Staff Technical Workshop Part 3: Agricultural Economic Effects and the Statewide Agricultural Production (SWAP) Model

December 12, 2016

State Water Board Presenter: Tim Nelson
Assisted by Josué Medellín-Azuara, UC Davis

Topics Covered

- Agricultural Economic Analysis
  - Overview of Analysis
  - Preparation of Inputs for the SWAP Model
  - Description of the SWAP Model
  - SWAP Model Equations and Assumptions
  - Model Results and Agricultural Economic Impacts

Agricultural Economic Analysis Framework

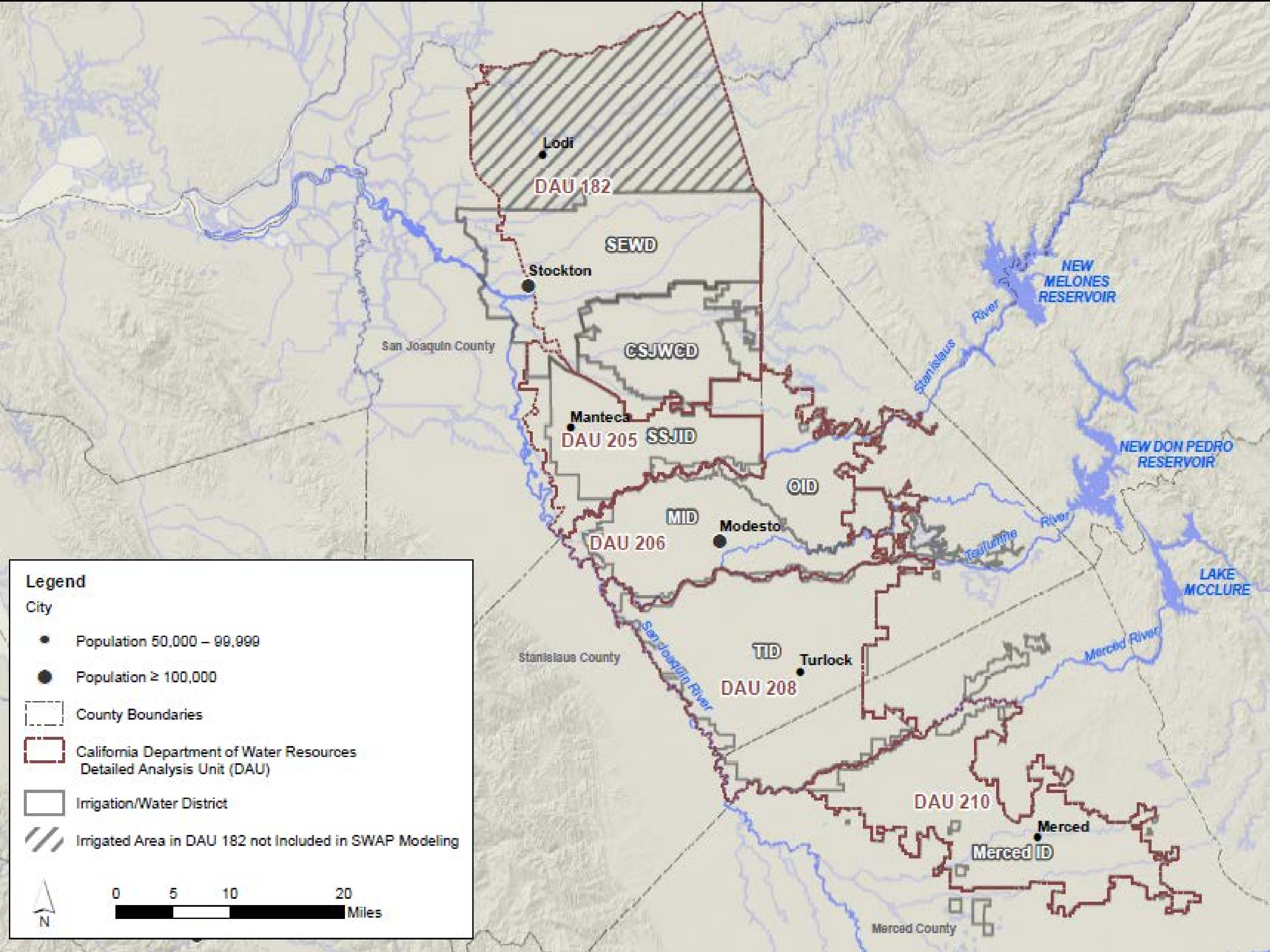
- Given the proposed unimpaired flow objectives, there will likely be more frequent agricultural water shortages
- Crop production could be lower in certain years, particularly during drier periods
- Fallowing of crops reduces gross revenues. Some changes in prices and adjusting of cropping patterns may dampen this effect

Suite of Models for Studying Economic Impacts in Agriculture

INPUTS	Potential UF Requirements	Change in Applied Surface Water	Change in Crop Applied Water
MODEL	Water Supply Effect (WSE)	Agricultural Groundwater Use Analysis	SWAP (Agricultural Production)
OUTPUT	Changes in • Surface Water Availability	Changes in • Groundwater Pumping	Changes in • Agricultural Revenues • Cropping Patterns

SWAP Model Setup

- Analysis covers six areas representing each of the 7 irrigation districts that receive surface water from the east side tributaries (with SEWD and CSJWCD combined)
- 19 crop categories following DWR classification for land and water use
- The primary inputs provided to the SWAP model are annual estimates of total applied water over the modeling period
- District Applied Water Demands are calibrated to 2010 levels using DWR DAU Crop Surveys for 2010

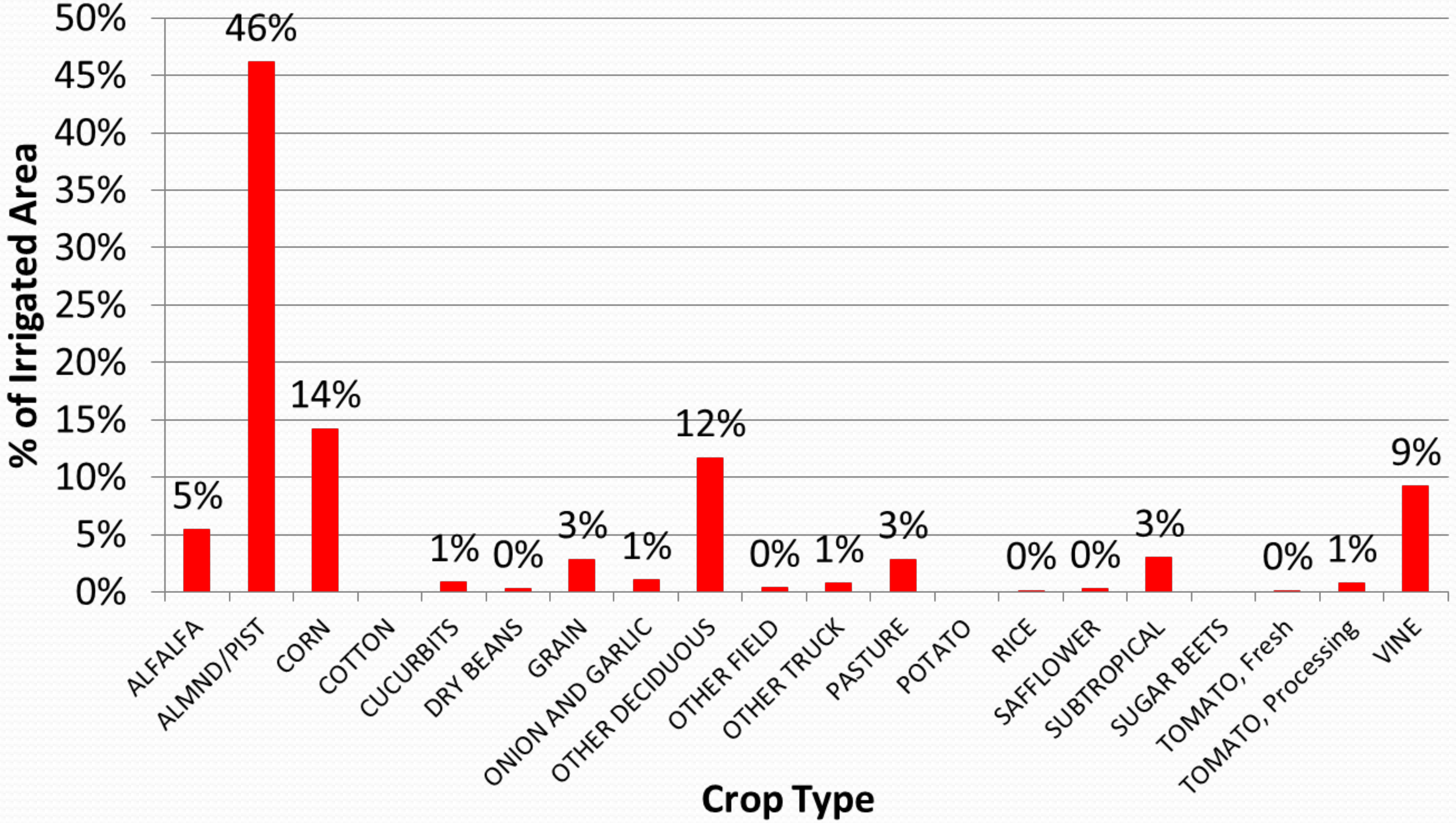


Lodi
DAU 182
SEWD
Stockton
San Joaquin County
CSJWCD
Manteca
DAU 205
SSJID
OID
MID
Modesto
DAU 206
Stanislaus River
NEW MELONES RESERVOIR
NEW DON PEDRO RESERVOIR
Tuolumne River
LAKE MCCLURE
Merced River
San Joaquin River
Stanislaus County
TID
Turlock
DAU 208
DAU 210
Merced
Merced ID
Merced County
Legend
City
Population 50,000 – 99,999
Population ≥ 100,000
County Boundaries
California Department of Water Resources Detailed Analysis Unit (DAU)
Irrigation/Water District
Irrigated Area in DAU 182 not Included in SWAP Modeling
N
0 5 10 20
Miles

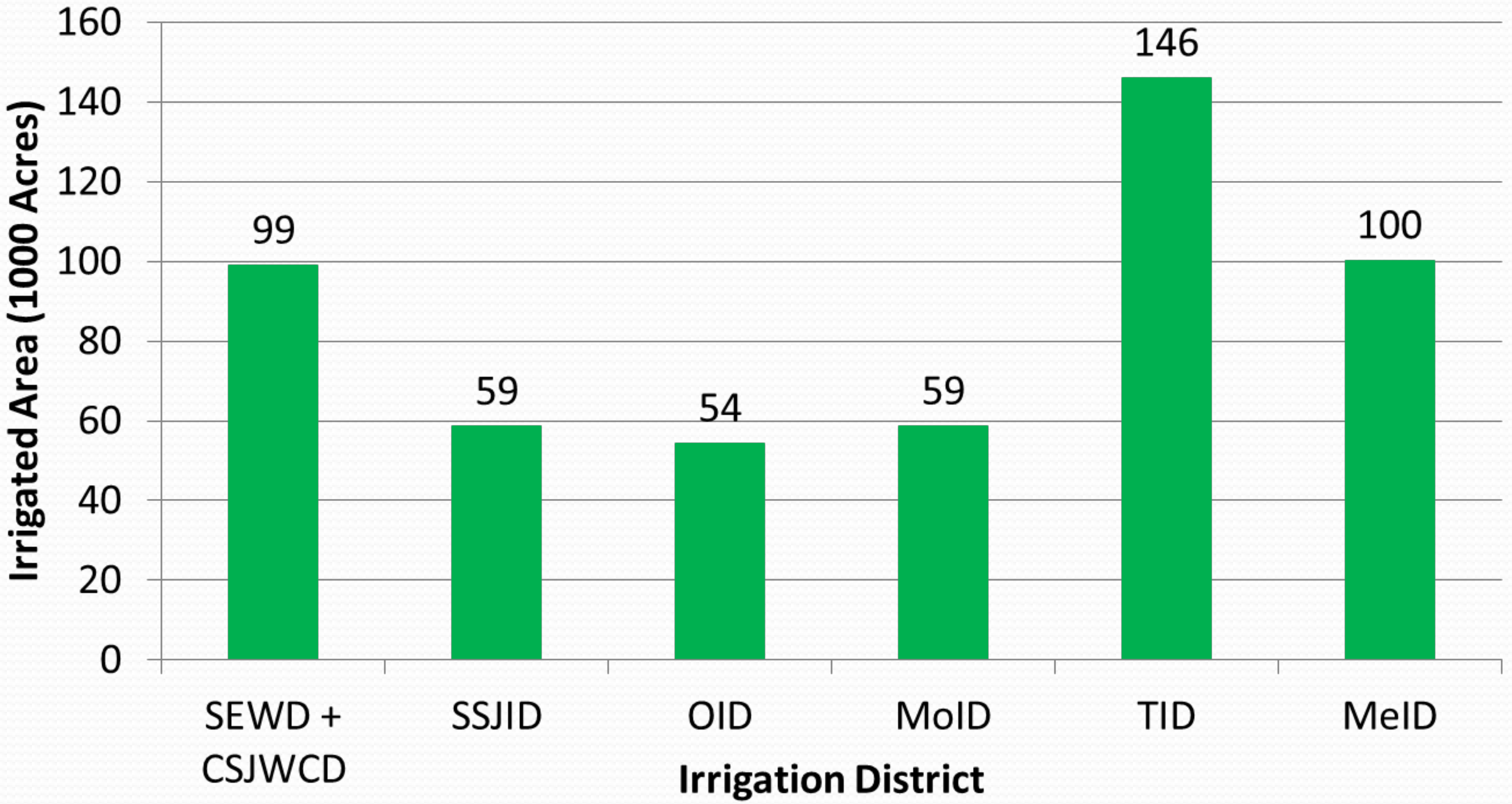
DWR DAU Crop Surveys

- DWR surveys land and water uses within each county periodically to develop crop distribution estimates for each DAU
- DWR uses the Agriculture Commissioner annual reports to then update crop yields appropriate for subsequent water years until a new crop survey is done
- This data can be found here: http://www.water.ca.gov/landwateruse/anlwuest.cfm

Crop Distribution for 2010 in DAU 205 (SSJID)

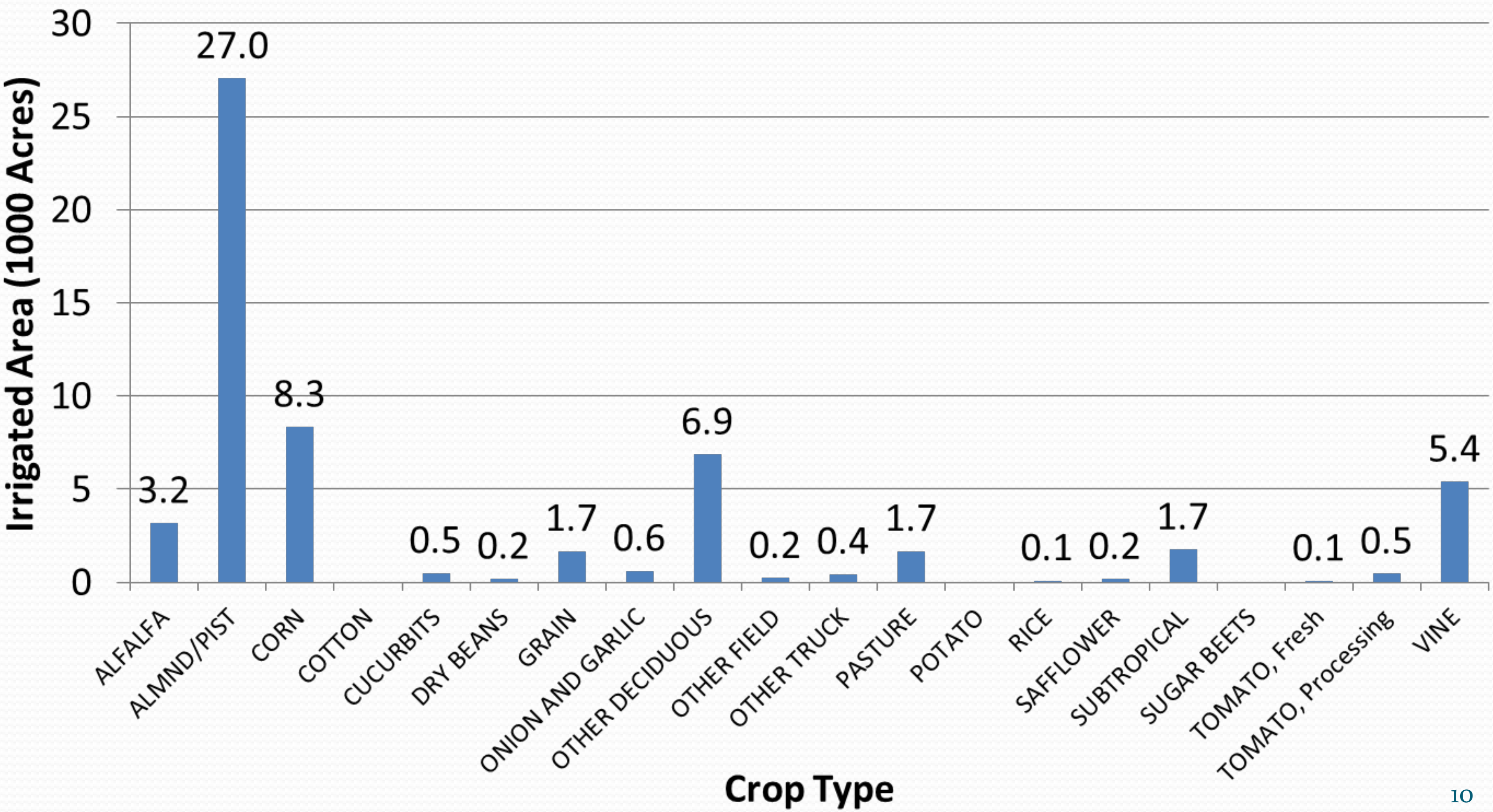


Total District Irrigated Area

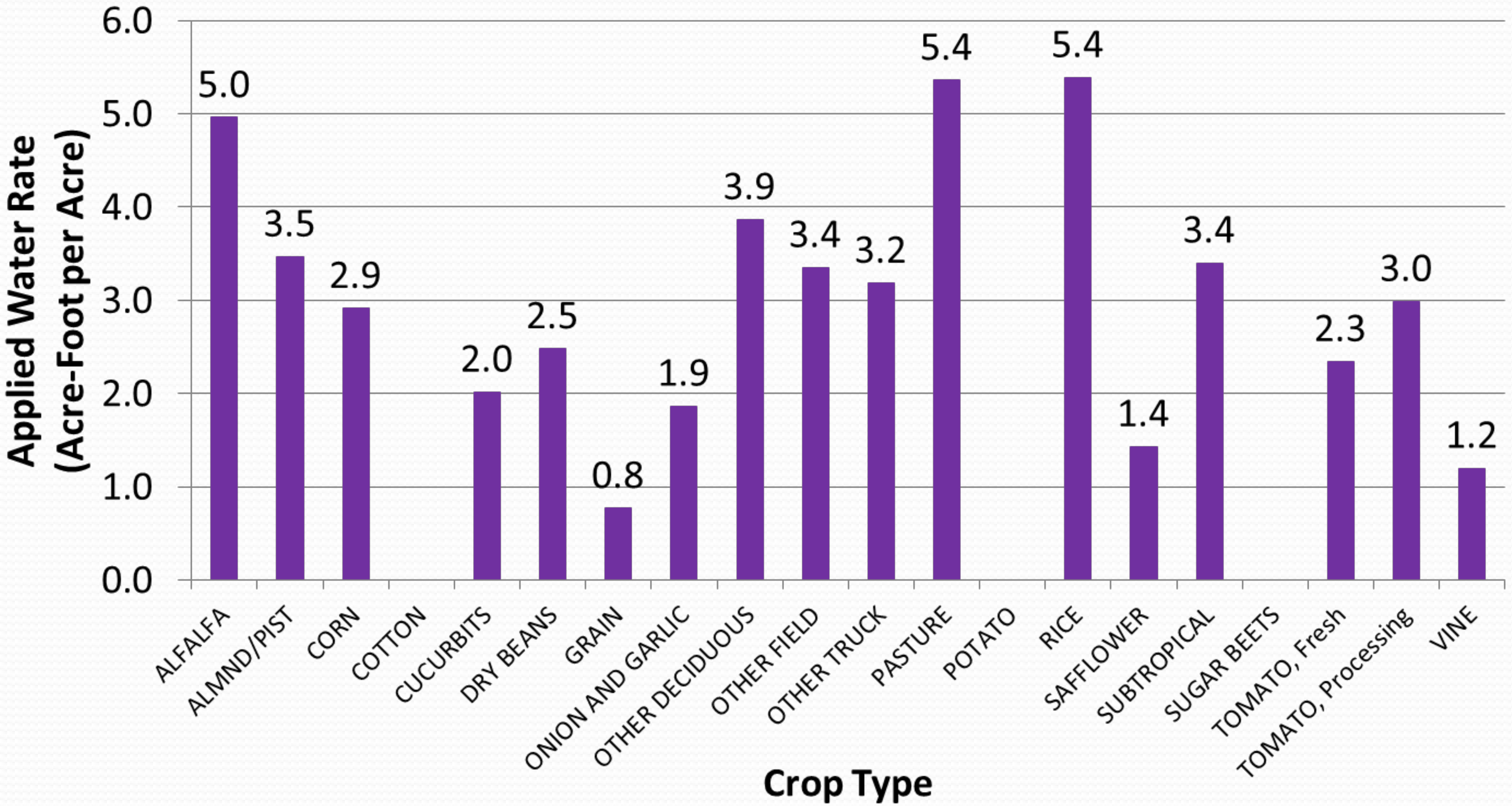


Values based on information in District AWMPs and WMPs

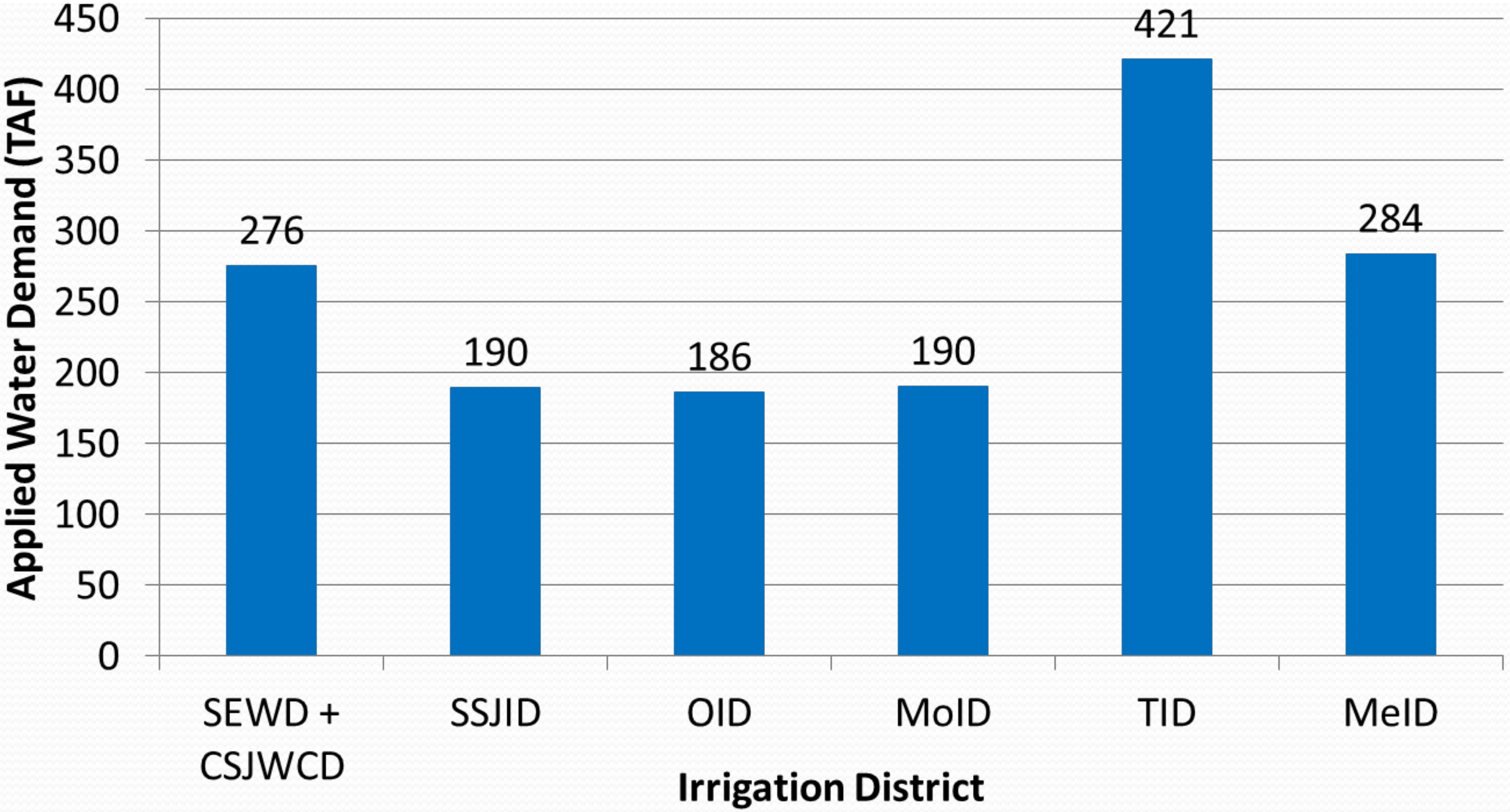
Irrigated Crop Area for 2010 in DAU 205 (SSJID)



Crop Applied Water Rate for 2010 in DWR DAU 205 (SSJID)



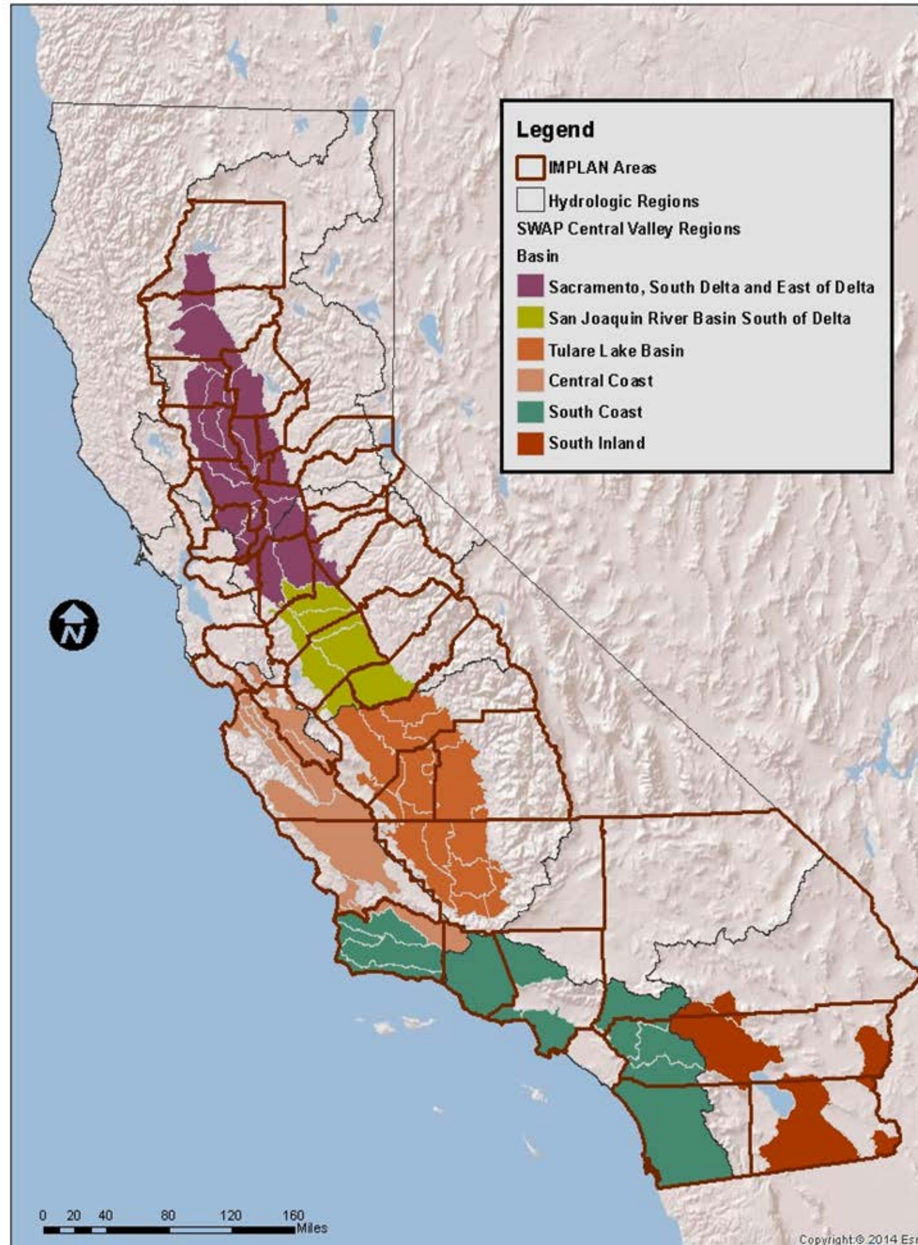
District 2010 Applied Water Demand



The Statewide Agricultural Production (SWAP) Model

SWAP Model

- Covers more than 90% of the irrigated agriculture
- Employs positive mathematical programming
- 20 Crop groups
- Information on land, water, labor, supplies, production costs, crop prices and yields
- County Ag Commissioners and UC Cooperative Ext.
- Maximizes net returns to land and management



Agricultural-Economic Analysis SWAP Model

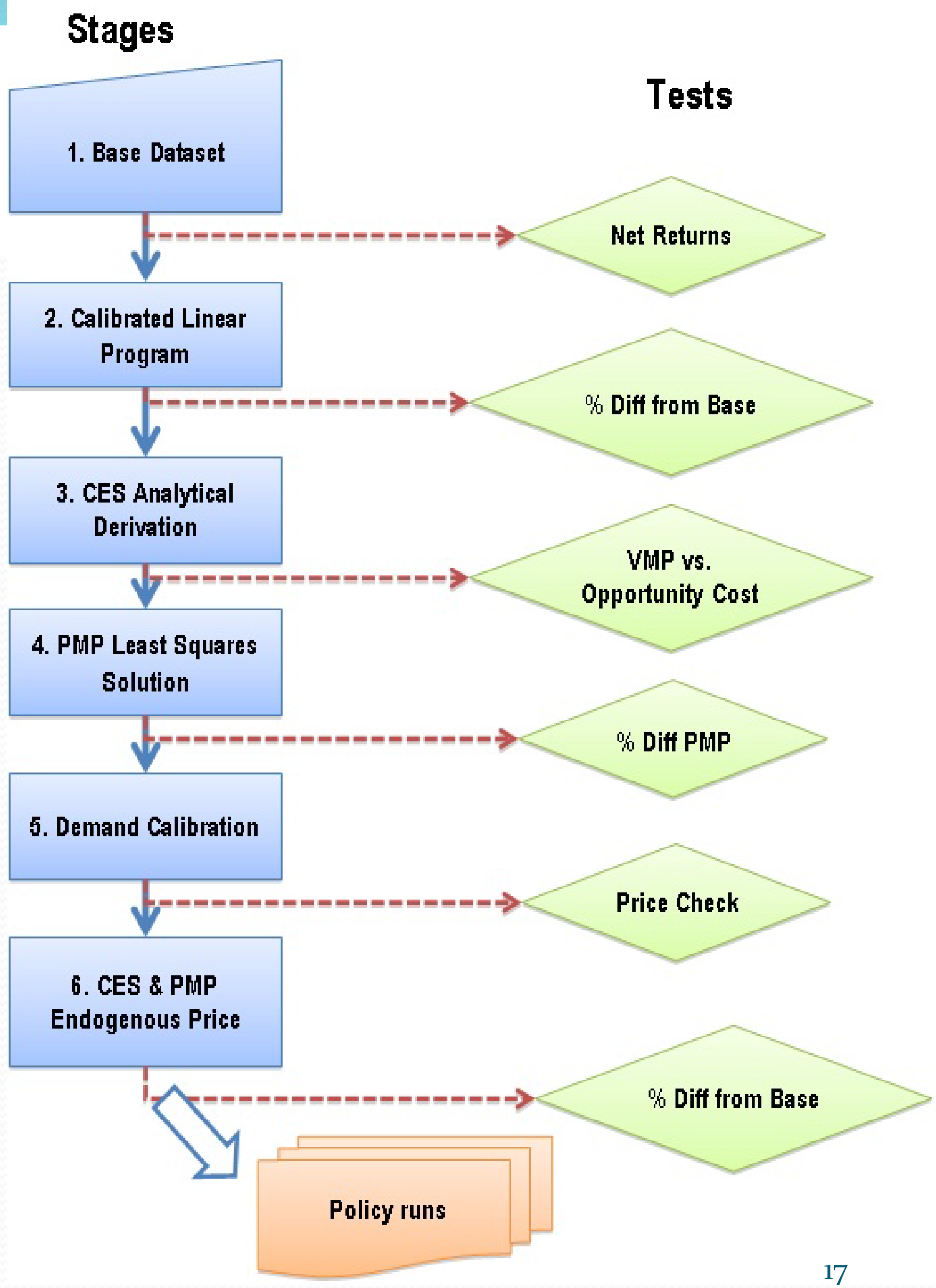
- Developed in the 1995s and constantly updated
- Studies agricultural adaptation to water scarcity
- Provides: cropping patterns, land and water use
- Calibrates exactly to a base dataset
- Dozens of applications for irrigated agriculture in California
- Framework employed in other irrigated areas in the US, the Americas and the Middle East
- An application exclusive to the study area was developed

Positive Mathematical Programming

- Considers a multi-region and multi-crop model where base production may be constrained by water or land
- Constant Elasticity of Substitution (CES) Production Function
  - CES productions allow for limited substitutability between inputs
- Non-Linear Land Cost Function
- Variables: X, input use (land, water, labor, supplies)
- Parameters: v(price), δ, γ and ω parameters in cost functions, β cost share parameter in production function

PMP Calibration

- Linear Calibration Program
- CES Parameter Calibration
- Exponential Cost Function Calibration
- Fully Calibrated Model



CES Parameter Calibration

- CES Production Function

$$y_{gi} = \tau_{gi}\left[\beta_{gi1}x_{gi1}^{\rho_i} + \beta_{gi2}x_{gi2}^{\rho_i} + \ldots + \beta_{gij}x_{gij}^{\rho_i}\right]^{1/\rho_i}$$

- Constant Elasticity of Substitution
  - Consider a single crop and region to illustrate the sequential calibration procedure:
  - Define: $\rho = \dfrac{\sigma - 1}{\sigma}$
  - define the corresponding farm profit maximization program:

$$\max_{x_j} \ \pi = \tau\left[\sum_j \beta_j x_j^{\rho}\right]^{\upsilon/\rho} - \sum_j \omega_j x_j .$$

CES Parameter Calibration

- Constant Returns to Scale requires:

$$\sum_j \beta_j = 1.$$

- Taking the ratio of any two first order conditions for optimal input allocation, incorporating the CRS restriction, and some algebra yields our solution for any share parameter:

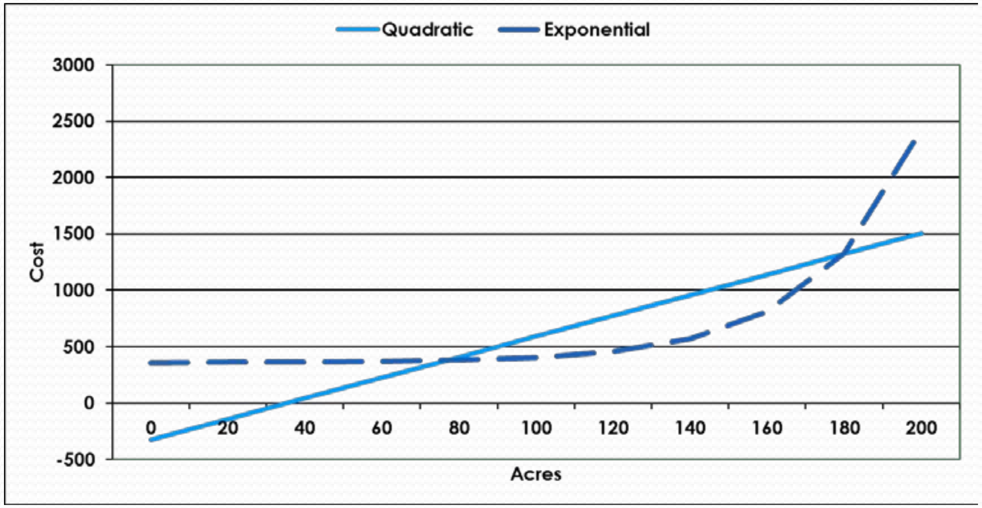
$$\beta_1 = \frac{1}{1 + \frac{x_1^{(-1/\sigma)}}{\omega_1}\left(\sum_l \frac{\omega_l}{x_l^{(-1/\sigma)}}\right)} \quad \textit{letting } l = \textit{all } j \neq 1$$

$$\beta_l = \frac{1}{1 + \frac{x_1^{(-1/\sigma)}}{\omega_1}\left(\sum_l \frac{\omega_l}{x_l^{(-1/\sigma)}}\right)} \frac{\omega_l}{\omega_1} \frac{x_1^{-1/\sigma}}{x_l^{-1/\sigma}}.$$

$$\tau = \frac{(yld / \tilde{x}_{land}) \cdot \tilde{x}_{land}}{\left[\sum_j \beta_j x_j^{\rho}\right]^{\upsilon/\rho_i}}.$$

Exponential PMP Cost Function

- The PMP and elasticity equations must be satisfied at the calibrated (observed) level of land use
- The PMP condition holds with equality
- The elasticity condition is fit by least-squares
- Functional form assumes marginal costs in production are non-negative
  - Total Cost= δ Exp (γX)



Calibrated Program

- The base data, functions, and calibrated parameters are combined into a final program without calibration constraints
- The program can now be used for policy simulations

Calibrated program

$$\underset{x_{gij},wat_{gw}}{Max}\ \Pi = \sum_g \sum_i v_{gi} \tau \left[\sum_j \beta_j x_j^{\rho} \right]^{\upsilon/\rho}$$

$$- \sum_g \sum_i \left(\delta_{gi} \exp\left(\gamma_{gi} x_{gi,land} \right) \right)$$

$$- \sum_g \sum_i \left(\omega_{gi,\text{supply}} x_{gi,\text{supply}} + \omega_{gi,labor} x_{gi,labor} \right)$$

$$- \sum_g \sum_w \left(\varpi_{gw} wat_{gw} \right).$$

Land constraint

$$\sum_j x_{gij} \le b_{gj} \quad for \quad j \ne \text{water},$$

Water source constraint

$$\sum_i x_{g,i,water} \leq \sum_w wat_{gw}\,.$$

Crop stress

$$\frac{x_{gi,water}}{x_{gi,land}} \geq \; 0.85\, aw_{gi}$$

Silage corn

$$x_{g,corn,land} \geq \tilde{x}_{g,corn,land}\,,$$

Perennials

$$x_{g,pren,j} \geq \tilde{x}_{g,pren,j}\left(1 - \min\left(1, \frac{yr}{prenlife_{pren}}\right)\right)$$

Consideration of Forward Linkages

What are forward linkages?

- Downstream effects to industry sectors from an industry change in the supply chain (e.g., dairies)

What did we do?

- Qualitative analysis
- Reviewed SWAP results for silage
- Reviewed SWAP results for alfalfa and pasture
- Review of influence of milk prices

Inputs to SWAP model

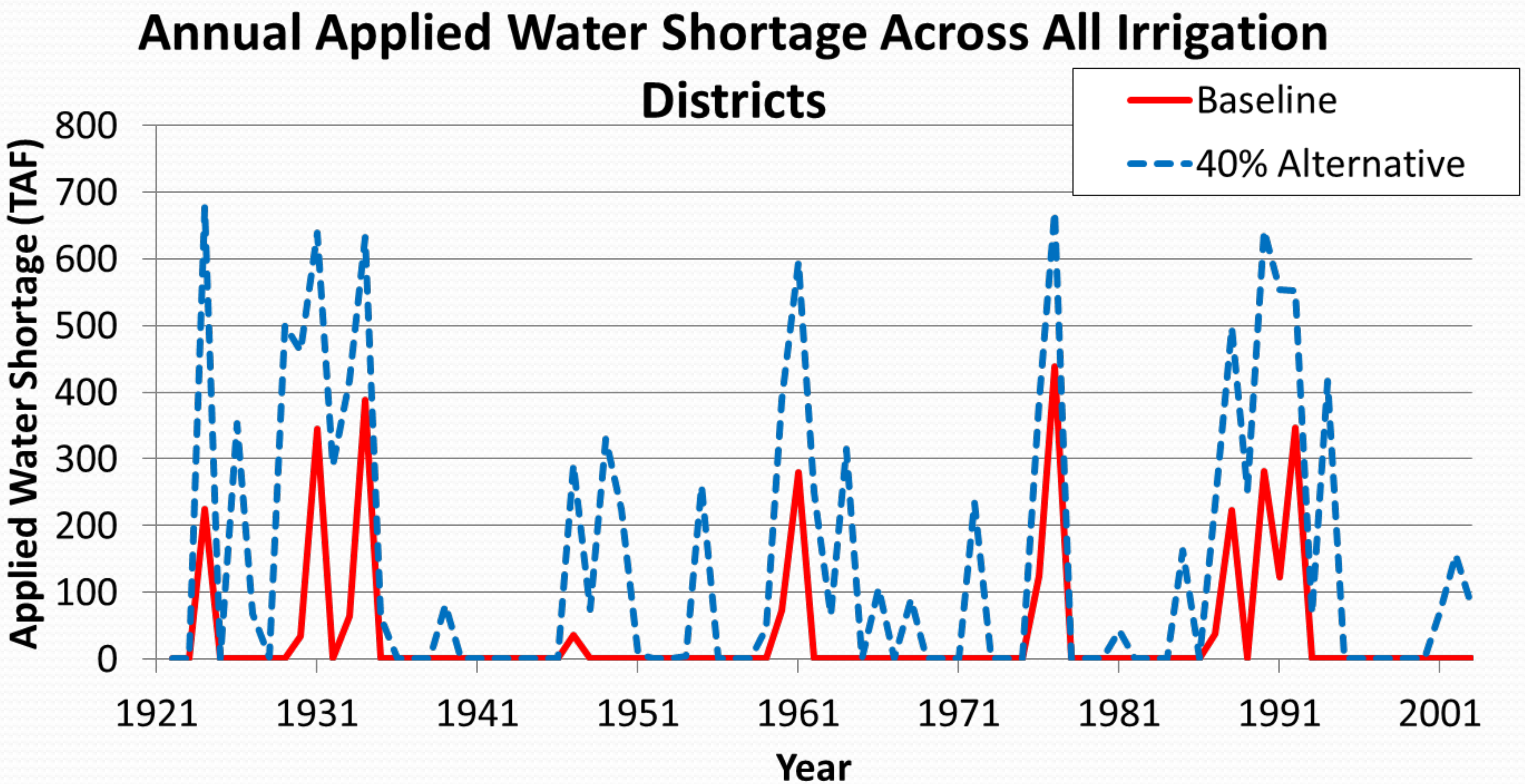
- Perennial constraints based on the life expectancy of the orchards 25-30 years
- Silage constrained based on the SWAP Federal Feasibility Study model version (2012)
- Crop stress 85% of the base applied water
- Base input information on water and land use by irrigation area was based on DWR DAU Crop distributions
- Applied Water Use information based on results of the WSE and the Groundwater Water Use Assessment
- Prices, yields, silage constraint, and production costs information provided from SWAP model

From changes in irrigated crop area to cropping patterns

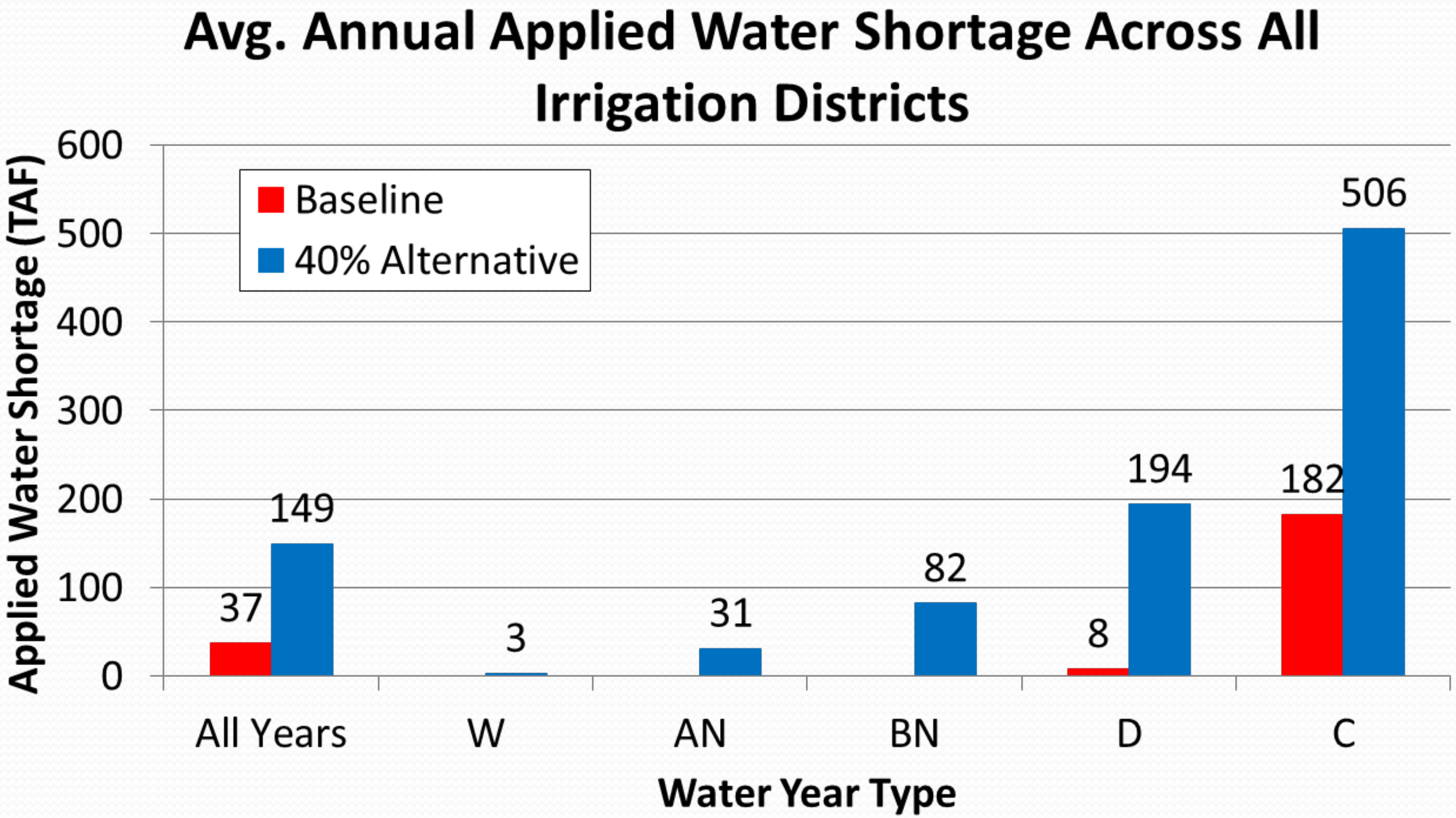
- Base irrigated areas and applied water are considered in the calibration
- Water shortages considering groundwater capacity to replace surface water losses are provided by the Water Supply model
- SWAP calculates the crop mix by irrigation district given the amount of water available and the systemwide constraints so that net returns to land and management every year are maximized
- Resulting cropping patterns and revenues are reported by SWAP

Agricultural Economic Impacts

Time Series of Annual Applied Water Shortage

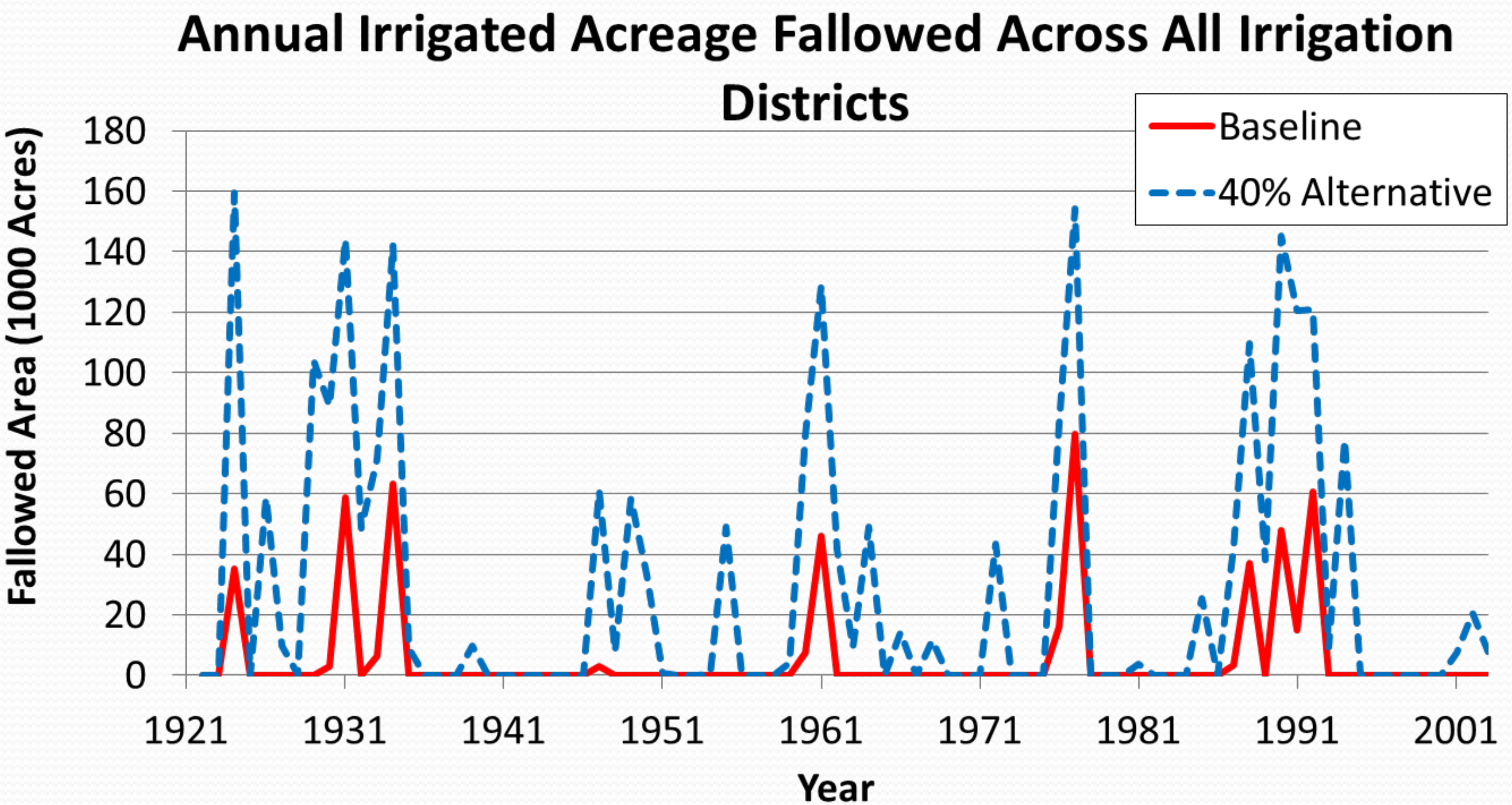


Avg. Annual Applied Water Shortage

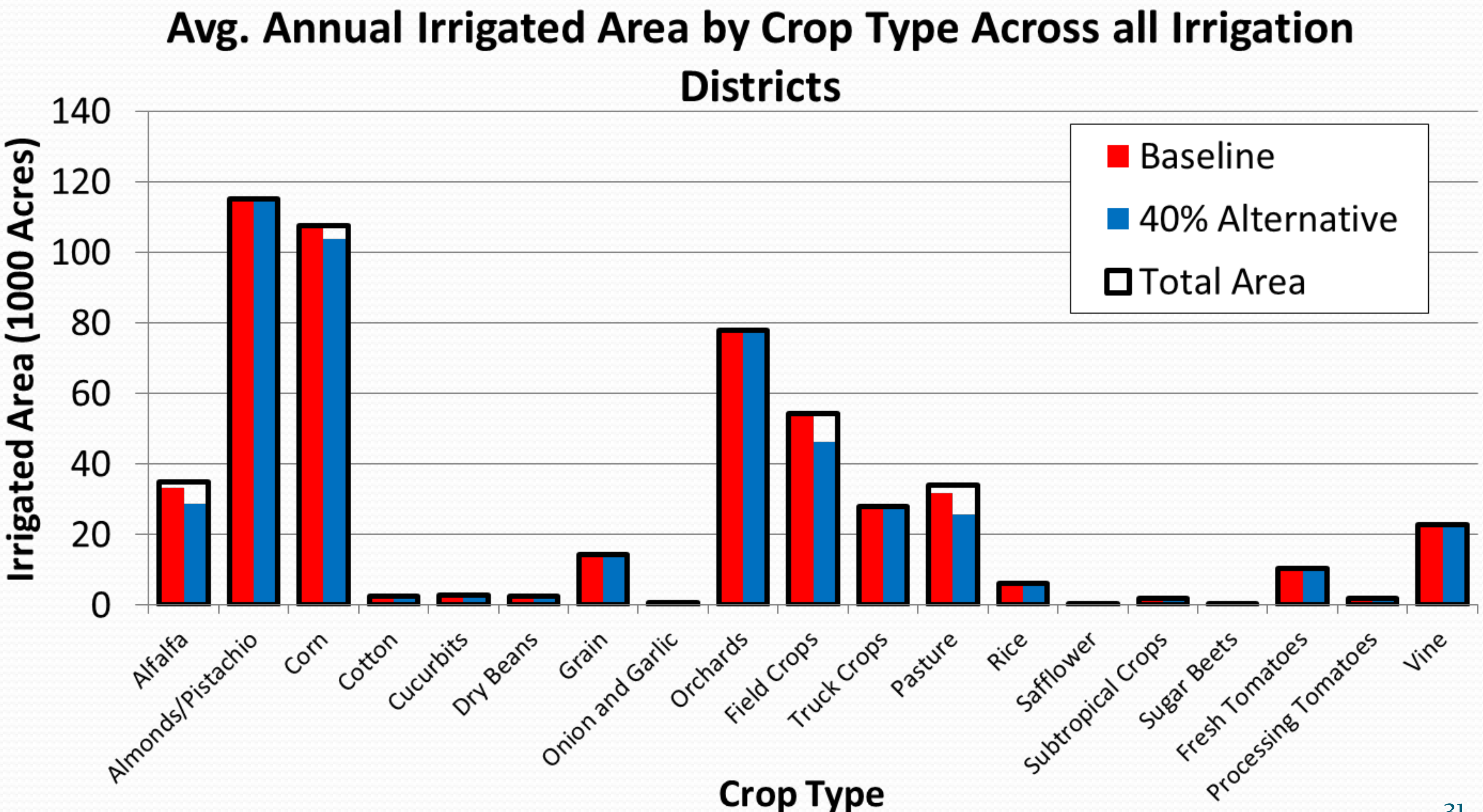


Total Applied Water Demand = 1547 TAF

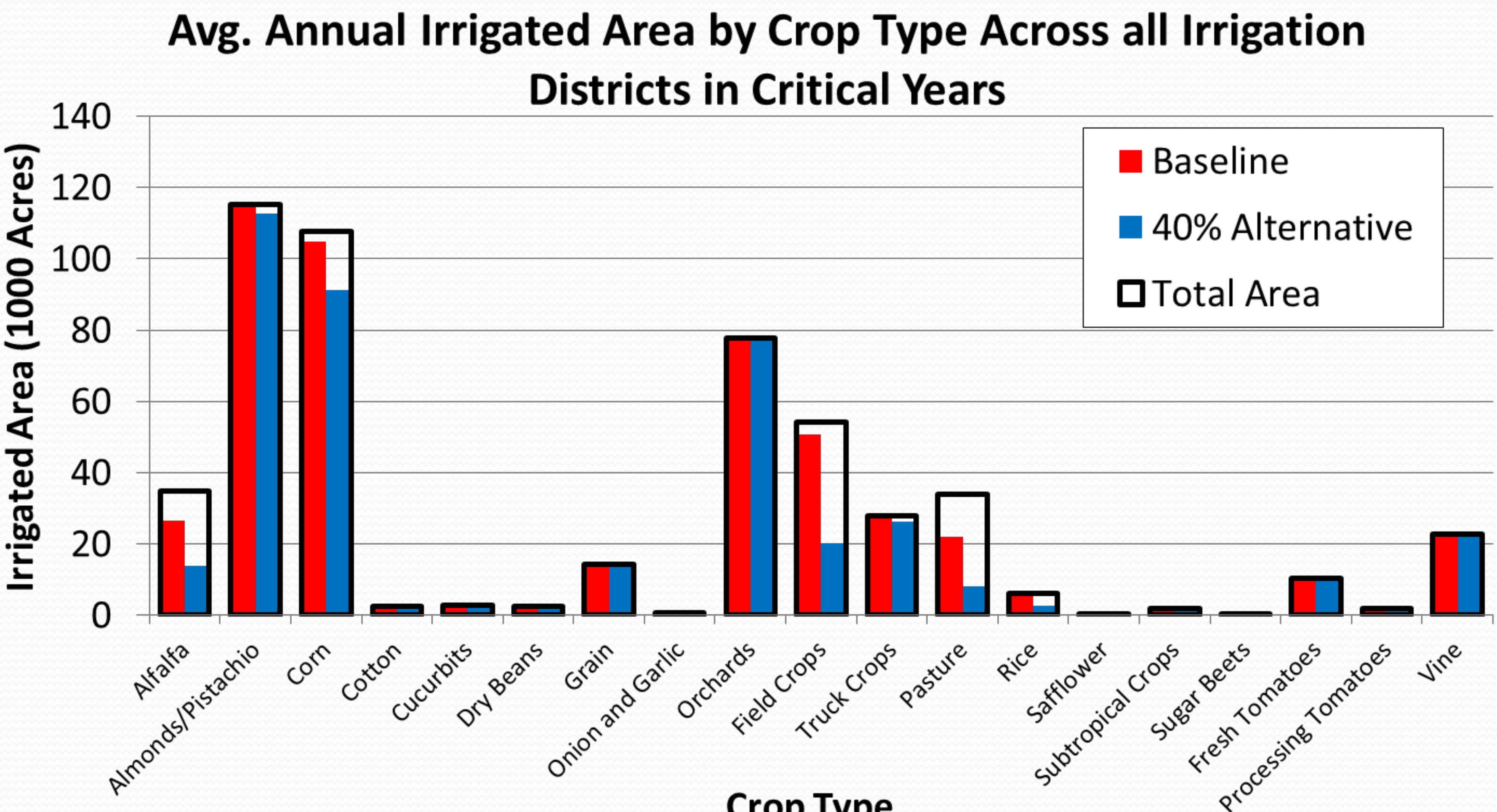
Time Series of the Impact to Irrigated Acreage



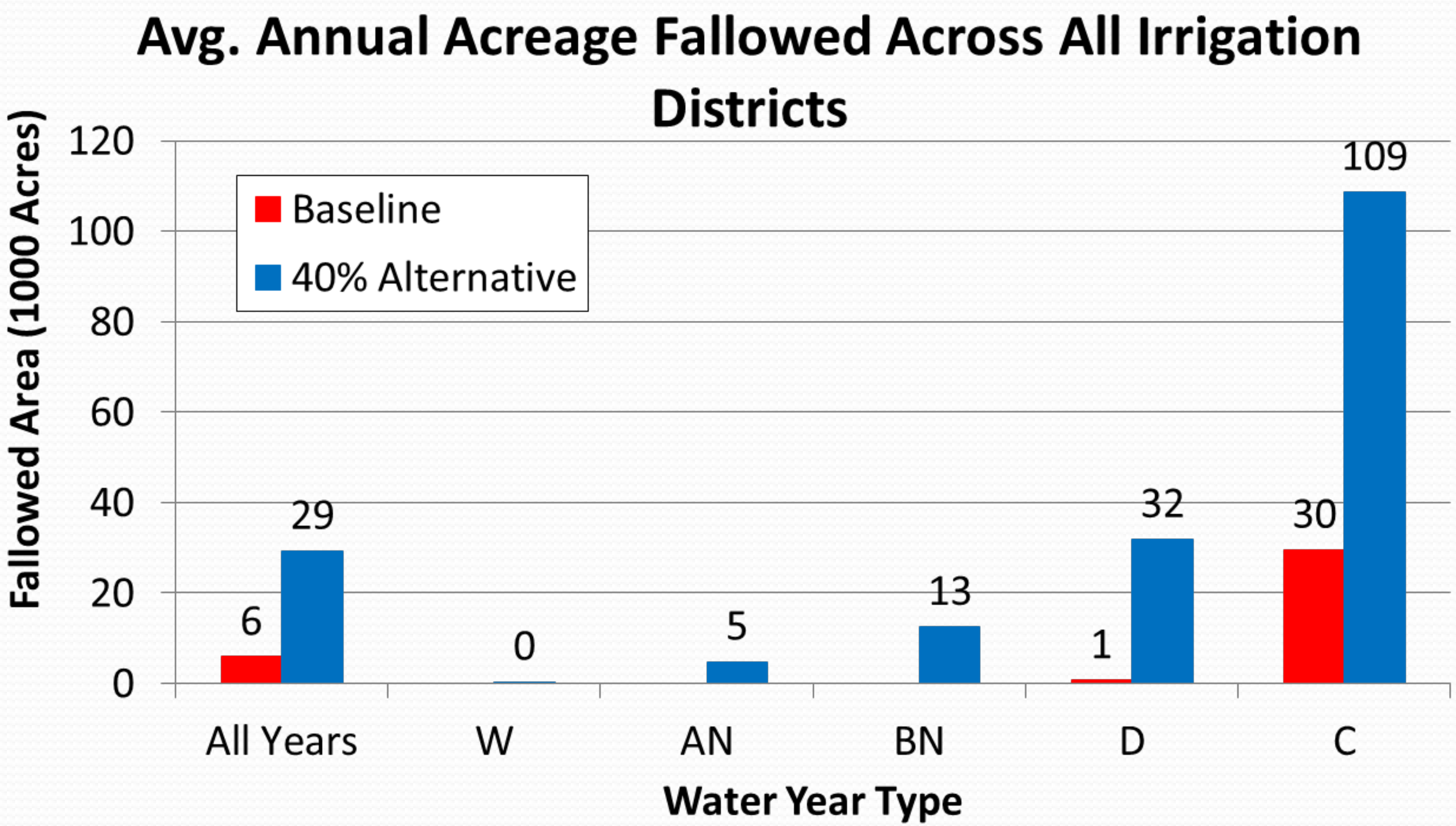
Average Annual Irrigated Area by Crop Type



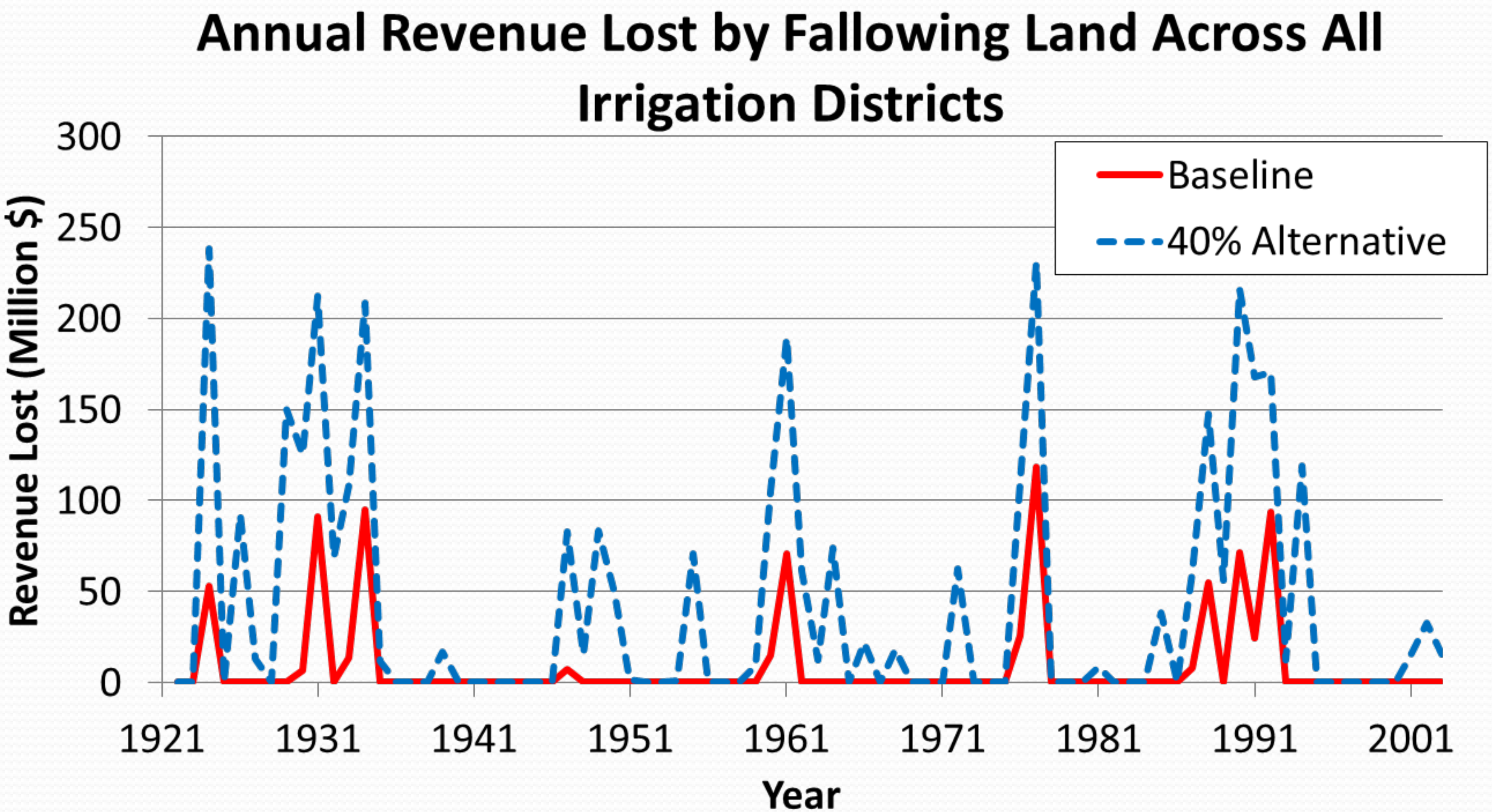
Average Annual Irrigated Area by Crop Type



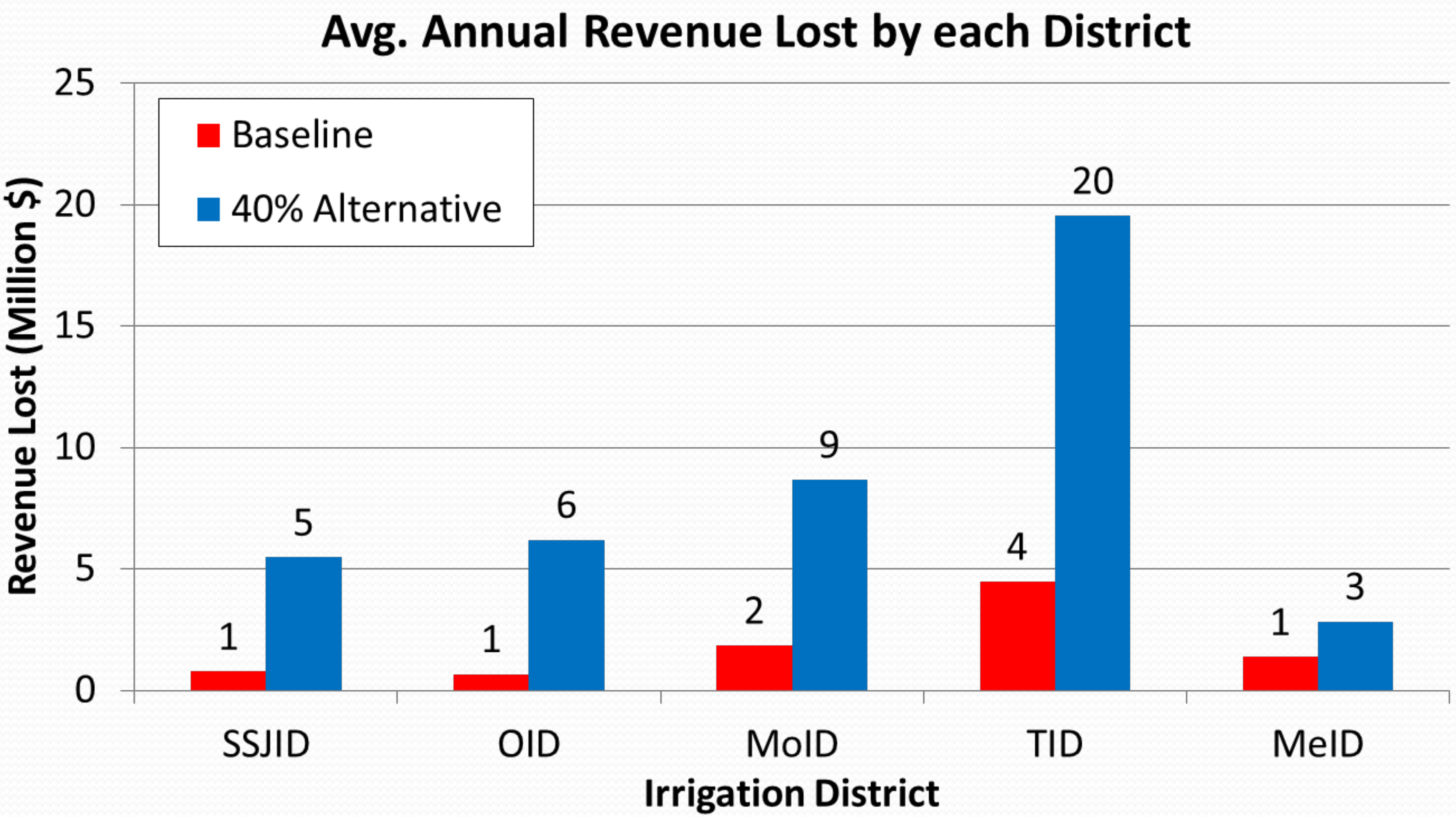
Avg. Annual Impact to Irrigated Acreage



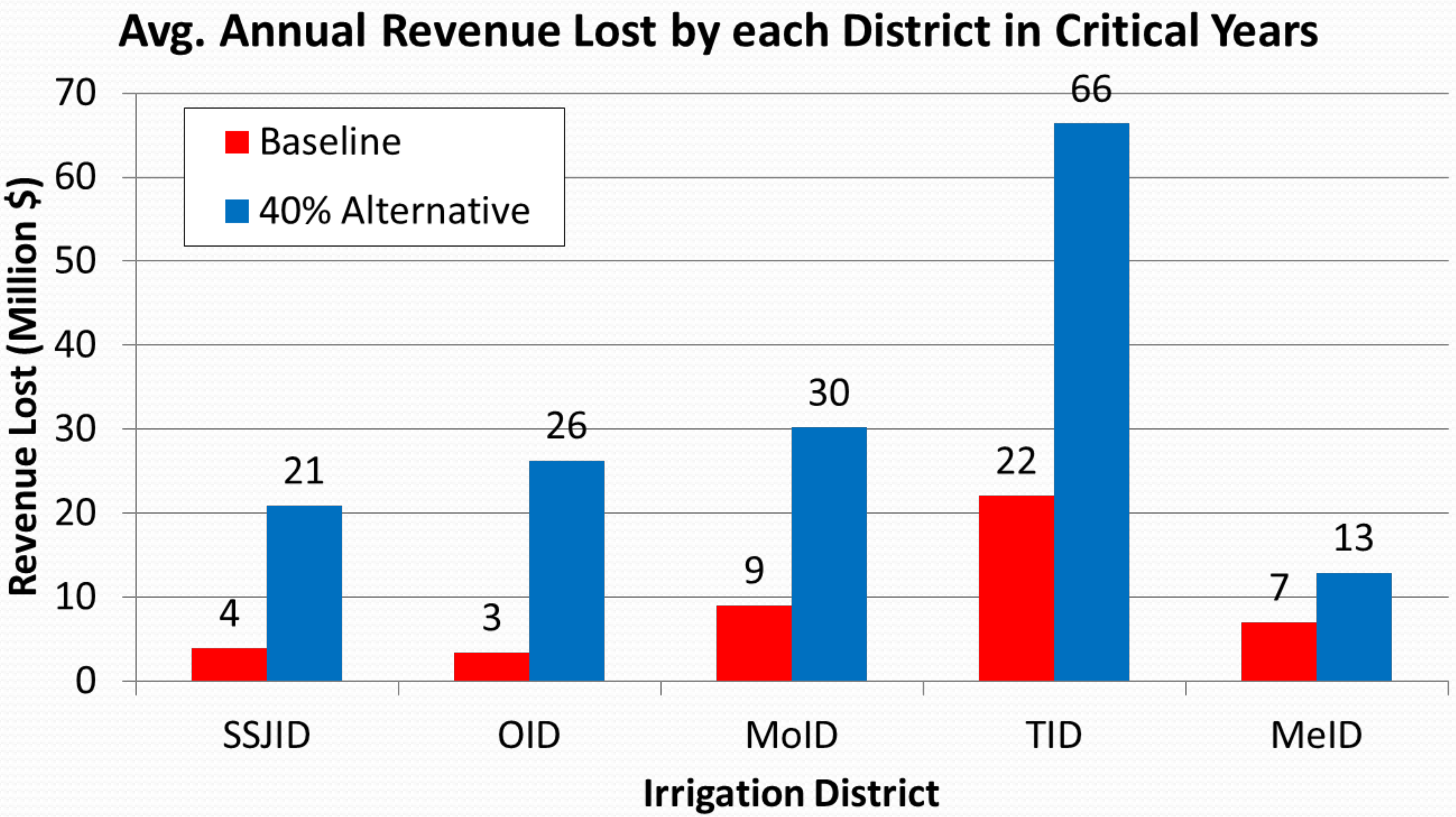
Time Series of the Impact to Agricultural Revenue



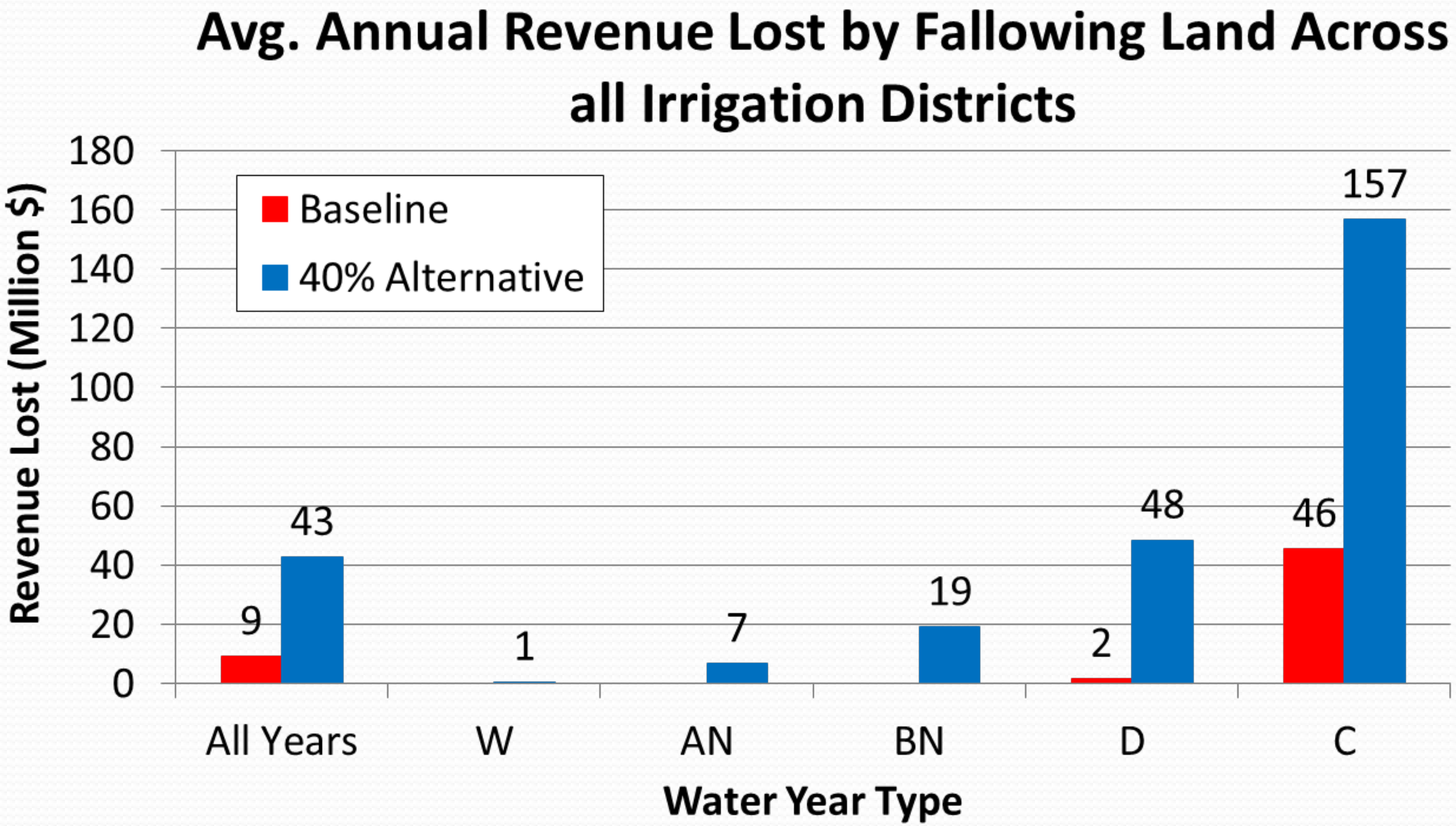
Avg. Annual Impact to Agricultural Revenue by District



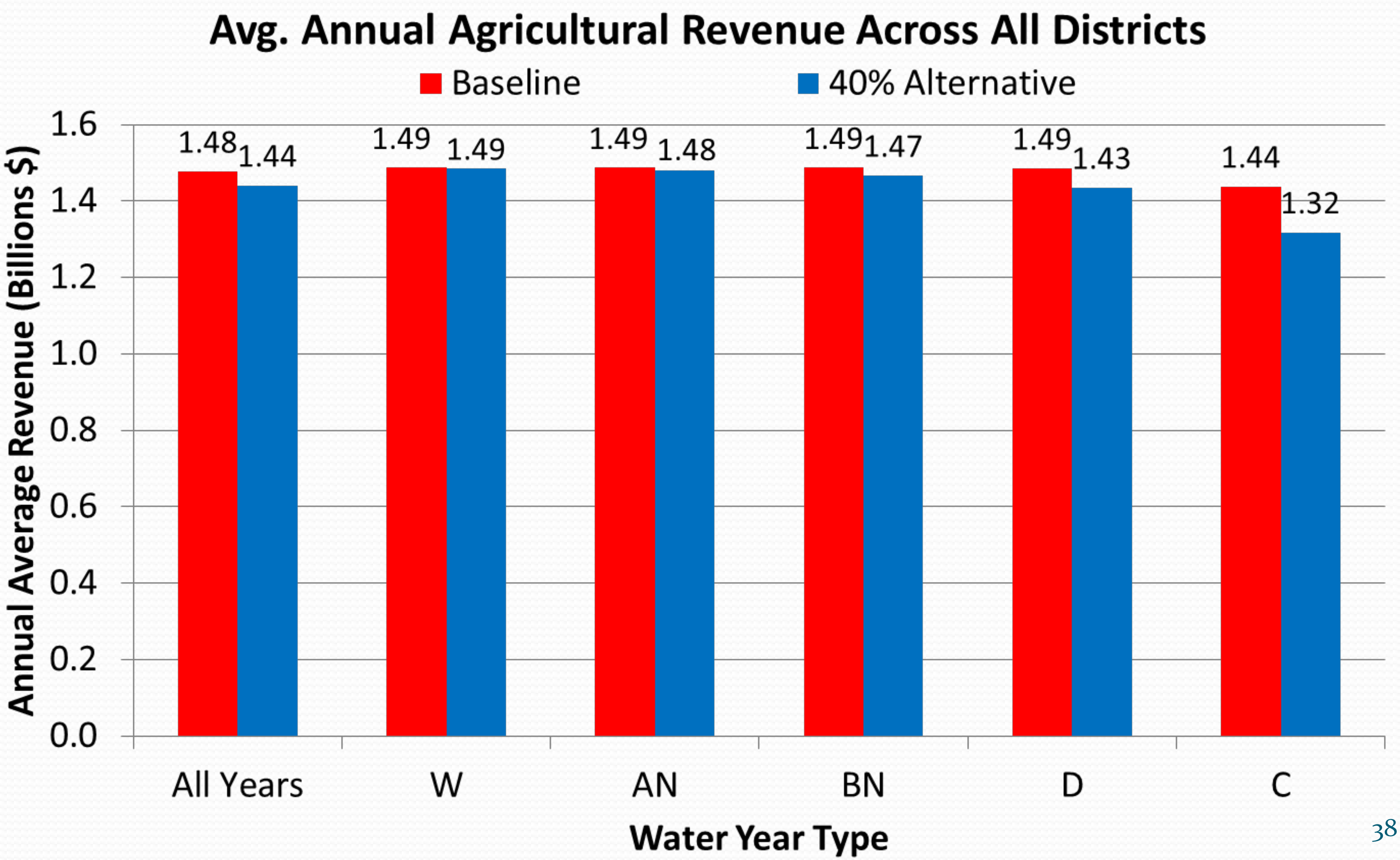
Avg. Annual Impact to Agricultural Revenue by District in Critical Years



Avg. Annual Impact to Agricultural Revenue



Avg. Annual Agricultural Revenue



Further information

- More information on these topics can be found in the following chapters and appendices of the SED:
  - Chapter 11, *Agricultural Resources*
  - Chapter 20, *Economic Analyses*
  - Appendix G, *Agricultural Economic Effects of the Lower San Joaquin River Flow Alternatives: Methodology and Modeling Results*
- These chapters, as well as the Agricultural Economic Analysis spreadsheet, can be found at:

http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/2016_sed/index.shtml.