards that have been identified by SID staff. Additionally, on-farm and system efficiencies remain at existing levels as determined by the water balance, the intensity of permanent crop water use (ET_{aw}) remains the same as it has been in recent years, and climate does not change. In view of easily observable trends of increasing permanent crops and associated adoption of pressurized on-farm irrigation systems, Scenario 1 is probably not a realistic depiction of future conditions. Nevertheless, it provides a useful point of reference.

Scenario 2

Scenario 2 is different from Scenario 1 only with respect to distribution system efficiency, which is assumed to increase from the existing average of 87 percent to an average of 92 percent. The increased efficiency results in a demand reduction of 7,518 AF annually. Scenario 2 represents a condition where SID implements system conservation measures but demands otherwise remain essentially as they are today.

Scenario 3

Under Scenario 3, it is assumed that cropping patterns in SID change, resulting in an increased proportion of permanent crops (consistent with ongoing trends) and a net increase in irrigated area from the existing 42,000 acres to 46,000 acres. Specifically, it is assumed that tree/vine crops will comprise 63 percent[2] of the crop mix, with the acreages of other crops reduced proportionally to accommodate the increase in tree/vine acreage. The crops comprising the Current and Increased cropping conditions are illustrated in Figure 3, along with actual cropping patterns for the averages of 1991 through 2014 and 2001 through 2014 and the individual years of 2014 and 2015, for purposes of comparison. Relative to 2015, the “Increased” cropping pattern appears to be reasonable and may even under-estimate SID’s future irrigated area.

Additionally, on-farm irrigation efficiency is assumed to increase from the existing 70 percent to 78 percent and the average intensity of permanent crop ET_{aw} is assumed to increase. The increased future permanent crop ET_{aw} is equal to the 75th percentile ET_{aw} for permanent crops in SID as determined by remote sensing energy balance analyses for 2007 and 2009. The effect of this assumption is that tree/vine ET_{aw} increases by an average of 4.1 inches per year over the period of analysis as shown in Table 3.

Under Scenario 3, it is assumed that despite the assumed increases in farm delivery requirements SID does not implement system conservation projects and the system efficiency remains at existing levels. No climate change is also assumed.

[2] Estimate based on representative soil textures and areas assumed suitable for high production almond cultivation.

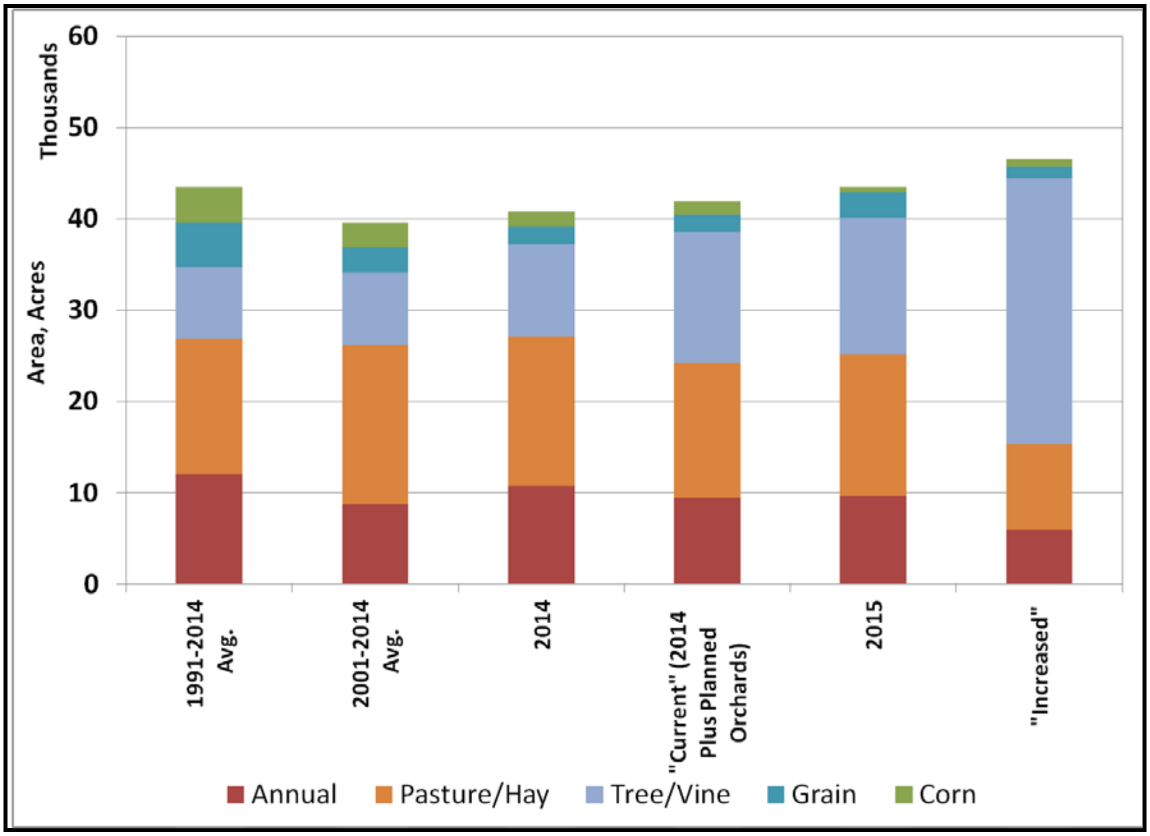

Figure 3. SID Recent Historical Cropping Compared to Cropping Assumed for Shortage Scenarios

Table 3. Increased Average Actual ET_{aw} for Trees/Vines Crop Group (Scenarios 3, 4 and 4 (2024))

IDC Model Results (1970-2014)	ET_{aw}, inches			Difference (75 Percent – Avg.)		
	Min.	Max.	Avg.	Min.	Max.	Avg.
ET_{aw} (Avg2007and2009 SEBAL)	15.9	29.0	23.2	2.1	6.2	4.1
ET_{aw} (Avg2007and2009 75 Percentile SEBAL)	19.1	33.7	27.2			

Scenario 4

Scenario 4 is identical to Scenario 3, except that system efficiency is assumed to increase from 87 to 92 percent, as described under Scenario 2. The increased efficiency results in a demand reduction of 8,180 AF annually. Scenario 4 is regarded as the "most likely" representation of future conditions. A variation of Scenario 4 with future urban demands increased to the levels allowed by existing contracts beginning in 2024 is also analyzed (representing the seventh demand scenario analyzed).

Scenarios 5 and 6

Scenarios 5 and 6 are identical to Scenario 4 except that agricultural demands are increased to reflect the possible effects of climate change. A reconnaissance-level assessment of the effects of climate change was completed through review of information developed by others. Reclamation's West-Wide Climate

Risk Assessment: Irrigation Demand and Reservoir Evaporation Projections (Reclamation, 2015), the primary resource, utilizes future climate projections from global climate models (GCMs) to simulate crop evapotranspiration and resulting net irrigation requirements.

Impact models used the projected temperature and precipitation results to develop projected ET. Increases in ET are projected to range from 1.5 to 3.4 percent during the 2020's period, 3.0 to 5.6 percent during the 2050's period, and 4.6 to 7.5 percent during the 2080's period. For this study, two plausible climate change scenarios were selected:

- Low Increase: 1.5 percent increase in ET_{aw} and no change for precipitation, and
- High Increase: 3.4 percent increase in ET_{aw} and no change for precipitation.

The Low Increase resulted in a demand increase of 2,135 AF to Scenario 4 and was used for Scenario 5. The High Increase resulted in a demand increase of 4,839 AF to Scenario 4 and was used for Scenario 6.

Shortage Analysis

The results of the shortage analysis are summarized in Table 4. Average annual agricultural water demands are projected to range between approximately 131,000 AF (Scenario 2) and 150,000 AF (Scenario 3). SID's annual surface water entitlement of 141,000 is roughly adequate for meeting projected agricultural demands across all scenarios (except for Scenario 2, which shows supply surplus) but is not adequate for meeting projected future agricultural and urban demands combined. Neglecting groundwater as a supply source, average annual surface water supply shortages range between approximately 9,000 AF and 36,000 AF. When the assumed 9,000 AF per year of groundwater is added to the supply, shortages are reduced commensurately but still occur for all scenarios except Scenario 2.

The frequencies (or probability, or risk) and associated magnitudes of projected future water supply shortages are illustrated in Figures 4 and 5. The two figures are based on identical data, but in Figure 4 the magnitude of the annual supply shortage is presented as a volume while in Figure 5 the shortage is expressed as a percentage of the total water demand in the year of shortage. Figure 4 indicates that under Scenario 1 (essentially representing a continuation of existing conditions) water shortages will occur in about 50 percent of years and be as large as 30,000 AF, or about 17 percent of the total agricultural and urban water demand (Figure 5). As indicated in Table 4, the average annual shortage for Scenario 1 is about 7,000 AF.

As described above, Scenario 2 represents a possible future condition where SID demands do not increase but SID implements conservation measures to reduce spills by 9,000 AF per year, essentially increasing available supplies by that amount. Consequently, Scenario 2 shortages are estimated to be infrequent and modest; however, Scenario 2 is regarded as an unlikely future demand scenario.

For all other scenarios, projected shortages significantly exceed those for Scenario 2, with shortages occurring between 53 percent (Scenario 4) and 96 percent (Scenario 4 (2024)) of the years and with maximum annual shortage volumes ranging between approximately 37,000 AF and 60,000 AF (Figure 4).

Expressed as a percentage of the annual total (agricultural and urban) demand, maximum shortages would range between about 20 percent and 28 percent (Figure 5).

Table 4. Summary of Average Annual Water Shortage Assessment Results for 2015 through 2059

Future Water Demands Scenario	Ag Demand (at heads of SID laterals)	Surface Water Supply (Reclamation Contract)	Surface Water Supply Minus Ag Demand	Urban Demand	Surface Water Supply Minus Ag and Urban Demand	Groundwater Supply (Total Avg. District + Private)	Total Water Supplies Minus Total Demands (Negatives Equal Unmet Demand)
Scenario 1	138,333	141,000	2,667	18,976	-16,310	9,000	-7,310
Scenario 2	130,815	141,000	10,185	18,976	-8,792	9,000	208
Scenario 3	150,497	141,000	-9,497	18,976	-28,474	9,000	-19,474
Scenario 4	142,318	141,000	-1,318	18,976	-20,294	9,000	-11,294
Scenario 4 (2024 Urban)	142,318	141,000	-1,318	34,929	-36,247	9,000	-27,247
Scenario 5	144,453	141,000	-3,453	18,976	-22,429	9,000	-13,429
Scenario 6	147,157	141,000	-6,157	18,976	-25,133	9,000	-16,133

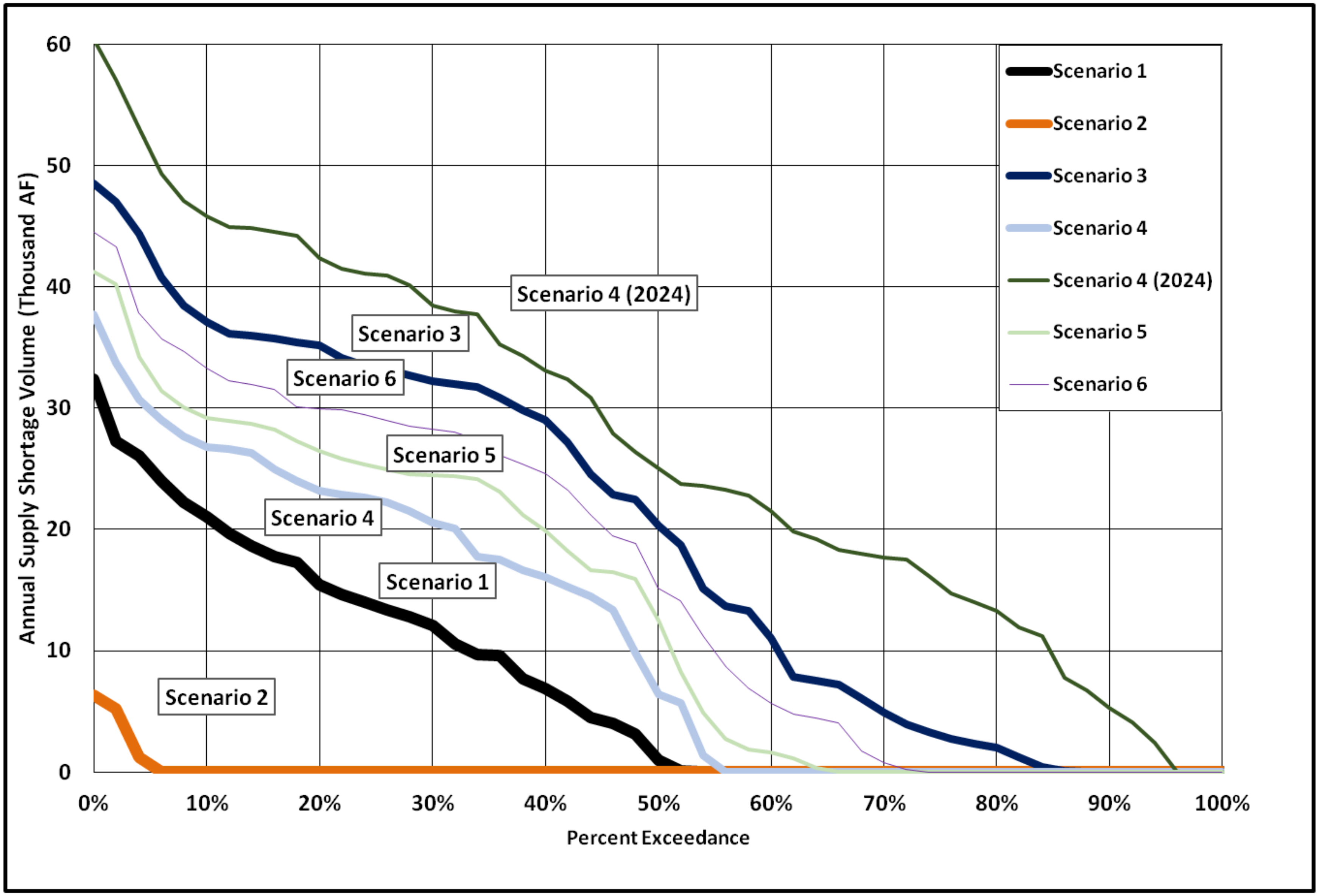

Figure 4. Frequency of Projected Future Annual Shortage Equaling or Exceeding the Volumes Indicated

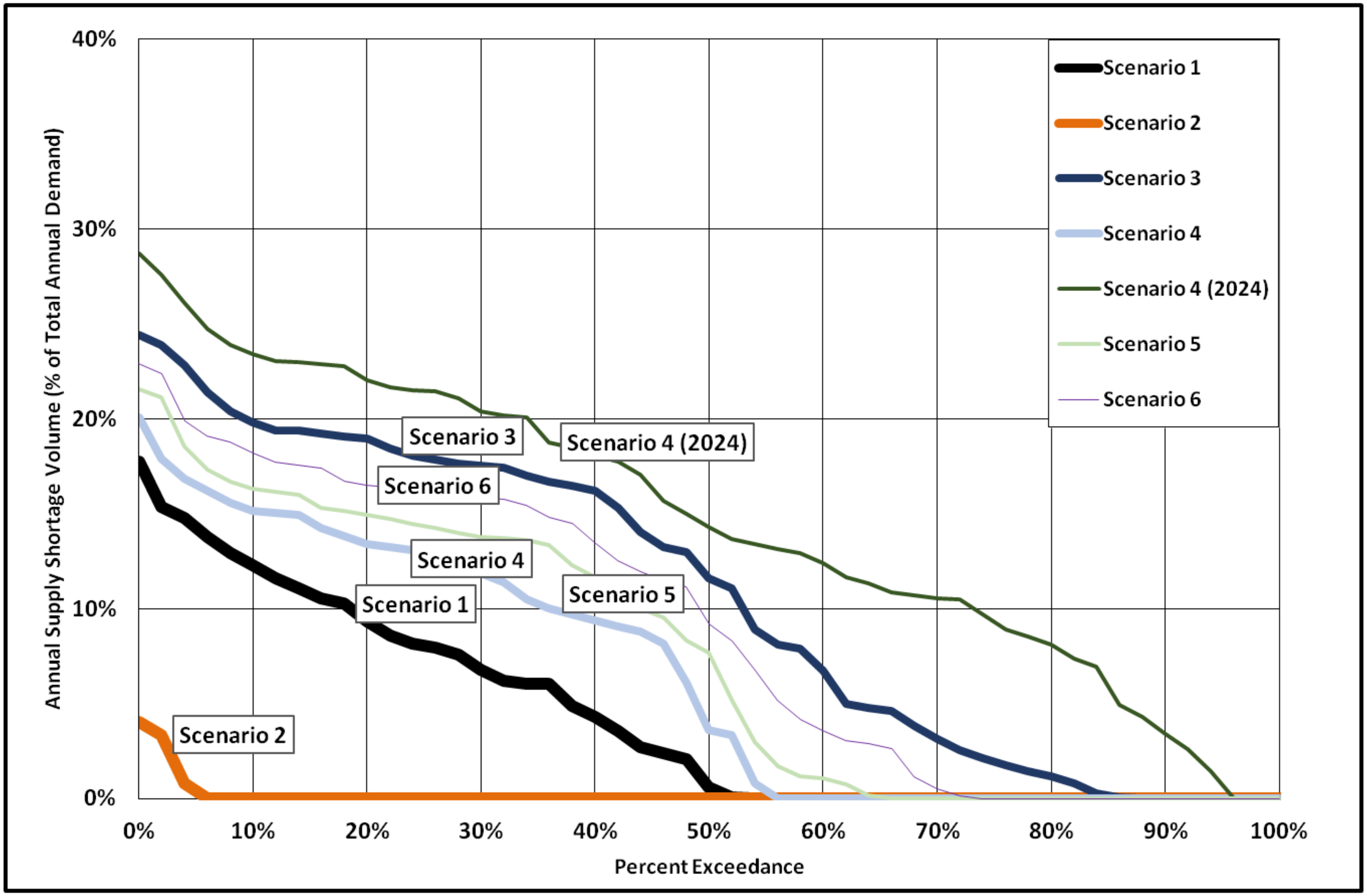

Figure 5. Frequency of Projected Future Annual Shortage Equaling or Exceeding the Percentages of Total Demand Indicated

Table 5 lists the maximum Lake Berryessa carryover and maximum shortage projected to occur over the 45-year period of analysis (2015-2059). Consistent with the foregoing results, the largest carryover and smallest maximum shortage are associated with Scenario 2 and the smallest carryover and largest maximum shortage are associated with Scenario 4 (2024).

Tables 6 and 7 present the shortage results in additional, different forms to allow further comparison among the supply and demand scenarios. For each scenario, Table 6 presents the percentage of years in the 45-year period of analysis that shortages would exceed zero, 5,000 AF and 20,000 AF. Table 7 presents the percentage of annual agricultural demand that would be unmet 10, 25 and 50 percent of the time.

Table 5. Maximum Carryover and Shortages by Scenario

Scenario	Maximum Carryover (AF)	Maximum Shortage (AF)
Scenario 1	48,030	32,416
Scenario 2	103,807	6,347
Scenario 3	23,138	48,532
Scenario 4	36,057	37,727
Scenario 4 (2024 urban)	11,123	60,429
Scenario 5	28,695	41,269
Scenario 6	25,560	44,518

Table 6. Percentage of Years in the 45-Year Period of Analysis with Shortages Exceeding Zero, 5,000 AF and 20,000 AF

Scenario	Percent Years with Shortage > 0 AF	Percent Years with Shortage > 5,000 AF	Percent Years with Shortage > 20,000 AF
Scenario 1	53	43	12
Scenario 2	6	2	0
Scenario 3	86	70	50
Scenario 4	55	53	32
Scenario 4 (2024 urban)	96	90	62
Scenario 5	66	54	40
Scenario 6	72	62	46

Table 7. Percentage of Annual Agricultural Demand Not Met in 10, 25 and 50 Percent of the Years in the 45-Year Period of Analysis

Scenario	Percent Demand Unmet 10% of the Time	Percent Demands Unmet 25% of the Time	Percent Demands Unmet 50% of the Time
Scenario 1	12	8	1
Scenario 2	0	0	0
Scenario 3	20	18	12
Scenario 4	15	13	4
Scenario 4 (2024 urban)	23	22	14
Scenario 5	16	14	8
Scenario 6	18	16	9

Conclusions and Recommendations

The future demand scenarios developed for this analysis represent a plausible range of possible future SID conditions, reflecting possible changes in irrigated area and cropping patterns, intensity of permanent crop water use, on-farm and system efficiency and climate. For all scenarios except Scenario 2, which is considered to be an unlikely future condition, frequent and appreciable shortages of SID surface water are forecast to occur given SID's current urban water supply obligations. Per existing contracts, these obligations increase in 2024 and will result in commensurate increases in future water supply shortages. Under the most challenging future conditions when urban supply obligations increase (Scenario 4 (2024)), SID agricultural customers are forecast to experience water supply shortages 96 percent of the time, with maximum shortages of up to 60,000 AF, or 28 percent of total demand (agricultural and urban), in any given year.

These results are based on the assumption that SID and its landowners will continue to pump groundwater at recent historical levels (approximately 9,000 AF per year). Actual shortages would be less to the extent that SID and/or landowners pump additional groundwater or water demands are reduced, or some combination of the two. Whether sufficient additional groundwater could be developed sustainably remains a question.

The results of this analysis may not be immediately intuitive because SID has never experienced a water shortage in its 56 years of operation. This apparent discrepancy is explained primarily by the assumption that the future conditions used to describe the various scenarios presently exist. In reality, SID is evolving toward these future conditions. Thus, while future shortages are likely to occur, exactly when they will begin is uncertain depending on SID actions and the rate at which on-farm practices and climate occur.

The potential effects of climate change on future agricultural water consumption and demands are small relative to the potential effects of changing cropping patterns and increased ET_{aw} due to improved farming practices.

Recommendations stemming from this assessment are as follows:

1) SID should develop and implement a policy for allocating available surface water supplies. A wide variety of options exist for doing this.

2) SID should not wait until water shortages occur to implement conservation measures, but should at a minimum identify the most cost-effective conservation projects and pursue grant and other funding to implement those projects.

3) There is some degree of uncertainty associated with the SID water balance results due primarily to data limitations. SID should assess the sources of uncertainty and identify measurement and recordkeeping improvements that could be implemented to improve data quality and the associated reliability of the water balance. In particular, SID should take measures to more accurately quantify groundwater pumping in the district.

4) SID's surface water allocation and pricing policies have direct implication to groundwater use and management. Particularly in view of the recently enacted Sustainable Groundwater Management Act, SID should undertake investigations to define the limits of sustainable groundwater management in SID and in the Solano Subbasin as a whole (working in collaboration with neighboring local agencies). Such investigation would provide the basis for a comprehensive conjunctive water use program that ensures a high level of water supply reliability and long-term sustainability.

5) The factors posing the greatest uncertainty to SID's future agricultural water supply are associated with cropping and management decisions made by its growers. Therefore, SID should track changes in on-farm conditions to provide a basis for anticipating changes in water demands (as well as in customer service preferences). By comparison, the potential effects of climate change on future agricultural demands appear to be modest.

6) SID should not increase its urban water supply obligations without first defining a regime of sustainable conjunctive water management. The outcome of this effort could be that SID cannot assign more water to urban entities without unacceptably jeopardizing the reliability of its agricultural water supplies, or that provisions should be incorporated into urban water supply agreements that give priority to agricultural water supply under certain conditions.

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