Attachment

SRH-1DV Vegetation Modeling of the San Joaquin River, Friant Dam to Merced River Confluence, California

Draft
Geomorphology, Sediment Transport, and Vegetation Assessment
Appendix

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
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Attachment

SRH-1DV Vegetation Modeling of the San Joaquin River, Friant Dam to Merced River Confluence, California

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Abbreviations and Acronyms

1D	one-dimensional
ALS	average levee setback
cfs	cubic feet per second
cm	centimeter
GIS	Geographic Information System
MLS	maximum levee setback
PEIS/R	Program Environmental Impact Statement/Report
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
SJRRP	San Joaquin River Restoration Program
SRH-1DV	one-dimensional flow, sediment transport, and vegetation growth model

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1.0 Introduction

The San Joaquin River Restoration Program (SJRRP) seeks to restore a self-sufficient Chinook salmon fishery while protecting water supply to users in the San Joaquin valley in central California. The program is a comprehensive, long-term effort to restore flows in the San Joaquin River from Friant Dam to the confluence of the Merced River.

Originating in the Sierra Nevada Mountains, the San Joaquin River flows southwest out of the mountains through Friant Dam and passing by outskirts of Fresno, California (Figure 1-1). At the southern end of the Central Valley, the river bends to the northwest along the floor of the valley, eventually discharging into San Francisco Bay. The southern end, and downstream section, of the study area at the Merced River confluence is generally midway through the Central Valley.

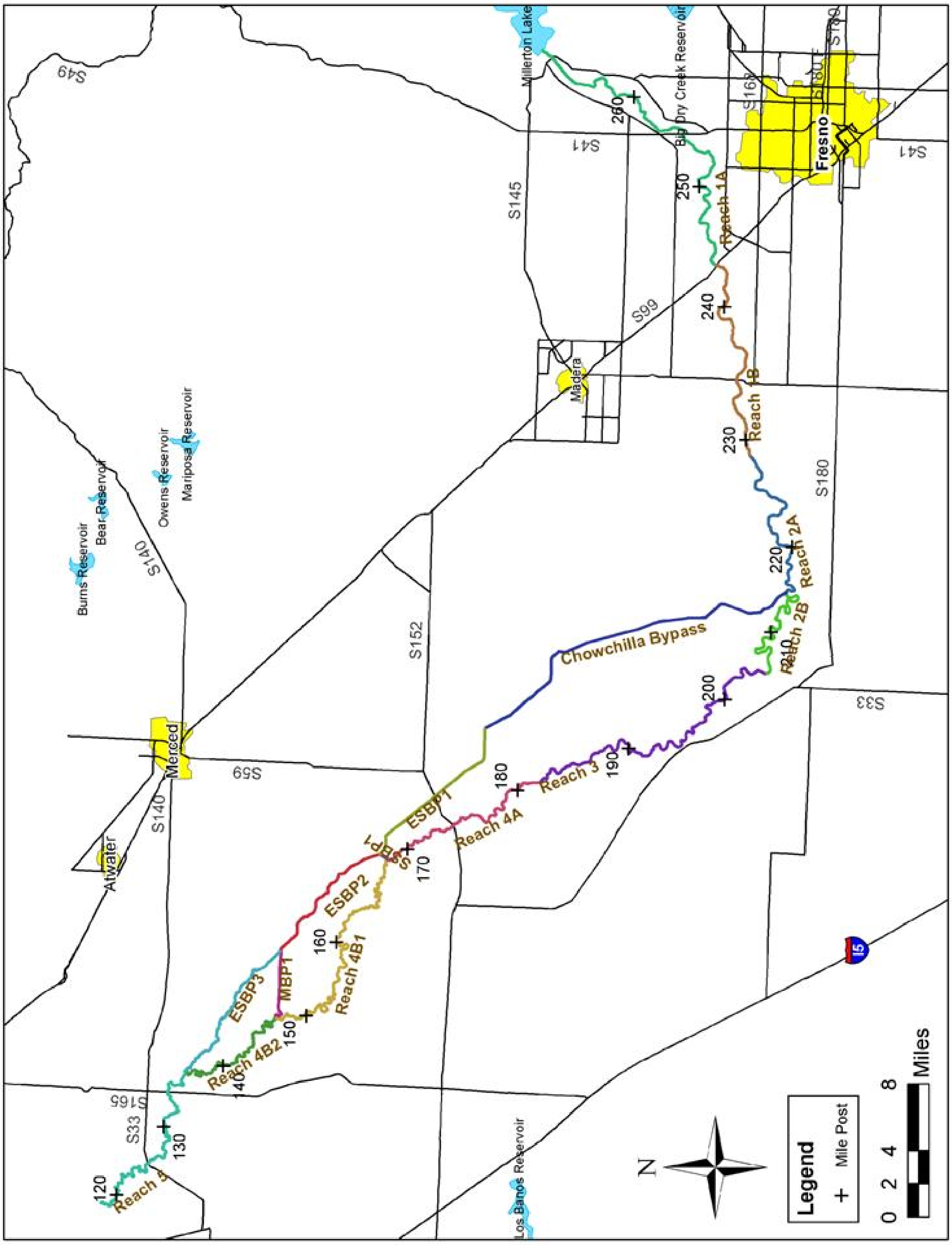
Vegetation changes interweave with the program goal in three areas:

- Establishment or enhancement of native riparian and floodplain vegetation for channel stabilization and salmonid aquatic cover habitat

- Management of low- and high-flow channel vegetation on fish passage channels to ensure restoration and floodway flow capacity and stage

- Management of invasive riparian plant infestations to maintain effectiveness of restoration actions including fish channel flow continuity

Vegetation modeling has been added to the suite of physical process models used by SJRRP to address these relationships. Numerical models with science-based linkages of physical processes can incorporate multiple independent and complex factors. Application of these models can aid in understanding the processes and support predictions of future physical conditions. Described here are the results of a vegetation numerical modeling study of the San Joaquin River from Friant Dam to the Merced River confluence. This report was prepared as an exhibit in the Geomorphology, Sediment, and Vegetation Assessment Technical Appendix to which this document is attached. A summary report and accompanying exhibits were prepared to aid development of the Program Environmental Impact Statement/Report (PEIS/R) for the SJRRP.



Key: ESBP = Eastside Bypass MBP = Mariposa Bypass SSBP = Sand Slough Bypass,

Figure 1-1.
Overview Map of Study Area

1.1 Vegetation Modeling

SRH-1DV is a one-dimensional (1D) flow, sediment transport and vegetation growth model used to assess river response, including changes to vegetation, resulting from management actions. SRH-1DV is a developmental model using core capabilities of sediment transport model SRH-1D (Huang and Greimann 2007), to integrate flow regime, sediment transport, and flood topography, with vegetation growth and removal. This deterministic model aids understanding of the system; aids examination of systemwide changes from an altered flow regime, altered flow routing, and implemented mechanical changes; and aids the design of management actions to maximize program benefits. SRH-1DV can be most effectively applied in comparative, not absolute, analyses, like this comparative analysis of vegetation for the PEIS/R. A 1999 pilot field project on San Joaquin River vegetation and flow (JSA 1998, JSA and MEI 2002a, and JSA and MEI 2002b), the San Joaquin River Restoration Study Background Report (McBain and Trush 2002), and two previous 1D flow-sediment-vegetation modeling projects (Greimann et al. 2007, and Murphy et al. 2006) are foundation work for this vegetation modeling study.

1.2 Purpose

The purpose of this report is twofold: to report information on vegetation and physical processes with respect to SJRRP management actions, and to document modeling efforts and approaches used in this study. Report structure is classic with this introduction followed by sections on methods, results, summary of conclusions, and suggestions for future efforts. Reaches and hydrologic scenarios referred to in this report are described in the main summary report. Specific topics addressed herein include:

- A general systemwide report on vegetation response to alternatives
- A reach assessment of vegetation response to alternatives including plant productivity and plant mortality
- Vegetation response to increased flows in Reach 2B
- Vegetation response to setting back levees in Reach 2B and vegetation sensitivity to groundwater
- Vegetation response to increased flows in Reach 4B1
- Vegetation in the Eastside and Mariposa bypasses
- Exhibit B flow effects on channel conveyance
- Sensitivity of plant productivity to root growth rate and groundwater conductivity
- Sensitivity of plant productivity to large peak flow events

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2.0 Methods-Vegetation Model

A 1D sediment transport model, SRH-1D, written by U.S. Department of the Interior, Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group, is the core of the flow-sediment-vegetation model (SRH-1DV) used to examine changes in San Joaquin River vegetation. Inputs to the sediment transport model include flow hydrographs, lateral flows and seepage losses, bed material grain sizes, flow and sediment boundary conditions, and hydraulic and sediment transport parameters. More information on sediment transport model SRH-1D can be found in Attachments 4 and 5.

2.1 Vegetation Parameters

The Sedimentation and River Hydraulics Group developed SRH-1DV by adding vegetation components to the core sediment transport model SRH-1D to describe vegetation establishment, growth, competition, and mortality in the river floodplain. Vegetation parameters are required for each simulated vegetation type. Six types were selected to represent species or communities of interest in this San Joaquin River study and to include vegetation having a string control on channel morphology. Fremont cottonwood *(Populus fremontii*) and Goodings black willow *(Salix gooddingii*) represent woody species, while narrow-leaved willow or sandbar willow *(Salix exigua*) is the single type representing riparian willow communities. Scarlet wisteria or red sespania *(Sesbania punicea*) is an invasive plant of interest to the program, and the second invasive, arundo or giant reed *(Arundo donax*), was included due to the potential of the plant to influence river geomorphology. Both red sespania and arundo are monoculture plants that often out-compete other riparian species. A generic grass was selected as the sixth vegetation type and is part of the competition mechanism for new plant establishment. This grass can also occupy high, dry areas since it is the only vegetation type not subject to desiccation in the models. A seventh vegetation assignment of no-grow was used to block growth at locations of impervious surfaces or alkali soils. Agricultural lands were also designated as a no-grow surface to distinguish between plant growth on cultivated and uncultivated lands. Cultivated lands are managed so roughness values for cultivated overbank areas are more a function of farming practices then groundwater availability.

Information including root growth rates, stem growth rates, capillary fringe, germination seasons, germination time, longevity of seeds, basal sprouting, and days for desiccation mortality are based primarily on values from Mahoney and Rood (1998), McBride and Strahan (1984), Shafroth et. al (1998), and Stella et. al (2006). Values are also selected from agency Web information and from previous flow-sediment-vegetation modeling by Reclamation's Sedimentation and River Hydraulics Group (Greimann et al. 2007, Murphy et al. 2006). When no other information is available regarding a particular species, values are assigned based on similar vegetation types or general field observations of physical attributes. Germination parameters for vegetation are listed in Table 2-1, and mortality parameters are in Tables 2-2 and 2-3. Stem, root and canopy growth parameters and the desiccation mortality parameter can be specified by age and month of the year, other mortality factors can be specified by age of the plant.

Additional vegetation input information includes rules for competition between vegetation types based on age of plants (Table 2-3) and competition from shading. SRH-1DV tracks canopy growth and the shading of locations under the spreading canopies. Plants susceptible to shading are eliminated. Competition and shading rules are assigned by the same hierarchy as used for other input parameters (i.e. rules based on peer-reviewed literature are used whenever this information is available, and when not available, assumptions are based on similar vegetation types and general field observations). Table 2-4 shows monthly desiccation information.

Table 2-1.
Vegetation Input Parameters for Germination

Germination Parameters-Dispersal										
Vegetation Type	Germination	Julian Days of Seed Dispersal Season	Days to Germination	Maximum Dry Days for Seeds	Maximum Height of Root Cap Above Groundwater (feet)	Depth Below Groundwater Germination Can Occur (feet)	Maximum Height Plant Can Establish Above Water Surface	Critical Flow Depth Needed to Move Seeds or Plant Parts	Maximum Travel Distance of Plant Part (feet)	Seed Survival Days
ctwd	air	113-161	1.5	54	1	0.01	200			
blwl	air	135-235	1	16	1	0.1	200			
nlwl	air	155-215	1	22	1	0.1	200			
grss	air	31-150	1	16	100	0.1	200			
arnd	water	1-365	1	6	3	0.1	12	1.5	25,000	10
rdss	water	1-365	1	3	2	0.5	3	1	25,000	1440
nogrw	none									

Germination Parameters-Lateral Spread Rate of Roots													
Type	Maximum lateral spread rate (ft/day) for each month												
	age	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
arnd	0	0	0	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0
rdss	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0

Key:
arnd =arundo
blwl = Gooding's black willow
ctwd = Fremont cottonwood
ft = feet
grss =Grass
nlwl = narrow-leaf willow
nogrw = no grow
rdss = red sespania
ft/day = foot/day

Table 2-2.
Vegetation Input Parameters for Plant Growth

Growth Parameters-Stalk Growth Rate

Type	Maximum Height	Max Stalk Growth Rate (foot/day) for Each Month											
		Age	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ctwd	65	0	0	0	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0
ctwd		3	0	0	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0
blwl	55	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.003	0
blwl		3	0	0	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.007	0
nlwl	6	0	0	0	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0
grss	3	0	0.01	0.01	0.01	0.01	0	0	0	0	0.01	0.01	0.01	0.01
arnd	12	0	0	0	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0
rdss	5	0	0	0	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0

Growth Parameters-Canopy Spread Rate

Type	Maximum Width	Max Shaded Canopy Spread Rate (foot/day) for Each Month											
		Age	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ctwd	50	0	0	0	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0
ctwd		2	0	0	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
ctwd		15	0	0	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0
ctwd		45	0	0	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0
blwl	40	0	0	0	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0
blwl		2	0	0	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
blwl		15	0	0	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0
blwl		45	0	0	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0
nlwl	2	0	0	0	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0
grss	1	0	1E-04	1E-04	1E-04	1E-04	0	0	0	0	1E-04	1E-04	1E-04	1E-04
arnd	4	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0
rdss	3	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0

Growth Parameters-Root Growth Rate

Type	Maximum Depth Below		Maximum Root Growth Rate (foot/day) for Each Month												
	GW	G	Age	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ctwd	0.1	20	0	0	0	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0
blwl	0.1	25	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0
nlwl	0.1	4	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0
grss	0.01	0.5	0	0.004	0.004	0.004	0.004	0	0	0	0	0.004	0.004	0.004	0.004
arnd	0.1	3.5	0	0	0	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0
rdss	1	1.5	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0

Key:
arnd = arundo
blwl = Gooding’s black willow,
ctwd = Fremont cottonwood
G = ground
grss = grass
GW = groundwater
nlwl = narrow-leaf willow
nogrw = no grow
rdss = red sespania

Table 2-3.
Vegetation Input Parameters for Mortality: Shading, Competition, Senescence, Scour, and Inundation

Vegetation Type X	Shad-ing	Competition								Senes-cense	Scour		Inundation		
	Age X is Shade Tolerant (years)	Age X (years)	Age of Y to Kill X ctwd	Age of Y to Kill X blwl	Age of Y to Kill X nlwl	Age of Y to Kill X grss	Age of Y to Kill X arnd	Age of Y to Kill X rdss	Age of Y to Kill X nogr	Age Death (years)	Age (years)	Critical velocity (feet/second)	Age (yrs)	Length of inundation Time (days)	Depth of Inundation (feet)
ctwd	5	0.1	99	99	1	0.25	1	1		75	0	2	0	15	0.25
		2	99	99	99	99	2	2			1	2.5	1	30	0.25
		3	99	99	99	99	2	2			2	3	2	60	0.25
		5	99	99	99	99	99	99			3	4	3	90	0.25
											4	5	4	180	0.25
													5	360	0.25
blwl	5	0.1	99	99	1	0.25	1	1	99	50	0	2	0	20	0.25
		2	99	99	99	99	2	2	99		1	2.5	1	35	0.25
		3	99	99	99	99	2	2	99		2	3	2	70	0.25
		5	99	99	99	99	99	99	99		3	4	3	100	0.25
nlwl	99	0.1	6	6	99	0.25	1	2	99	99	0	2	0	30	0.25
		2	6	6	99	99	2	2	99		1	2.1	1	60	0.25
		5	6	6	99	99	5	5	99		2	2.6	2	120	0.25
											3	3.5	3	180	0.25
											4	4	4	360	0.25
													5	720	0.25
grss	99	0.1	6	6	1	99	1	1	99	5	0	0.75	0	10	0.1
		1	6	6	1	99	1	1	99		0.5	1	1	15	0.1
arnd	99	0.1	6	6	1	0.25	99	1	99		0	1.5	0	20	0.25
		1	6	6	3	99	99	1	99		1	2	1	40	0.25
		3	6	6	99	99	99	2	99		2	2.5	2	80	0.25
													3	120	0.25
													4	240	0.25
rdss	99	0.1	6	6	2	0.25	1	99	99		0	2	0	30	0.25
		1	6	6	99	99	2	99	99		1	2.1	1	60	0.25
	99	3	6	6	99	99	99	99	99	99	2	2.6	2	120	0.25
											3	3.5	3	180	0.25
											4	4	4	360	0.25
nogw	0.1	0.1	99	99	99	99	99	99	99						

Note: Competition specifies the age of plant Y, when it can kill another plant X at X's specified age. An age value of 99 for competition or senescense indicates this mortality does not eliminate the vegetation type during the simulation.

Key:
arnd =arundo
blwl = Gooding's black willow
grss =grass
ctwd = Fremont cottonwood
nlwl = narrow-leaf willow
nogrw = no grow
rdss = red sespania
yrs = years

Table 2-4.
Mortality Parameter: Desiccation

Vegetation Type X	Desiccation			Months drying is allowed											
	Age (years)	Time (days)	Height Above Capillary to Die (feet)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ctwd	0	2	0.5	0	1	1	1	1	1	1	1	1	1	1	0
	1	7	0.5												
	2	14	0.5												
	3	28	0.5												
	20	180	0.5												
blwl	0	2	.01	0	1	1	1	1	1	1	1	1	1	1	0
	1	7	.01												
	2	14	.01												
	3	28	.01												
	20	150	.01												
nlwl	0	2	.01	0	1	1	1	1	1	1	1	1	1	1	0
	1	7	.01												
	2	14	.01												
	3	28	.01												
grss	0	2	0	0	0	0	1	1	1	1	1	1	1	0	0
	0.5	7	0												
arnd	0	2	.01	0	1	1	1	1	1	1	1	1	1	1	0
	1	7	.01												
	2	14	.01												
	3	28	.01												
rdss	0	2	.01	0	1	1	1	1	1	1	1	1	1	1	0
	1	7	.01												
	2	14	.01												
	3	28	.01												

Note: The binary format shown in the table indicates a 0 if drying is not allowed during that month and a 1 if drying is allowed. The time is the length of time the species can be dry before desiccation occurs.

Key:
arnd = arundo
blwl = Gooding’s black willow
ctwd = Fremont cottonwood
grss =Grass
nlwl = narrow-leaf willow
nogrw = no grow

2.2 Existing Vegetation Input

Geographic Information System (GIS) mapping of existing vegetation communities from 2002 was provided by the California Department of Natural Resources, and 2008 mapping of invasive species was provided by Reclamation Mid-Pacific Regional Office. Vegetation existing at the site at startup of the simulation was assigned to model cross-section points from the mapped GIS vegetation polygons. Vegetation mapping for the San Joaquin River was done by plant communities, which were translated to combinations of the seven vegetation types, as shown in Table 2-5. Arundo and red sespania were mapped in 2002 as polygons. In 2008, red sespania was mapped as polygons and arundo was mapped as points. Polygons for arundo in 2008 were later estimated from the point data and surrounding topographic features.

Table 2-5.
Translation of Vegetation Communities from GIS Mapped Polygons to Seven Vegetation Types in SRH-1DV Models to Represent Existing Vegetation Conditions

Abbrev	Description	ctwd	blwl	nlwl	grss	arnd	rdss	no-grw
AG	agrarian field	0	0	0	0	0	0	1
AR1	Arundo, 2002 polygons	0	0	0	0	8	0	0
AR2	Arundo, 2008 points	0	0	0	0	2	0	0
AS	alkali sink	0	0	0	0	0	0	1
CW1	Cottonwood riparian	40	40	0	2	0	0	0
CW2	Cottonwood riparian	40	40	0	0	0	0	0
CW3	Cottonwood riparian	25	25	0	2	0	0	0
CW3CW3	Cottonwood riparian	25	25	0	2	0	0	0
CW4	Cottonwood riparian	25	25	0	0	0	0	0
CW5	Cottonwood riparian	8	8	0	2	0	0	0
CWLD2	Cottonwood riparian low density	0	0	0	0	0	0	0
CWLD4	Cottonwood riparian low density	0	0	0	0	0	0	0
CWLD6	Cottonwood riparian low density	0	0	0	0	0	0	0
D	Disturbed	0	0	0	0	0	0	1
EB	EB savannah	0	0	0	1	0	0	0
EXO	exotic tree	25	25	0	1	0	0	0
H	Herbaceous	0	0	0	1	0	0	0
MR1	mixed riparian	40	40	0	2	0	0	0
MR2	mixed riparian	40	40	0	0	0	0	0
MR3	mixed riparian	25	25	0	1	0	0	0
MR4	mixed riparian	25	25	0	0	0	0	0
MRLD2	mixed riparian low density	0	0	0	0	0	0	0
MRLD4	mixed riparian low density	0	0	0	0	0	0	0
MRLD6	mixed riparian low density	0	0	0	0	0	0	0
RESEE	red sespania, extensive- 2008	0	0	0	0	0	3	0
RESES	red sespania, scattered shrubs-2008	0	0	0	0	0	0.5	0
OAK1	riparian oak	0	40	0	2	0	0	0
OAK2	riparian oak	0	40	0	0	0	0	0
OAK3	riparian oak	0	25	0	2	0	0	0
OAK4	riparian oak	0	25	0	0	0	0	0
RS	riparian scrub	0	0	0	0.5	0	0	0
RW	riverwash	0	0	0	0	0	0	0
SW5	willow scrub	0	4	1	2	0	0	0
URB	urban	0	0	0	0	0	0	1
WA	open water	0	0	0	0	0	0	0
WET	wetland/marsh	0	0	0	0.5	0	0	0
WR1	willow riparian	0	40	2	2	0	0	0
WR2	willow riparian	0	40	0	0	0	0	0
WR3	willow riparian	0	25	2	2	0	0	0
WR4	willow riparian	0	25	0	0	0	0	0
WRLD	willow riparian low density	0	0	0	0.5	0	0	0
WRLD2	willow riparian low density	0	0	0	0	0	0	0
WRLD3	willow riparian low density	0	0	0	0.5	0	0	0
WRLD4	willow riparian low density	0	0	0	0.5	0	0	0
WS5	willow riparian low density	0	0	0	0.5	0	0	0
WS6	willow scrub	0	0	0	0.5	0	0	0
WSLD6	willow scrub low density	0	0	0	0.5	0	0	0

Note: The numbers in the table represent the assumed age of the particular species for a particular vegetation code.

Key:
arnd = arundo
blwl = Gooding's black willow
ctwd = Fremont cottonwood
grss = grass
nlwl = narrow-leaf willow
nogrw = no grow
rdss = red sespania

2.3 Groundwater Input

Riparian vegetation growth processes are related to both the water surface elevation in the channel and also to the elevation of groundwater in the banks and floodplain. Groundwater parameters that determine the rise and fall of the groundwater surface and the pattern of decline extending outward from the channel are shown in Table 2-6. In addition to hydraulic conductivity of the soils, capillary fringe height, and a drop velocity, a maximum value for groundwater decline is assigned if the channel goes dry for long periods. During dry periods, the groundwater table is allowed to drop to the maximum assigned depth, and recovers from this elevation as flow returns to the channel. Groundwater elevations with respect to the banks and floodplain vary between simulations to develop a maximum and minimum range for plant productivity. A value of -1 indicates groundwater is held to a maximum value of 1 foot below the ground surface at every cross-section point outside of the channel.

Table 2-6.
Groundwater Variables

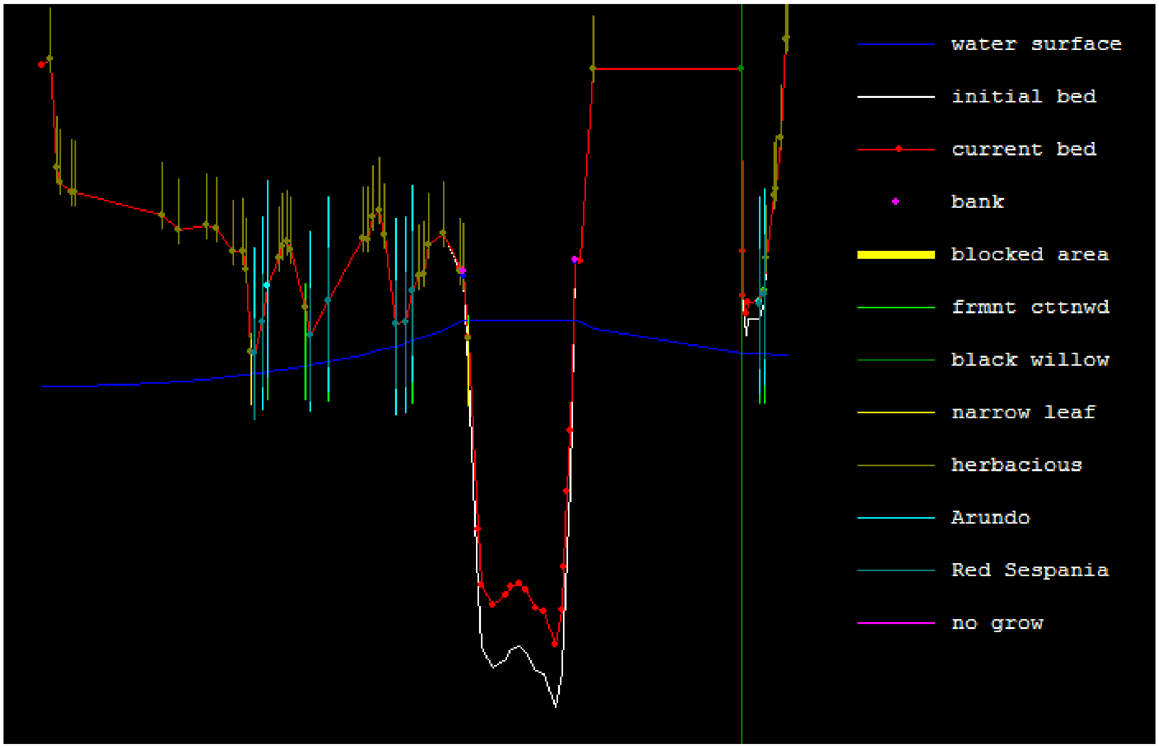
Longitudinal Location Relative to Mendota Dam (ft)	Left Bank Hydraulic Conductivity K (ft/day)	Right Bank Hydraulic Conductivity K (ft/day)	Capillary height/ fringe (ft)	Drop Velocity (ft/day)	Maximum Groundwater Decline Below Thalwag h_{min} (ft)	Groundwater Outside of Channel, with Respect to Ground Surface
Upstream of 105,000	100,000	100,000	2	1	50	-1 or 1
Downstream of 104,800	100,000	100,000	2	1	50	-1 or 1

Key:
H_{min} =
ft = feet

2.4 Vegetation Computations

In addition to sediment transport computations, SRH-1DV tracks vegetation germination, growth, competition, and mortality processes. Two types of germination are represented in the model: airborne seeds, which establish in season at all wetted sites, and waterborne seeds or parts that are conveyed downstream during high-flow events of a specified magnitude. Vegetation growth is computed for roots, stems, and canopy. Groundwater elevation for root growth is tracked in the model based on a dynamic groundwater surface linked to the channel water surface. In the San Joaquin River models, plants may die due to velocity-based scour, inundation, desiccation, senescence (age), competition, or shading. Growth and mortality are defined for each vegetation type by the parameters in Tables 2-1 through 2-4.

Hydraulics and sediment transport of the model are updated every 4 hours, while vegetation growth computations occur every 24 hours. For each day of the hydrologic record (17 to 23 years), vegetation establishment, growth, and mortality is assessed at every point (approximate average of 80 points per cross section) of every cross section (143 to 188 cross sections) and for every vegetation type (maximum of six vegetation types at each point), as shown in Figure 2-1. Although the model computes vegetation growth at daily time steps, vegetation measurements are recorded on a less frequent cycle due to the large quantity of information. Vegetation output is recorded at one-half year intervals over the period of hydrologic record.



Note: Arundo and red sespania have replaced grass in low points and are growing in the side channels in close proximity to groundwater. Multiple vegetation types may exist at a single point as detectible by multiple colors at the tips of stems and roots.

Figure 2-1.
Cross-Section 155 of the Mendota to Merced Model, Alternate A Flow Regime, in Reach 5A from SRH-1DV

Vegetative cover is computed for the area surrounding a data point that supports vegetation. Plant productivity area is the indicator used for vegetation coverage, and is the sum of areas surrounding each point for the specified vegetation. Because one point in a cross section can support growth of multiple vegetation types, and because plant productivity is calculated separately for each vegetation type, values for native or invasive plant productivity area can be as much as two (invasive plants – red sespania and arundo) to three (native plants – cottonwood, black willow, and narrow-leaf willow) times larger than actual predicted area of vegetation coverage in the field. Plant productivity area divided by reach length provides a second indicator (plant productivity width) for comparing vegetation conditions between reaches of varying lengths.

2.5 Representative Vegetation

Vegetation types occupy distinct niches in the channel cross section based on parameters entered to describe growth and mortality. Cottonwood has the fastest growing roots but has less tolerance to wet roots in comparison to black willow and narrow-leaf willow. Black willow and cottonwood have the largest maximum root depth. Consequently, cottonwood and black willow will establish higher in the channel cross section in overbank areas and also on the floodplain if there is a high-flow event and the groundwater decline is not disparate from maximum root growth rates. Black willow and narrow-leaf willow can establish closer to the average low-water surface. Narrow-leaf willow, although tolerant of wet roots and inundation, has a relatively shallow root system. These plants must occupy river banks adjacent to the water surface or locations in overbank areas where the groundwater is in close proximity to the ground surface.

Invasive species red sespania and arundo were modeled with relatively shallow root systems and low tolerance for desiccation. Most of these plants establish on banks in close proximity to more steady water supplies with less fluctuation. Arundo was modeled with a slightly longer root system and less tolerance for wet roots than red sespania to mimic locations commonly observed in the field. Both vegetation types grow on the channel banks or near ponding water in close proximity to the water surface, but arundo is located at a slightly higher elevation.

One distinguishing characteristic between the native and invasive groups of plants is the primary plant establishment process. Cottonwood, black willow, and narrow-leaf willow establish in this modeling study primarily by air-borne seed germination. Red sespania and arundo establish primarily from water-borne parts that consist of large seed pods for red sespania and broken pieces of the plant, including stems and roots, for arundo. Spread of invasive plants is not limited to seed-dispersal periods as native vegetation types, but is linked to high-flow events capable of transporting and depositing plant parts for germination. To represent natural conditions within the model, invasive plants are also limited to colonizing areas downstream from existing plants, while native species can germinate at any location. It is assumed in the model that there is an airborne seed supply at all locations in the model.

2.6 Model Structure

Three models and simulations were required to describe all locations of the study area. Presented in Table 2-7 are cross sections assigned to each reach division in three SRH-1DV models:

- Friant Dam to Mendota Pool – Reaches 1 and 2 (Figure 1-1)
- Mendota Pool to Merced with Bypass – Reaches 3 and 4A, Eastside and Mariposa bypasses, and Reaches 4B2 and 5
- Mendota Pool to Merced, Main Channel – Reaches 3, 4A, 4B1, 4B2, and 5

In place of a flow loop, the flow split at Sand Slough between the Mendota Pool and the Merced River confluence was represented by two separate models: the bypass simulation and the main channel simulation. Results for Reach 4B1 are available from the main channel simulation, and results from the Eastside and Mariposa bypasses are available from the bypass simulation. Standard reach designations were used with the exception of Reach 5, which was divided into Reach 5A, upstream from the confluence with Salt Slough, and Reach 5B, downstream from the confluence with Salt Slough.

Table 2-7.
Numerical Model Construction

Reach	XSec Label	Model XS No.	Upstream Reach Boundary	Length (feet)	Length (mile)
Friant Dam to Mendota Pool					
1A	596	1-64	Friant Dam	125,682	23.8
1B	227	65-103	Hwy 99 Bridge	83,231	15.8
2A	214	104-125	Gravelly Ford	61,936	11.7
2B	94	126-143	Chowchilla Bifurcation	58,377	11.1
			Mendota Pool		
Mendota Pool to Merced River Confluence via Main Channel					
3	764	1-47	Mendota Pool	116,689	22.1
4A	482	48-78	Sack Dam	71,623	13.6
4B1	301.7	79-123	Sand Slough Diversion	73,519	13.9
4B2	36	124-148	Mariposa Bypass Return	61,450	11.6
5A	234M	149-163	Bear Creek	36,839	7.0
5B	144M	164-188	Salt Slough	56,715	10.7
			Merced River		
Mendota Pool to Merced River Confluence via Bypasses					
3	764	1-47	Mendota Pool	116,689	22.1
4A	482	48-78	Sack Dam	71,623	13.6
SS	1ES	79-81	Sand Slough Diversion	2.250	0.4
ES	6ES	82-93	Eastside Bypass	48,983	9.3
MP	MP5042.5	94-105	Mariposa Bypass Diversion	22,678	4.3
4B2	35	106-132	Main Ch. at Mariposa Return	63,165	12.0
5A	234M	133-149	Bear Creek	34,285	6.5
5B	144M	150-175	Salt Slough	57,163	10.8
			Merced River		

2.7 Hydrology

Predictive modeling was assessed for two flow alternatives: Baseline and Alternative A. The Baseline flow regime represents flows in the system under Existing Conditions if current operating rules were closely observed. Alternative A is the Exhibit B flow schedule, and represents with-project flow conditions under all Program Alternatives described in the PEIS/R. A Historical flow regime was constructed from available gage data but its use in simulations has been limited to some sensitivity investigations due to data limitations, including insufficient gages for system variability and gaps in the records of gage data. The three flow regimes at Friant Dam are presented in Figures 2-2 and 2-3, and the flow regimes at Mendota Pool are presented in Figure 2-4. Historical Gage Conditions at Friant Dam have the largest peak flows (Figure 2-2), and Alternative A has more base-flow and low-flow peaks (Figure 2-3). A maximum Historical Gage peak of 38,000 cubic feet per second (cfs) was reduced to a peak of 27,000 cfs in Baseline Conditions, and all peak flows greater than 8,000 cfs have been removed from Alternative A.

The Alternative A flow regime at Mendota Pool (Figure 2-4) is similar to the Alternative A flow regime at Friant Dam with frequent peak flows below 8,000 cfs. However, these peak flows at Mendota Pool are larger than Baseline or Historical Gage peak flows. Unlike the upstream Friant Dam location, Historical Gage peak flows are the smallest of the three flow regimes at Mendota Pool. Alternative A base flow at Mendota Pool is similar to Alternative A base flow at Friant Dam. Although Alternative A base flow is distinct from Baseline and Historical Gage base flows at Friant Dam, it is similar to Baseline and Historical Gage base flows at Mendota Pool.

Baseline and Alternative A flow regimes are constructed for a 23-year period from 1980 to 2003. The Historical Gage regime was developed from Historical Gage data at Friant Dam, which was available between 1980 and 1997, and from gage data for Mendota Pool to Merced, which was available between October 1981 and May 1997. There are three periods in the Historical Gage record for Friant Dam when no discharge data were available. During these periods, the simulation repeated the last known flow until gage data were again available. Dates of missing data and repeated flows included:

- November 1 to December 31, 1982, 88 cfs
- October 1, 1983 to March 31, 1984, 2080 cfs
- January 1, 1987 to December 31, 1987, 23 cfs

Flow regimes can vary largely from reach to reach due to water supply systems that divert or return irrigation flows and due to groundwater losses between each reach. Estimated groundwater losses were tracked in the model as point losses or continuous losses along the reach, and variability in each reach due to water delivery diversions or returns was also simulated by the model.

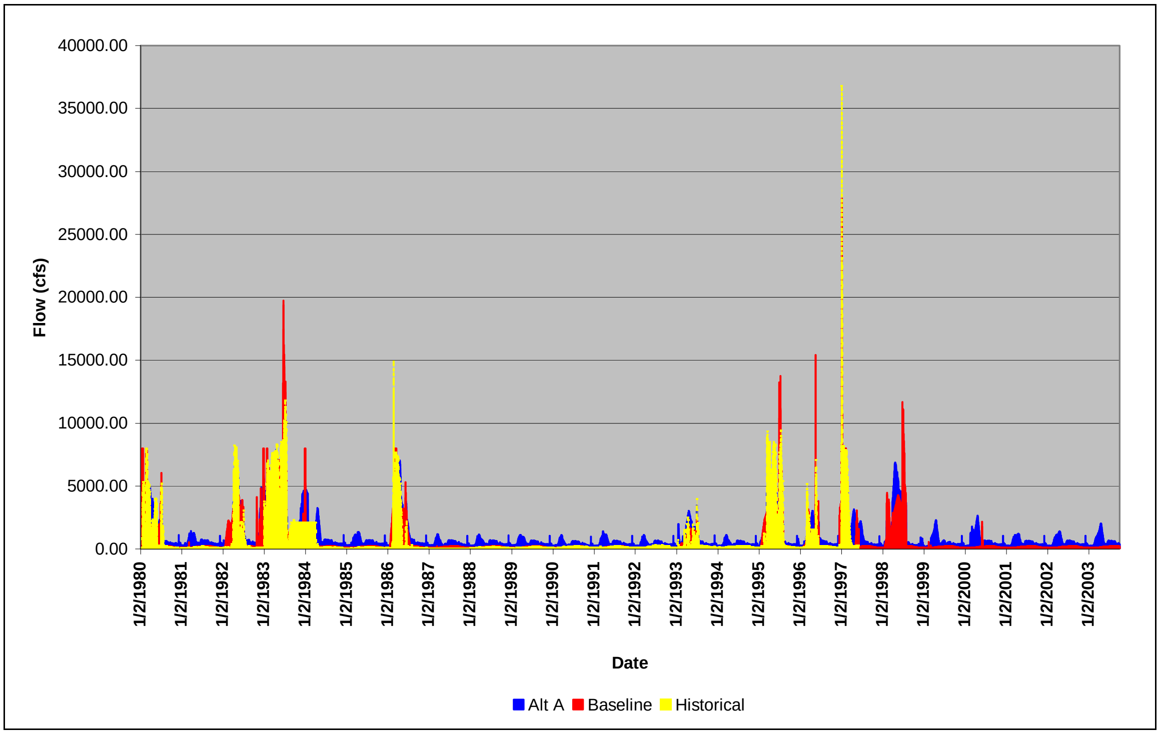


Figure 2-2.
Discharge at Friant Dam: Alternative A, Baseline, and Historical Gage Flow Regimes

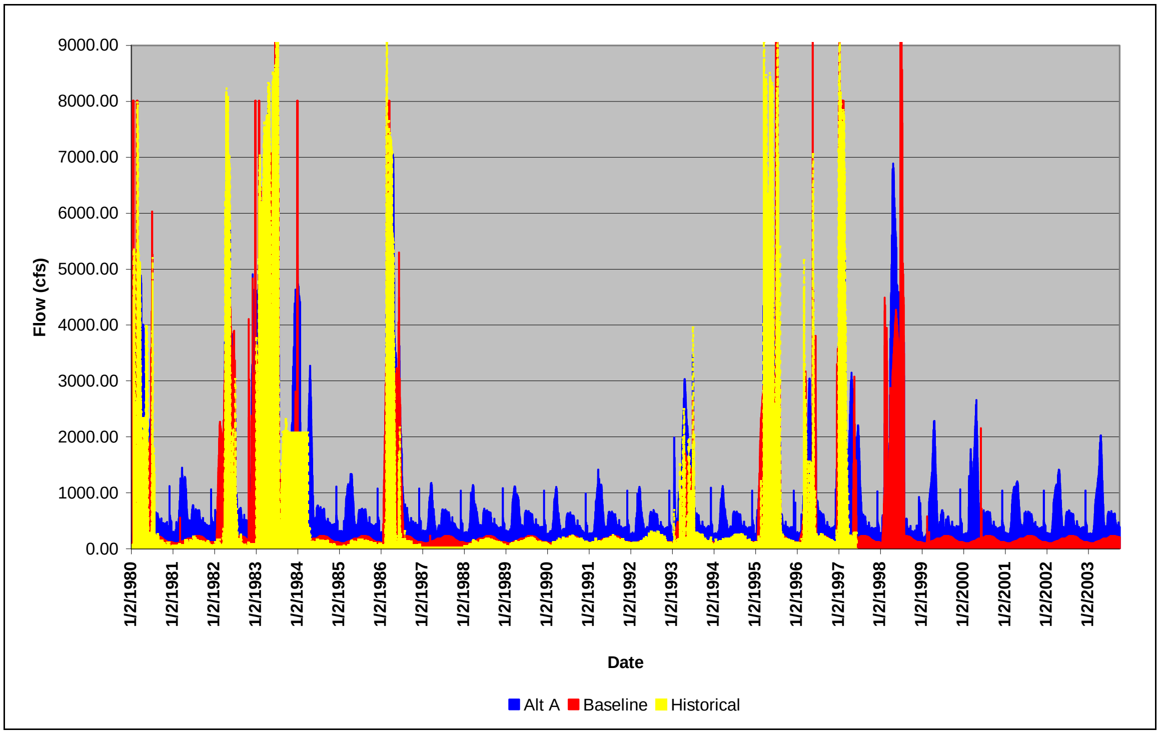


Figure 2-3.
A closer view of discharge at Friant Dam Between 0 and 9,000 cfs: Alternative A, Baseline, and Historical Gage Flow Regimes

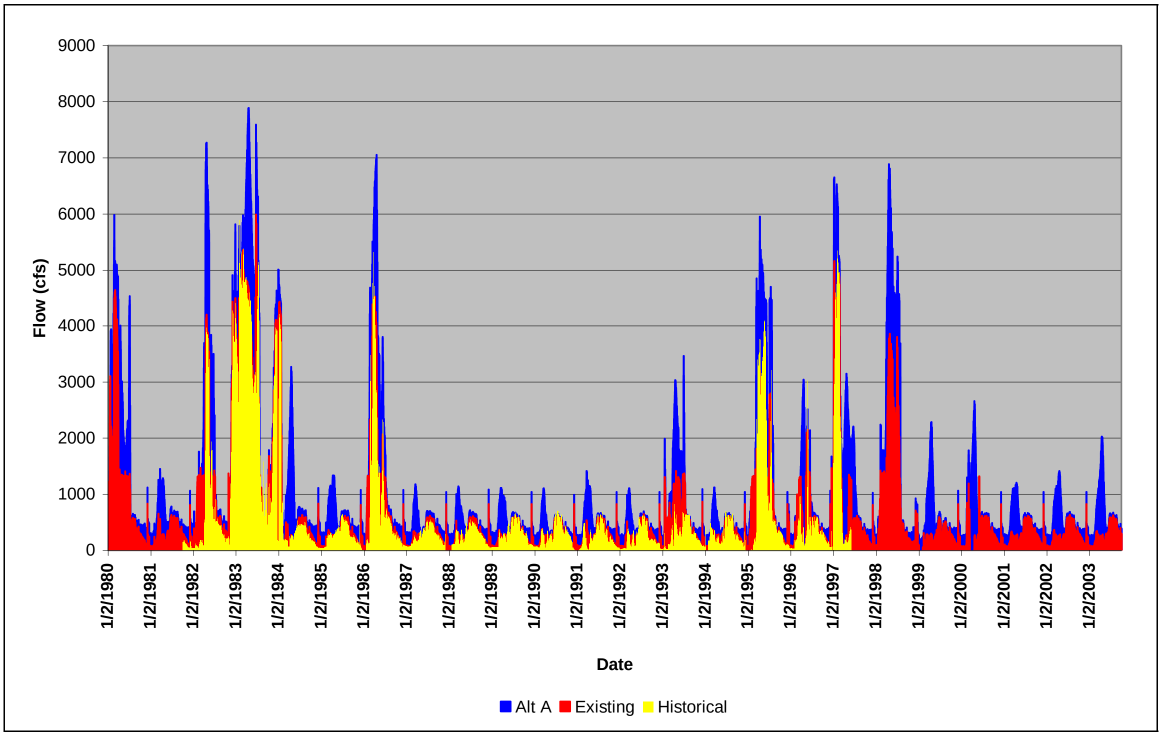


Figure 2-4.
Discharge at Mendota Pool: Alternative A, Baseline, and Historical Gage Flow Regimes

3.0 Results

Results from each simulation were compared using a vegetation measure of plant productivity area in square feet, plant productivity width in feet, or as a ratio comparing Alternative A productivity values to Baseline productivity values. Plant productivity is a measure of total vegetation output for the reach, while plant productivity width relates vegetation output to cross-section geometry.

Plant productivity is computed from vegetated area for each vegetation type. Vegetated area for each vegetation type was recorded in the simulations every 183 days, providing one summer (July) and one winter (December) measurement for each year of the flow record. The number of 183-day periods is 47 for the Baseline and Alternative A simulations, 31 for Historical Gage regime from Friant Dam to Mendota Pool, and 34 for Historical Gage regime between Mendota Pool and Merced River. Plant productivity area is the average sum of native or invasive vegetated area based on winter and summer measurements. There are three native vegetation types: Fremont cottonwood, Gooding's black willow, and narrow-leaf willow; and two invasive vegetation types: arundo and red sespania. Subsequently, plant productivity area and plant productivity width may be as great as two to three times larger than actual predicted area of vegetation since it is calculated as the summation of two to three vegetation types that may share the same cross-section points. Grass plant productivity was not reported since, as used here, these dry land plants can persist outside the floodplain.

3.1 System Comparison of Alternatives

Plant productivity width and mortality for Baseline and Alternative A conditions in the main channel from Friant Dam to the Merced River confluence are shown in Figure 3-1. When Reach 4B1is included, there is 47 percent more native plant productivity predicted from Alternative A Conditions then from Baseline Conditions. The estimate of existing vegetation in R4B1 however is low, making the increase between Baseline and Alternative A plant productivity larger. The vegetation in Reach 4B1 under Baseline Conditions is probably not accurately represented because this reach is not under riverine conditions for which the SHR-1DV is designed. If Reach 4B1 is excluded from the computation, Alternative A Conditions have 33 percent more native plant productivity than Baseline Conditions. Both values of percent difference exclude vegetation in the Eastside and Mariposa bypasses.

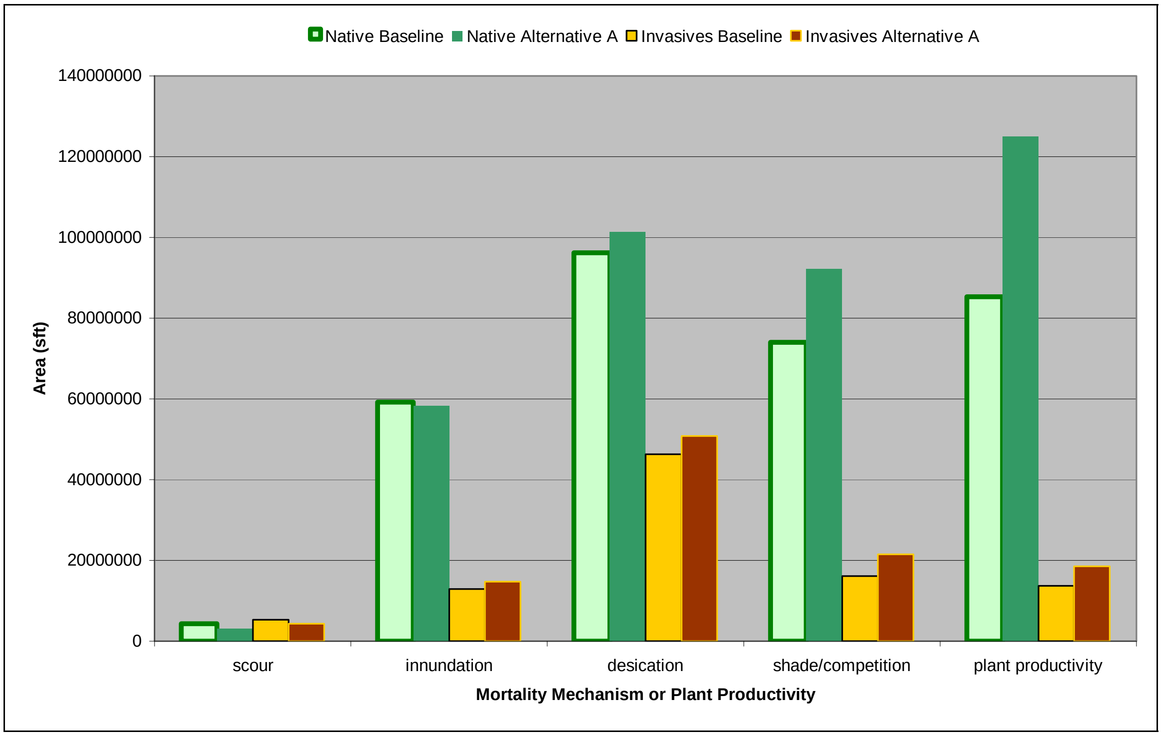


Figure 3-1.
Systemwide Comparison of Mortality Area and Plant Productivity

3.1.1 Native Vegetation

Mortality values for both conditions are listed in Table 3-1 as ratios of total mortality area to growth area. Results suggest that a Baseline flow regime on average removed almost three times (2.74) the native vegetation growth area by scour, inundation, desiccation, or competition/shading, and the Alternative A flow regime removed twice the growth area. Mortality-to-growth values greater than 1 indicate that the model allows reestablishment of plants at the same point in a single season.

Table 3-1.
Ratio of Total Mortality Area for Each Mortality Mechanism Divided by Baseline Total Plant Productivity Area

Hydrologic Condition	Scour	Inundation	Desiccation	Shade/ Competition	Removal Area/Growth Area
Natives					
Baseline	0.05	0.69	1.13	**0.87**	2.74
Alt A	0.03	0.47	0.81	0.74	2.04
Invasives					
Baseline	0.39	0.94	3.37	1.17	5.87
Alt A	0.23	0.79	2.75	1.16	4.94

3.1.2 Invasive Vegetation

Despite their pervasiveness in the field, computed invasive plant numbers were smaller than native plant numbers. If plant productivity is divided by number of plant types (i.e., invasive productivity divided by two for two invasive plant types and native productivity divided by three for three native plant types), there is more than four times more native plant area than invasive plant area. Shallow roots of invasive plants restrict invasive coverage to a fairly narrow elevation band along the banks of the river. However, germination periods for invasive plants are not restricted to narrow seed dispersal windows of native plants, and therefore, their reestablishment numbers (ratio of removal to growth) are higher at five to six for invasive vegetation in contrast to two to three for native vegetation.

3.1.3 Type of Vegetation Removal

In a systemwide comparison, both native and invasive vegetation was removed most often by desiccation (Figure 3-1). Desiccation was the dominant mortality for invasive vegetation. Shading and competition between plants and inundation also removed many native plants. Scour removes very little vegetation with either Baseline or Alternative A Conditions.

3.2 Comparison of Alternatives by Reach

Reach divisions presented in Table 2-7 were used in this comparison of Alternative A and Baseline conditions. Reach profiles are illustrated in Figure 3-2. For reach comparisons, the vegetation indicator plant productivity area is replaced by width of plant productivity to remove independent factor reach length (area/reach length equals reach width) from the assessment. Because multiple species can occupy the same point, productivity width may be two (two invasive vegetation types) to three (three native vegetation types) times wider than the actual width measured along the cross section in the field.

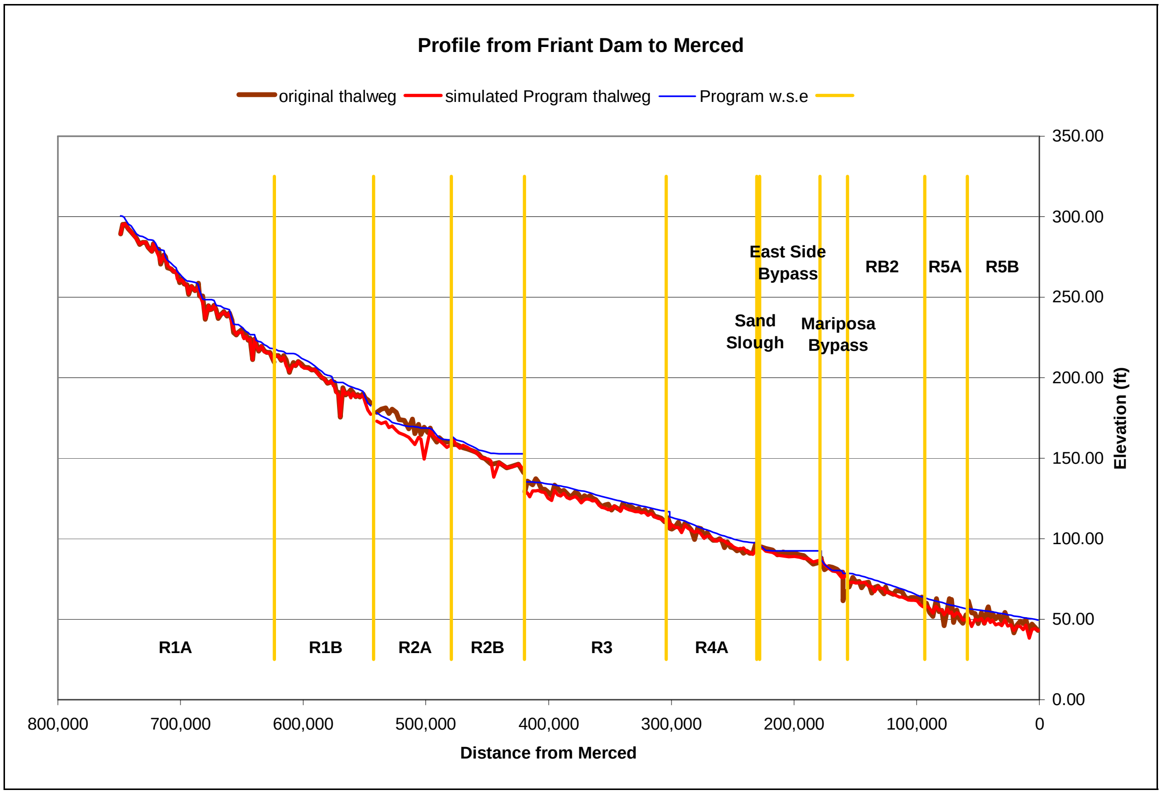
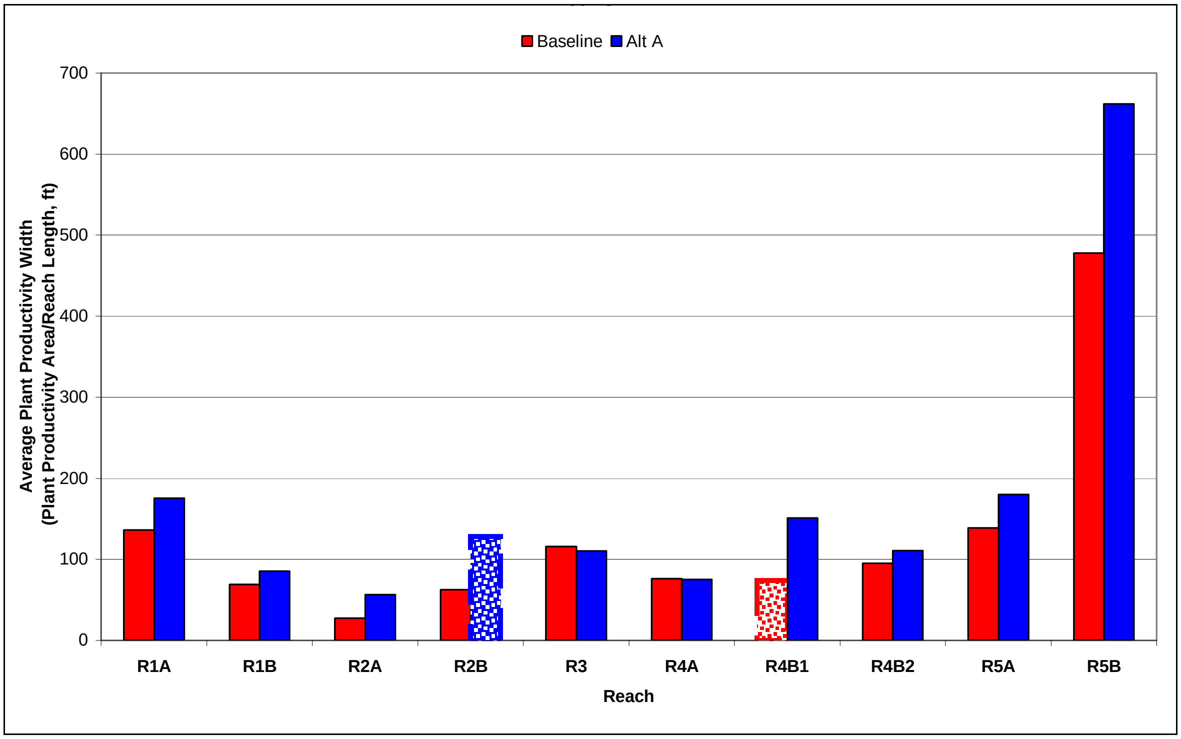


Figure 3-2.
Profile of San Joaquin Thalweg from Friant Dam to Merced

3.2.1 Native Vegetation

Average productivity width for each reach with either Baseline or Alternative A flow regimes are shown in Figure 3-3 for native vegetation. Baseline vegetation in Reach 4B1 is estimated from similar Reach 2A results, based on current conditions with no flow release into this reach. An Alternative A value for Reach 2B1 is also estimated from similar Reach 2A conditions. Both Reach 2A and Reach 2B1 results are discussed in later sections. Large base flow and more frequent, less than 8,000 cfs, peaks simulated in Alternative A hydrology appear to have a measurable effect on native vegetation. In most reaches, modeling predicted Alternative A Conditions would increase plant productivity width from Baseline Conditions. Exceptions are Reaches 3 and 4A, where plant productivity width decreased slightly or remain the same. Compared with Baseline flows, predicted increases in invasive plant productivity widths under Alternative A flows was an average of 30 percent excluding reaches with estimated values. “Estimated” values mean that there was some modification to the values obtained directly from SRH-1DV. The procedure for this estimation is discussed in later sections. When estimated values for Reaches 2B and 4B1 are included, predicted average increase is 44 percent.

Results suggest that as the channel and overbank area become more complex, productivity increases. Examples are Reaches 1A, 5A, and 5B. Reach 1A is complex due to multiple channels and gravel ponds. Wide floodplains and more side channels are present in Reaches 5A and 5B, within the San Luis National Wildlife Refuge, where the channel was not confined for agricultural development (Figure 3-4). Productivity width was considerably greater in Reach 5B than all other reaches. Reaches 2A and 2B had unique conditions discussed in a later section.



Note: Reach 2B Alternative A and Reach 4B1 Baseline are estimated from the percent difference between R2A Baseline and Alternative A.

Figure 3-3.
Native Plant Productivity Width for Baseline and Alternative A Flow Regimes

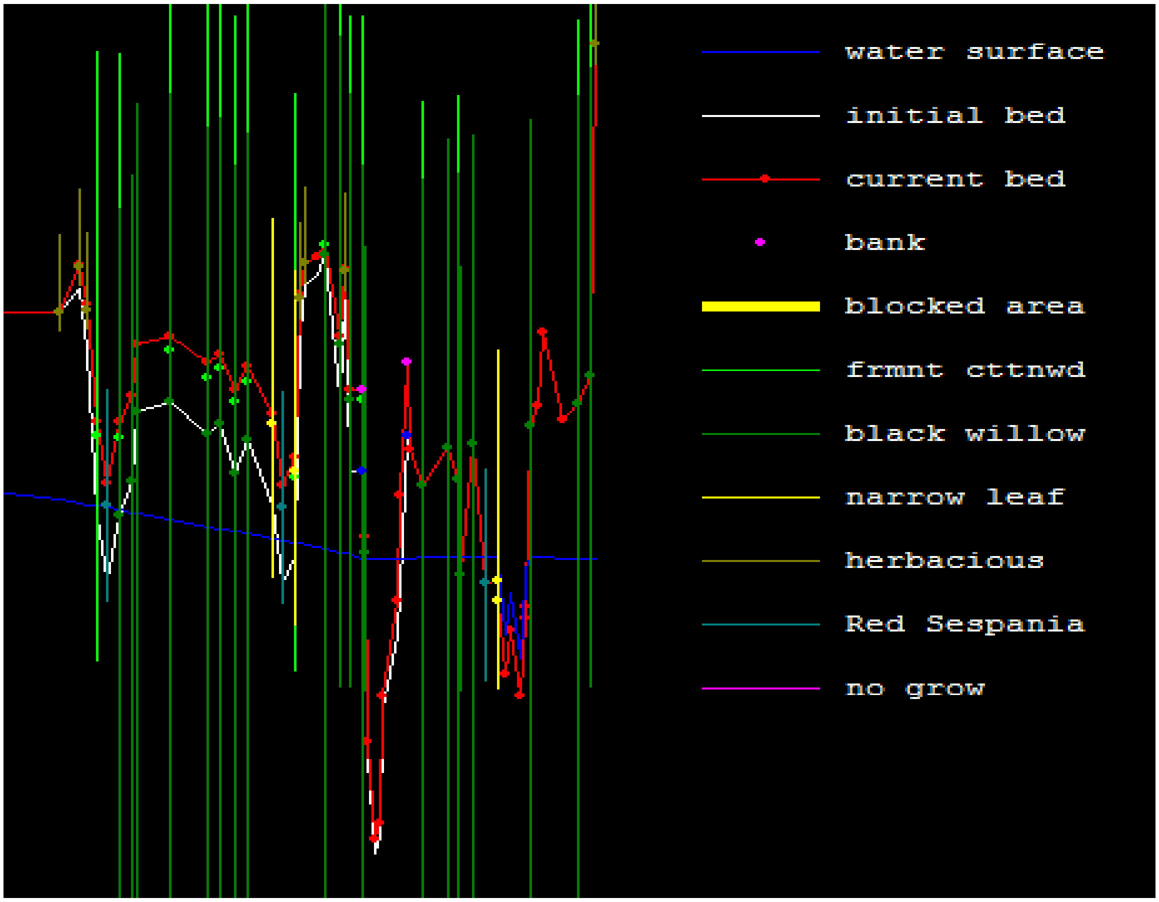
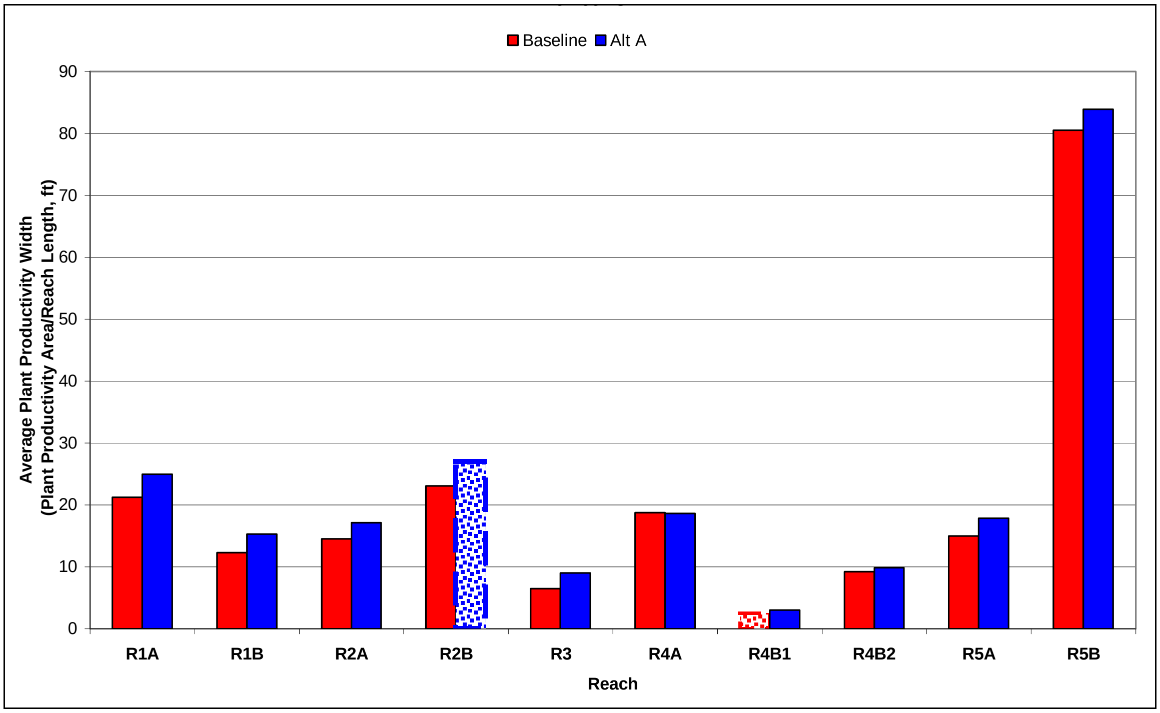


Figure 3-4.
Complex Channel from Reach 5B (MMxs170) with Cottonwood and Black Willow Across the Wide Floodplain, Narrow-Leaf Willow in Side Channels and Grass on High Points

3.2.2 Invasive Vegetation

Plant productivity widths for invasive plants were smaller than values for native plants (Figure 3-5). This distinction may be due to the shallower root system of both invasive vegetation types represented in the model. Invasive roots extend a maximum of 3.5 feet into the ground surface, while native species can have taproots up to 30 feet below the surface. These root depths limit invasive species to locations in close proximity to relatively stable groundwater and surface water. Compared with Baseline flows, predicted increases in invasive plant productivity widths under Alternative A flows was an average of 16 percent excluding reaches with estimated values. Plant productivity width for invasive vegetation in all reaches in the study area have a similar pattern to native plant productivity values.



Note: Reach 2B Alternative A and Reach 4B1 Baseline are estimated from the percent difference between R2A Baseline and Alternative A

Figure 3-5.
Average Invasive Plant Productivity Width for Baseline and Alternative A Flows

3.3 Mortality by Reach and Flow Alternative

Plant mortality for native vegetation is shown in Figure 3-6 and mortality for invasive vegetation is shown in Figure 3-7. Shading and competition removed most native plants in Reaches 1A, 1B, and 2A, while desiccation removed more plants in the downstream reaches with accessible overbank areas. Scour accounted for very little plant removal and most often occurred in the upstream, steepest reaches, Reaches 1A and 1B. Invasive vegetation showed similar trends with desiccation accounting for more plants in the downstream reaches. Desiccation accounted for the most invasive plant removal followed by shading and competition, which eliminated the most plants in the upstream reaches.

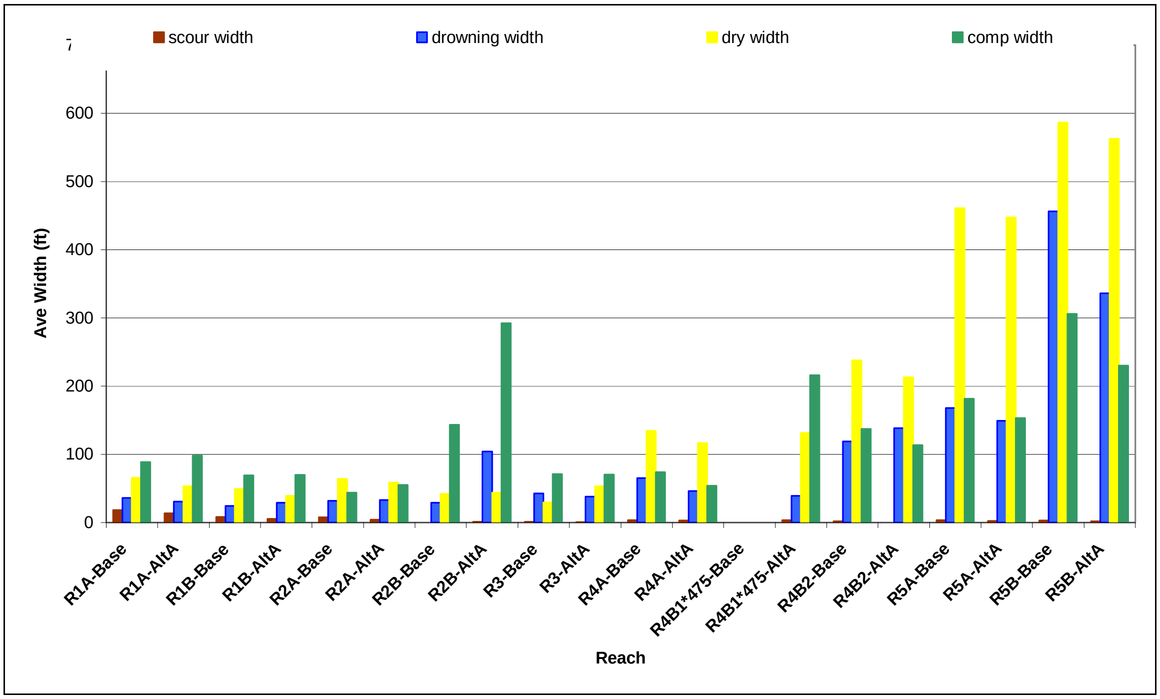


Figure 3-6.
Native Vegetation Mortality with Baseline and Alternative A Flows

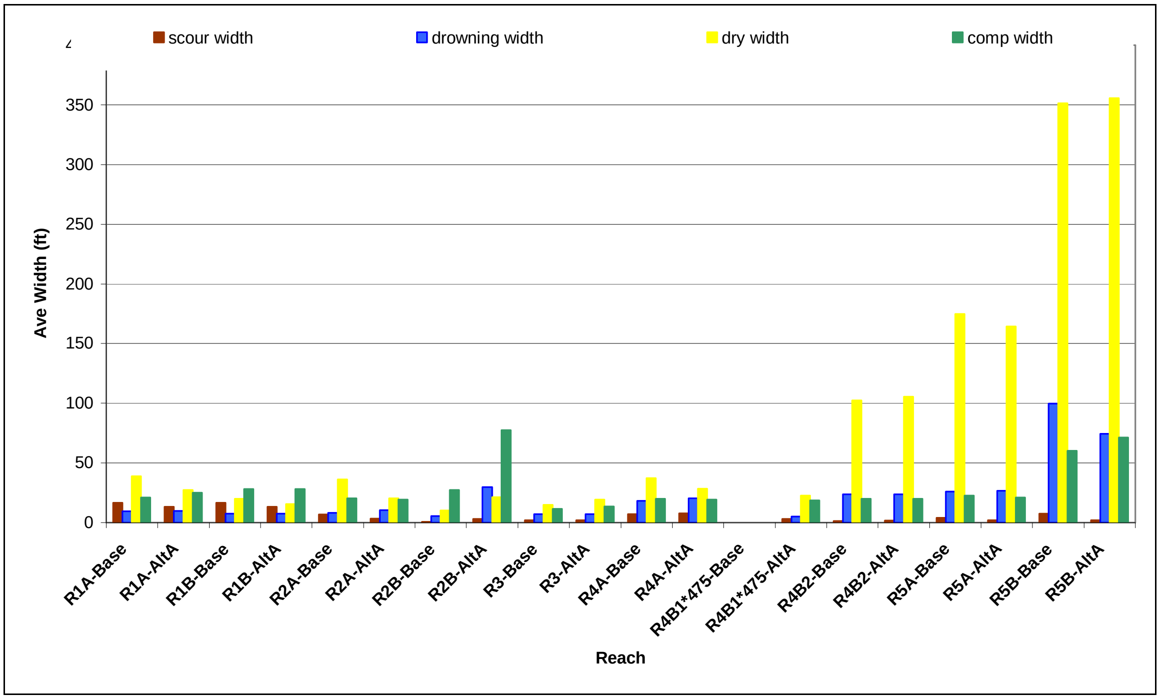


Figure 3-7.
Invasive Vegetation Mortality with Baseline and Alternative A Flows

3.4 Wetting Reach 2A and 2B

There is limited flow and vegetation in Reaches 2A and 2B under Existing Conditions and vegetated width is anticipated to increase with an Alternative A flow regime. Important distinctions between the flow regimes are the base flow and peak flows. Discussion of the Historical Gage flow regime is included here to help anticipate future change. In Reach 2B Historical Gage regime has large peak flows but multiple years of no-flow periods at Reach 2B; Baseline hydrology has similar no-flow periods but with substantially smaller peak flows (less than 7,000 cfs) of shorter durations; and Alternative A hydrology has the largest base flows with periodic small (less than 7,000 cfs) peak flows (Figure 3-8). Base flow in Alternative A with periodic small peak flows is more successful than Baseline flows in supporting greater native vegetation coverage with Reach 2B.

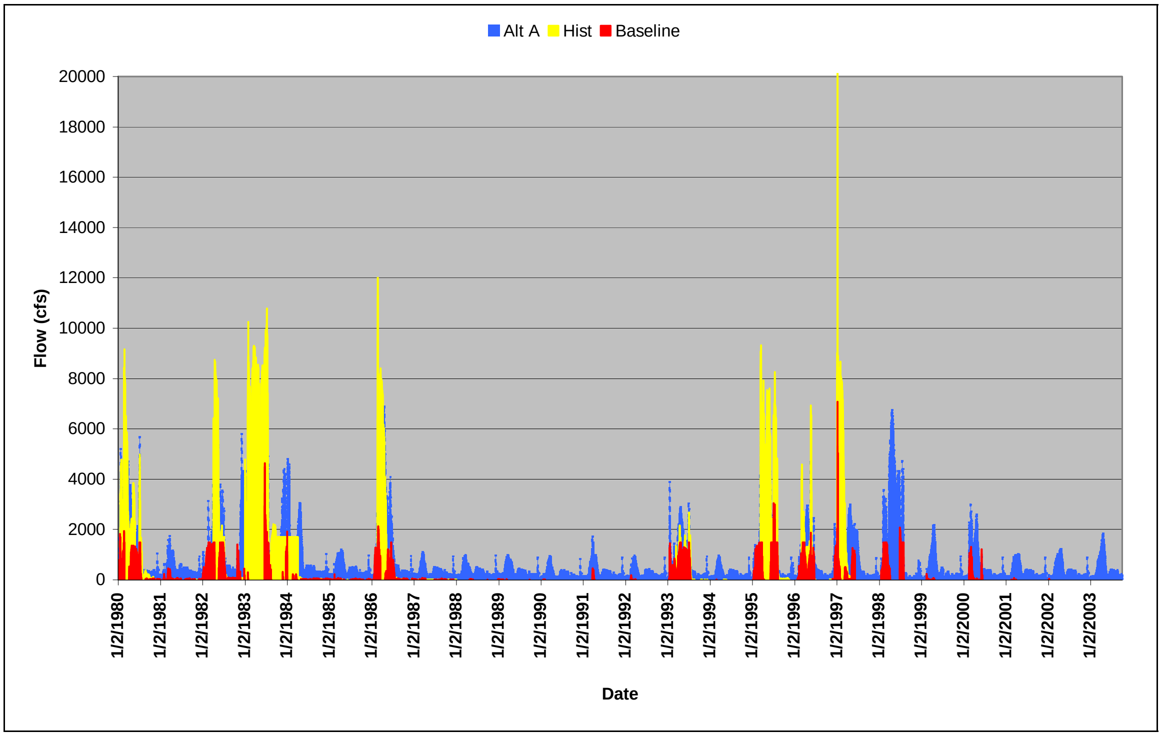


Figure 3-8.
Historical, Baseline, and Alternative A Flow Regimes at Reach 2B

3.4.1 Limited Vegetation

Reach 2B has historically been a dry reach with most flows diverted to the Chowchilla Bypass. Aerial photographs from 2004 show Reach 2A has also been dry due to seepage. Figure 3-9 shows an upstream section of Reach 2A below Gravelly Ford where the channel goes dry. The lack of vegetation in the 2004 aerial photographs continues from Gravelly Ford downstream to the upstream end of Reach 2B, shown in Figure 3-10. Native plant productivity width under Baseline flows is small compared to upstream Reaches 1A and 1B (Figure 3-4), reflecting the lack of flows to sustain vegetation. Increased base flow with Alternative A is predicted to double plant productivity, if no vegetation control measures, such as those included in the PEIS/R Program Alternatives, were applied. Invasive plant productivity width reflects a similar trend but has a much smaller increase (18 percent). Even with the increased flow under Alternative A flow management, plant productivity width in Reach 2A is less than values for Reach 1B and much less than Reach 1A values. This smaller number is presumably due to less available and accessible floodplain resulting from levees beginning in this reach.

Figure 3-9.
Downstream form Gravelly Ford at the Upstream End of Reach 2A, Both Flow and Vegetation End in the Channel in this 2004 Aerial Photo

Note: White channel on right is dry sand and green channel on left has some wetted area and vegetation.

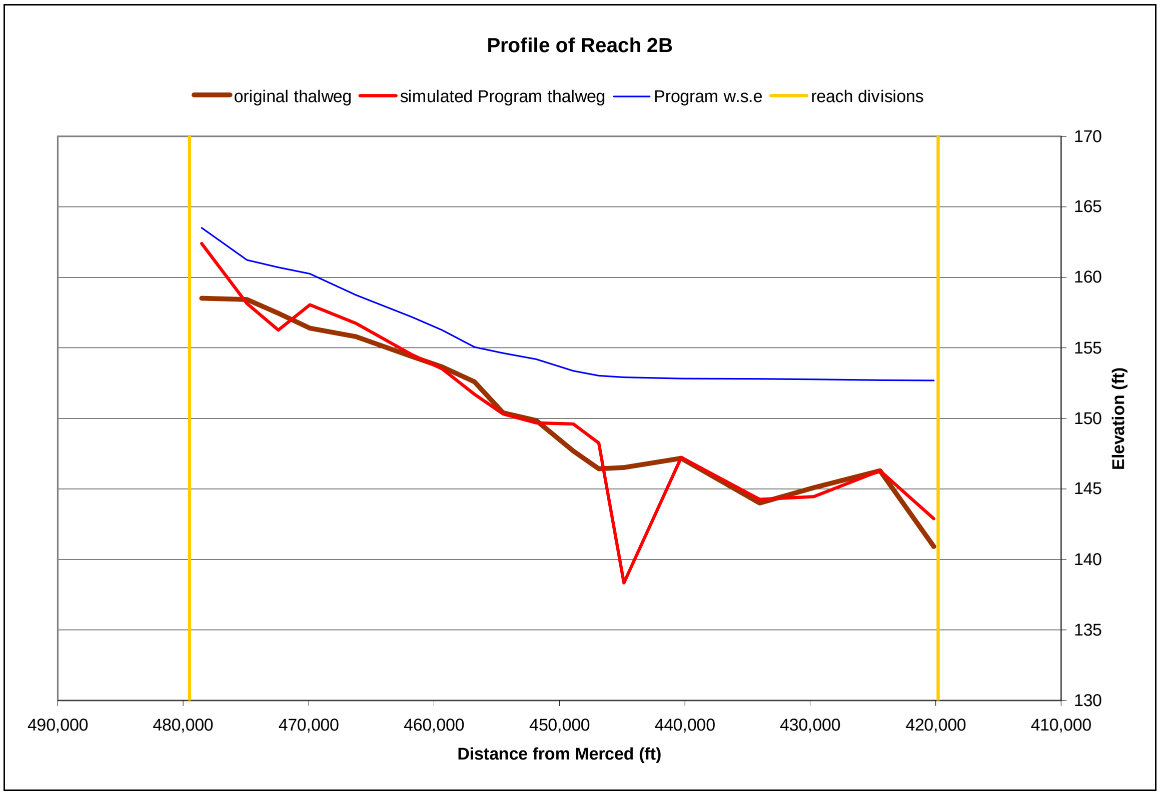
Figure 3-10.
Downstream from Chowchilla Bifurcation Structure (at the flow split in the lower right corner), Wet Conditions and Vegetation Return to Reach 2B in the Center of this 2004 Aerial Photo

3.4.2 Backwater in Reach 2B

Although there is no flow delivery to Reach 2B there is a transition in this river section from dry to wet with vegetation appearing in the floodplain. Numerical modeling predicts this transition (Figure 3-11) with surface water, groundwater, and vegetation interactions that demonstrate the effect of Mendota Pool backwater that extends upstream approximately one-half the distance of Reach 2B (Figure 3-12). The modeled location of backwater effects on surface water and groundwater in Figure 3-13 is similar to the location of vegetated area in the Figure 3-11 aerial photo. A groundwater pillow maintained by the Mendota Pool water surface helps to maintain vegetation in the downstream half of Reach 2B.

Note: Transition from dry channel to vegetated channel with surface water occurs more than one-half the distance upstream the reach from the Mendota Dam.

Figure 3-11.
Reach 2B Beginning at the Chowchilla Bifurcation and Ending at Mendota Pool Downstream from the Fresno Slough



Note: Thalweg profiles of Existing Conditions (1998 topography) and of Alternative A in Reach 2B after a simulation of 24 years of Alternative A flow regime.

Figure 3-12.
Channel Surface Water Computed in Modeled Reach 2B Indicates Backwater Effect of Mendota Pool Extends Upstream One-Half the Distance of Reach 2B, or More

Modeling predictions for Reach 2B indicate native plant productivity width should be almost 200 feet for Alternative A Conditions. This is higher than the value shown in Figure 3-4, for Reach 2B, Alternative A Conditions. A value of 200 feet appears artificially high and may be explained by two considerations. First, as the Mendota Pool backwater increases, roots of more vegetation in the overbank area have access in the model to groundwater, increasing plant productivity in low points of overbank areas behind the levees. To reduce the variability in plant productivity behind the levees, a no-grow designation was assigned to all cultivated lands, including those lands behind the levees in Reaches 2A and 2B (Figure 3-13). However, not all lands behind the levees are cultivated, so a set of simulations was used to assess groundwater sensitivity. This study is described in a later section and indicated plant productivity is sensitive to the maximum height of groundwater. A maximum groundwater height of 1 foot above the ground is used to provide conservative plant productivity numbers.

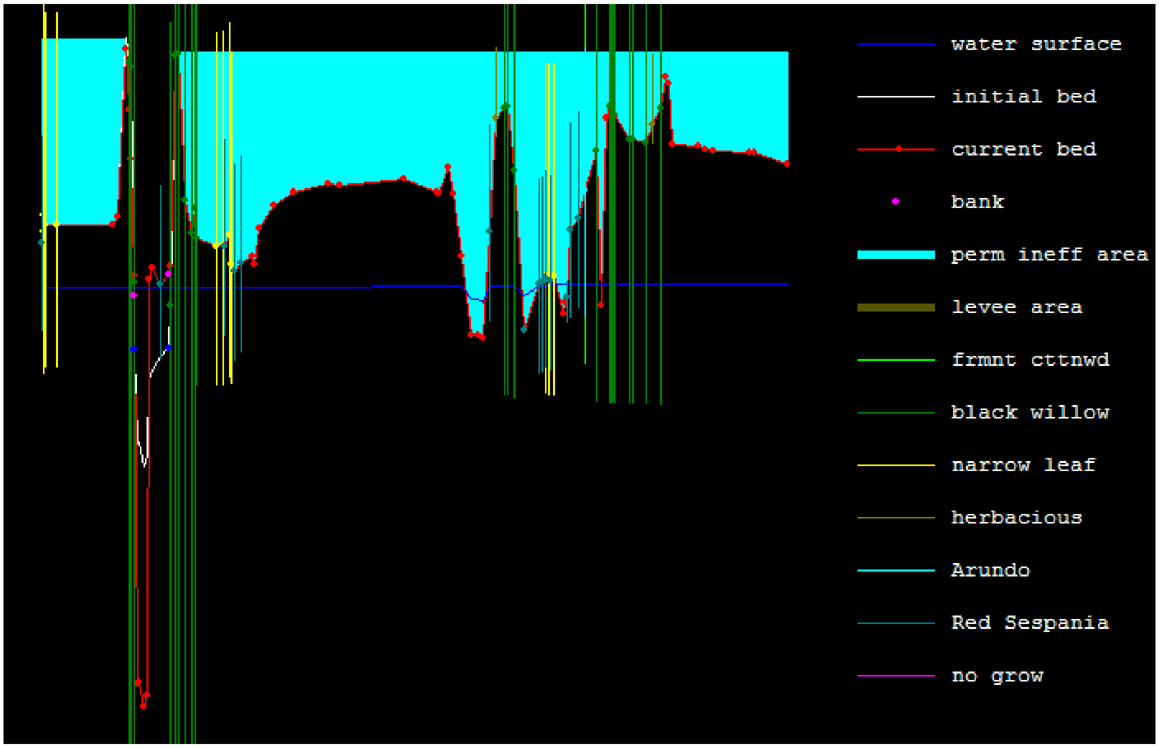


Figure 3-13.
Complex Channel in Reach 2B with a No Grow Area (agricultural lands) on the Right Side of the Figure Behind the Short Levee, and Black Willow, Narrow-Leaf Willow, Arundo and Red Sespania at Low Areas and in Remnant Side Channels

Vegetation in the overbank area is also overestimated due to the use of simple 1D calculations (width * depth equals vegetated area) in computing coverage. This computation works well at most locations along the river but when meander bends are closely spaced and aligned both down valley and cross valley, which occurs in the downstream end of Reach 2B (Figure 3-12), the area represented by cross sections can overlap and the vegetated overbank area can be double counted. Both factors contribute to an over-large plant productivity width for Alternative A in Reach 5B. The overestimate in Reach 2B was adjusted by applying the same percent difference between Baseline and Alternative A values from Reach 2A to Reach 2B. The simulated difference between alternatives in Reach 2B is a factor of 3, while estimated difference is a factor of 2. The estimated difference is shown in Figure 3-4.

3.5 Overbank Areas and Levees in Reach 2B

Two simulations of levee setback conditions were modeled with Alternative A flows: an Average Levee Setback (ALS) condition and a Maximum Levee Setback (MLS) condition. Both levee setbacks resulted in increased vegetated area. Contrary to initial expectations, the MLS produced less vegetation than the ALS for both native and invasive vegetation. One possible explanation is associated with a finding for Reach 2B in the sediment transport analysis. More deposition occurred in the channel with the ALS simulation, while more floodplain deposition occurred with the MLS. With more overbank deposition and less channel deposition, there was less occurrence of overbank wetting and subsequently less opportunity for vegetation establishment. Also, the topography resulting from the MLS predicted a larger elevation difference between base flow water surface elevations and adjacent overbank surface, thereby requiring slightly deeper roots and faster root growth rates. Modeled results indicate levee setbacks may double vegetated area, but this value is also subject to the overestimation described in the previous section (double counting at the cross valley aligned meander bends and some uncertainty in the actual groundwater elevation at low points in the overbank areas). Allowing for some overestimation, increases in vegetation from levee setbacks could range from a factor of 1.5 to 2. Considerations for levee design should include sediment transport deposition patterns and elevations of peak flow access to the benches.

3.6 Wetting Reach 4B1 vs. Bypass Flows

Reach 4B1 has historically been dry with flows diverted down the Eastside Bypass and returned via the Mariposa Bypass at the upstream end of Reach 4B2 or returned via the Eastside Bypass at the upstream end of Reach 5. Under Alternative A Conditions, Reach 4B1 flow is a maximum of 475 cfs with all flows exceeding this rate diverted to Eastside Bypass through the Sand Slough. Consequently, low variability is associated with this flow regime, as shown in Figure 3-14.

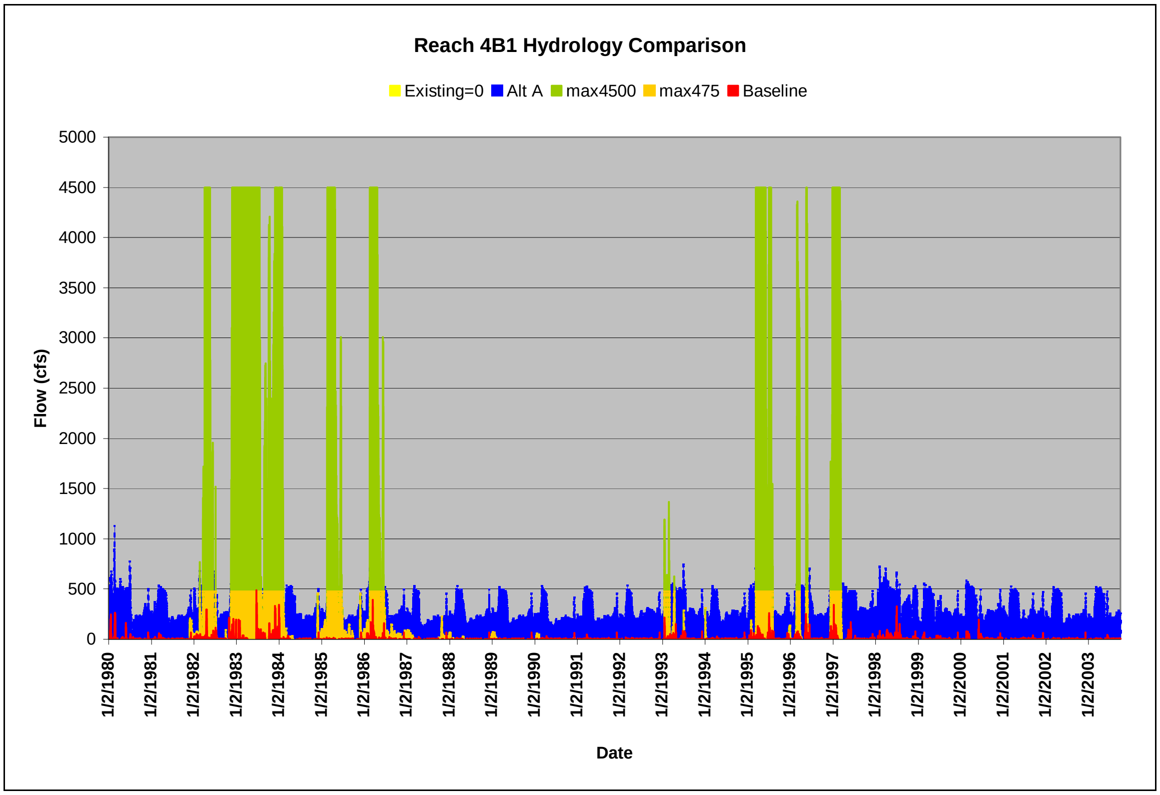


Figure 3-14.
Main Channel Flow Alternatives for Reach 4B1

Currently, the Reach 4B1 channel is filled with well-established vegetation (Figures 3-15 and 3-16). The productivity width for this reach is predicted to be almost as large as Reaches 1A and 5A under Alternative A flows. It would take multiple years for mature woody vegetation to be eliminated and even longer for debris to be removed with natural processes, but over time the productivity width is predicted to decrease. Decrease in vegetation coverage is anticipated to occur in the low-flow channel where there is continuous flow.

Figure 3-15.
2004 Aerial Photograph Showing the Channel of Reach 4B1 Filled with Vegetation

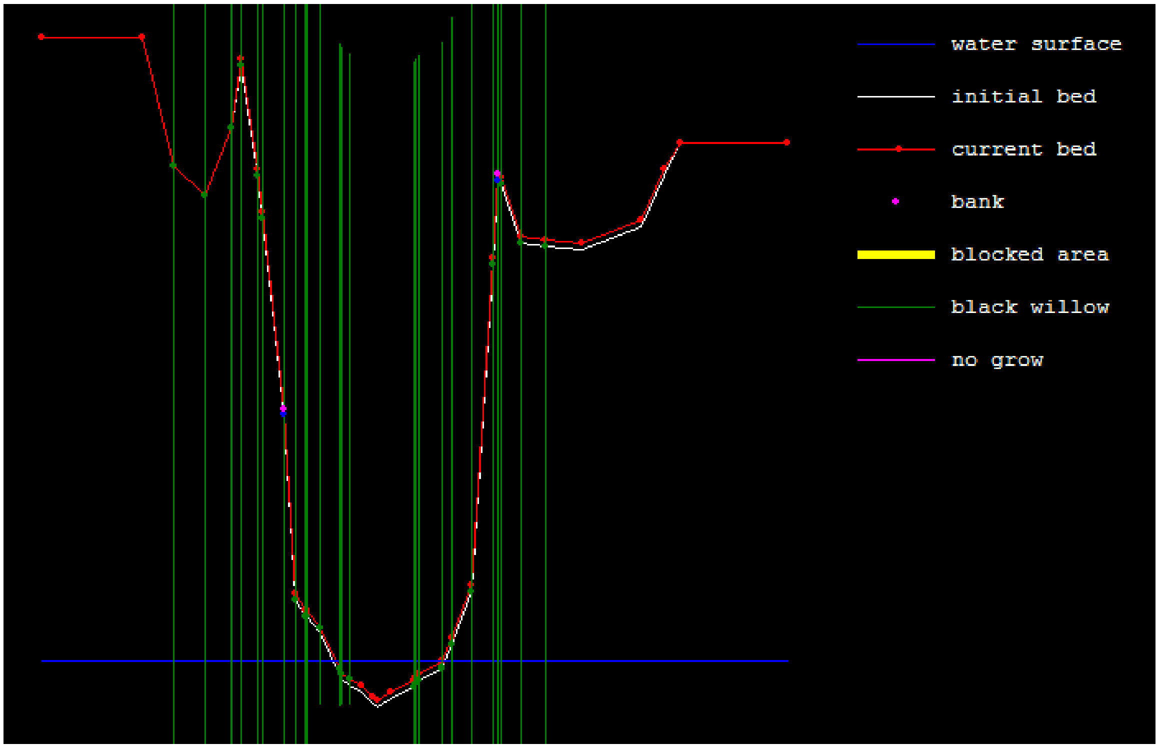


Figure 3-16.
A Simple Cross Section in Reach 4B1 with Mature Gooding's Black Willow Filling Much of the Channel

3.7 Reach 5B

Reach 5B has substantially more plant productivity with both Baseline and Alternative A flows. This increase is justifiable because Reach 5 has a wider, less-limited floodplain, a lower gradient that promotes overbank interactions, and good floodplain connectivity and interactions from both surface water and groundwater processes. However, similar to Reach 2B, there are compressed and cross-valley meander bends in Reach 5 (Figure 3-17), and necessary doglegs in the cross sections can create overestimates of vegetative cover when computed with simple 1D area computations (productivity area equals river length multiplied by cross-section width). Plant productivity widths in Figures 3-4 and 3-6 are probably overestimated; however, this reach is still believed to support more vegetation than upstream reaches and still anticipated to have more increase with implementation of project flows.

Note: Not all cross sections shown here were used in the flow-sediment and flow-sediment-vegetation models, but the cross sections help visualize how simple 1D computations of area can result in overestimates of plant productivity.

Figure 3-17.
Example from Reach 5B of complex meander bends.

3.8 Eastside and Mariposa Bypasses

Alkali soils in the area of the Eastside and Mariposa bypasses are believed to be slowing vegetation growth. Alkali soils are modeled as no-growth areas. However, if alkali soils are not limiting vegetation establishment and growth, vegetation in both the Eastside and Mariposa bypasses would be expected to decline due to reductions in flows to the bypass under Alternative A hydrology. Up to 475 cfs would remain in the main channel of the formerly dry Reach 4B1with Alternative A. Reductions in flow in the Eastside Bypass would be less noticeable than reductions in the Mariposa Bypass because more flow is conveyed in the Eastside Bypass.

3.9 Sensitivity to Groundwater

A set of simulations of the program area were used to test the sensitivity of plant productivity to overbank groundwater elevations. Maximum elevation can be specified with respect to the ground to prevent groundwater surfaces outside of levees and specified confining bank locations, from rising to the elevation of the channel water surface. Testing was repeated with a maximum groundwater level of 1 foot above the ground and 1 foot below the ground. A maximum groundwater level of 1 foot below ground prevented most new seedling generation, which underestimated plant productivity. A water surface 1 foot above ground provided maximum plant productivity in most cases that was comparable to an unrestricted groundwater surface. At 1 foot above ground, groundwater could cover the root cap of plants and was sufficient to cause inundation.

Simulations with -1 foot groundwater compared to maximum groundwater elevation of +1 foot caused differences in plant productivity typically ranging from 3 to 40 percent in most reaches. Groundwater was assigned a maximum elevation +1 foot above the ground surface in the final simulations.

3.10 Sensitivity to Root Growth Rate and Groundwater Conductivity

Model sensitivity to the input parameters of maximum root growth rate and groundwater conductivity were tested with root growth rates of 1.5 centimeter (cm)/day versus 2.5 cm/day and groundwater conductivity of 100,000 feet/day versus 500,000 feet/day. Results are shown in Figure 3-18. In most cases, the difference in results was relatively small, even when both parameters were adjusted. Values used in the final simulations were 2.5 cm/day for root growth rate and 500,000 feet/day for conductivity.

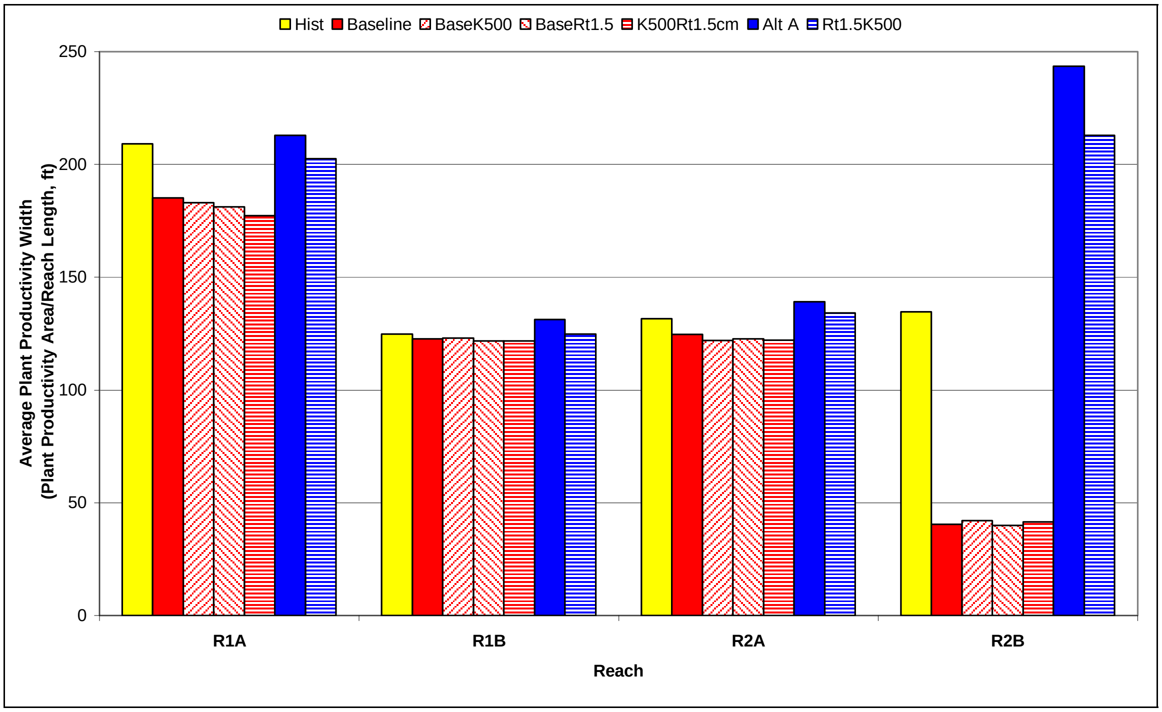


Figure 3-18.
Sensitivity Testing of Root Growth Rate Values of 2.5 cm/Day and 1.5 cm/Day, and Groundwater Conductivity of 100,000 and 500,000

3.11 Sensitivity to 1997 Flow Year

The 1997 flow year was a wet year and contained a large peak flow event. To check that this flow was not having an undue effect on results, the simulations for the Mendota–to-Merced bypass route were repeated with discharge data for 1997 removed from Baseline hydrology and Alternative A hydrology. Average widths of native vegetation in Reaches 3 and 4A remained identical, and differences in average widths for native vegetation in downstream bypasses and reaches were small. Results for invasive vegetation were similar. Effects of 1997 flow year on vegetation were detectible but small enough to include daily discharge for 1997 in later simulations.

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4.0 Reach Summary

Vegetation modeling of the San Joaquin River study area is used as a quantitative predictive tool to understand natural processes and address SJRRP vegetation questions. Modeling results are first reviewed in a system assessment, and then considered by reach. Results from the system assessment showed Alternative A flows had 47 percent more native plant productivity area and 34 percent more invasive plant productivity area. This is considered an overestimate of increases in plant productivity and should not be applied directly in conveyance estimates as an increase in vegetated area in the field because there are:

- Increases from overbank areas in Reaches 2B and 5B where compressed and cross-valley meander bends and doglegs in the cross sections create double-counting of actual plant productivity area
- Increases in plant productivity can occur in overbank areas of the floodplain, occasionally behind levees where there are limited changes to actual flow conveyance
- Plant productivity is a multiple of actual vegetated area depending on the number of vegetation types modeled (native vegetation is a multiple of 3 for Fremont cottonwood, Gooding's black willow, and narrow-leaf willow and invasives are a multiple of two for red sespania and arundo)

These values represent a maximum increase in plant productivity, not to be confused with an average field-measured increase in vegetated area. A comparison of plant productivity by reach for Baseline and Alternative A conditions is presented in Table 4-1.

Table 4-1.
Ratio of Alternative A to Baseline Plant Productivity Width (Feet) for Native and Invasive Vegetation

Reach	Alternative A/Baseline	
	Natives	Invasives
R1A	1.29	1.17
R1B	1.23	1.24
R2A	2.05	1.18
R2B	2.05*	1.17*
R3	0.95	1.39
R4A	0.99	0.99
R4B1*	2.04*	1.20*
R4B2	1.17	1.07
R5A	1.30	1.19
R5B	1.38	1.04

Note: *Ratio contains an estimated value.

4.1 Reach 1A

Reach 1A begins at Friant Dam and continues to the Highway 99 crossing. Plant productivity width in Reach 1A with Project Conditions (Alternative A) was predicted to increase by 29 percent from Baseline Conditions (Table 4-1). Examining plant productivity width eliminates the variable of reach length from the analysis. Plant productivity width of Reach 1A is larger than downstream Reaches 1B and 2A (Figure 3-5). As the steepest thalweg profile, less fluctuation in the water surface may occur within Reach 1a than in downstream reaches, but the complex shape of the channel and pools within the channel from gravel mining operations provides multiple margins for vegetation establishment. The current channel is located within a wider channel, which is a remnant from pre-dam flows. The oversized floodplain in Reach 1A appears wider and more complex than in downstream Reach 1B.

Increases in base flow and more frequent pulse flows with Alternative A flow actions have increased the simulated amount of riparian vegetation. Reach 1A, like all downstream sections of the river, have been affected by the spread of red sespania and arundo. Red sespania plants colonized the San Joaquin River main channel in recent years and they continue to establish downstream when high flow transports large seed pods. Arundo can be spread through rhizoids or other parts of the plant that break off and wash downstream during high flows. Invasive vegetation is predicted to increase by 17 percent under Alternative A, as compared to Baseline Conditions (Table 4-1). Native plants under Baseline and Alternative A conditions are primarily removed by shading/competition, while invasive plants under Baseline and Alternative A conditions are primarily removed by desiccation.

4.2 Reach 1B

Reach 1B begins at the Highway 99 crossing and continues to Gravelly Ford. In Reach 1B, the floodplain leaves the terraced configuration of the upstream Reach 1A but the floodplain width is reduced by agrarian practices that abut the river (Figure 4-1). Reflecting this topography difference, plant productivity for Reach 1B is less than plant productivity in Reach 1A (Figure 3-4). Despite this feature change, cross sections in Reaches 1A, 1B, and 2A are similar in shape with the current channel often incised within an oversized channel that is a remnant from pre-dam flows. However, in Reach 1B, water surface fluctuations often remain within the incised location with only occasional overtopping to the higher bench of the former river bed, which can often support vegetative cover. Plant productivity width for native vegetation in Reach 1B is predicted to increase 23 percent (Table 4-1) with Alternative A Conditions in response to increased base flows and consistent small flow peaks. Invasive vegetation is predicted to increase 24 percent from Baseline Conditions to Alternative A Conditions.

Main causes of plant mortality with Baseline and Alternative A flows are shading/competition for both native and invasive plants and there is some plant mortality resulting from scour. Native and invasive vegetation is also removed by inundation and dessication (Figures 3-6 and 3-7).

Note: Cross sections and vegetation mapping define the outer edge of the floodplain that narrows downstream from the highway.

Figure 4-1.
Transition from Reach 1A to Reach 1B at Highway Crossing 99

4.3 Reach 2A

Reach 2A begins at Gravelly Ford and continues to the Chowchilla Bifurcation Structure. Typically the river ceases to flow a few hundred feet downstream from Gravelly Ford and the channel is dry the majority of the year under Existing Conditions in Reach 2A. Plant productivity width decreases from Reach 1B to Reach 2A due to the dryer conditions of Reach 2A. More vegetation is present in the upstream quarter of the reach than in the downstream three-quarters. The downstream subreach of Reach 2A is constricted by levees on both sides of the channel, and limited space is available for vegetation to establish. However native plant productivity doubles from Baseline Conditions when Alternative A flow is introduced. Invasive plants also increase by 18 percent. Desiccation removed most native and invasive plants in Reach 2A, with both Baseline and Alternative A conditions.

In the downstream subreach of Reach 2A, Alternative A flows increased the base level of low flows and subsequently increased vegetation coverage along the banks. However, flows tended to stay in the channel, and the degree of in-channel complexity did not support large increases in vegetation in the downstream reach. There was also deposition predicted in the overbank areas that could limit vegetation coverage on the raised overbank surface.

4.4 Reach 2B

Reach 2B begins at the Chowchilla Bifurcation Structure and continues to Mendota Pool. Like Reach 2A, the upper section of Reach 2B between the Chowchilla Bypass and San Mateo Crossing is generally devoid of flow and supports little vegetation. In contrast, there is riparian vegetation in the lower subreach sustained by groundwater from the backwater effect of Mendota Pool. Vegetation response is determined by location with respect to the Mendota Pool backwater. Alternative A Conditions add surface flow to the upstream subreach to increase the density of vegetation in a relatively barren area. In the downstream subreach, Alternative A flows increase the extent of backwater from Mendota Pool for both surface water and groundwater. Consequently. vegetation survival in the lower subreach is increased both on the banks of the channel and at irregularities in the overbank area where less root depth is needed to access the groundwater surface.

A change in vegetation cover resulting from setting back levees was also assessed in Reach 2B. ALS topography and MLS were compared to existing locations of levees with Project Conditions. Based on current results, levee setbacks could increase native plant productivity by a factor of 1.5 to 2.

In Reach 2B, the main cause of plant removal for both native and invasive vegetation was shading and competition. This mortality value was larger than in other reaches, only exceeded by shading and competition values in Reach 5B. Inundation also removed a large number of both native and invasive plants with Alternative A flows.

4.5 Reach 3

Reach 3 begins at Mendota Pool and continues to Sack Dam. Reach 3 is a single-thread channel with dense riparian vegetation along its banks. There are levees and delivery canals bordering Reach 3 that reduce much of the active floodplain; however, upstream from Firebaugh and at Firebaugh, cultivated fields do not always extend to the banks of the river, leaving some locations of wider floodplain. Flows are relatively constant so management of this reach is similar to operation of a delivery canal. Some additional floodplain and consistent large base flows contribute to a plant productivity value with Baseline Conditions that is larger than plant productivity with Baseline Conditions in upstream Reaches 1B, 2A, and 2B, and downstream Reach 4.

Base flow for Baseline Conditions is similar to base flow for Alternative A Conditions with increases in base flow peaks from about 600 cfs to 1,000 cfs. Peak flows increase 2,000 cfs between the two conditions. This does not create large differences in predicted native vegetation despite increases in flow peaks, native vegetation decreases slightly (5 percent). Invasive vegetation increases by 39 percent. Mortality based on plant productivity is the lowest of any reach for invasive plants and has the third smallest plant removal, behind only Reaches 1B and 1A, for native plants. Shading and competition remove the most native plants while desiccation is the largest cause of invasive plant mortality.

4.6 Reach 4

Reach 4 begins at Sack Dam and continues to the Eastside Bypass at Sand Slough. Reach 4A begins at Sack Dam and ends at the Sand Slough Diversion to the Eastside Bypass. Agricultural land and levees continue to confine much of this reach but the reach is typically dry due to the diversion of flow at Sack Dam. However, seepage from Sack Dam and irrigation return flows provide sufficient quantities of water to support some vegetation between the levees. Seepage from Sack Dam seems to maintain water in the channel for approximately 2 to 3 miles downstream from the dam where vegetation is correspondingly denser. More than 3 miles downstream from Sack Dam, the vegetation is not continuous, and sections of the reach contain only sparsely located woody vegetation. In this downstream subreach, periodically located deep pools can be found that maintain vegetation in the bed of the channel.

Reflecting the lack of flows and confined floodplain, plant productivity drops 35 percent from Baseline Conditions in Reach 3 to Baseline Conditions in Reach 4A. Plant productivity estimates for Baseline Conditions in Reach 4A are still somewhat high because the model at this time does not differentiate between sparsely located woody vegetation and densely located vegetation. Actual plant productivity width for Reach 4A with Baseline Conditions is probably close to the value for Reach 2B Baseline Conditions. As expected, desiccation is the primary mortality mechanism for both native and invasive plants. Plant productivity for Alternative A is equal to productivity for Baseline Conditions in the model simulations. However, with a correction to Baseline Conditions for the density of woody vegetation, the Alternative A value represents an increase.

4.7 Reach 4B1

Reach 4B1 extends from the Sand Slough Control Structure to the return of the Mariposa Bypass. This reach has had very little flowing water since the construction of the Sand Slough Control Structure and has sparsely located woody vegetation with sections of dense riparian vegetation. Levees are not present in the reach to contain flood flows and the downstream subreach of Reach 4B1 is within the San Luis National Wildlife Refuge. Channel within the wildlife refuge is wider and has a well-developed floodplain. The slope is 0.00017, which is the lowest slope of all project reaches. This slope would promote the wider floodplain until it evolves to a steeper grade matching upstream and downstream slopes.

Only Alternative A Conditions were modeled in Reach 4B1. The simulation predicts that the increased flows will sustain more productivity than found in Reach 4A and almost as much plant productivity width as Reach 1A. This is consistent with an increase in available floodplain and increased surface flows. Typical for most reaches of the study area, shading/competition is the primary mortality mechanism with Alternative A flows for native plants, and desiccation is the primary mechanism with invasive plants. Invasive plant mortality values are relatively small in comparison to downstream reaches.

4.8 Reach 4B2

Reach 4b2 extends from the Mariposa Bypass at the upstream end to the return of the Eastside Bypass into the San Joaquin River at the downstream end. This reach is bordered on the south side by the San Luis National Wildlife Refuge. Levees bound the river, but the width between the levees is generally more than 1,000 feet. Plant productivity width for Baseline Conditions is similar to Baseline plant productivity width for Reach 3. Plant productivity in Reach 4B2 is predicted to increase by 17 percent for natives and 7 percent for invasive vegetation with Alternative A flows.

There was limited new vegetation establishment in this reach. Base flows increased the groundwater level, but the simulated flow remained mostly well below the floodplain bench. If there is incision, this condition will be exacerbated. Simulated root depths of narrow-leaf willow roots cannot reach the water surface for long periods and will eventually die from desiccation. One large and long high flow is simulated near the start of the hydrologic record that persisted long enough to remove grasses and establish new native and invasive plants. Root growth of the cottonwood and black willow could reach the new base flow levels and survive while other plants eventually die. Remaining peak flow events occasionally overtopped the floodplain bench, but with grass cover and shaded areas from woody vegetation, very little area was available for new growth.

4.9 Reach 5

Reach 5A extends from the confluence of Bear Creek (which is also the return of flow from the Eastside Bypass) to Salt Slough, and Reach 5B extends from the Salt Slough to the confluence of the Merced River. Both reaches are located within the Fremont Ford State Park and San Luis Wildlife Refuge and are the least disturbed of the project reaches. With access to a wide floodplain and return flow from the Eastside Bypass, plant productivity in Reaches 5A and 5B is larger than in upstream reaches. Plant productivity for Reach 5A is similar to Reach 1A while Reach 5C is substantially larger.

Similar to Reach 2B, compressed and cross-valley meander bends in Reach 5 can contribute to an overestimate of vegetative cover when computed with simple 1D area computations (productivity area equals river length multiplied by cross-section width). Plant productivity width of Reach 5B is probably overestimated, but this reach is still believed to support more vegetation than upstream reaches and still anticipated to have more increase with implementation of project flows. There is good access to the floodplain and roots of narrow-leaf willow extend to base flow/groundwater. New growth occasionally occurred even after the one long-duration peak flow. Desiccation is the primary mortality mechanism for both Reach 5A and Reach 5B.

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