Climate Ready North Bay

Napa County

Project Overview and Sample Data Products

January 2016

prepared by TBC3.org members
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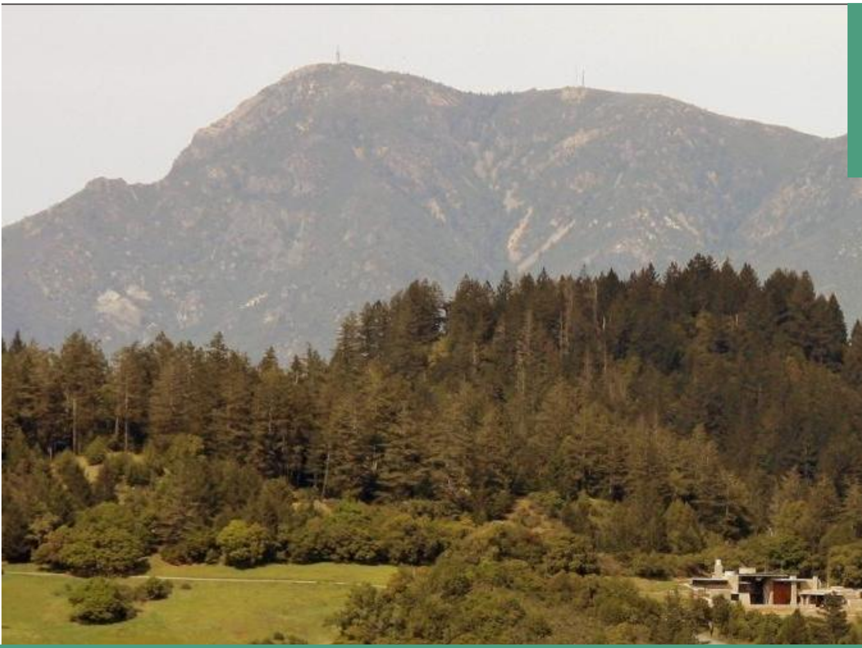
Pepperwood Mission: to advance science-based conservation across our region and beyond

Pepperwood served as project manager of the Climate Ready North Bay vulnerabilty assessment with TBC3 partners including USGS, Point Blue Conservation Science, and University of California at Berkeley.



3200-acre reserve in Mayacamas, partnered with CA Academy of Sciences

The new Dwight Center for Conservation Science

USGS science for a changing world

Berkeley UNIVERSITY OF CALIFORNIA

Point Blue Conservation Science™

Pepperwood PRESERVE Inspiring conservation through science

Table of Contents

RCPA
regional climate protection authority

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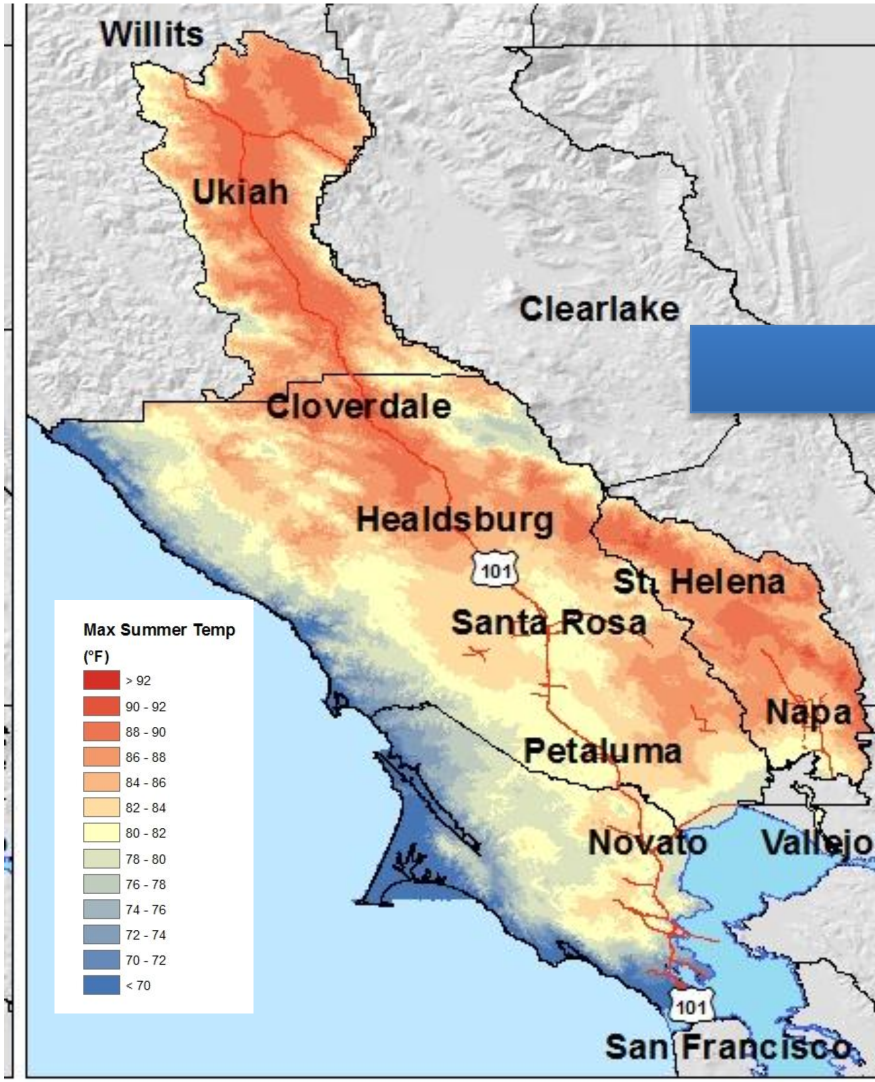
Project overview

Climate Ready North Bay: translating a landscape-level climate-hydrology database into inputs for long-term planning



Source: Climate Ready North Bay 2015

- Warmer temperatures
- Greater hydrologic variability
- Greater evapo-transpiration
- Increased water demand
- Variable runoff and groundwater recharge
- Shifts in natural vegetation types
- Increased wildfire risk
- (Not sea level rise!)

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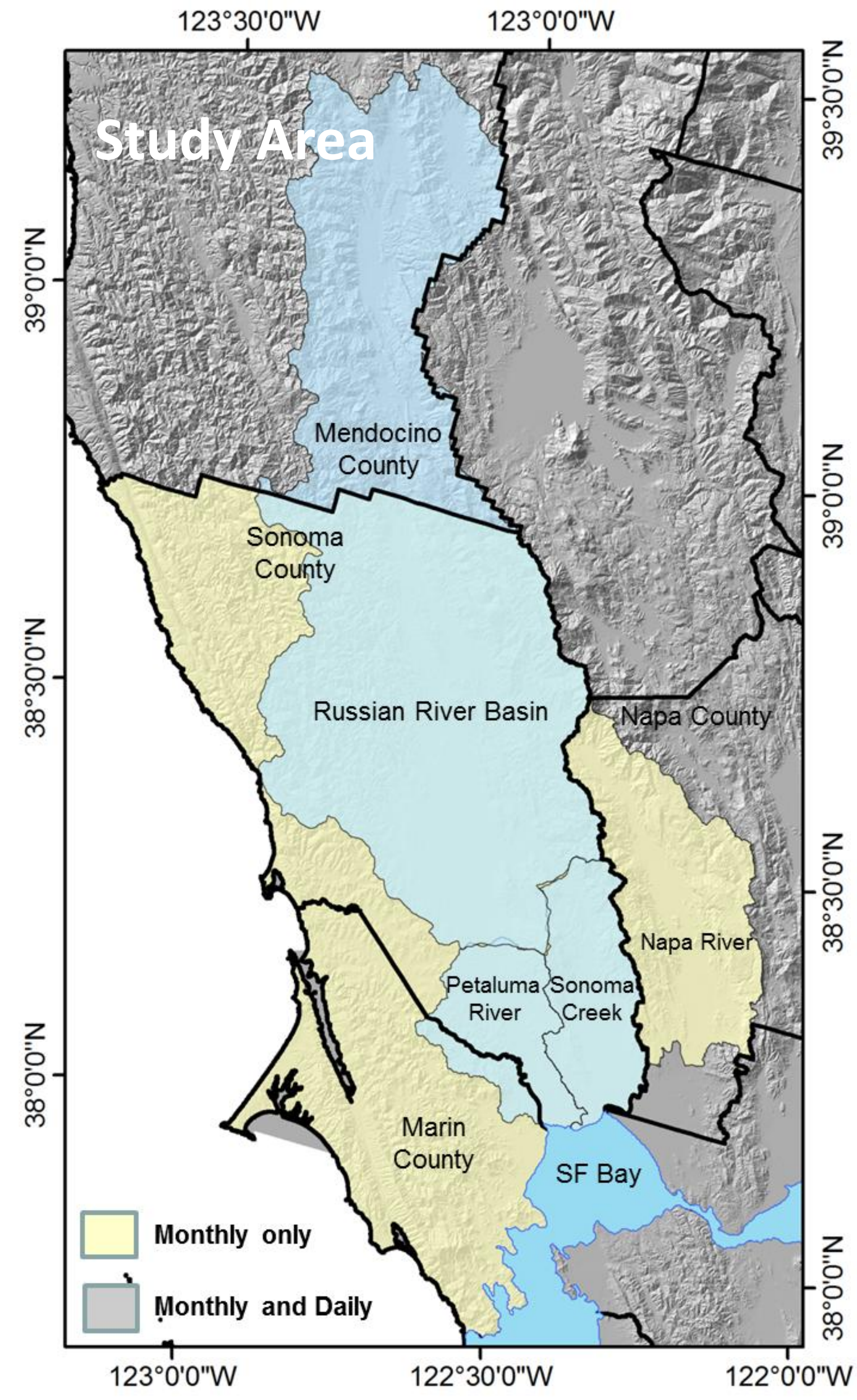

project overview

North Bay Climate Ready

Serving natural resource agencies in Marin, Sonoma, Napa and Mendocino Counties

Funding: a *Climate Ready* Coastal Conservancy grant to Sonoma's Regional Climate Protection Authority plus match funds from partners

Pepperwood is the lead analyst on vulnerability assessment with TBC3 members from USGS, and Point Blue Conservation Science, and University of California

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North Bay Climate Ready

User Groups and Partners

User Group 1: Sonoma County Water Agency with Mendocino County Water Conservation and Flood District

Domain: Sonoma County plus Russian River Basin of Mendocino County

User Group 2: Sonoma County Agricultural Protection and Open Space District and Sonoma County Regional Parks

Domain: Sonoma County

User Group 3: Napa County, Departments of Planning and Public Works plus the Watershed Protection District

Domain: Napa Valley

User Group 4: Marin Municipal Water District (MMWD)

Domain: Marin County

User Group 5: Regional Climate Protection Authority (RCPA) Municipal Users Group: all nine cities of Sonoma County-public works and planning officers

Domain: Sonoma County and sub-watersheds

Climate Ready Process

Part 1

Engage managers at the outset: define key management questions for each jurisdiction, and then refine questions through process.

First meeting: based on their concerns, managers selected one set of climate “futures” based on concerns-focus on “extreme cases” and central tendencies for entire North Bay region, with one “mitigated” emissions scenario for comparison.

Climate Ready Process

Part 2

Managers survey: how does climate variability, including current drought, impact your operations today? What are your concerns for the future?

Agency-specific meetings to introduce our Basin Characterization Model, data menu and sample products, refine management questions and data queries via an iterative process.

Climate model selection

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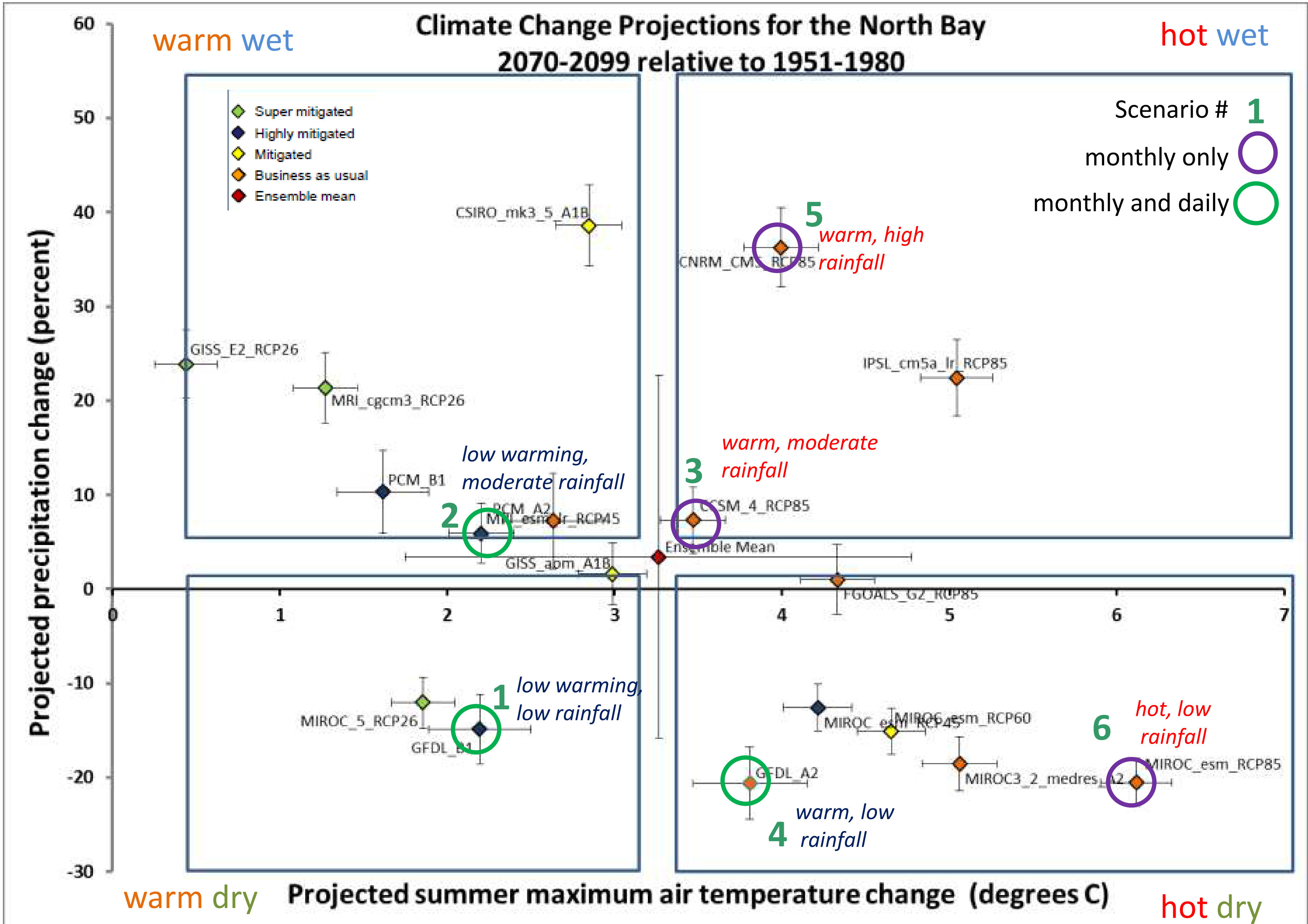
Selected Futures for North Bay Regional Vulnerability Assessment (in yellow)

Scenario #	Model	Emissions Scenario	Assessment Report Vintage	Time Period	Summer Tmax °C	Summer Tmax Increase	Winter Tmin °C	Winter Tmin Increase °C	Annual Precipitation (mm)	% Change Precipitation	% Change Water Deficit
	historic (hst)	N/A	N/A	1951-1980	27.9		3.9		1087		
	current	N/A	N/A	1981-2010	27.9		4.3	0.4	1095	1%	1%
	Assumption: Business as Usual										
6	miroc-esm	rcp85	AR5	2070-2099	34.0	6.1	8.4	4.6	865	-20%	24%
	miroc3_2_mr	A2	AR4	2070-2099	33.0	5.1	7.1	3.2	887	-18%	20%
	ipsl-cm5a-lr	rcp85	AR5	2070-2099	33.0	5.0	9.6	5.7	1325	22%	16%
	fgoals-g2	rcp85	AR5	2070-2099	32.3	4.3	7.1	3.2	1099	1%	22%
5	cnrm-cm5	rcp85	AR5	2070-2099	31.9	4.0	7.7	3.9	1477	36%	12%
4	GFDL	A2	AR4	2070-2099	31.7	3.8	7.7	3.9	861	-21%	21%
3	ccsm4	rcp85	AR5	2070-2099	31.4	3.5	7.1	3.2	1163	7%	12%
2	PCM	A2	AR4	2070-2099	30.6	2.6	6.3	2.4	1159	7%	11%
				Business as Usual Average	**32.2**	**4.3**	**7.6**	**3.7**	**1104**	**2%**	**17%**
	Assumption: Mitigated										
	miroc-esm	rcp60	AR5	2070-2099	32.6	4.7	7.1	3.2	922	-15%	14%
	giss_aom	A1B	AR4	2070-2099	30.9	3.0	6.4	2.5	1104	2%	11%
	csiro_mk3_5	A1B	AR4	2070-2099	30.8	2.8	6.5	2.6	1506	38%	4%
				Mitigated Average	**31.4**	**3.5**	**6.6**	**2.8**	**1177**	**8%**	**10%**
	Assumption: Highly Mitigated										
	mpi-esm-lr	rcp45	AR5	2070-2099	30.1	2.2	5.8	1.9	1148	6%	5%
	miroc-esm	rcp45	AR5	2070-2099	30.1	2.2	6.9	3.0	949	-13%	14%
1	GFDL	B1	AR4	2070-2099	30.1	2.2	6.1	2.2	923	-15%	10%
	PCM	B1	AR4	2070-2099	29.5	1.6	5.5	1.7	1197	10%	5%
				Highly Mitigated Average	**30.0**	**2.1**	**6.1**	**2.2**	**1055**	**-3%**	**8%**
	Assumption: Super Mitigated										
	miroc5	rcp26	AR5	2070-2099	29.8	1.9	5.2	1.3	953	-12%	9%
	mri-cgcm3	rcp26	AR5	2070-2099	29.2	1.3	4.8	0.9	1315	21%	2%
	giss-e2-r	rcp26	AR5	2070-2099	28.4	0.4	4.6	0.7	1344	24%	-4%
				Super Mitigated Average	**29.1**	**1.2**	**4.8**	**1.0**	**1204**	**11%**	**2%**
				ALL Scenarios Average	**31.1**	**3.2**	**6.7**	**2.8**	**1122**	**3%**	**11%**

TBC3 downscaled 18 global climate models selected to represent the full range of IPCC projections. 6 were selected by a consensus of all the managers engaged in Climate Ready. Scenario numbers correlate to chart version of the North Bay TBC3 ensemble.

North Bay Climate Ready: Selected Futures for Regional Vulnerability Assessment

map products in red, daily products available for Russian River basin only



Climate Ready North Bay Scenarios

6 selected futures: monthly values, observed vs mid-century

	Model	Emissions Scenario	IPCC Assessment	Short-hand name	Time Period	Summer Tmax °F	Summer Tmax Increase °F	Winter Tmin °F	Winter Tmin Increase °F	Annual Precipitation (in)	% Change Precipitation	% Change Water Deficit
Observed	historical baseline	N/A	N/A		1951-1980	82.2		39.0		42.8		
	current	N/A	N/A		1981-2010	82.2		39.7	0.7	43.1	1%	1%
Scenario #												
1	GFDL	B1	AR4	low warming-low rainfall	2040-2069	85.2	2.9	42.7	3.7	42.6	-1%	6%
2	PCM	A2	AR4	low warming-mod rainfal	2040-2069	85.0	2.7	41.1	2.1	43.8	2%	7%
3	CCSM-4	rcp85	AR5	warm-mod rainfall	2040-2069	86.0	3.7	42.0	3.0	42.2	-1%	8%
4	GFDL	A2	AR4	warm-low rainfall	2040-2069	86.3	4.0	43.2	4.2	39.8	-7%	12%
5	CNRM-CM5	rcp85	AR5	warm-high rainfall	2040-2069	86.5	4.2	43.0	4.0	53.8	26%	6%
6	MIROC-ESM	rcp85	AR5	hot-low rainfall	2040-2069	89.2	6.9	41.4	2.4	35.0	-18%	14%
Average						**86.3**	**4.1**	**42.2**	**3.2**	**42.9**	**0%**	**9%**

Climate Ready North Bay Scenarios

6 selected futures: monthly values, observed vs end-century

Climate Ready North Bay: 6 Selected Futures for North Bay Regional Analysis-End of Century Values

	Model	Emissions Scenario	IPCC Assessment	Short-hand name	Time Period	Summer Tmax °F	Summer Tmax Increase °F	Winter Tmin °F	Winter Tmin Increase °F	Annual Precipitation (in)	% Change Precipitation	% Change Water Deficit
Observed	historical baseline	N/A	N/A		1951-1980	82.2		3.9		42.8		
	current	N/A	N/A		1981-2010	82.2		4.3	0.4	43.1	1%	1%
Projections												
1	GFDL	B1	AR4	low warming-low rainfall	2070-2099	86.2	4.0	6.1	2.2	36.3	-15%	10%
2	PCM	A2	AR4	low warming-mod rainfal	2070-2099	87.0	4.7	6.3	2.4	45.6	7%	11%
3	CCSM-4	rcp85	AR5	warm-mod rainfall	2070-2099	88.5	6.2	7.1	3.2	45.8	7%	12%
4	GFDL	A2	AR4	warm-low rainfall	2070-2099	89.1	6.9	7.7	3.9	33.9	-21%	21%
5	CNRM-CM5	rcp85	AR5	warm-high rainfall	2070-2099	89.5	7.2	7.7	3.9	58.1	36%	12%
6	MIROC-ESM	rcp85	AR5	hot-low rainfall	2070-2099	93.3	11.0	8.4	4.6	34.0	-20%	24%
Average						88.9	**6.7**	**7.2**	**3.3**	**42**	**0.0**	**15%**

USGS Basin Characterization Model (BCM) methods

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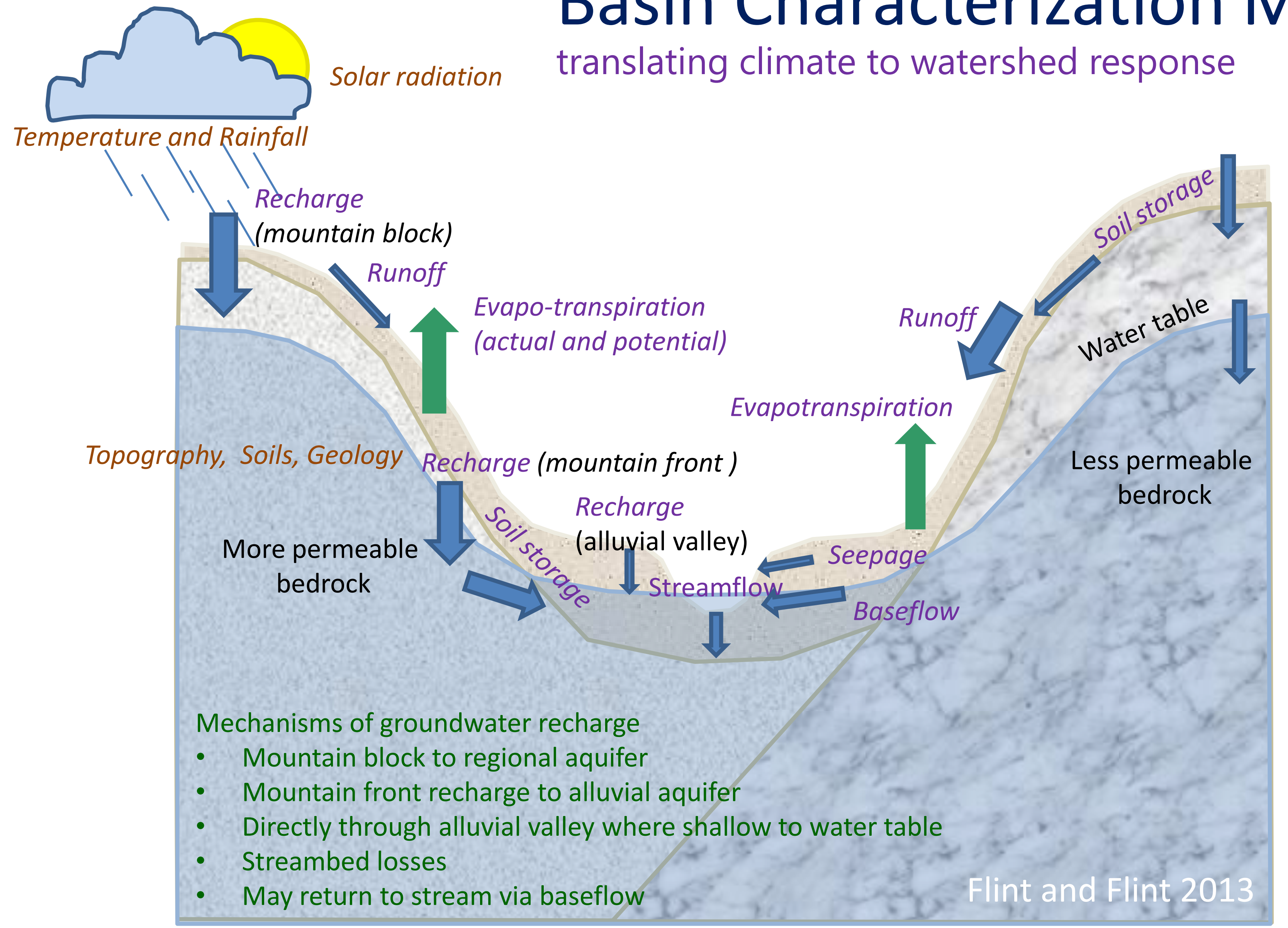
Basin Characterization Model

translating climate to watershed response



Size of arrows reflect relative magnitude of water flow

USGS science for a changing world

Brown text is BCM input, Purple text is BCM output

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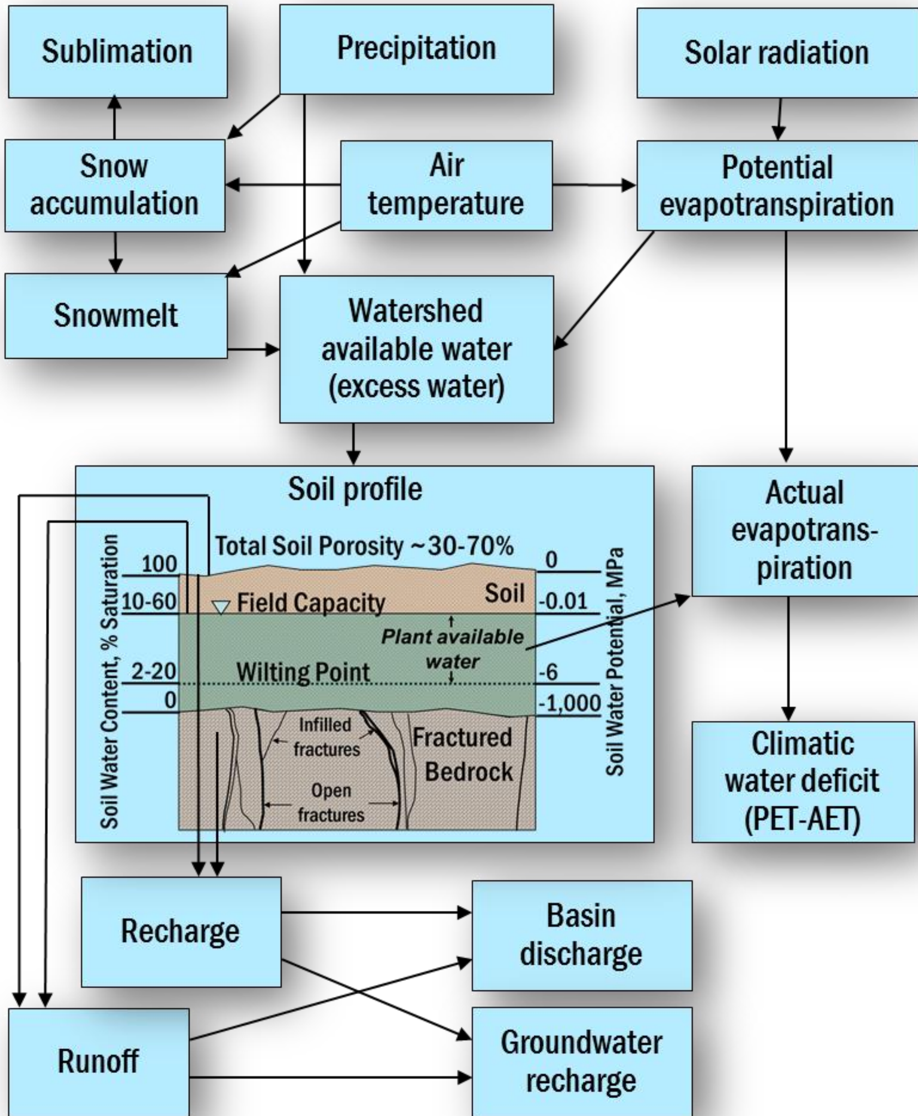
USGS California Basin Characterization Model:

translating climate to watershed response



Flint and Flint 2013

BCM methods

BCM output: Climatic Water Deficit

Annual evaporative demand
that exceeds available water=
drought stress

Potential – Actual Evapotranspiration

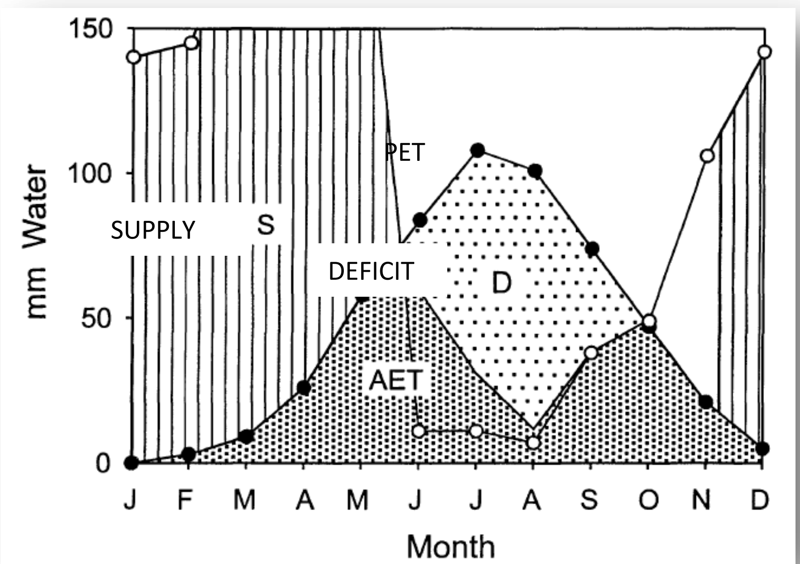
Integrates climate, energy loading, drainage, and available soil moisture storage

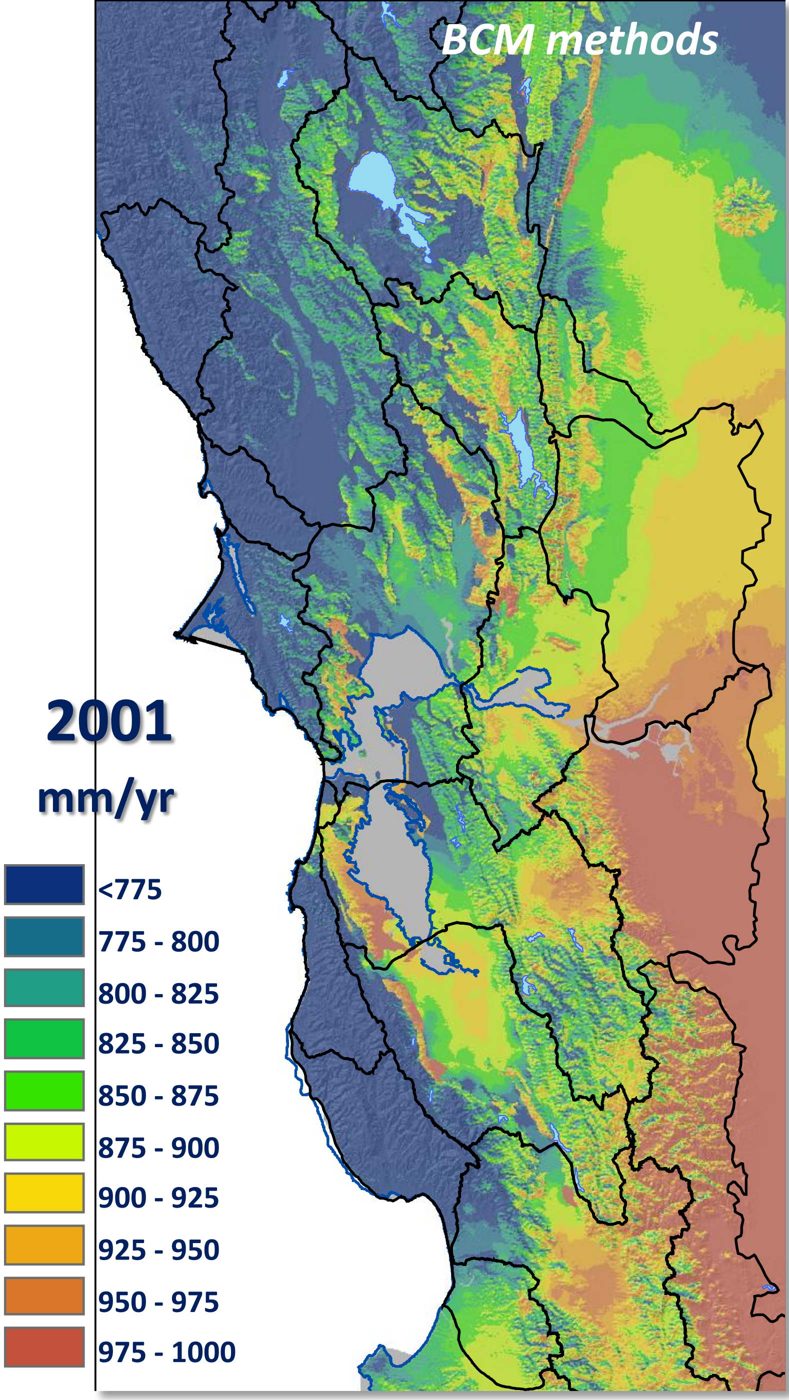
Vegetation independent (indicator)

Surrogate for irrigation demand

Generally increases with all future climate scenarios

- Correlates with vegetation type and fire risk





Data menu

Primary (BCM outputs):

climate and hydology-temperature, rainfall, runoff, groundwater recharge, evapo-transpiration, soil moisture, climatic water deficit

Secondary:

Fire frequency (either percent likelihood of burn or return interval)

Potential native vegetation transitions

Time scales-historical (1910-2010) and projected (2010-2100)

30-y averages

Annual data

Monthly/Seasonal data

Spatial scales

Regional summaries-whole North Bay study area

County Summaries

Sub-regions-watershed, landscape unit, service area

Large parcels

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Regional data samples

- Cover entire North Bay Climate Ready Study Area (Russian River basin, Sonoma County, Marin County, Napa Valley)
- Show primary temperature and rainfall outputs from CA Basin Characterization Model (USGS)
- Put local results in regional context and facilitates regional planning

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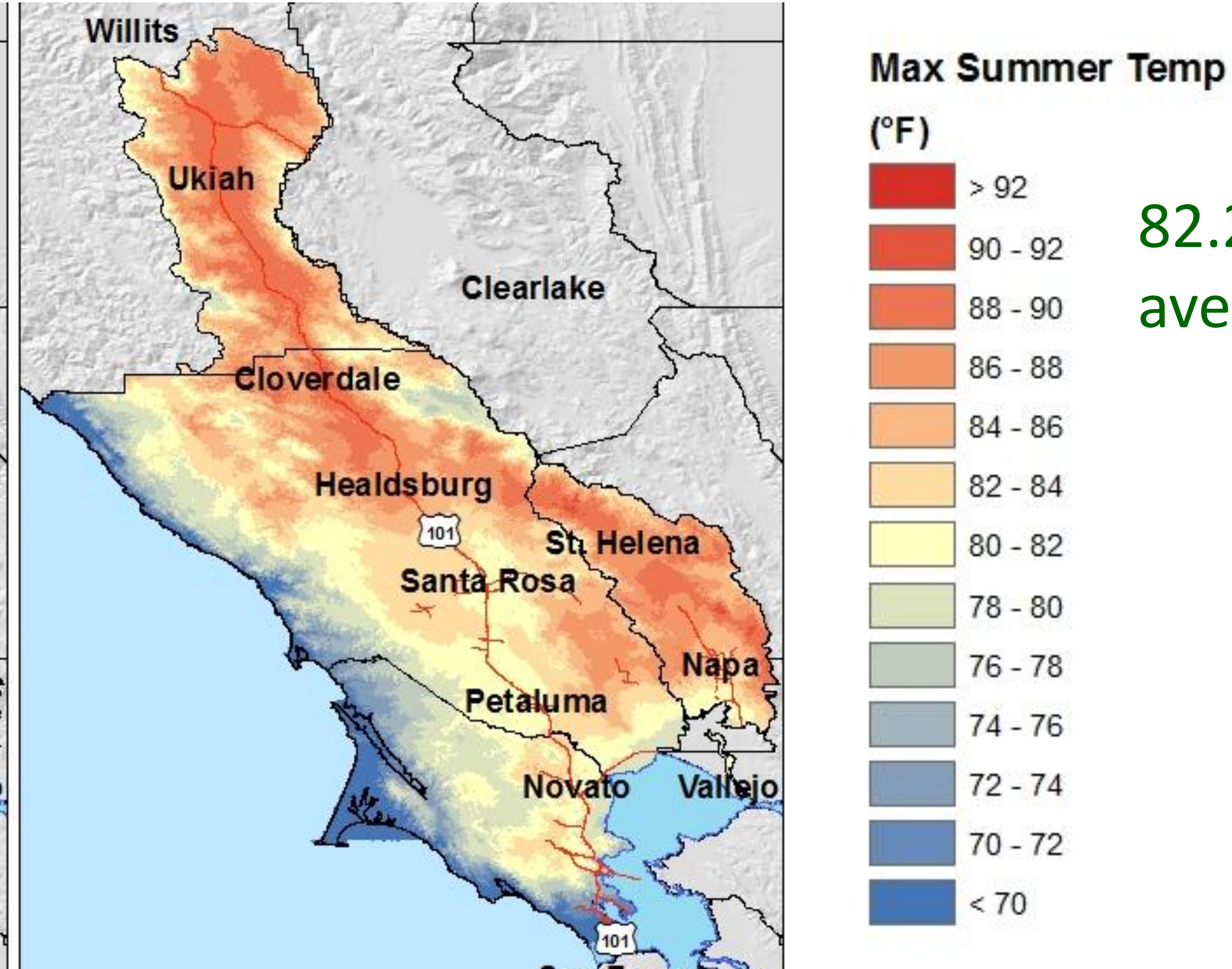
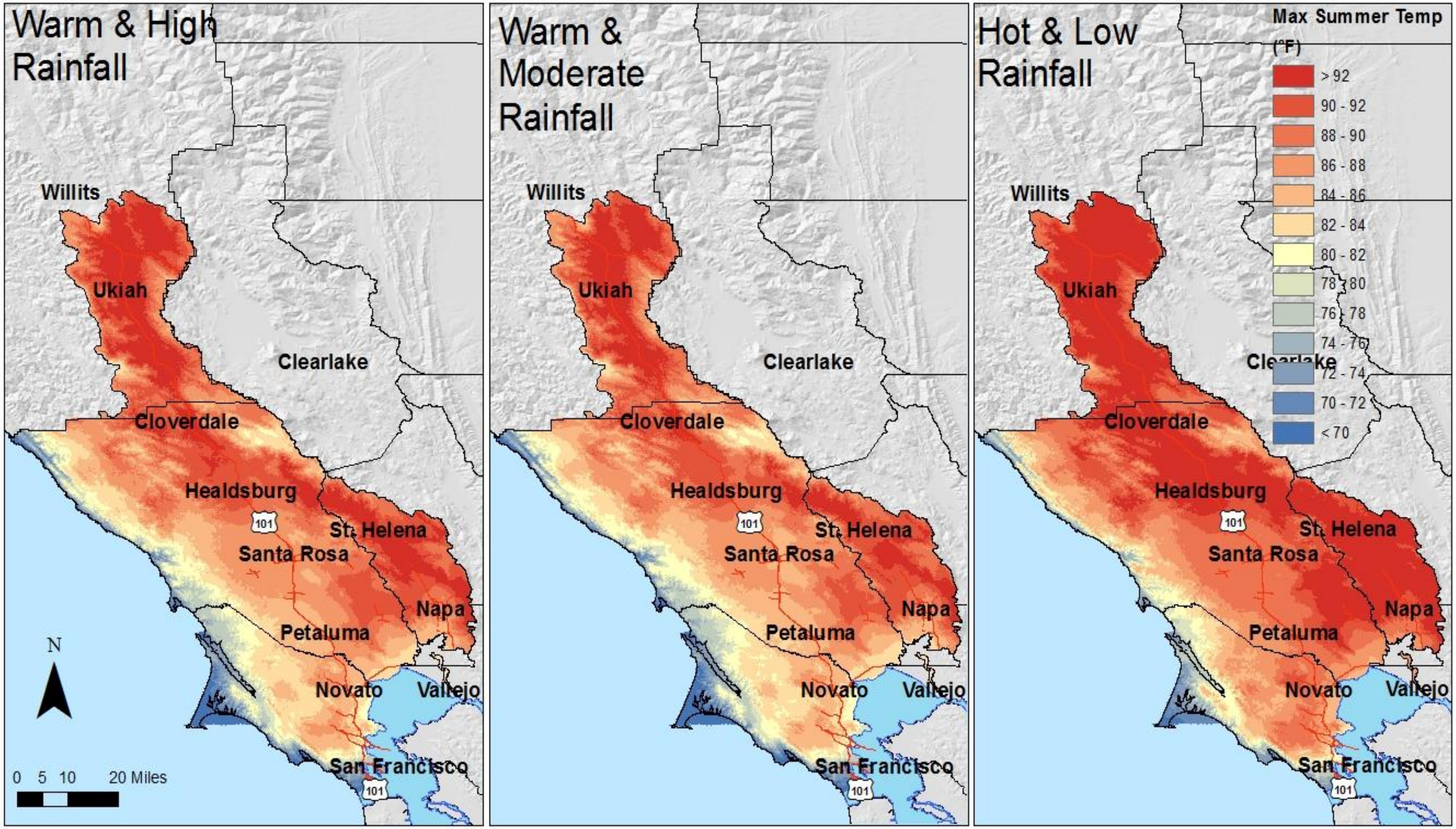
Maximum summer temperature (monthly avg) (degF)

30-year average, current-1981-2010



82.2 deg F average

Projected Maximum Summer Air Temperature, 2040-2069



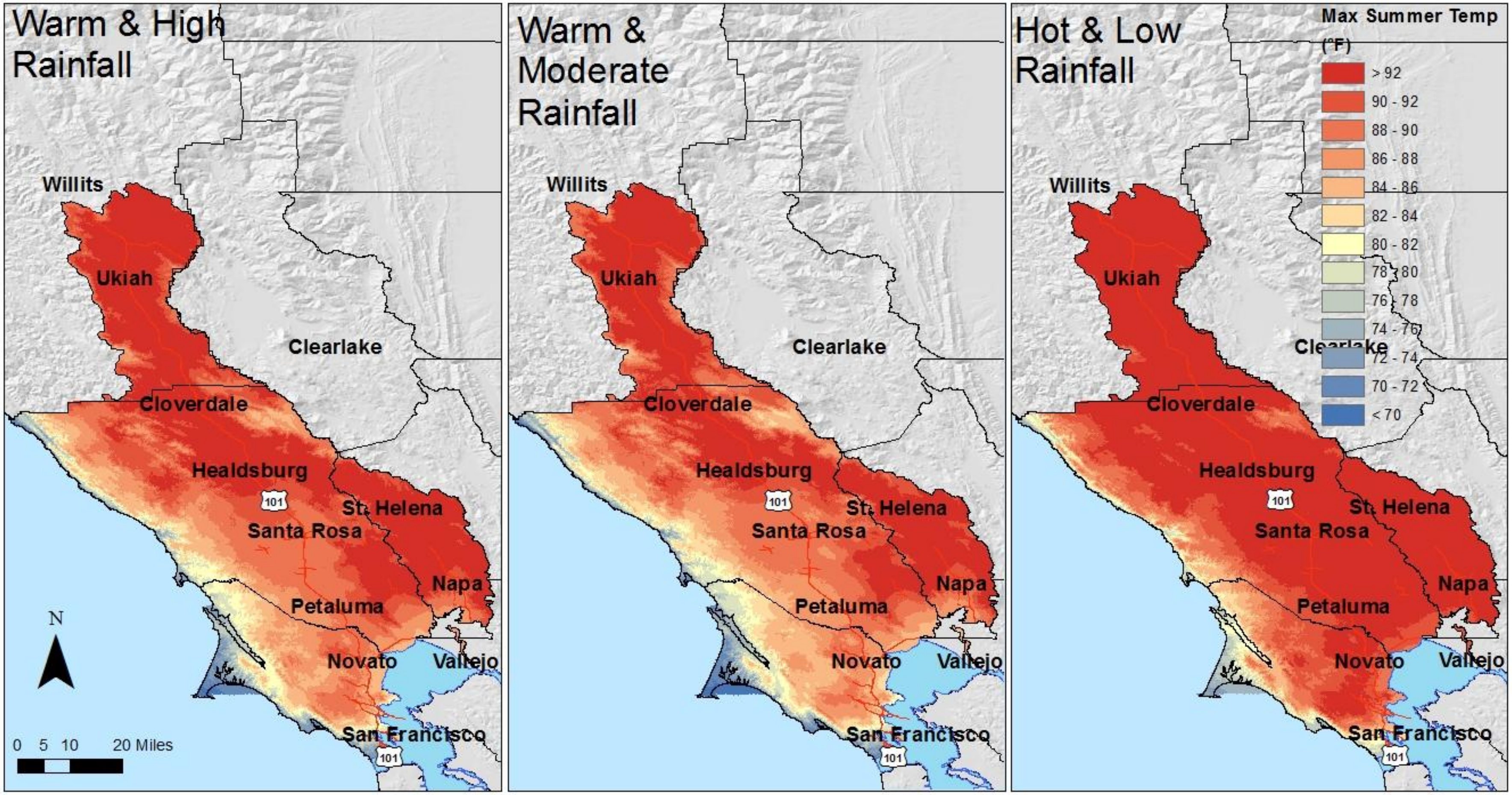
86.4 average
+4.2 deg F

86.0 average
+3.8 deg F

89.2 average
+7.0 deg F

"business as usual" mid-century temperatures-30 y monthly average

Projected Maximum Summer Air Temperature, 2070-2099



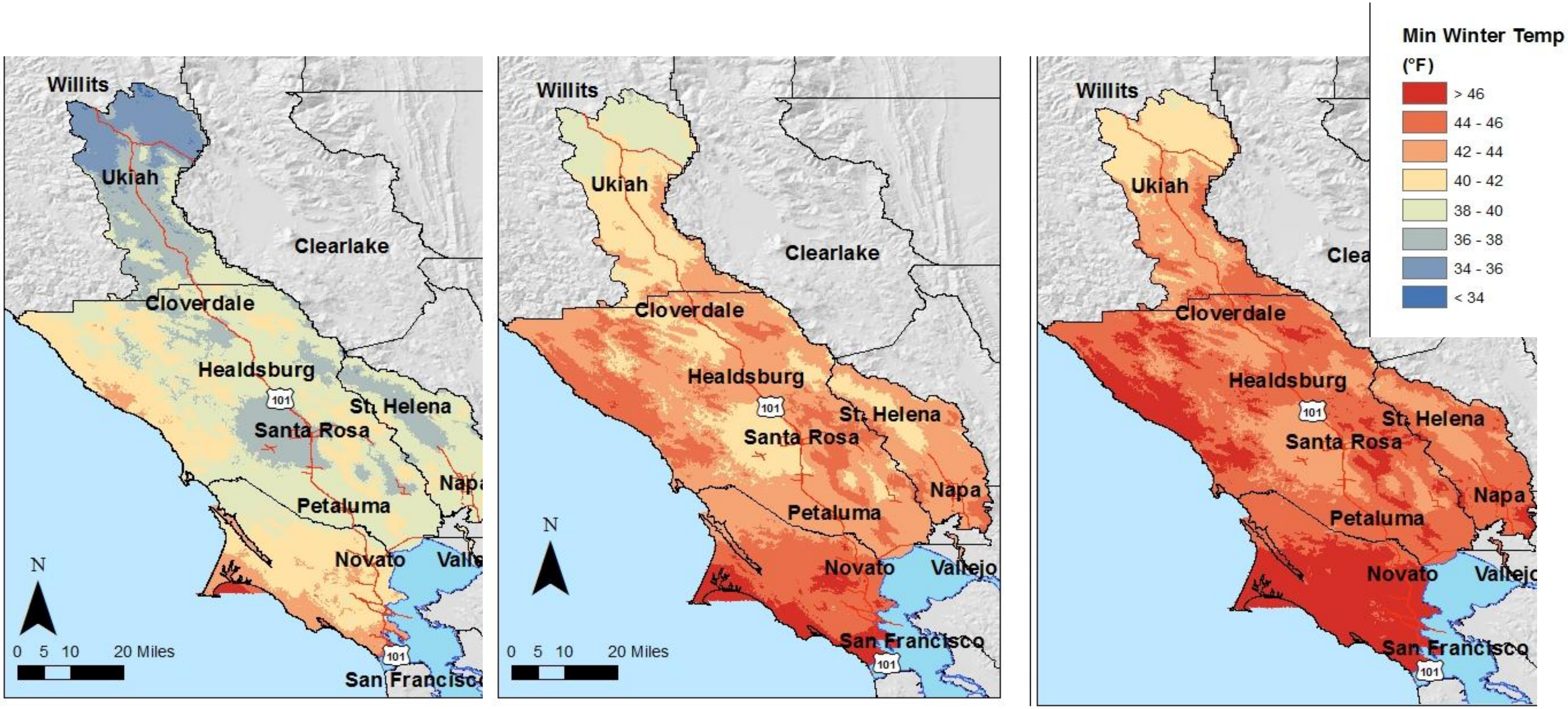
89.4 average +7.2 deg F	88.45 average +6.3 deg F	93.4 average +11.2 deg F

"business as usual" end of century temperatures-30 y monthly average

Minimum winter temperature (monthly) (degF)

30-year average, current-moderate warming (projected)

(mod rainfall scenario)



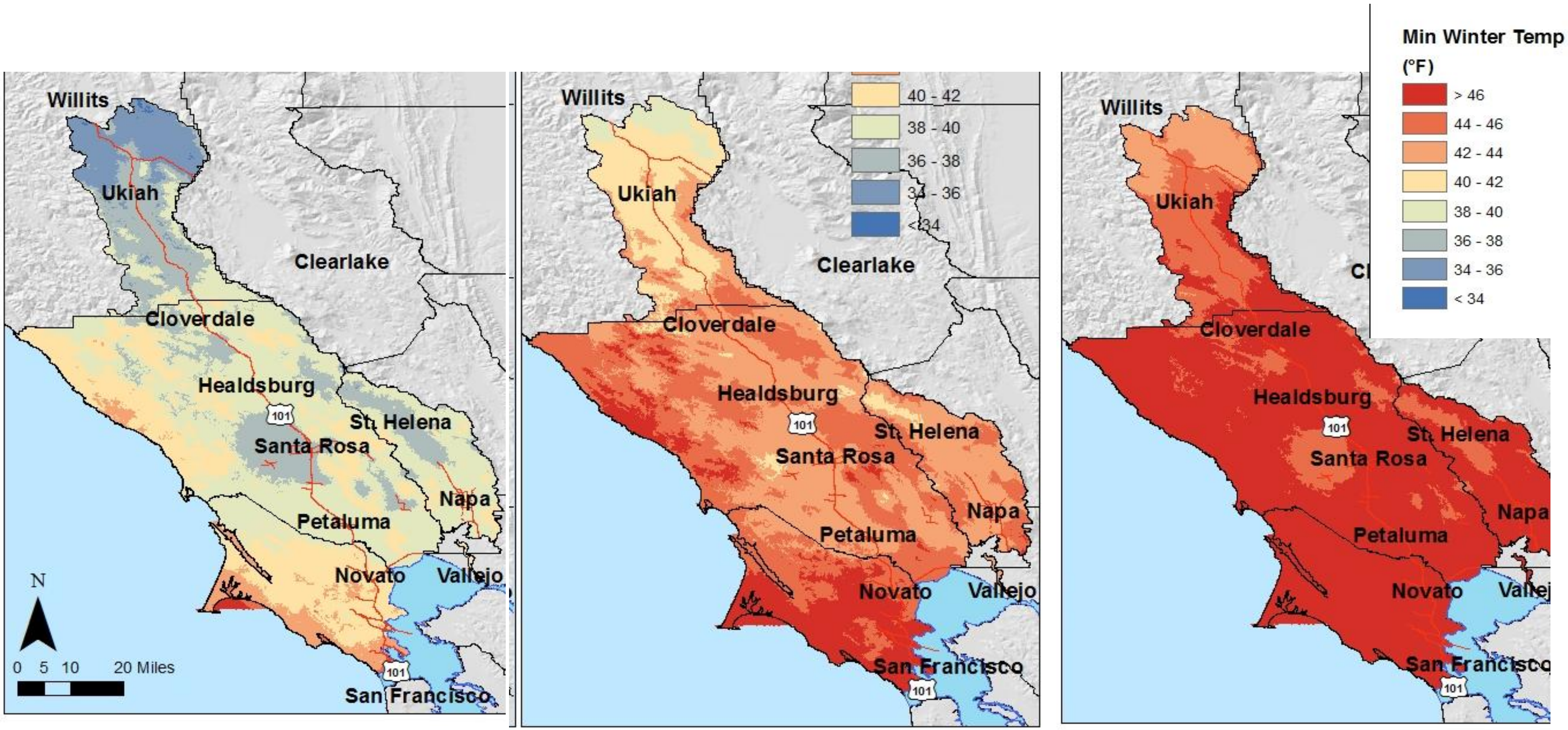
Current 1981-2010
39.7 average

Projected 2040-2069
43.0 average

Projected 2070-2099
44.8 average

5.1 degF greater by end of century than current

Minimum winter temperature (monthly) (degF)
30-year average, current-high warming (projected)



Current 1981-2010
39.7 average

Projected 2040-2069
44.1 average

Projected 2070-2099
47.3 average

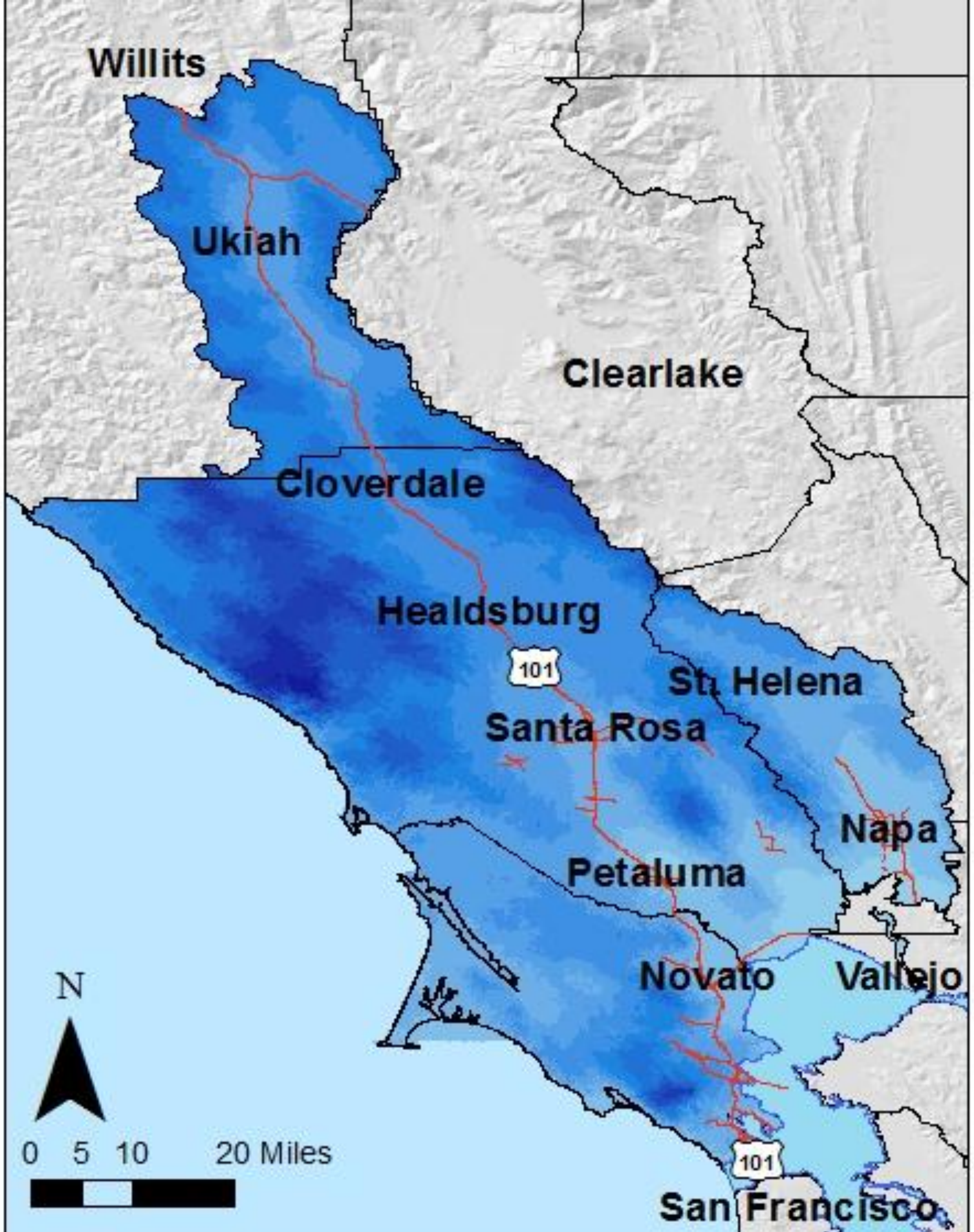
8.6degF greater by end of C than current, 2.5 degF greater than moderate warming scenario

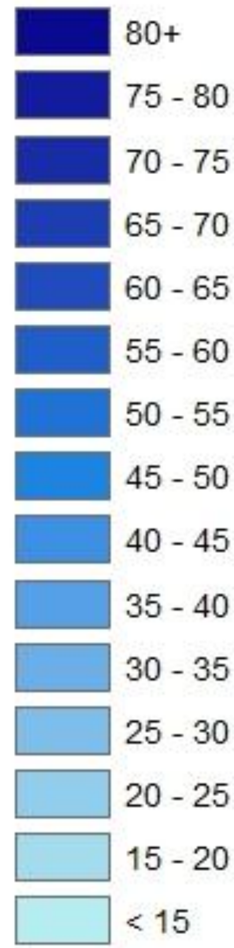
Precipitation (PPT)

30 year average

Historic 1951-1980

Regional average 43 in/y



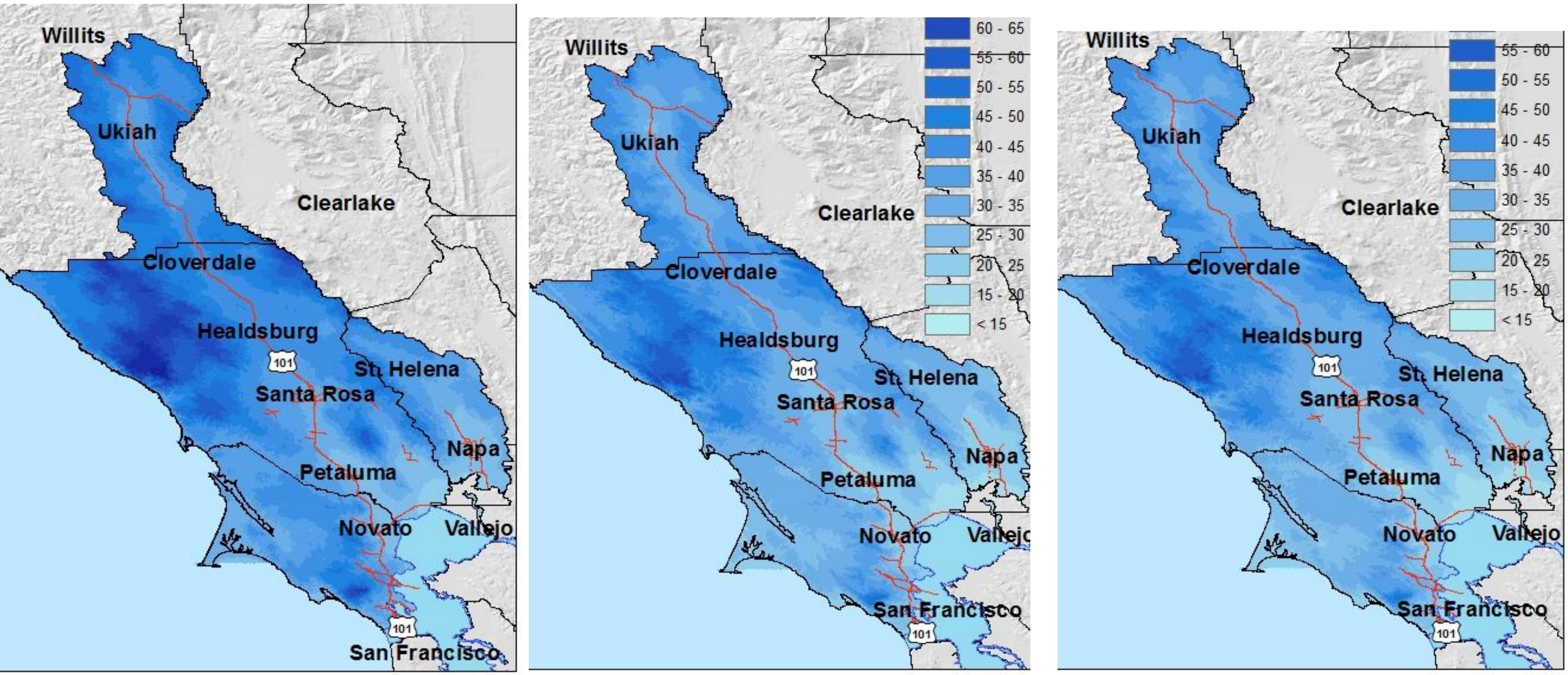


PPT (in/yr)

Precipitation (PPT, annual in/y)

30-year average, current to projected-low rainfall

(hot scenario)



Current 1981-2010
43.0 average

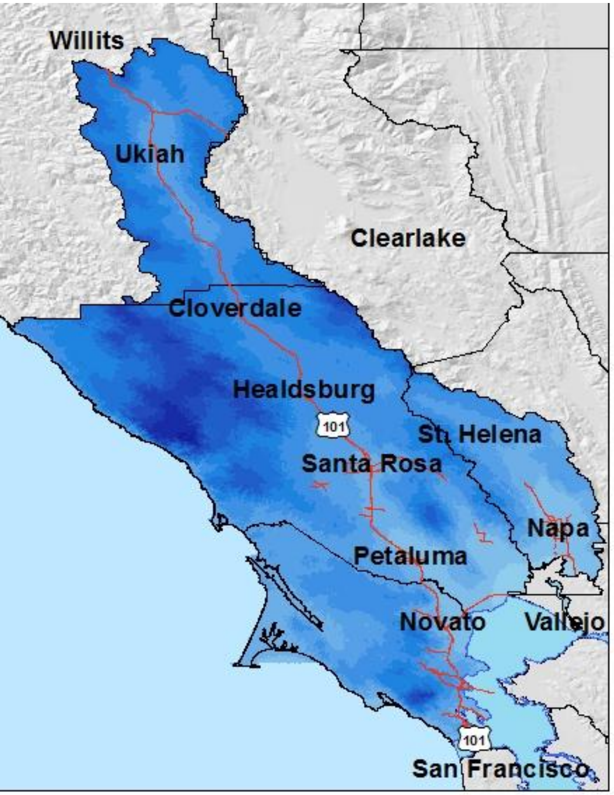
Projected 2040-2069
35.0 average

Projected 2070-2099
34.0 average

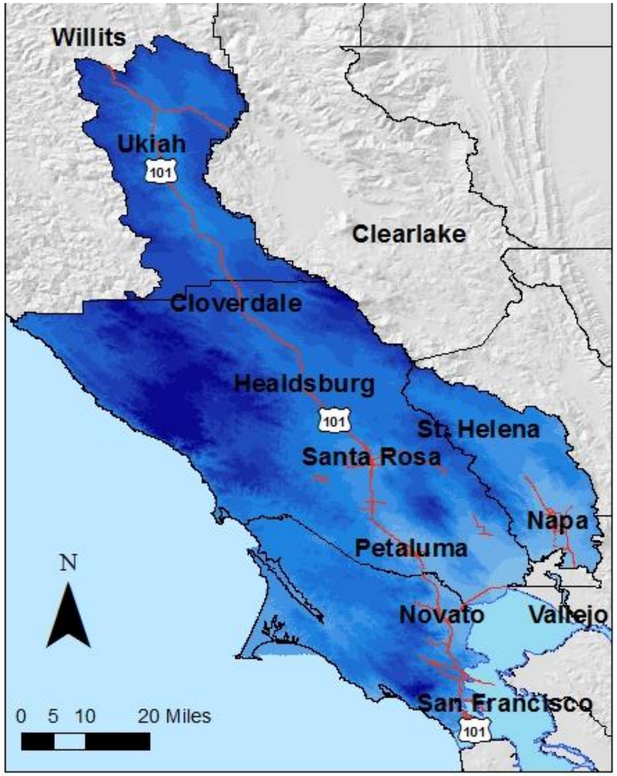
projecting 19-21% less rainfall than current

Precipitation (PPT, annual in/y)
30-year average, current to projected-high rainfall

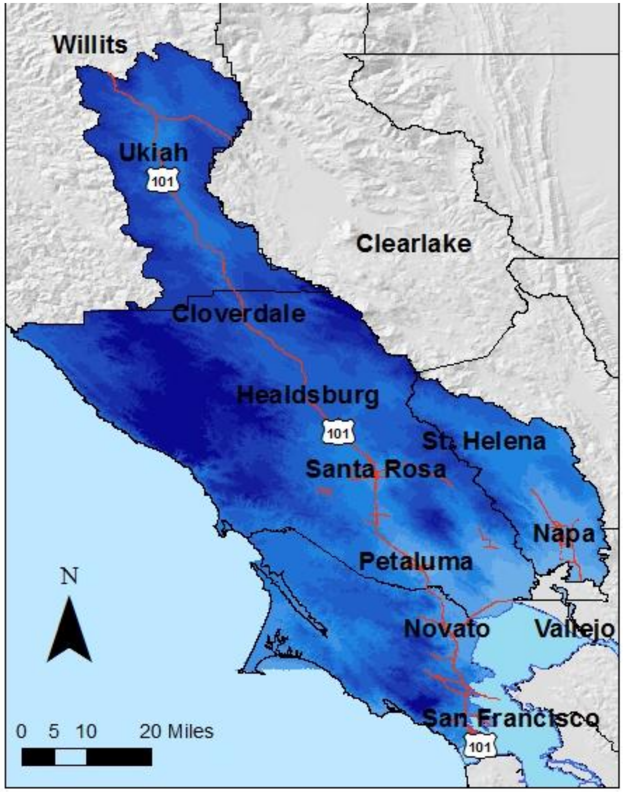
(warm scenario)



Current 1981-2010
43.0 average



Projected 2040-2069
54.0 average



Projected 2070-2099
58.0 average

projecting 25-35% greater rainfall than current

Basin Characterization Model: North Bay Region
Trends in 30-year average values, historic-2099

		Historical	Current	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
Variable	Units	1951-1980	1981-2010	2040-2069	2070-2099	2040-2069	2070-2099	2040-2069	2070-2099
Ppt	in	43	43	54	58	42	46	35	34
Tmn	Deg F	38.8	39.7	43.0	45.9	41.9	44.8	44.1	47.3
Tmx	Deg F	82.2	82.2	86.4	89.4	86.0	88.5	89.2	93.4
CWD	in	28	28	30	31	30	31	32	35
Rch	in	11	10	13	13	11	11	8	9
Run	in	14	14	23	27	14	17	10	9

				Percent Change from Current					
		Historical	Current	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
Variable	Units	1951-1980	1981-2010	2040-2069	2070-2099	2040-2069	2070-2099	2040-2069	2070-2099
Ppt	in	43	43	25%	35%	-2%	6%	-19%	-21%
Tmn	Deg F	38.8	39.7	8%	15%	5%	13%	11%	19%
Tmx	Deg F	82.2	82.2	5%	9%	5%	8%	9%	14%
CWD	in	28	28	5%	10%	7%	11%	12%	22%
Rch	in	11	10	25%	29%	4%	6%	-20%	-17%
Run	in	14	14	61%	90%	-1%	22%	-32%	-34%

VARIABLES: Ppt=precipitation, Tmn=minimum winter temperature (monthly), Tmx=maximum summer temperature (monthly), CWD=climatic water deficit, Rch=recharge, Run=runoff

USGS, Point Blue, Pepperwood 2015

Management Question

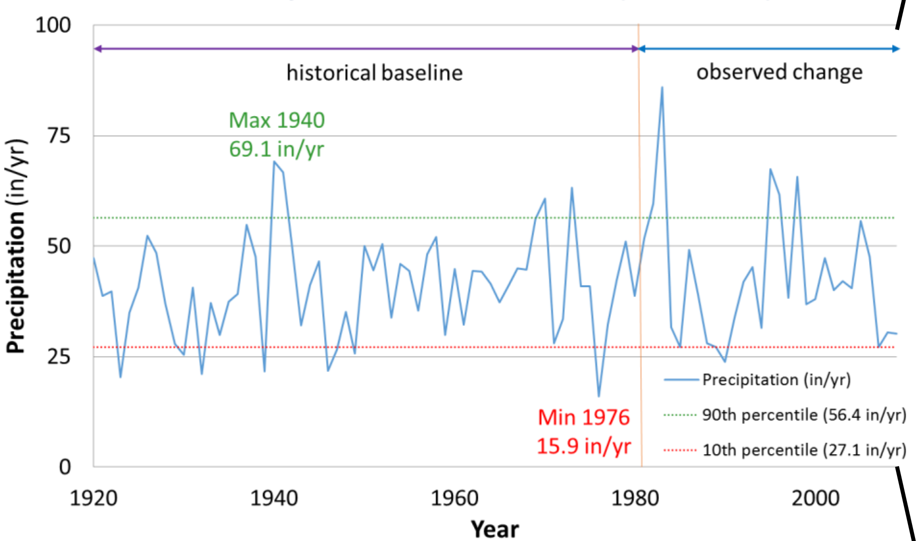
How is climate change projected to impact the variability of regional annual rainfall relative to the historic record?

North Bay Climate Ready

Regional Annual Rainfall: Historical and Projected

(comparison of 90-year periods)

North Bay Annual Rainfall Record (1920-2009)



Extremes (1920-2009)

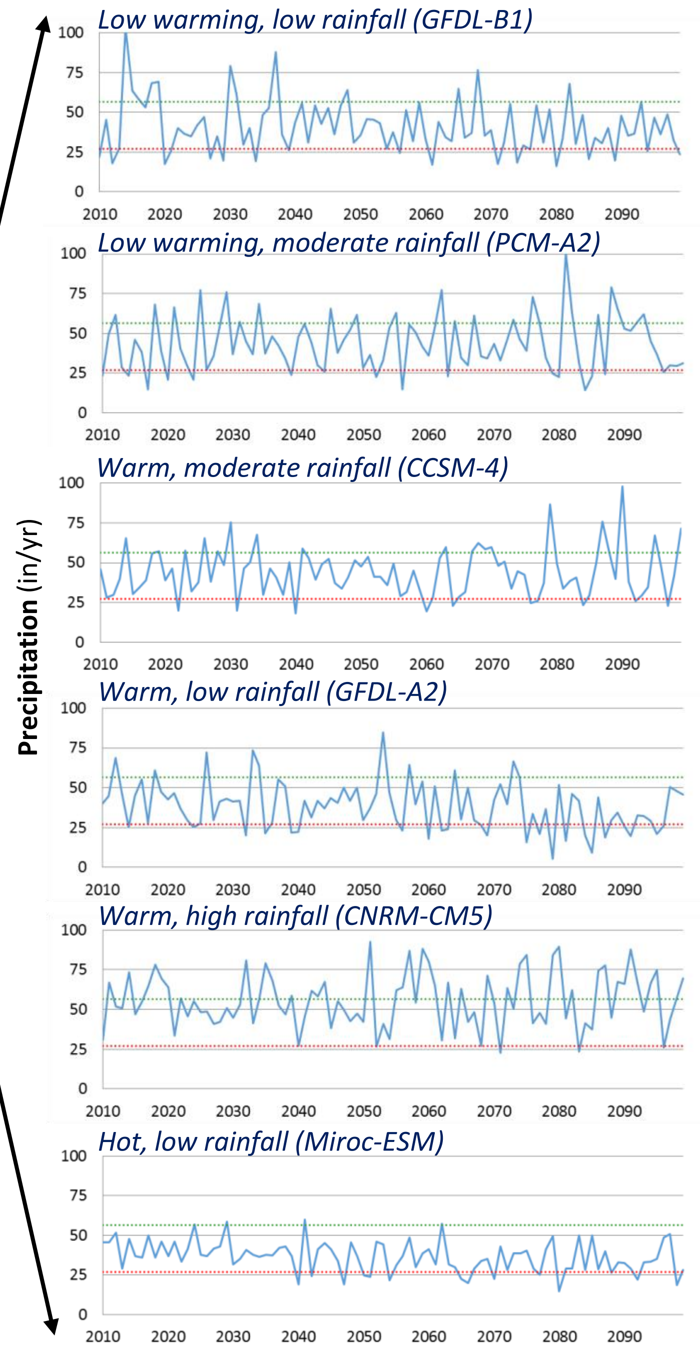
2 events >=1940

9 events >90th % (56.4in/y)*

1 events <=1976

9 events <10th % (27.1 in/y)*

North Bay Annual Rainfall Projections (2010-2099)



Scenario 1
5 events >=1940
13 events >90th %
0 events <=1976
18 events <10th %

Scenario 2
6 events >=1940
23 events >90th %
3 events <=1976
17 events <10th %

Scenario 3
5 events >=1940
19 events >90th %
0 events <=1976
10 events <10th %

Scenario 4
3 events >=1940
10 events >90th %
3 events <=1976
23 events <10th %

Scenario 5
19 events >=1940
41 events >90th %
0 events <=1976
6 events <10th %

Scenario 6
0 events >=1940
4 events >90th %
1 events <=1976
14 events <10th %

* 10^{th} and 90^{th} percentile benchmarks based on 1920-2009 record

Climate Ready North Bay

Annual Rainfall Extremes per Decade

Frequency of extreme annual events per decade

Scenario #	Model	Time Period	Name	Annual Peaks (floods) >=1940 (69.1 in/yr)	Annual Peaks (floods) >90th % (56.4 in/yr)	Annual Lows (droughts) <10th % (27.1 in/yr)	Annual Lows (droughts) <=1976 (15.9 in/yr)
	Historic & Observed Change	1920-2009		0.22	1.00	1.00	0.11
1	GFDL_B1	2010-2099	Low warming, Low rainfall	0.56	1.44	2.00	0.00
2	PCM_A2	2010-2099	Low warming, Mod rainfall	0.67	2.56	1.89	0.33
3	CCSM4_rcp85	2010-2099	Warm, Mod rainfall	0.56	2.11	1.11	0.00
4	GFDL_A2	2010-2099	Warm, Low rainfall	0.33	1.11	2.56	0.33
5	CNRM_rcp85	2010-2099	Warm, High rainfall	2.11	4.56	0.67	0.00
6	MIROC_rcp85	2010-2099	Hot, Low rainfall	0.00	0.44	1.56	0.11

Percent increase or decrease (projected relative to 1920-2009): Frequency extreme annual events per decade

Scenario #	Model	Time Period	Name	Annual Peaks (floods) >=1940 (69.1 in/yr)	Annual Peaks (floods) >90th % (56.4 in/yr)	Annual Lows (droughts) <10th % (27.1 in/yr)	Annual Lows (droughts) <=1976 (15.9 in/yr)
	Historic & Observed Change	1920-2009					
1	GFDL_B1	2010-2099	Low warming, Low rainfall	150%	44%	100%	-100%
2	PCM_A2	2010-2099	Low warming, Mod rainfall	200%	156%	89%	200%
3	CCSM4_rcp85	2010-2099	Warm, Mod rainfall	150%	111%	11%	-100%
4	GFDL_A2	2010-2099	Warm, Low rainfall	50%	11%	156%	200%
5	CNRM_rcp85	2010-2099	Warm, High rainfall	850%	356%	-33%	-100%
6	MIROC_rcp85	2010-2099	Hot, Low rainfall	-100%	-56%	56%	0%
			Average	***217%***	***104%***	***63%***	***17%***

* 10th and 90th percentile benchmarks based on 1920-2009 record

Management Question

How is climate change projected to impact the variability of regional annual rainfall relative to the historic record?

Talking points:

Using the 90th percentile of the annual rainfall record from 1920-2009 as a threshold for "high" rainfall years, four out of five models project increases in the frequency of high rainfall years for 2010-2099. Estimated increases in frequency of high rainfall years range from approximately 40-350%, with only the extreme "hot and low rainfall" scenario 6 projecting a reduction in frequency of high rainfall years. The average frequency increase across all models is approximately 100% (equivalent to a doubling of the current frequency of high rainfall events).

Using the 10th percentile of the annual rainfall record from 1920-2009 as a threshold for "low" rainfall years, four out of five models project increases in the frequency of low rainfall years for 2010-2099 . Estimated increases in frequency of low rainfall years range from approximately 10-100%, with only the extreme "high rainfall" scenario 5 projecting a reduction in frequency of low rainfall years. The average frequency increase for low rainfall years across all models is approximately 60%.

Thus, the majority of projections suggest that climate change will increase the frequency of ***both*** high and low rainfall years in the coming century.

Napa Valley
Basin Characterization Model
Outputs

Basin Characterization Model: Napa Valley Watershed

Trends in 30-year average values, historic-2099

Variable	Units	*Historical*	*Current*	*Moderate Warming, High Rainfall*		*Moderate Warming, Moderate Rainfall*		*Hot, Low Rainfall*	
		1951-1980	*1981-2010*	*2040-2069*	*2070-2099*	*2040-2069*	*2070-2099*	*2040-2069*	*2070-2099*
Ppt	in	35.6	36.4	44.8	48.6	35.1	38.2	28.7	27.7
Tmn	Deg F	38.4	39.4	42.8	45.9	41.6	44.4	43.6	46.7
Tmx	Deg F	86.6	86.5	90.9	93.9	90.5	93.1	93.8	98.0
CWD	in	30.2	30.6	31.9	33.4	32.3	33.6	34.3	36.8
Rch	in	10.9	10.6	13.4	13.4	10.5	11.1	7.5	7.8
Run	in	7.1	7.8	13.0	16.1	6.9	9.5	4.3	3.8

VARIABLES: Ppt=precipitation, Tmn=winter minimum temperature (monthly), Tmx=summer maximum temperature (monthly), CWD=climatic water deficit, Rch=recharge, Run=runoff

USGS, Point Blue, Pepperwood 2015

Basin Characterization Model: Napa Valley Watershed

Comparison of 30-year average values, historic-2099

				Projected change in temperature (Deg F) and hydrologic indicators (%)					
Variable	**Units**		**Current**	**Moderate Warming, High Rainfall**		**Moderate Warming, Moderate Rainfall**		**Hot, Low Rainfall**	
			1981-2010	***2040-2069***	***2070-2099***	***2040-2069***	***2070-2099***	***2040-2069***	***2070-2099***
Ppt	in		36.4	+23%	+34%	-3%	+5%	-21%	-24%
Tmn	Deg F		39.4	+3.4	+ 6.4	+ 2.1	+ 4.9	+4.2	+ 7.3
Tmx	Deg F		86.5	+4.4	+7.4	+ 4.0	+6.6	+ 7.3	+ 11.5
CWD	in		30.6	+4%	+ 9%	+6%	+10%	+12%	+20%
Rch	in		10.6	+27%	+ 27%	-1%	+ 5%	-29%	-27%
Run	in		7.8	+67%	+107%	-11%	+ 22%	-44%	-51%

VARIABLES: Ppt=precipitation, Tmn=winter minimum temperature, Tmx=summer maximum temperature, CWD=climatic water deficit, Rch=recharge, Run=runoff

USGS, Point Blue, Pepperwood 2015

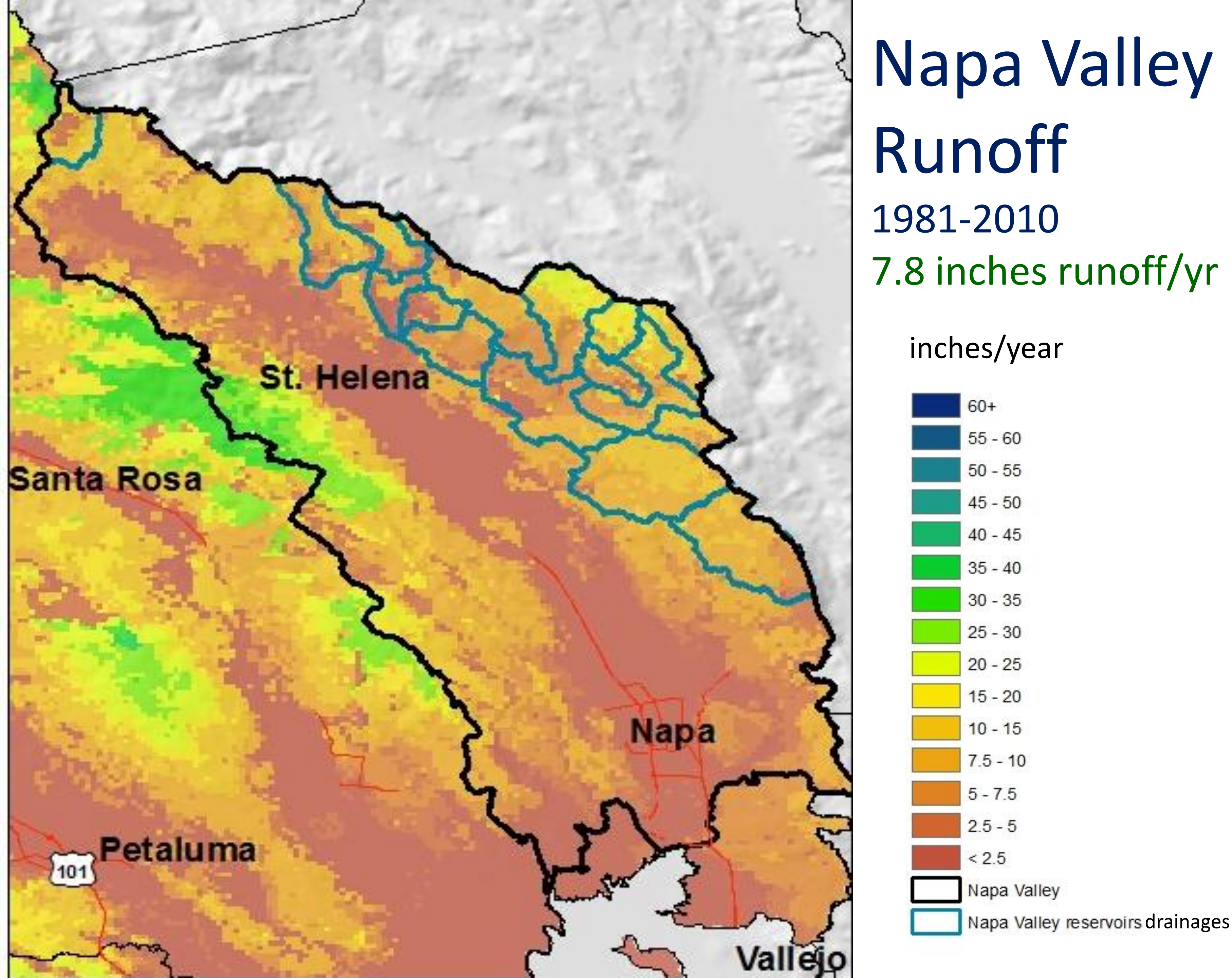
Management Question

How does rainfall variability translate to variability in Napa Valley watershed-wide water availability and potential delivery to reservoirs?

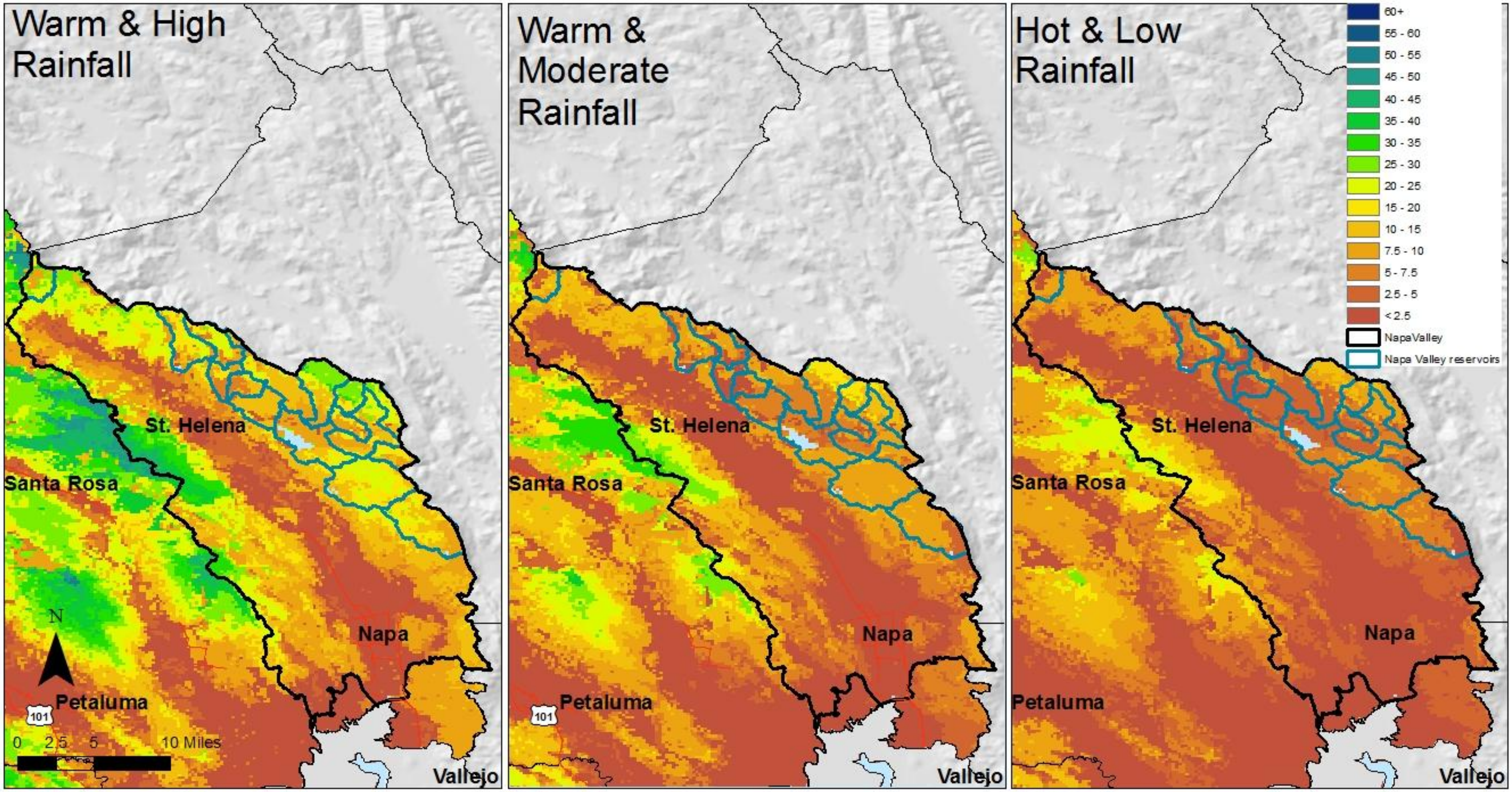
Napa Valley Runoff

1981-2010

7.8 inches runoff/yr



Projected Runoff, 2040-2069

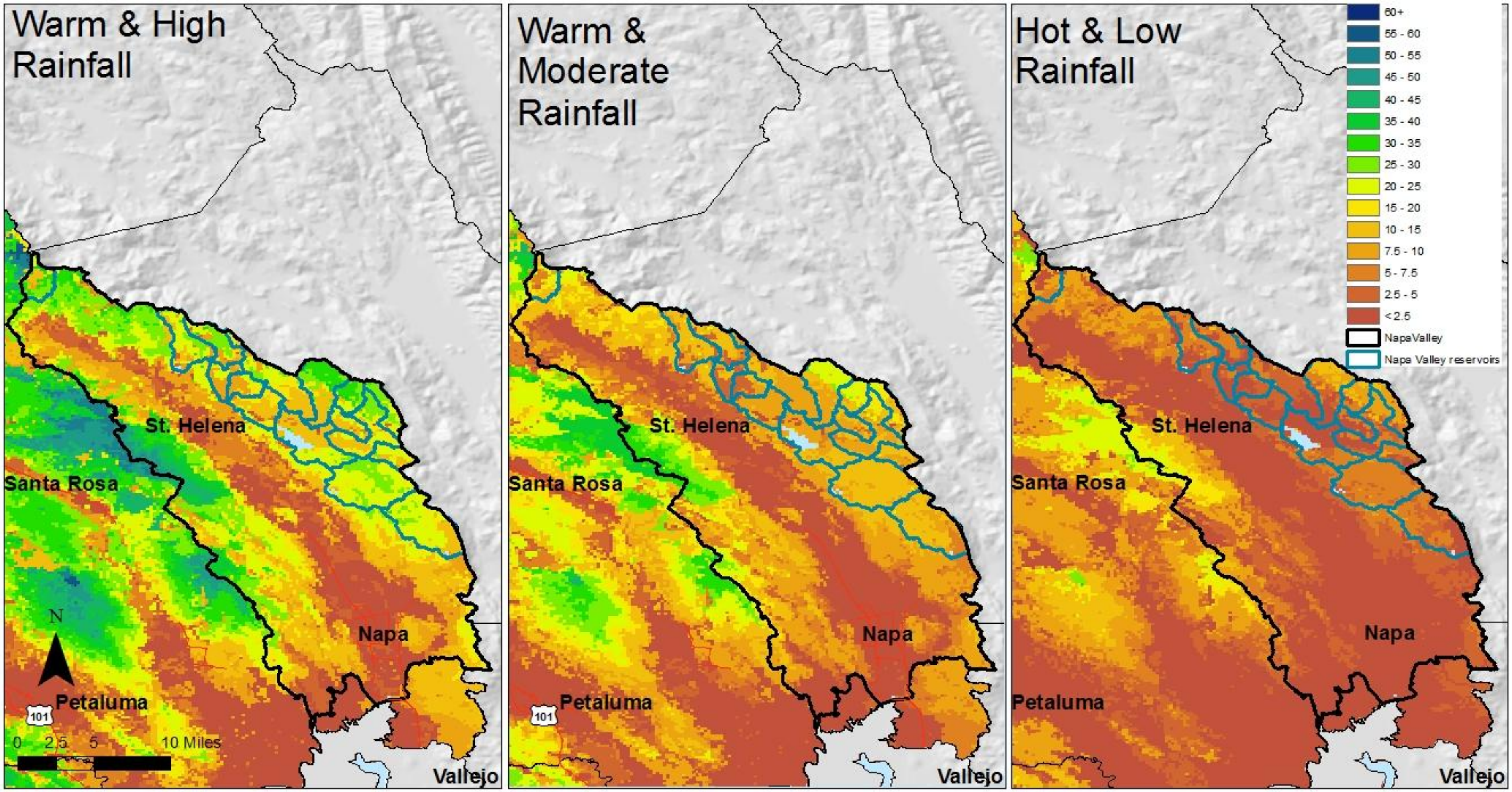


13 in/y average
67% greater than current

6.9 in/y average
11% less than current

4.3 in/y average
44% less than current

Projected Runoff, 2070-2099



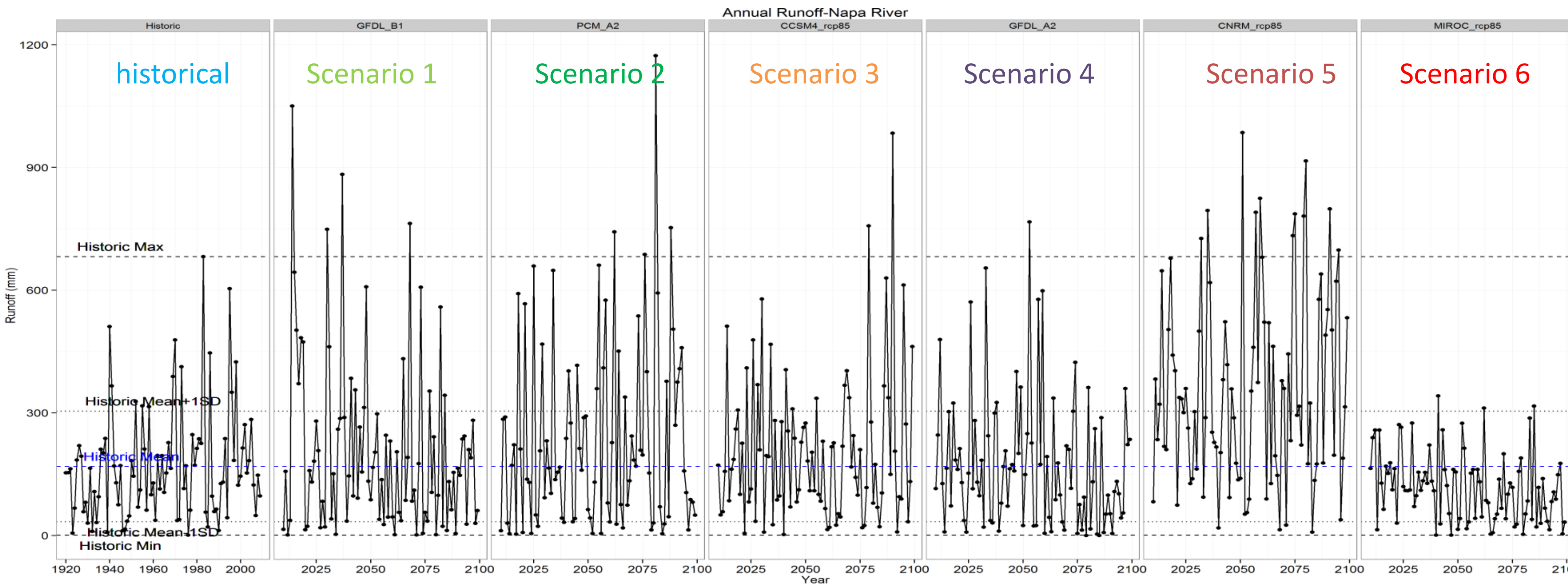
16.0 in/y average
107% greater than current

9.5 in/y average
22% greater than current

3.8 in/y average
51% less than current

Napa River Valley Annual Runoff

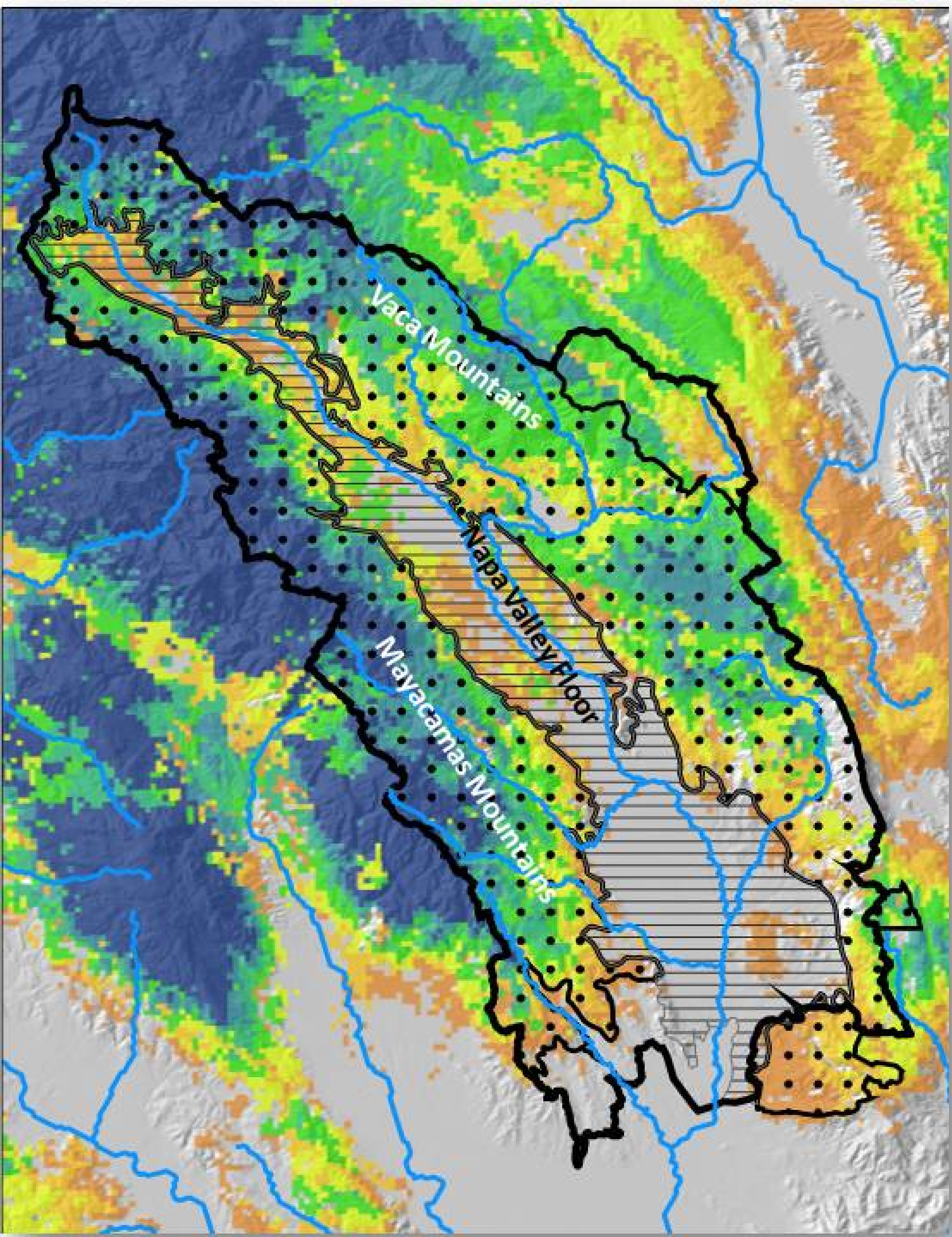
historical vs 6 model projections

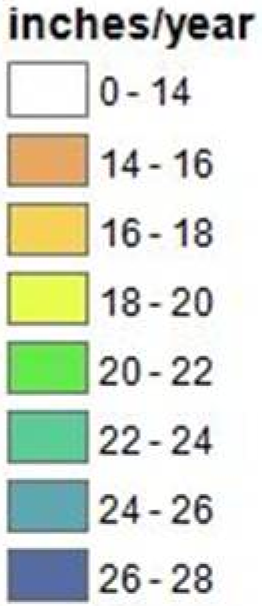


•Four out of five of the modeled futures project the same or more annual runoff peaks than the historic record (compared to 1983 historic max)

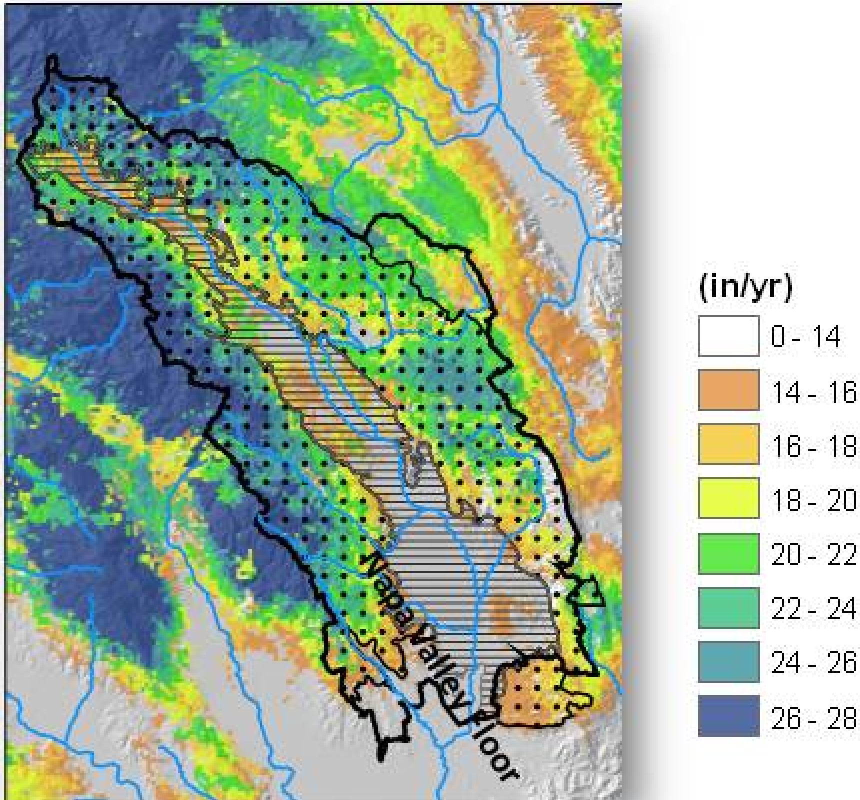
•Only Scenario 6 (hot, low rainfall) projects fewer runoff peaks, with projected max values on the order of the historic mean

Water Supply Indicator Recharge + Runoff 1981-2010





Water Supply: Recharge and Runoff projections, 30-y summaries



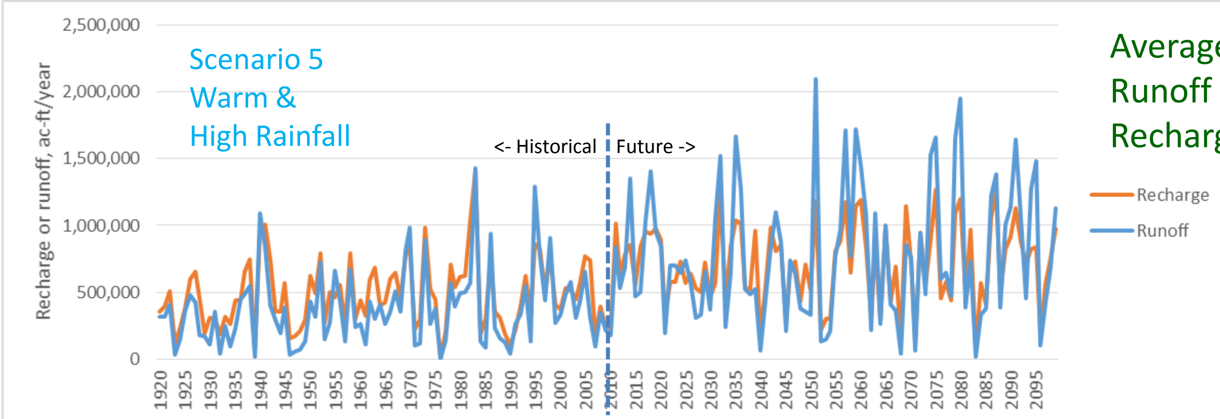
			Current	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
Rch+Run (acre-ft)		Area (acres)	1981-2010	2040-2069	2070-2099	2040-2069	2070-2099	2040-2069	2070-2099
Mountains	total	452,476	243,131	344,656	392,444	233,723	272,710	163,522	160,806
	SD		58,769	71,890	76,404	56,910	59,658	45,580	46,690
	% change			42%	61%	-4%	12%	-33%	-34%
Valley floor	total	189,418	59,142	89,894	107,424	53,860	67,413	33,201	31,061
	SD		21,889	28,335	30,616	22,300	23,755	17,066	17,567
	% change			52%	82%	-9%	14%	-44%	-47%

Water Supply Indicator projections generated for each reservoir drainage area-30 y averages

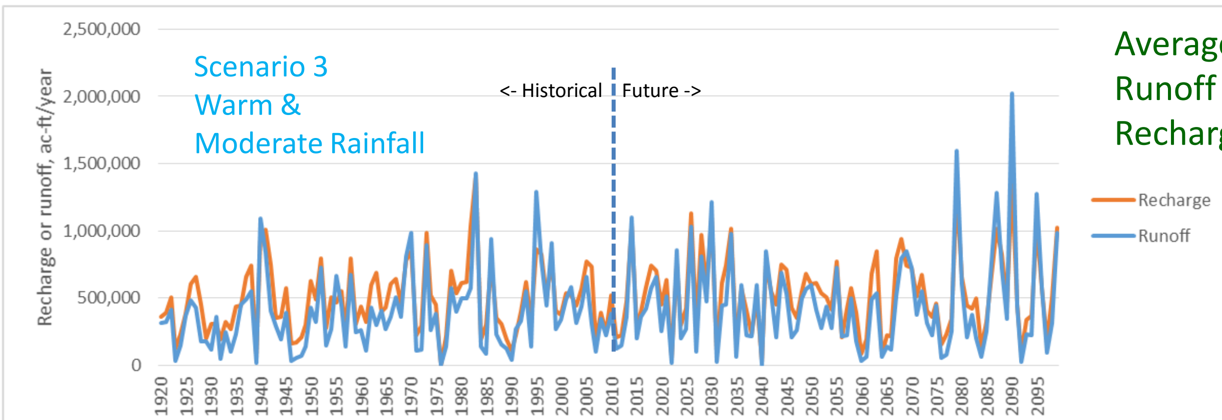
Reservoir Attributes		Current	Scenario 5-Warm, High Rainfall		Scenario 3- Warm, Mod Rainfall		Scenario 6, Hot, Low Rainfall	
NAME	Area (acres)	1981-2010	mid-century	end-century	mid-century	end-century	mid-century	end-century
Kimball Reservoir	2,159	5,243	7,568	8,450	5,308	5,981	3,826	3,812
Bell Canyon Reservoir	3,526	6,737	9,928	11,194	6,800	7,776	4,776	4,722
Conn Creek - Upper Reach	2,622	5,014	7,233	8,168	4,906	5,629	3,407	3,355
Moore Creek	4,571	8,347	11,819	13,377	8,034	9,287	5,607	5,537
Chiles Creek - Main Fork	4,125	7,216	10,110	11,451	6,868	7,955	4,792	4,730
Conn Creek - Main Fork	4,435	7,312	10,697	12,240	7,092	8,325	4,849	4,745
Conn Creek - East Fork	1,531	2,579	3,768	4,305	2,498	2,921	1,700	1,666
Chiles Creek - East Fork	1,720	2,941	4,047	4,581	2,746	3,186	1,914	1,891
Elder Valley Creek	1,845	2,637	3,602	4,116	2,386	2,816	1,628	1,600
Sage Creek	4,246	6,977	9,568	10,852	6,485	7,563	4,532	4,473
Lake Hennessey	5,164	7,355	12,137	13,812	8,214	9,625	5,772	5,679
Clear Creek	1,485	2,405	3,361	3,827	2,253	2,632	1,548	1,522
Fir Canyon	1,565	2,904	3,769	4,255	2,606	3,022	1,856	1,839
Rector Reservoir	6,971	12,886	18,197	20,491	12,656	14,639	9,112	9,000
Milliken Reservoir	6,141	9,829	14,053	16,089	9,285	11,017	6,322	6,122
All Reservoirs Average	*3,474*	*6,026*	*8,657*	*9,814*	*5,876*	*6,825*	*4,109*	*4,046*
% change from current			*44%*	*63%*	*-2%*	*13%*	*-32%*	*-33%*

Napa Valley: Recharge and Runoff Comparison

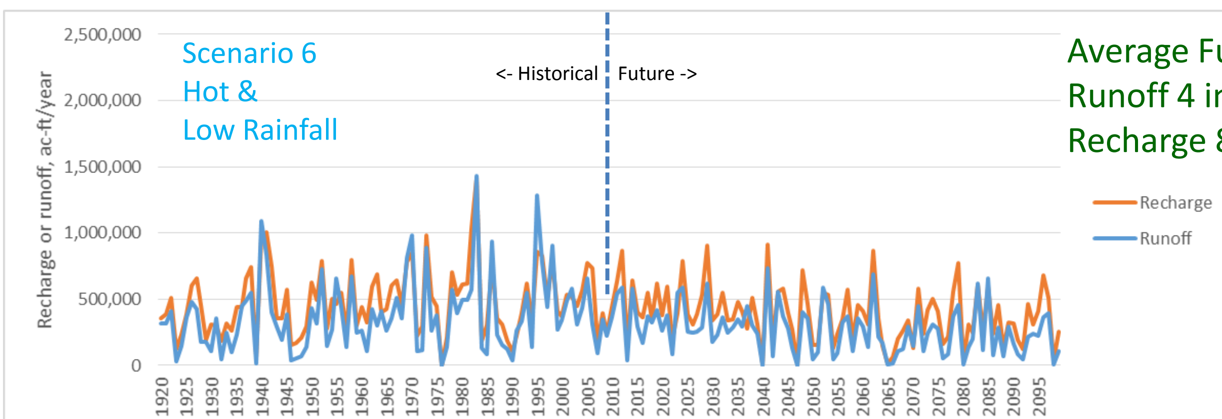
Average Historical
Runoff 8 in/yr
Recharge 11 in/yr



Average Future
Runoff 15 in/yr
Recharge 10 in/yr



Average Future
Runoff 8 in/yr
Recharge 11 in/yr

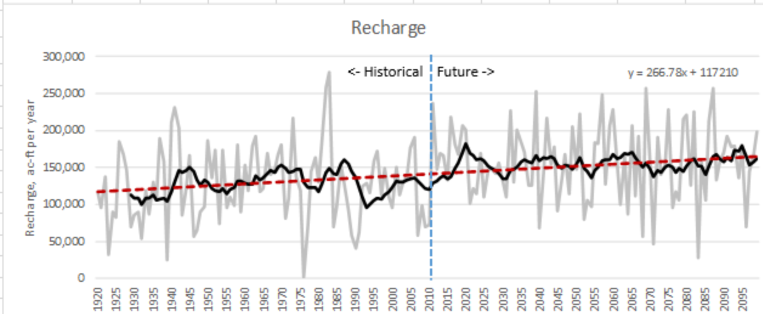


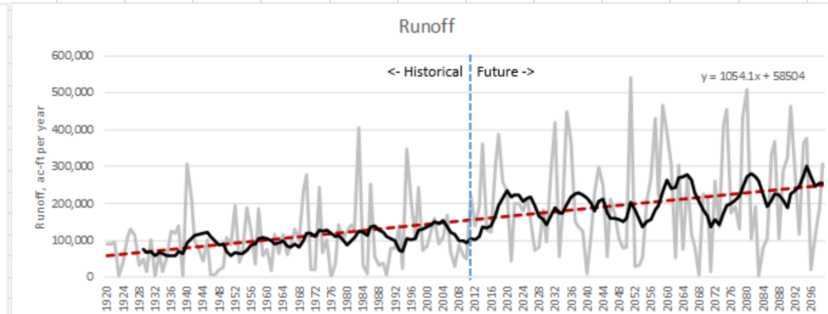
Average Future
Runoff 4 in/yr
Recharge 8 in/yr

Annual Values-Water Supply

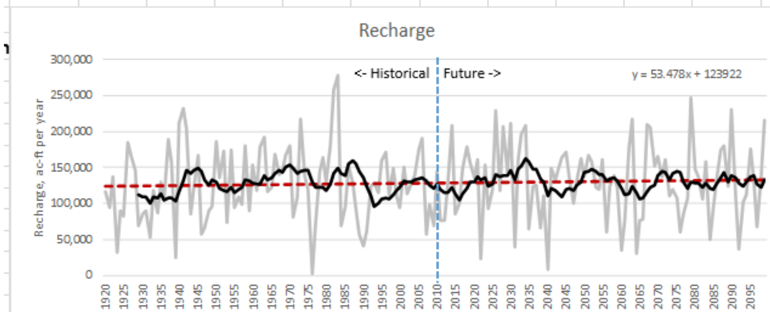
Napa Mountains

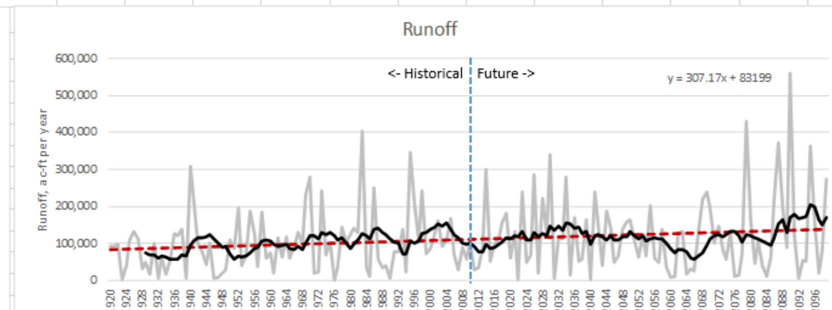
Warm &
High Rainfall



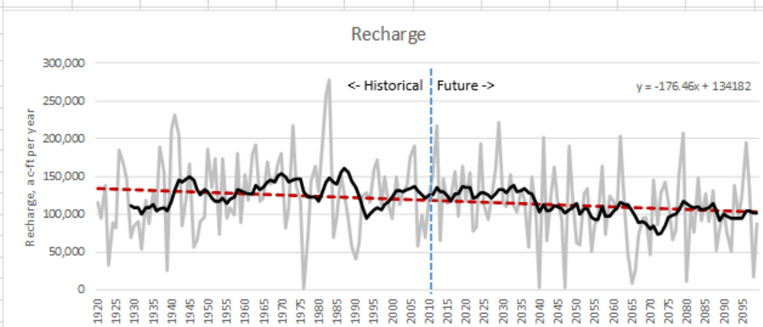


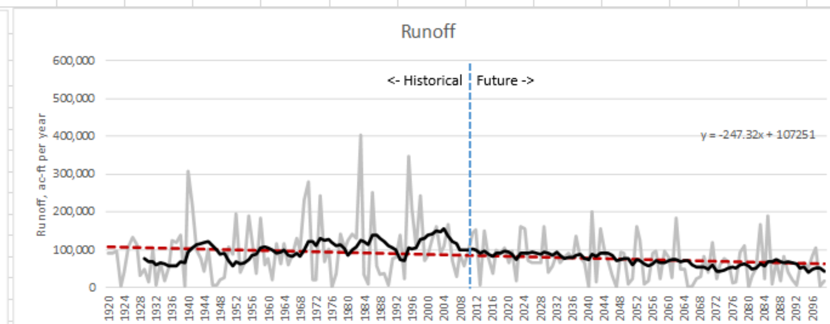
Warm &
Moderate
Rainfall





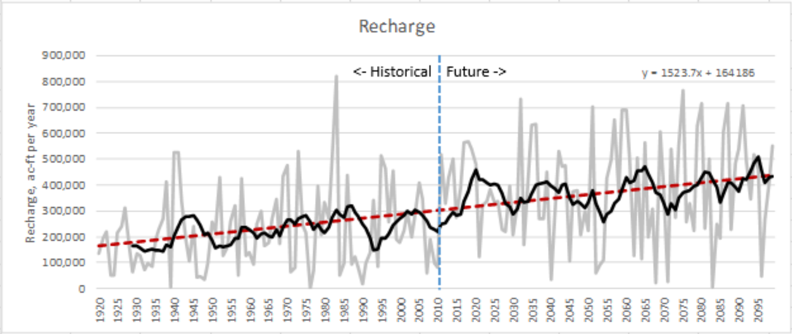
Hot &
Low Rainfall

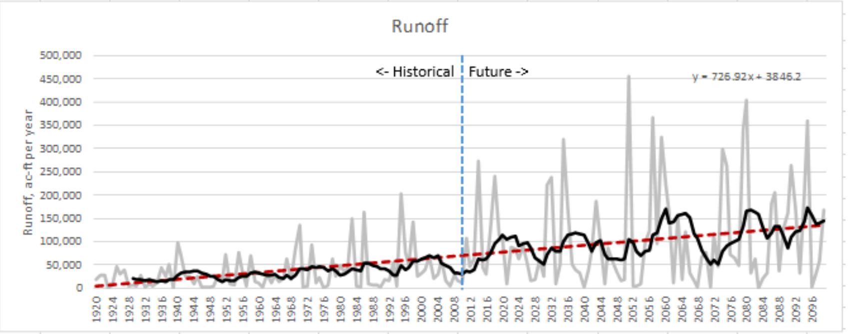




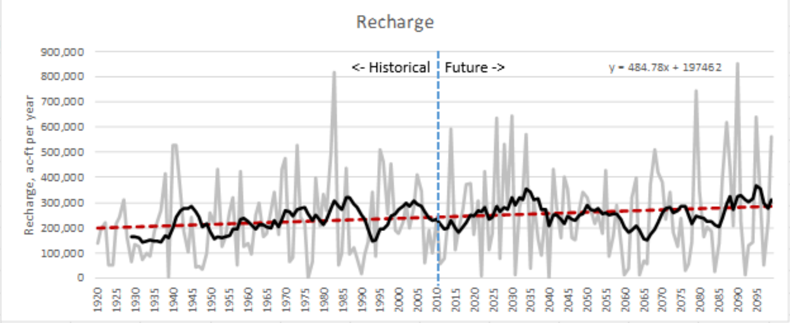
Annual Values-Water Supply
Valley Floor

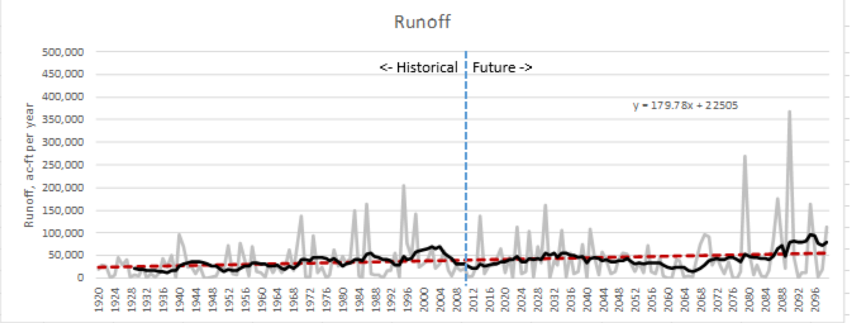
Warm &
High Rainfall



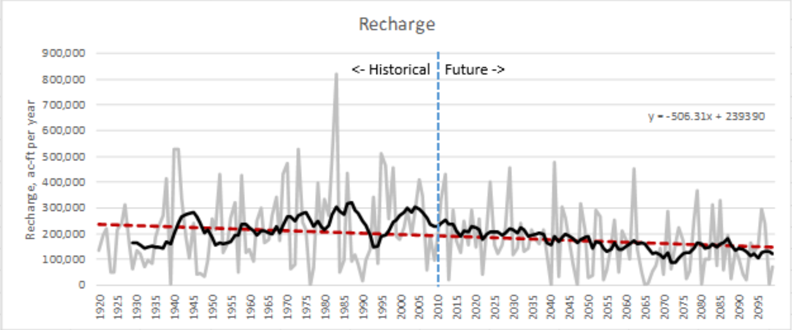


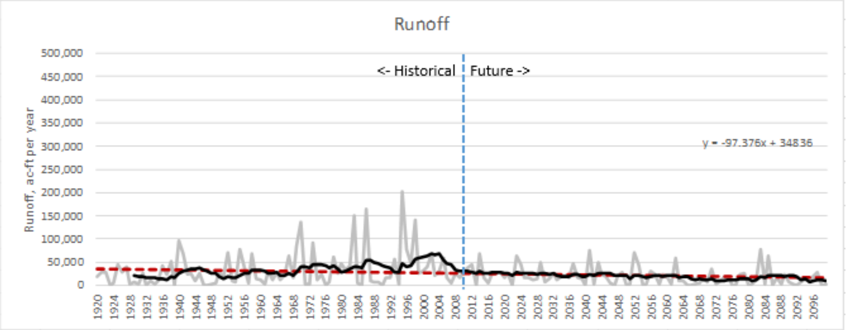
Warm &
Moderate
Rainfall





Hot &
Low Rainfall



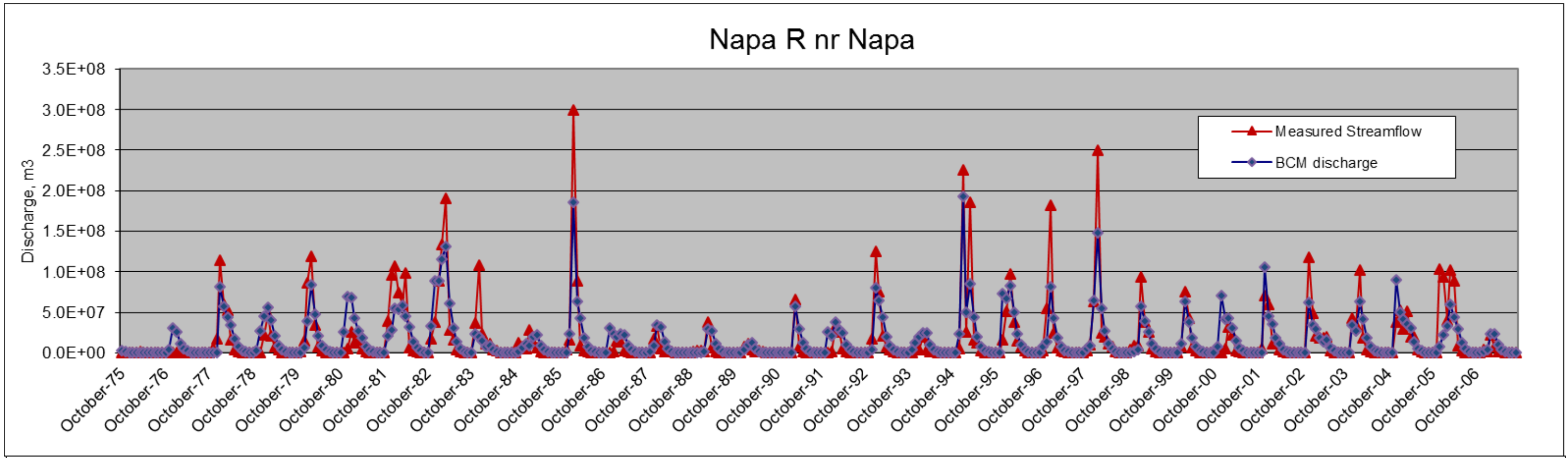


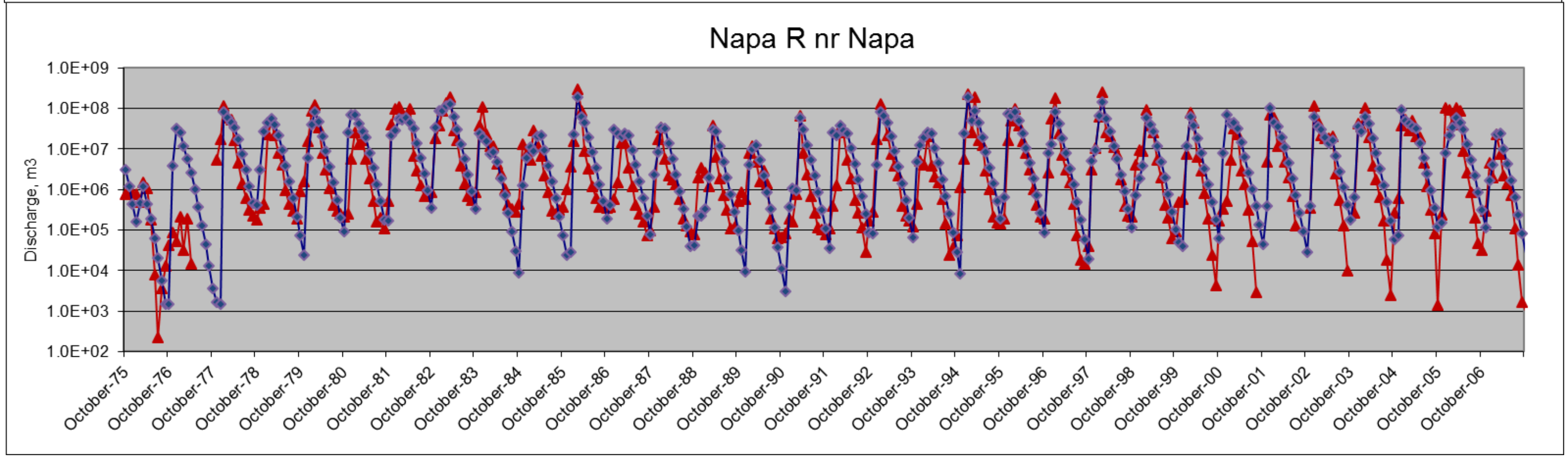
Management Question

What are the potential impacts of climate change on the flow regime of the Napa River?

Napa River Discharge

BCM calibration to stream flow data

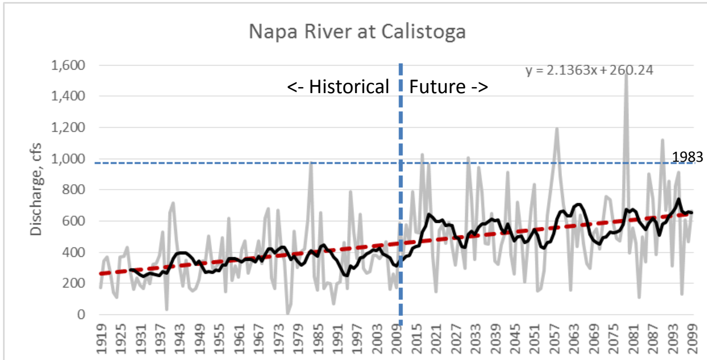


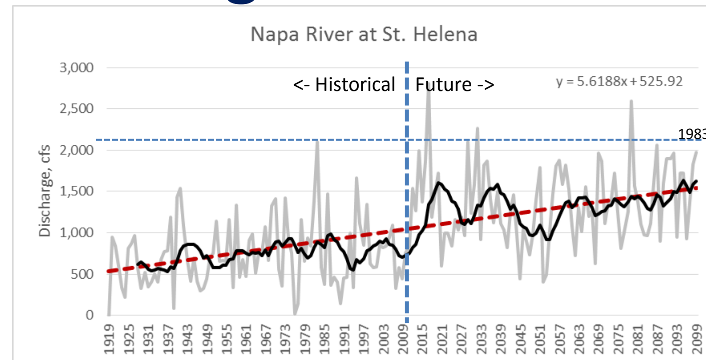


Napa River Flow Upstream

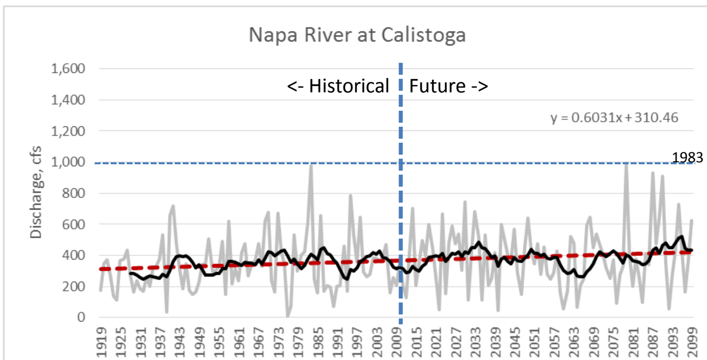
Calistoga and Saint Helena Gages

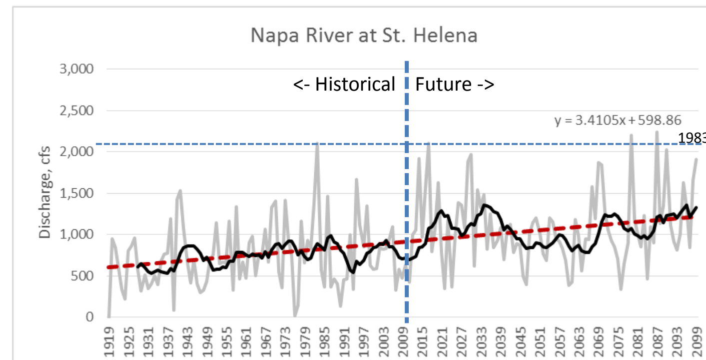
Scenario 5
Warm &
High Rainfall



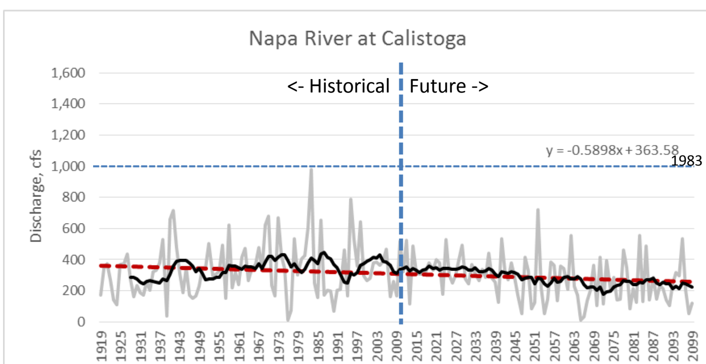


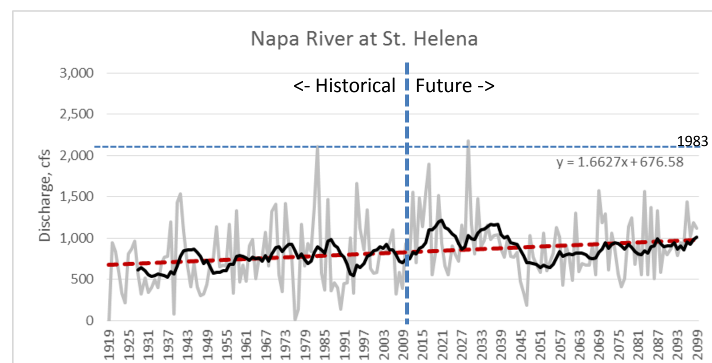
Scenario 3
Warm &
Moderate
Rainfall





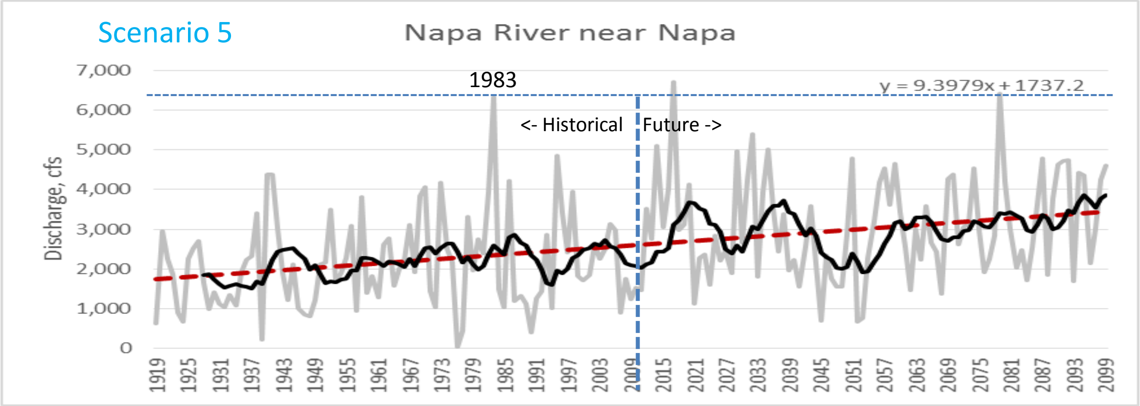
Scenario 6
Hot &
Low Rainfall



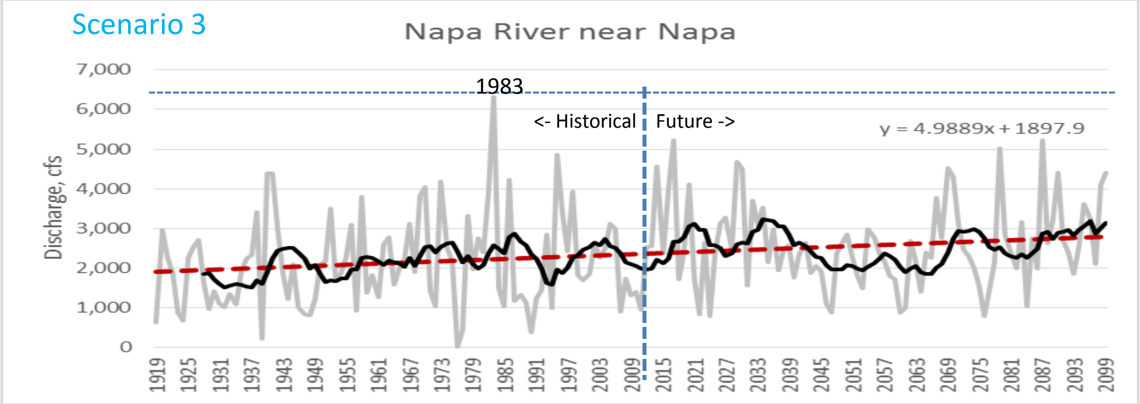


Napa River Annual Flows: Napa Gage

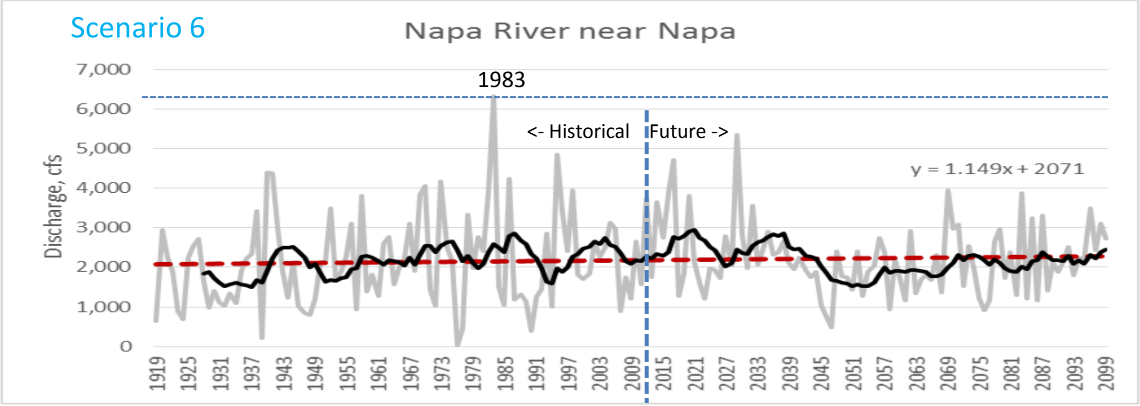
Warm &
High Rainfall



Warm &
Moderate Rainfall

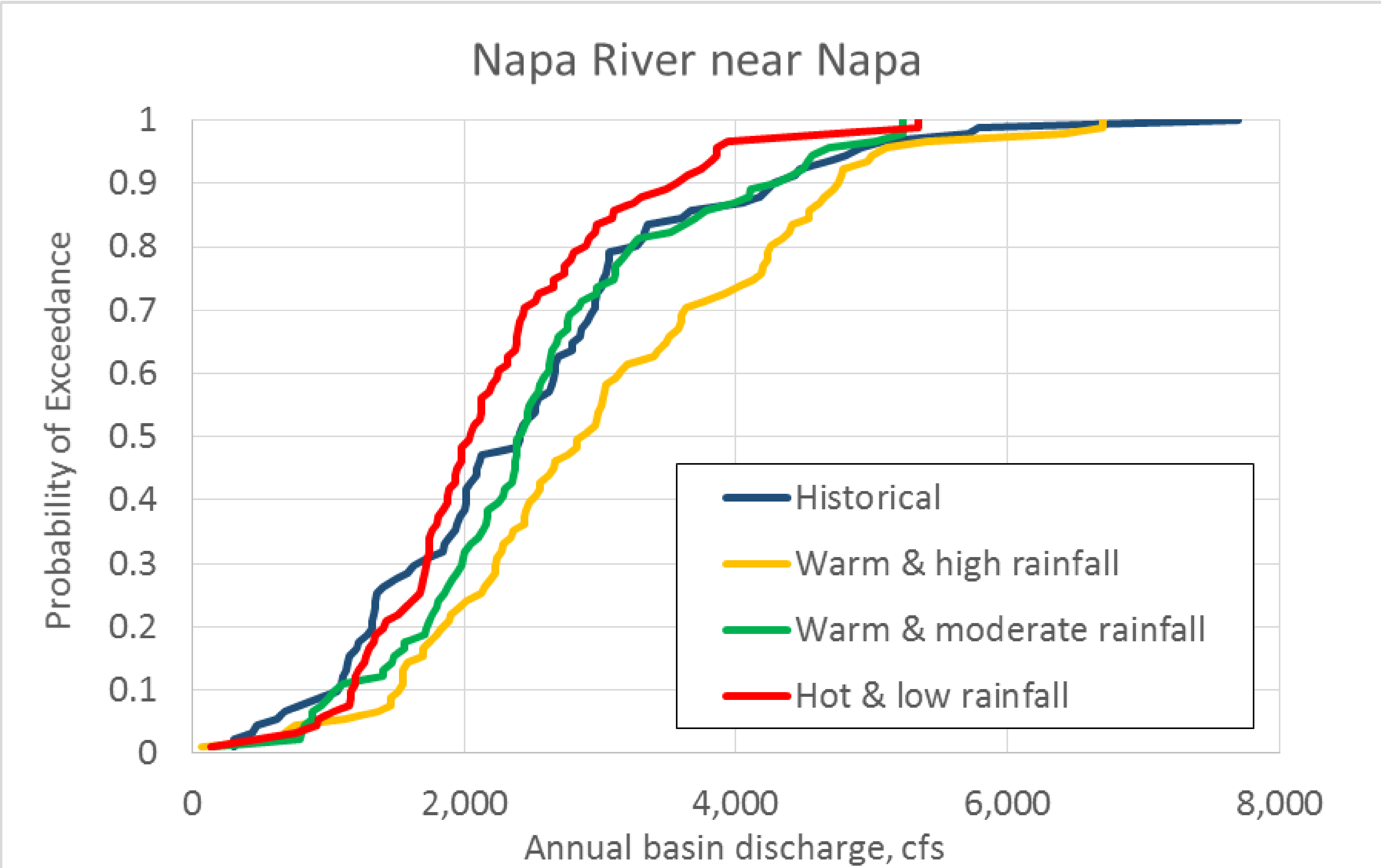


Hot &
Low Rainfall



- The alluvial valley widens, soils are deeper in the downstream direction
- With warming there is additional room in the soils to store rainfall, less runs off, a larger fraction becomes recharge
- This translates into smaller peaks compared to upstream and potential for a larger fraction of baseflow

Runoff can be translated to annual or monthly in-river flows at a gage



Management Question

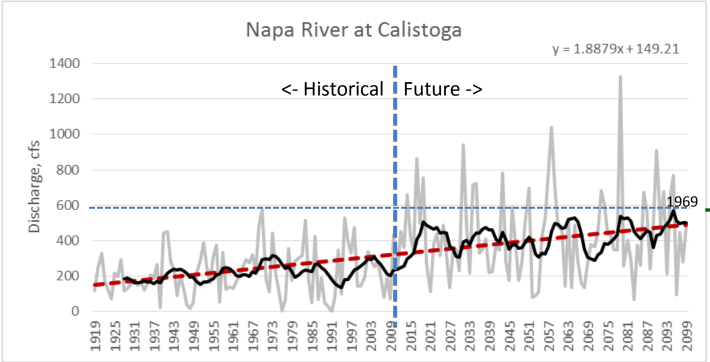
What is the potential increase in flood risks from drainages that exit into urban areas of the Napa Valley prone to flooding?

Napa River Upstream

Winter peaks (Dec-Jan-Feb)

1969 is reference peak “year” of historical record

Scenario 5
Warm &
High Rainfall



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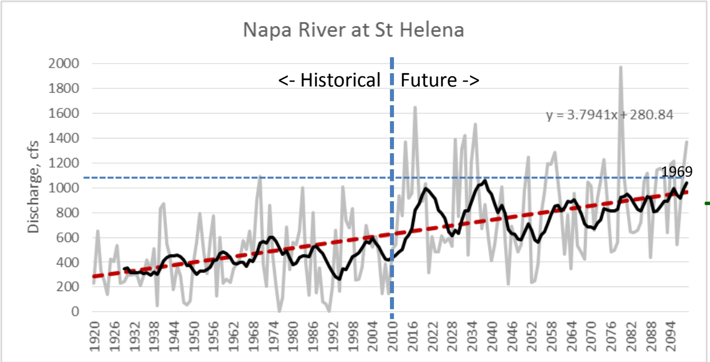

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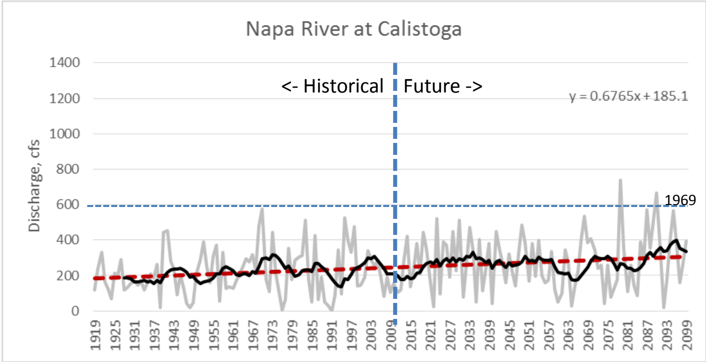
Scenario 3
Warm &
Moderate
Rainfall



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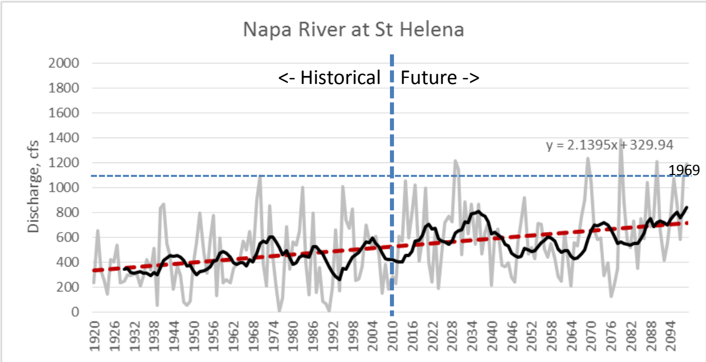

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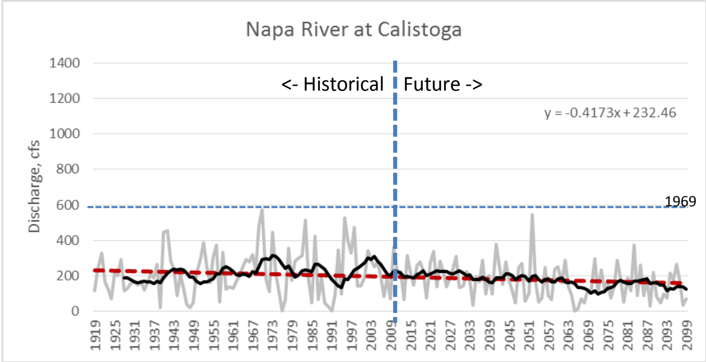
Scenario 6
Hot &
Low Rainfall



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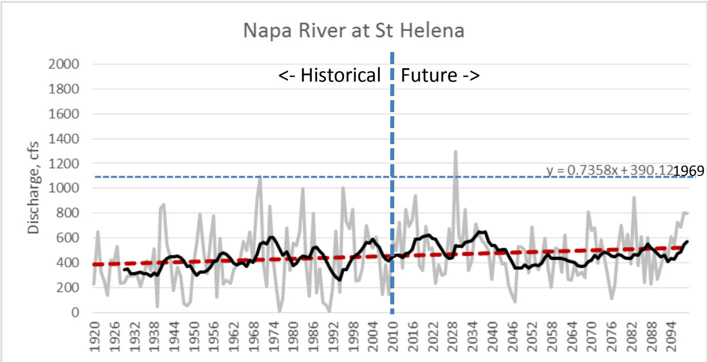

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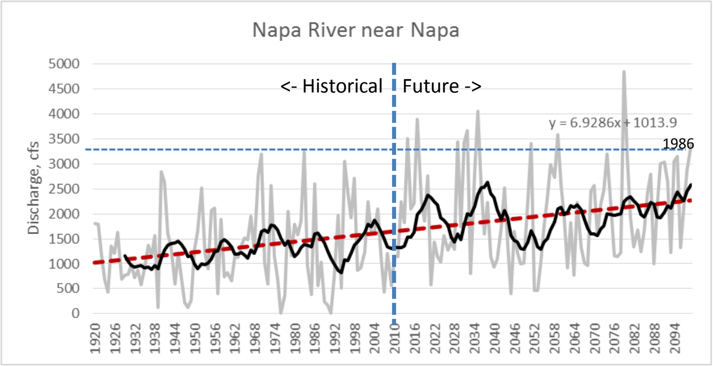
Napa River Downstream

Winter peaks (Dec-Jan-Feb)

1986 is reference peak “year” of historical record

Scenario 5
Warm &
High Rainfall



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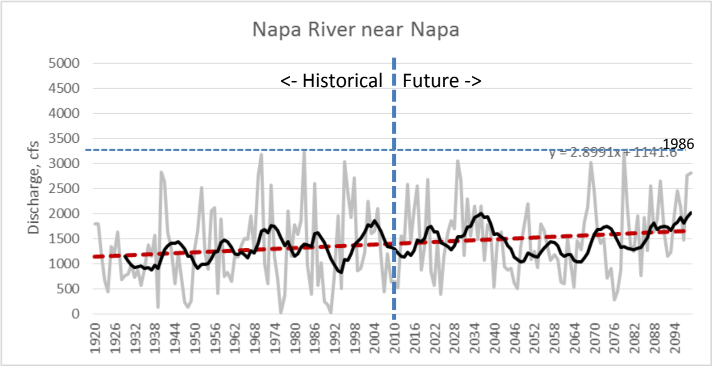
Scenario 3
Warm &
Moderate
Rainfall



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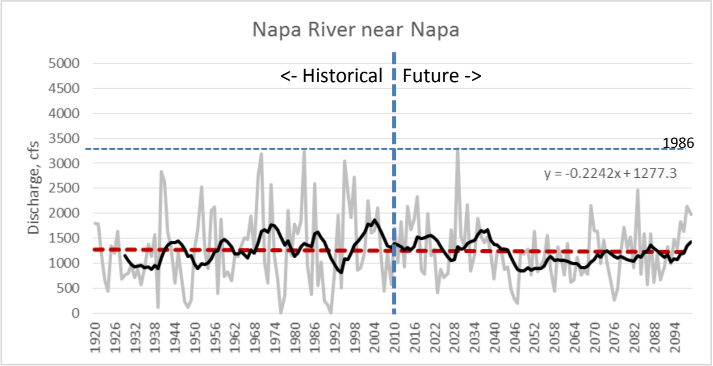
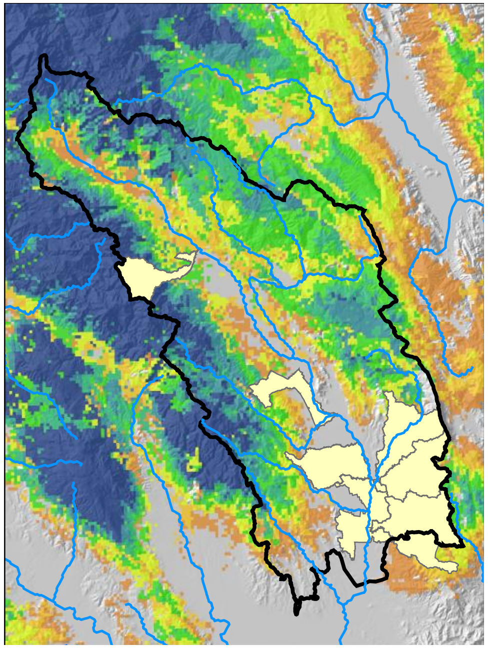
Scenario 6
Hot &
Low Rainfall

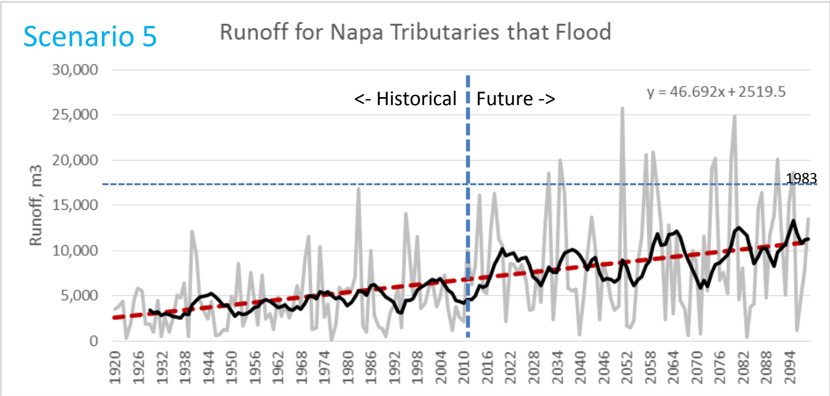


+0

Napa Tributaries that Flood

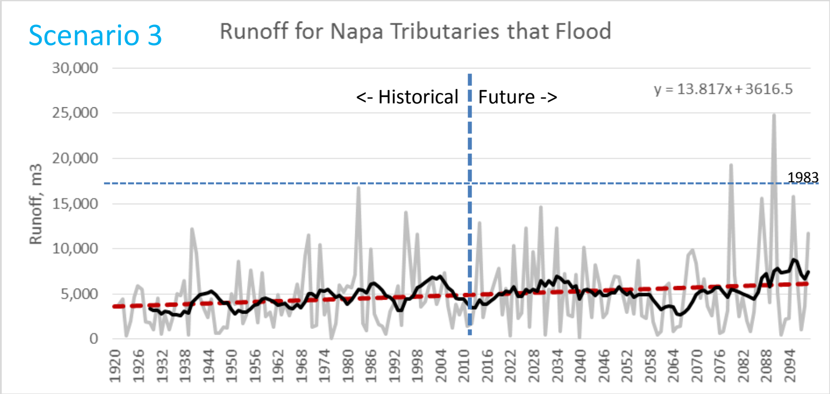


Warm &
High Rainfall



10 years exceeding historical peak threshold in future

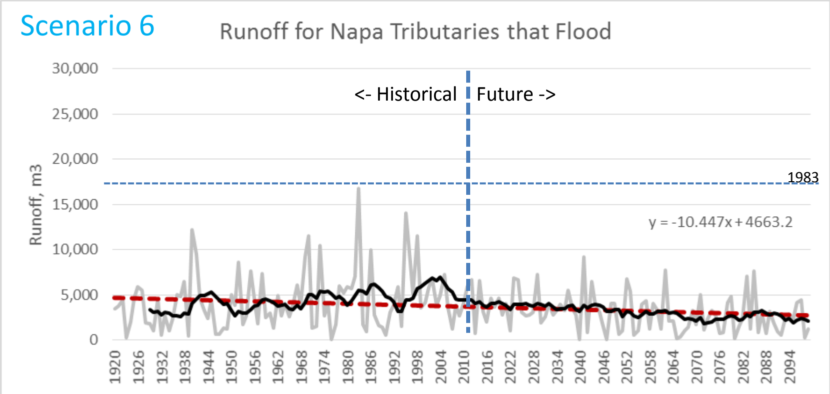
Warm &
Moderate Rainfall



2 years exceed threshold

1983 is reference peak "year" of historical record

Hot &
Low Rainfall



None exceed threshold

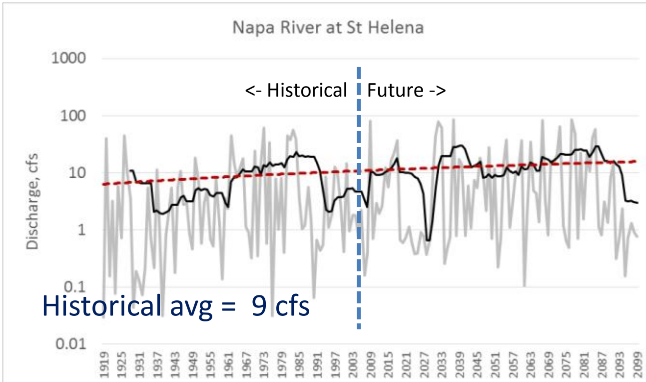
Management Question

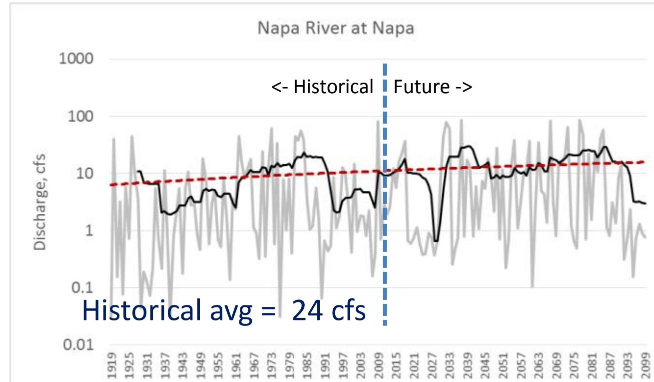
How will climate changes potentially impact the hydrology of high value main stem reaches and tributaries for fish?

Napa River: Saint Helena and Napa Gages

Summer low flows (Aug-Sep-Oct)

Warm &
High Rainfall

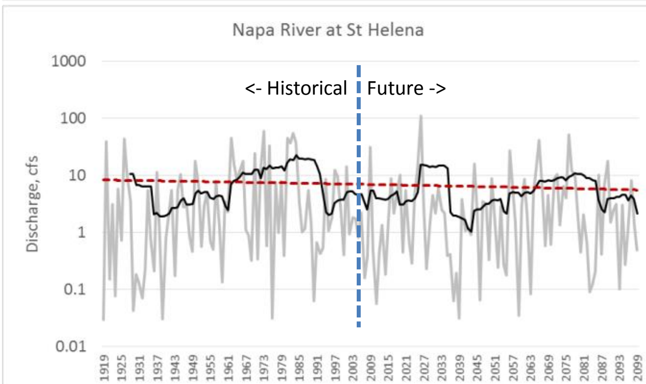


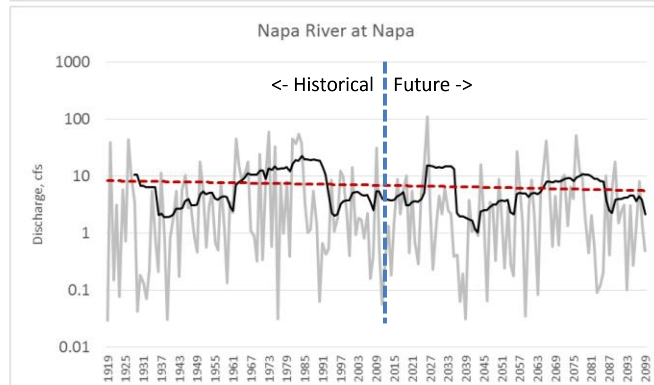


St Helena
Projected = 13 cfs

Napa
Projected = 36 cfs

Warm &
Moderate
Rainfall

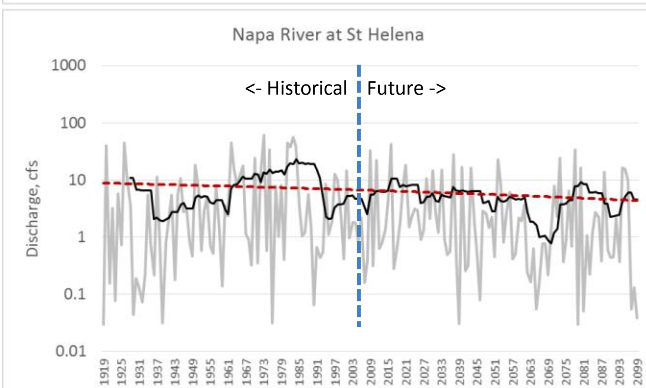


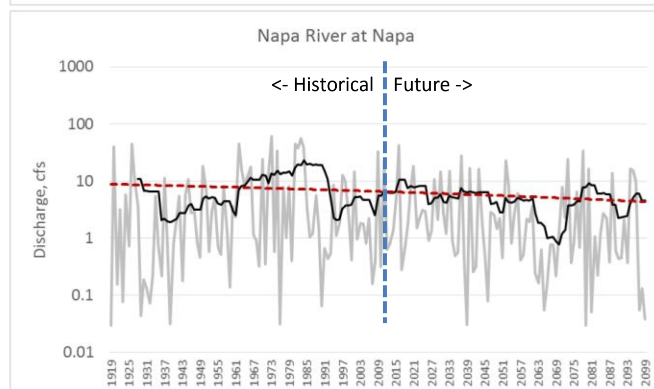


St Helena
Projected = 6 cfs

Napa
Projected= 15 cfs

Hot &
Low Rainfall





St Helena
Projected = 5 cfs

Napa
Projected= 13 cfs

Napa Fisheries Tributaries

Recharge plus Runoff in acre-feet, 30-y time steps

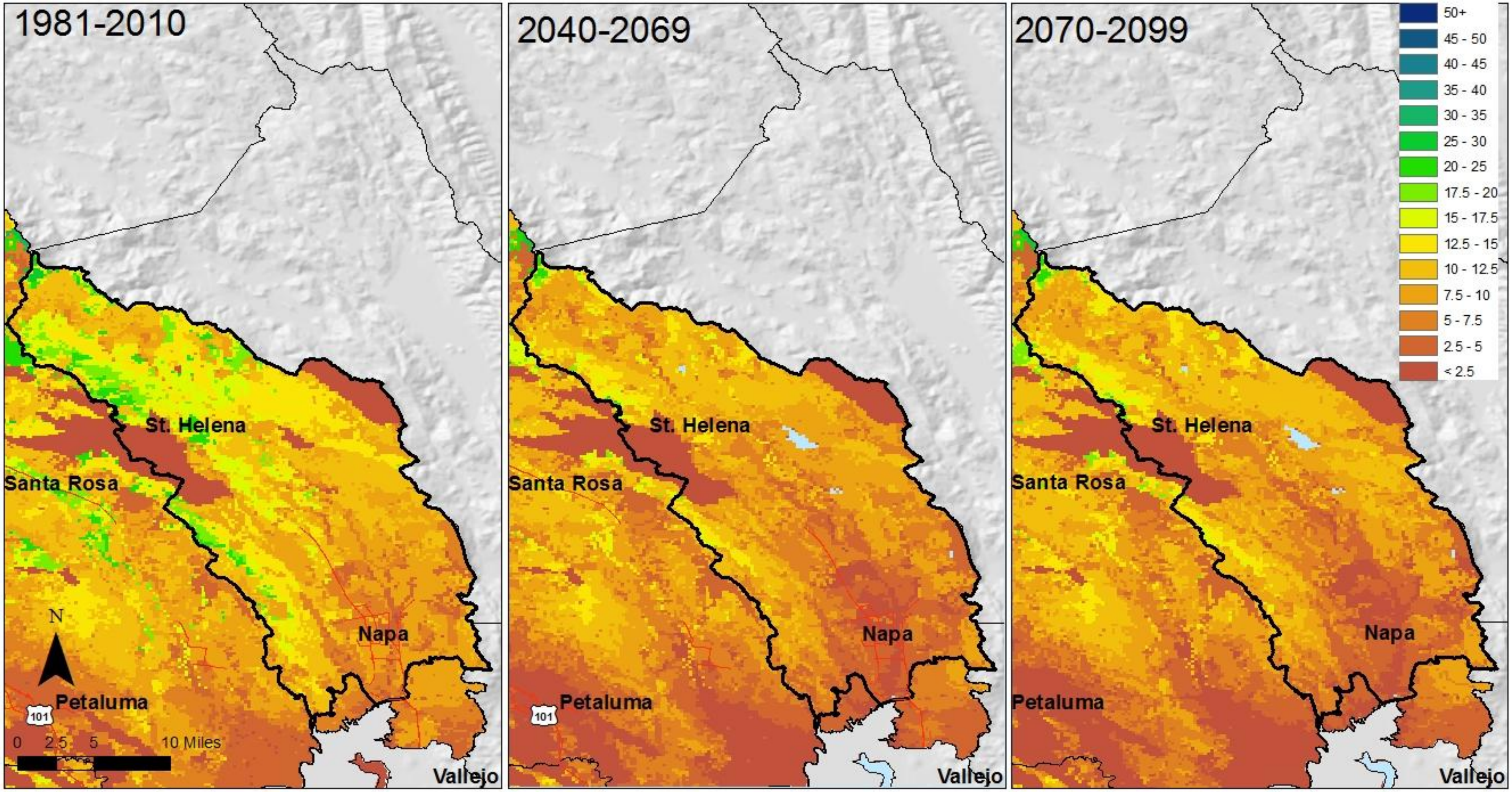
		Scenario	Warm, High Rainfall		Warm, Mod Rainfall		Hot, Low Rainfall		
Fish Bearing Stream Name	***Area***	*1981-2010*	*mid-century*	*end-century*	*mid-century*	*end-century*	*mid-century*	*end-century*	*end-century*
	(acres)	(acre-feet/yr)	(acre-feet/yr)	(acre-feet/yr)	(acre-feet/yr)	(acre-feet/yr)	(acre-feet/yr)	(acre-feet/yr)	% change
Garnett Creek	4780	120022	176393	198605	121283	137948	85508	84781	*-29%*
Napa River - Upper Calistoga Reach	1507	30282	45270	51887	30024	34739	20332	19917	*-34%*
Simmons Canyon Creek	2087	48547	70820	80026	48488	55421	34076	33726	*-31%*
Selby Creek	3755	86229	126050	142448	85918	98425	60087	59325	*-31%*
Blossom Creek	2442	49295	72873	83497	48337	55915	32749	32144	*-35%*
Cyrus Creek	1888	41404	59477	67792	39906	46013	27508	27025	*-35%*
Kortum Canyon Creek	1799	44252	62692	70676	43329	49366	30840	30521	*-31%*
Bell Creek	2673	52945	79733	91040	53214	62142	36718	36092	*-32%*
Ritchie Creek	1536	38698	54321	61449	37118	42501	25960	25596	*-34%*
Mill Creek	1410	34545	47784	54213	32464	37386	22671	22304	*-35%*
York Creek	2509	60831	82908	94223	56268	65151	39356	38785	*-36%*
Napa River - Lower St. Helena Reach	4381	69199	105269	123662	65947	80203	42718	40707	*-41%*
Sulphur Creek - Main Fork	3428	92821	122412	138120	85117	97612	61182	60582	*-35%*
Conn Creek - Lower Reach	7298	115363	170126	199131	108644	131510	72051	69166	*-40%*
Heath Creek	1782	48299	64577	72682	45048	51628	32523	32223	*-33%*
Bear Creek	6142	124454	174639	200881	116567	137505	80865	79044	*-36%*
Dry Creek	12728	287807	394976	451298	268022	314045	188026	184618	*-36%*
Soda Creek	2966	53081	78056	89041	52806	62382	37063	36399	*-31%*
Hopper Creek	3003	43527	61690	72938	38674	47568	24748	23667	*-46%*
Milliken Creek - Main Fork	5695	76765	113104	132056	71604	88155	47527	45718	*-40%*
Redwood Creek - Upper Reach	4485	107863	146929	168481	99447	116968	69157	67376	*-38%*
Pickle Canyon	1807	41423	55046	63231	37087	43854	25699	25135	*-39%*
Sarco Creek	5398	64364	97206	115271	59412	74474	37532	35239	*-45%*
Carneros Creek	5710	90805	128544	151488	81394	100362	53185	50928	*-44%*
Tulucay Creek	8058	113506	163566	190459	107216	130370	72190	69996	*-38%*
Huichica Creek	4028	57300	84348	99601	53240	66078	34723	33282	*-42%*
Average Values		*76678*	*109185*	*125546*	*72561*	*85682*	*49807*	*48627*	*-37%*
Percent Change			*42%*	*64%*	*-5%*	*12%*	*-35%*	*-37%*	

Management Question

What is the spatial variability in potential groundwater recharge and where are high value recharge zones located? How will climate change impact potential groundwater recharge in the Napa Valley?

Napa River Valley Groundwater Recharge

Map time series, current to end of century, Scenario 6-hot and low rainfall



10.6 in/y average for valley

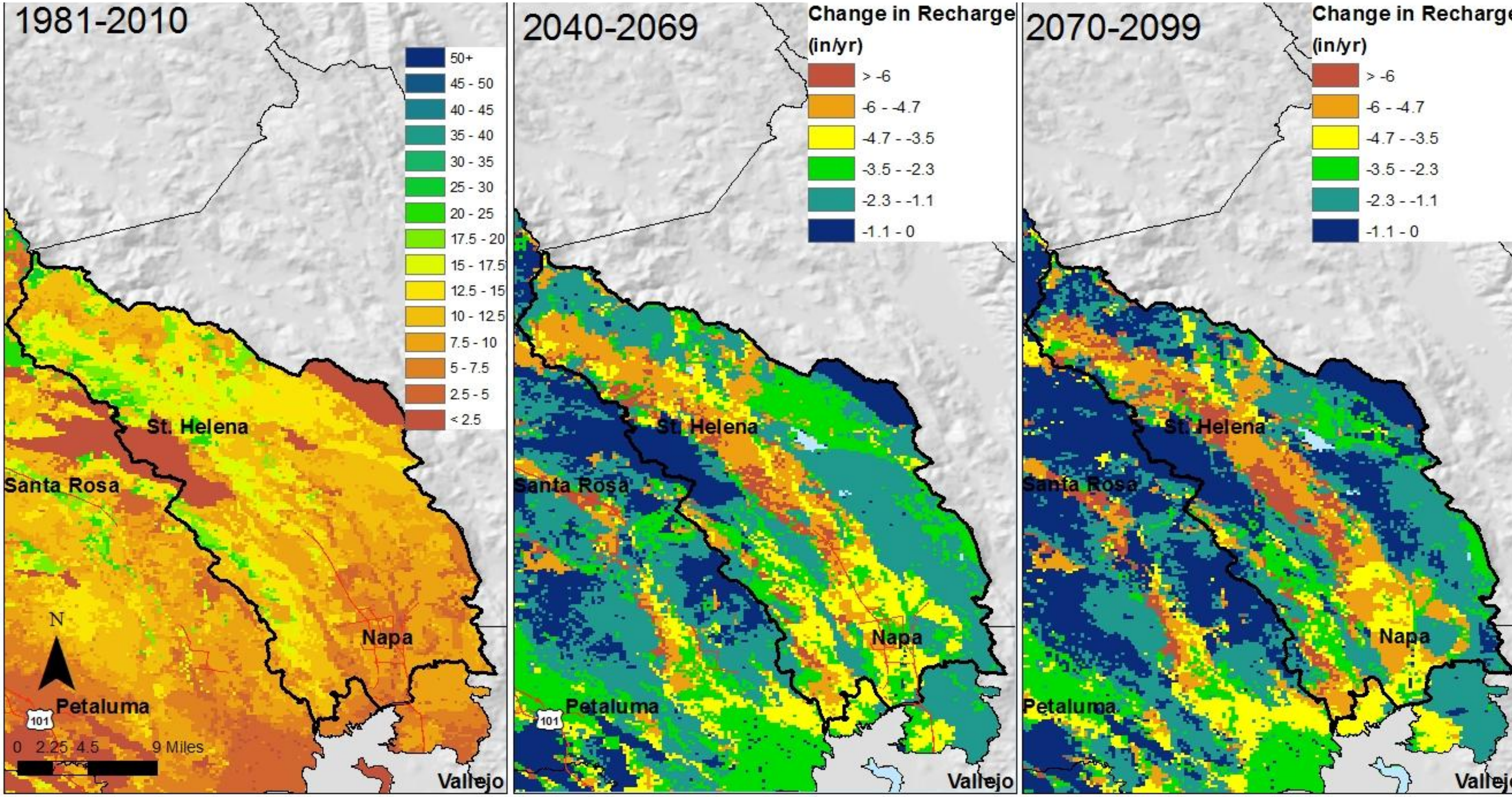
7.5 in/y average for valley
29% reduction

7.8 in/y average for valley
27% reduction

BCM recharge layers shows the spatial distribution of high versus low recharge value

Napa River Valley Groundwater Recharge

Mid- and end-century change compared to current, Scenario 6-hot and low rainfall



11 in/y average for valley

29% reduction
to 7.5 in/y average for valley

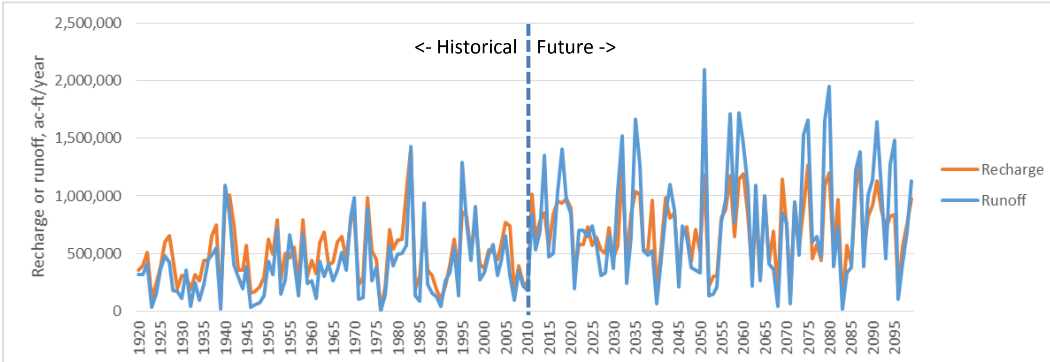
27% reduction
to 7.8 in/y average for valley

Low rainfall scenario results in losses of 2.5 inches of groundwater recharge per unit area annually

Napa Valley: Recharge and Runoff Comparison

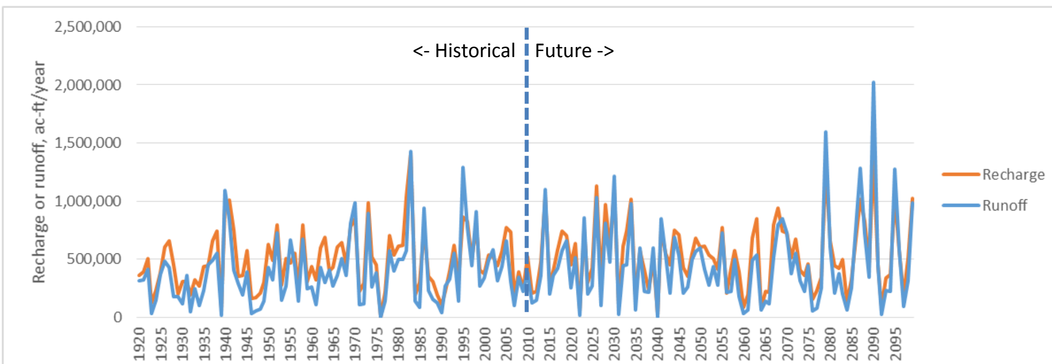
Average Historical
Recharge 11 in/yr
Runoff 8 in/yr

Scenario 5
Warm &
High Rainfall



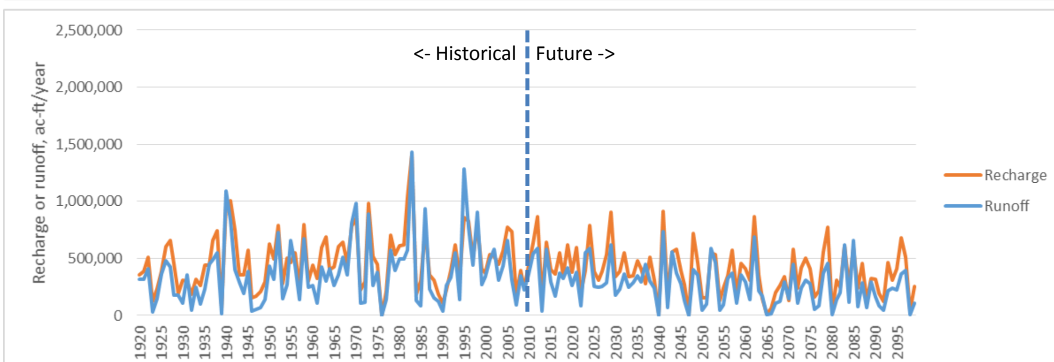
Warm and high rainfall future
Recharge 10 in/yr
Runoff 15 in/yr

Scenario 3
Warm &
Moderate
Rainfall



Warm and mod rainfall future
Recharge 11 in/yr
Runoff 8 in/yr

Scenario 6
Hot &
Low Rainfall



Hot and low rainfall future
Recharge 8 in/yr
Runoff 4 in/yr

Management Question

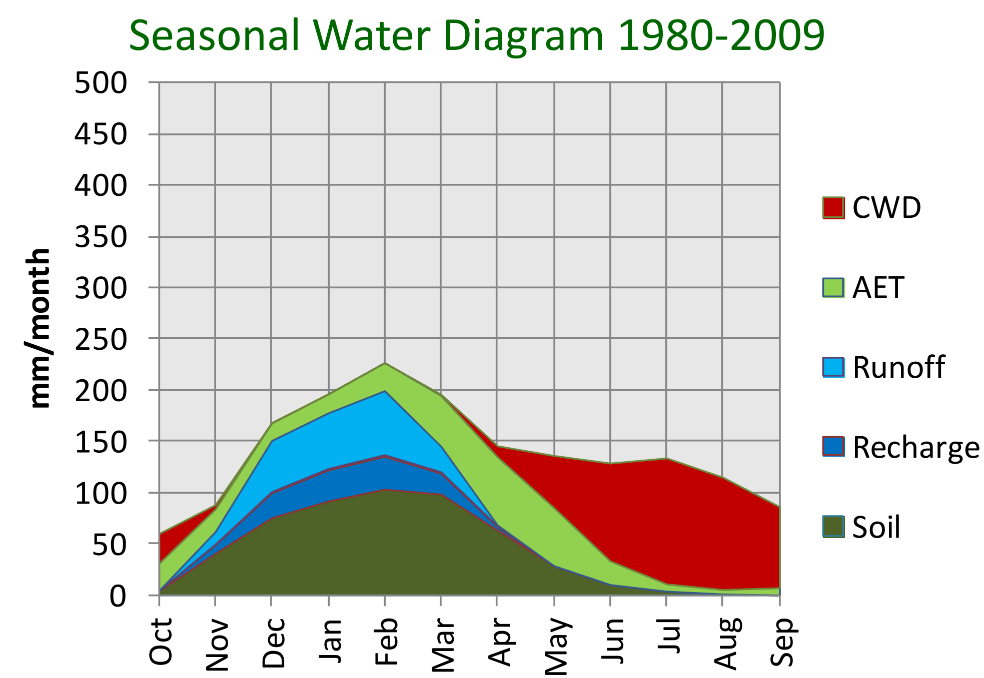
What is the spatial variability in potential groundwater recharge and where are high value recharge zones located? How will climate change impact potential groundwater recharge in the Napa Valley?

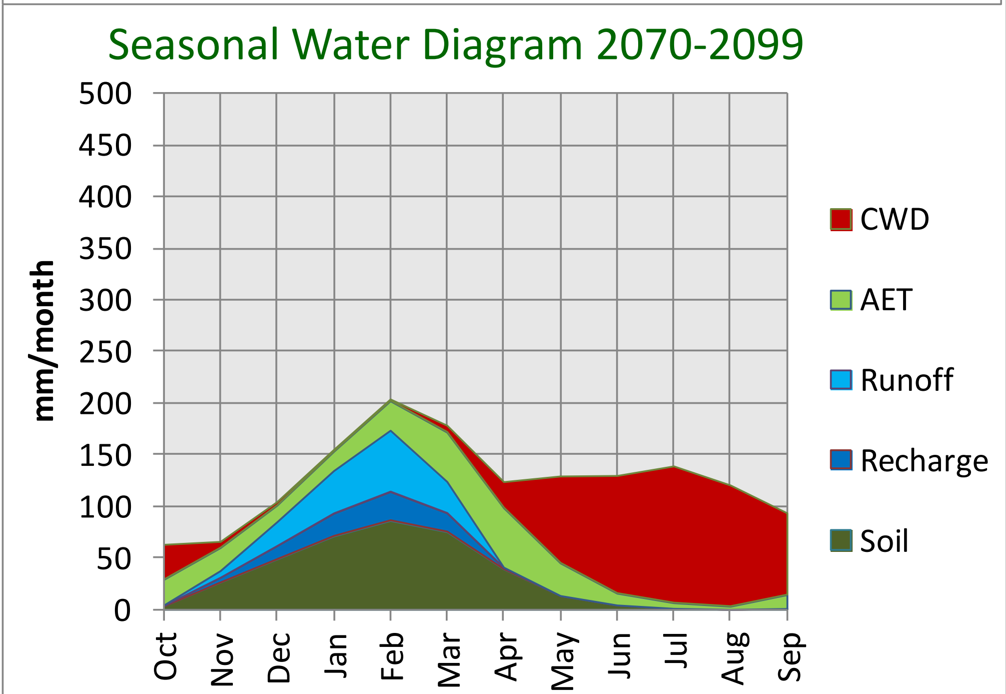
Talking Points:

- The valley-wide average for groundwater recharge estimated for 1981-2010 is 11 in/y.
- Potential groundwater recharge ranges includes highs of 20-30 in/y in alluvial fans located in the Northern end of the valley and at the flanks of the Eastern Mayacamas.
- Recharge lows are estimated at <2.5 inches per year in the most high elevation, resistant bedrock in both the Mayacamas and Berryessa Ranges.
- On the valley floor, groundwater recharge rates vary from 7.5-12.5 in/y in the Northern Valley, and 2.5-12.5 in/y in the Southern Valley.
- Low rainfall climate change scenarios have the potential to reduce rates of groundwater recharge up to approximately 30%, or 2.5 in/y.

Management Question

How will climate change potentially impact the seasonality of the Napa Valley's water cycle?





Seasonality of Water Cycle

1980-2009	**Annual Average**	
PPT	25.9	in
CWD	19.8	in
AET	13.0	in
Runoff	8.2	in
Recharge	4.8	in
Recharge/runoff	0.58	
Tmax	59.2	F
Tmin	41.7	F

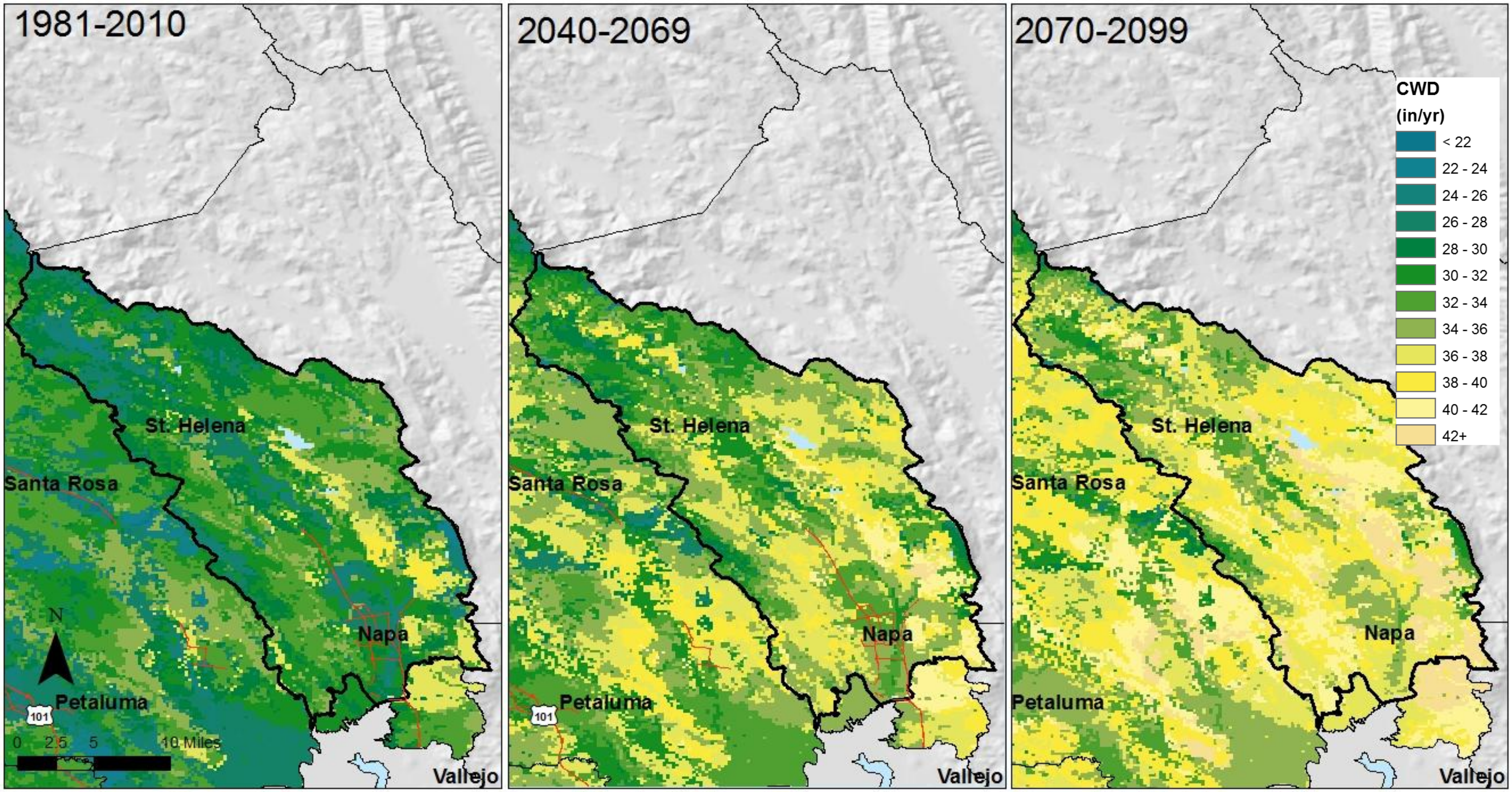
2070-2099	**Annual Average**	
PPT	20.8	in
CWD	23.8	in
AET	11.1	in
Runoff	6.4	in
Recharge	3.4	in
Recharge/runoff	0.53	
Tmax	63.7	F
Tmin	45.5	F

Coming soon: Climate Smart Watershed Analyst ***climate.calcommons.org***

Management Question

How will the agricultural lands of the Napa Valley be potentially impacted by climate change in terms of irrigation demand?

Climatic Water Deficit, Hot and Low Rainfall

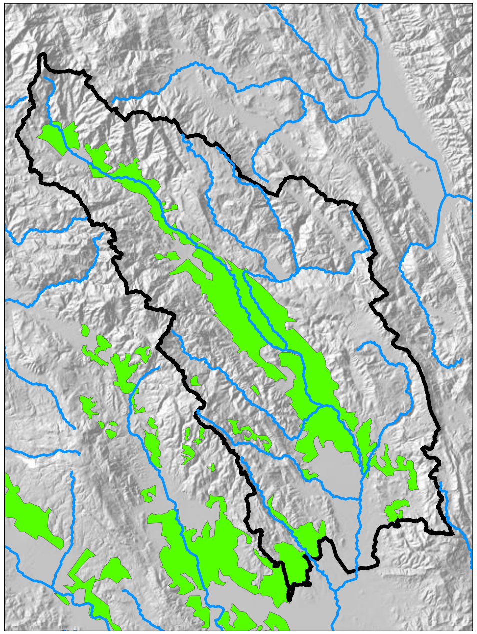


31 in/y average
(36 in/y rainfall)

34 in/y average
(29 in/y rainfall)

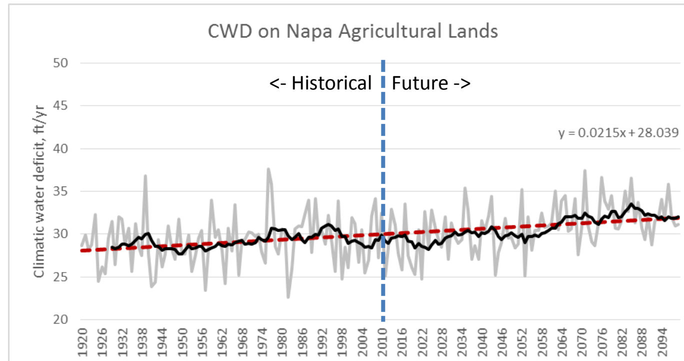
37 in/y average
(28 in/y rainfall)

Climatic Water Deficit on Napa Agricultural Lands



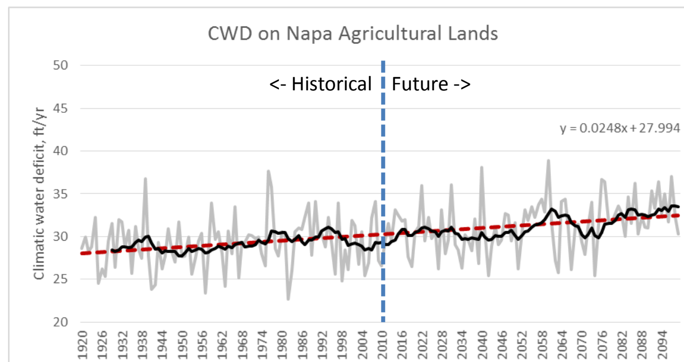
Water deficits increase in even high rainfall scenarios

Scenario 5
Warm &
High Rainfall



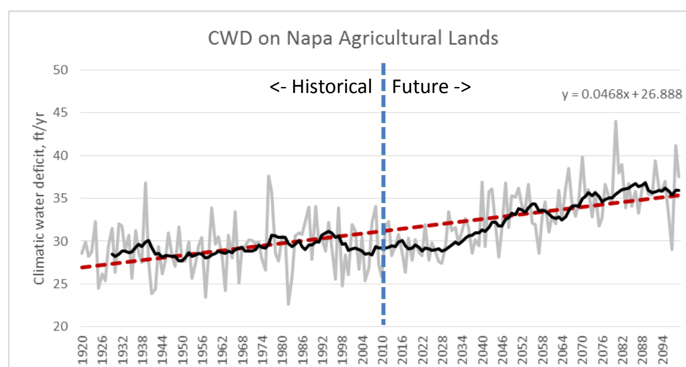
last 30 years 9 % greater deficit

Scenario 3
Warm &
Moderate Rainfall



last 30 years 10 % greater deficit

Scenario 6
Hot &
Low Rainfall



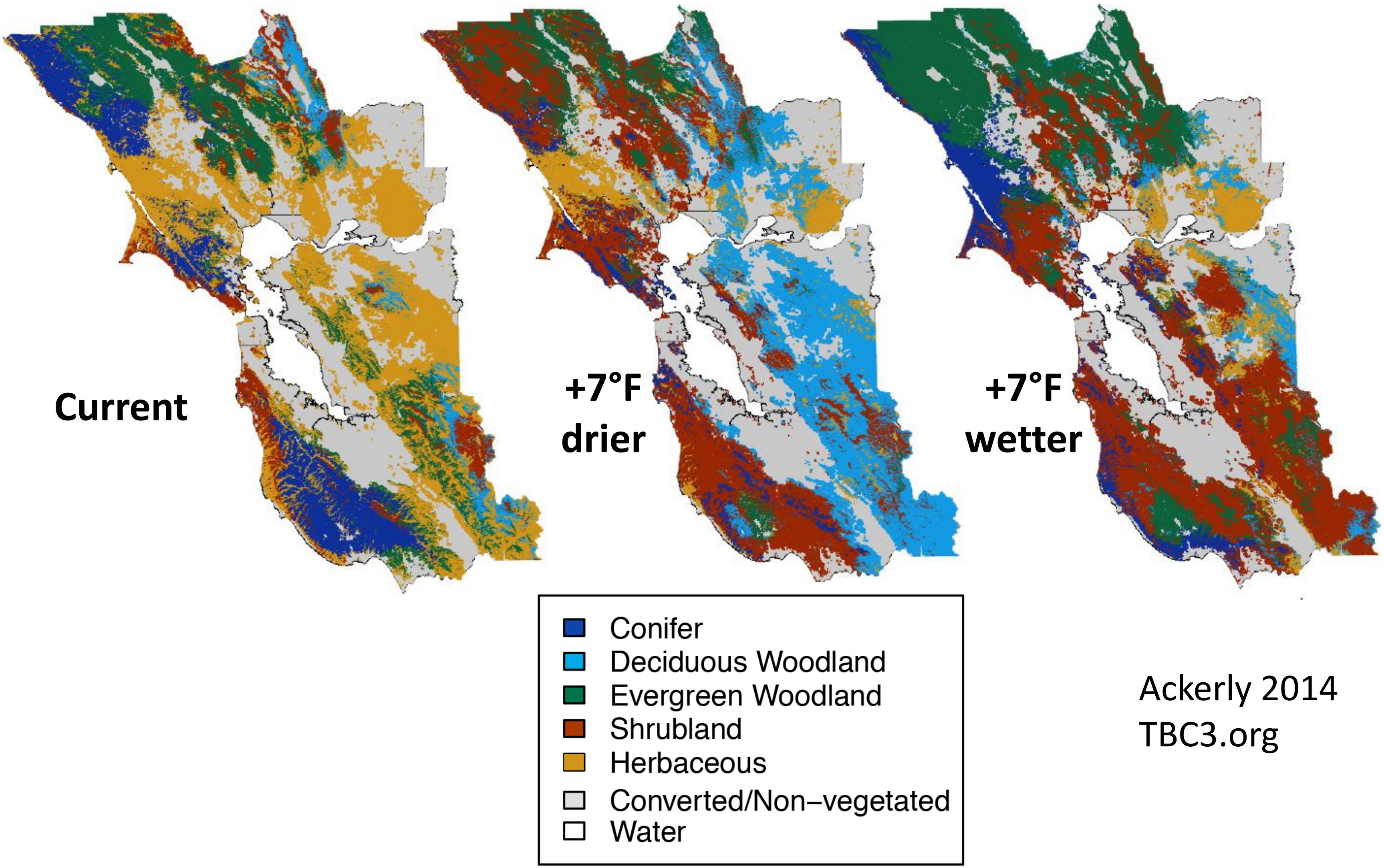
last 30 years 20 % greater deficit

Potential native vegetation responses to changing climate

Management Question

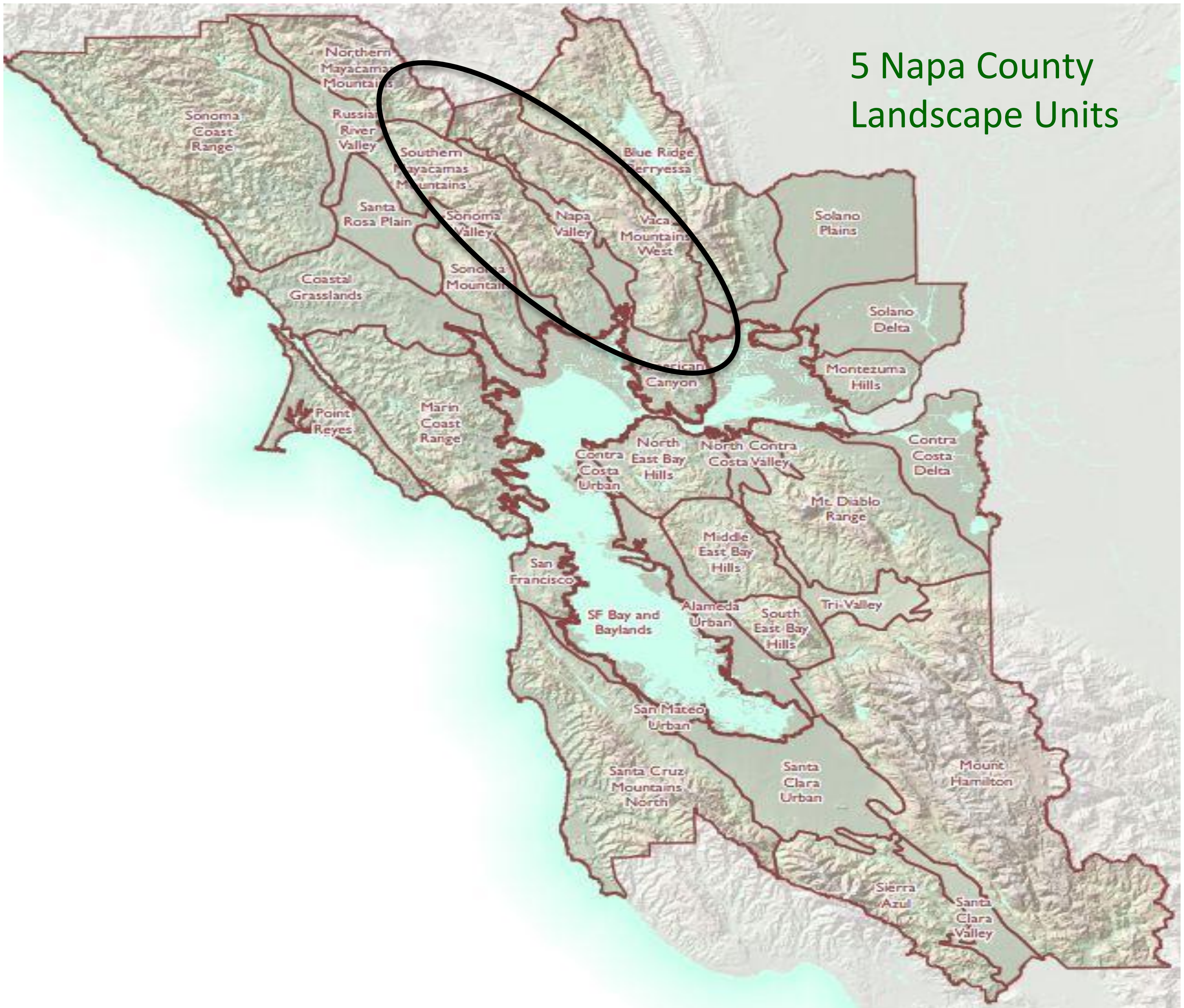
What will be the impact of climate change on important upland vegetation types and can you identify potentially stable vegetation communities for conservation planning?

what might the Bay Area vegetation of the future look like?



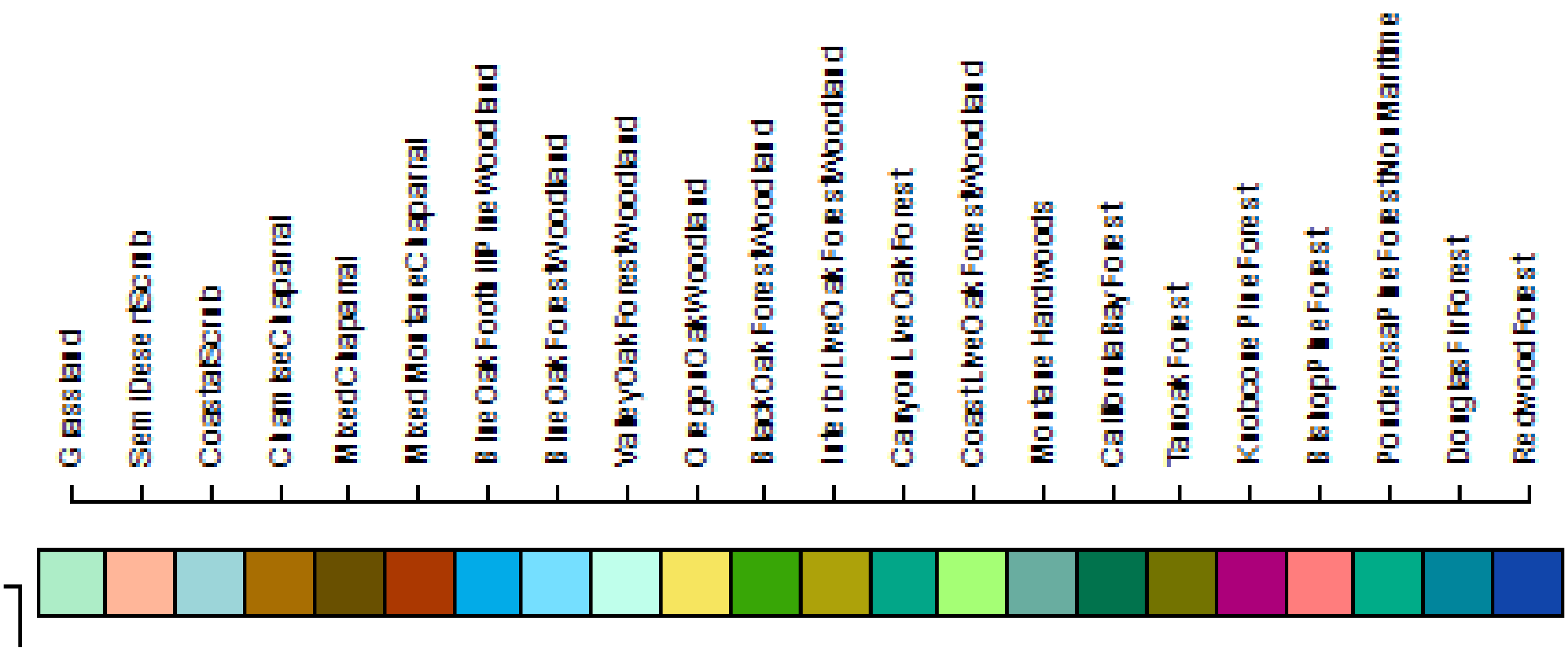
Ackerly 2014
TBC3.org

Landscape Units defined by Bay Area Upland Habitat Goals Project (2011)



Equilibrium vegetation response to climate change in Napa County

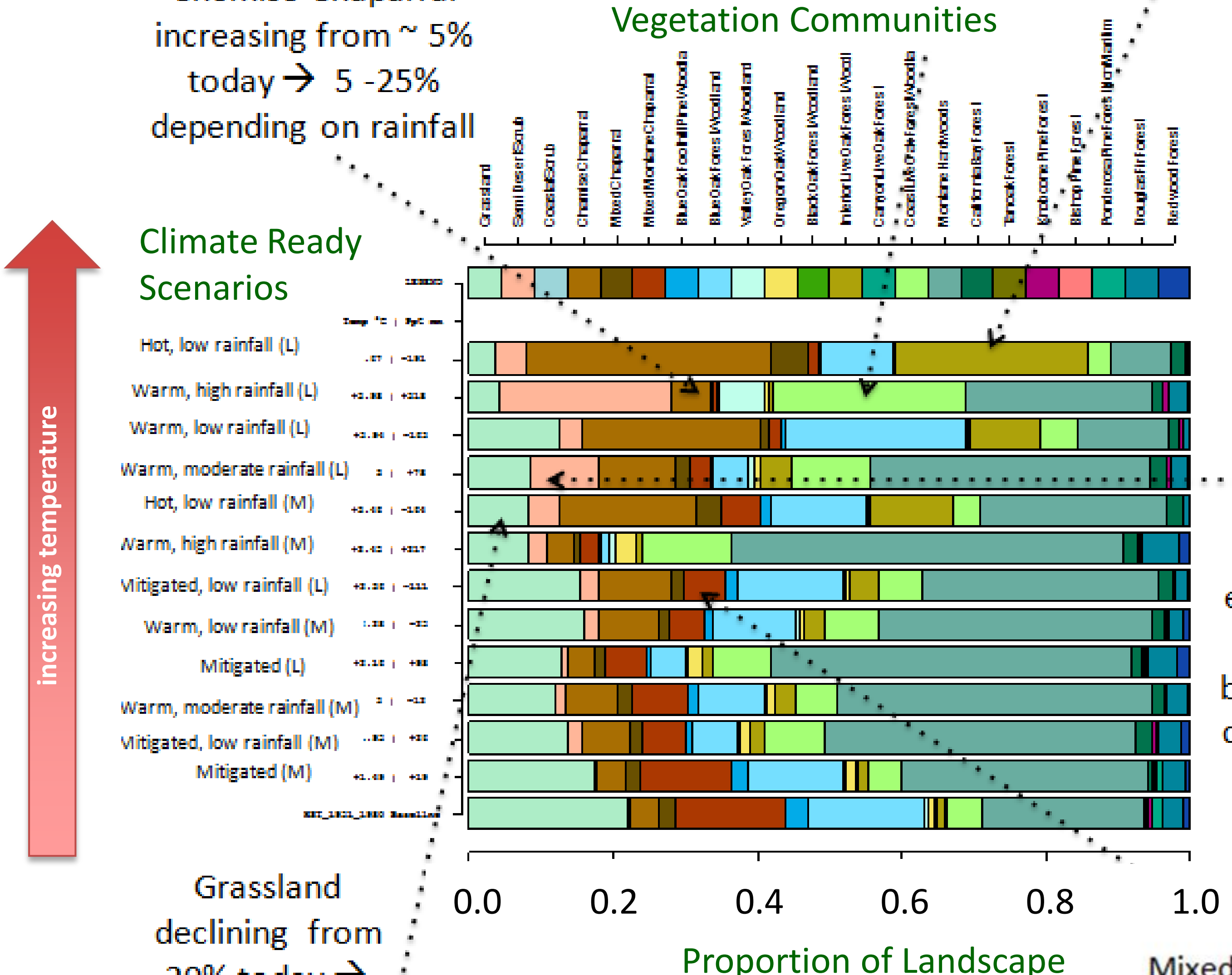
Projected proportional landscape cover of 22 vegetation types under both historical conditions and six future scenarios, organized from top to bottom by increasing temperature. This is an equilibrium model so this assumes vegetation has had time to adjust to climate conditions. In reality , vegetation turnover will take time. Fires and other disturbance can accelerate shifts. How land is managed will also affect rate of change. For example, grasslands may be maintained by active grazing, burning or mowing. Data from D.D. Ackerly 2015.



Napa County Vegetation Report Summary

Coast Live Oak and Interior Live Oak increasing from ~ 5% today → 5 - 25% late century, depending on rainfall

Conditions for Chemise Chaparral increasing from ~ 5% today → 5 -25% depending on rainfall

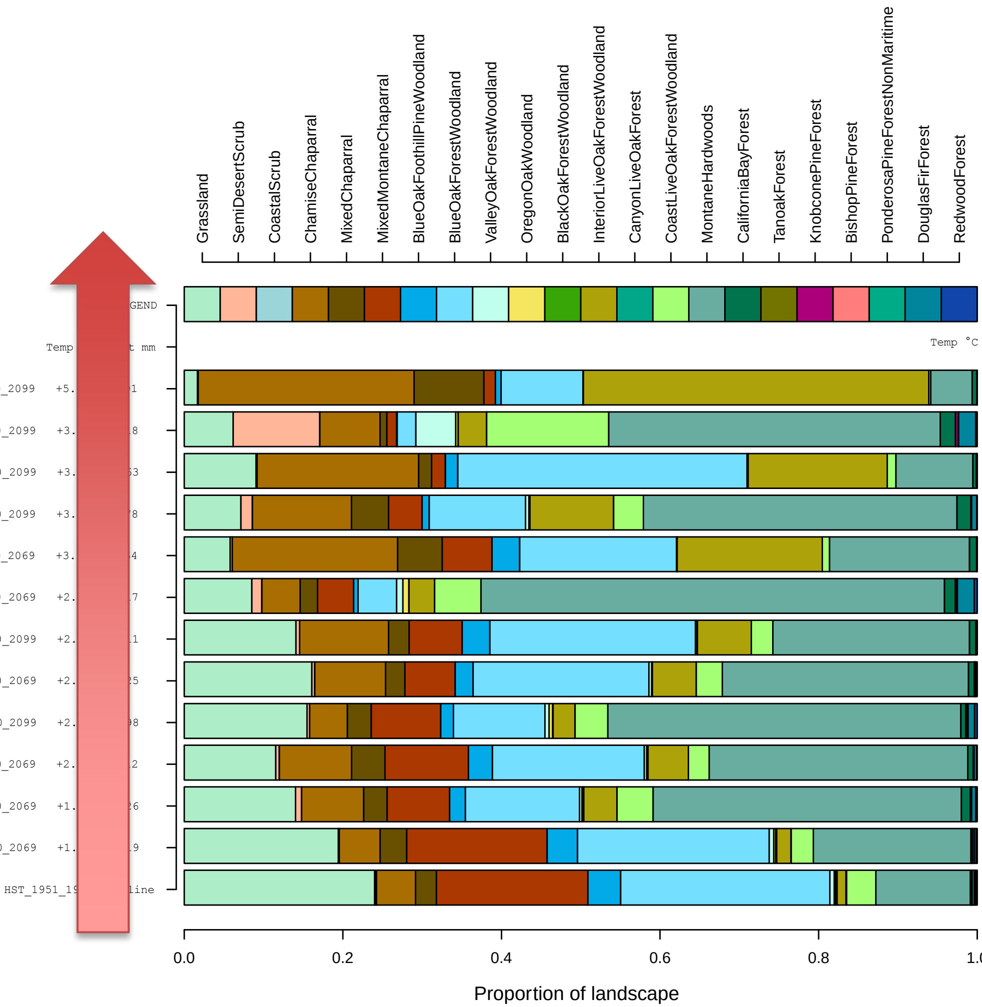


Semi-desert Scrub emerges and becomes common

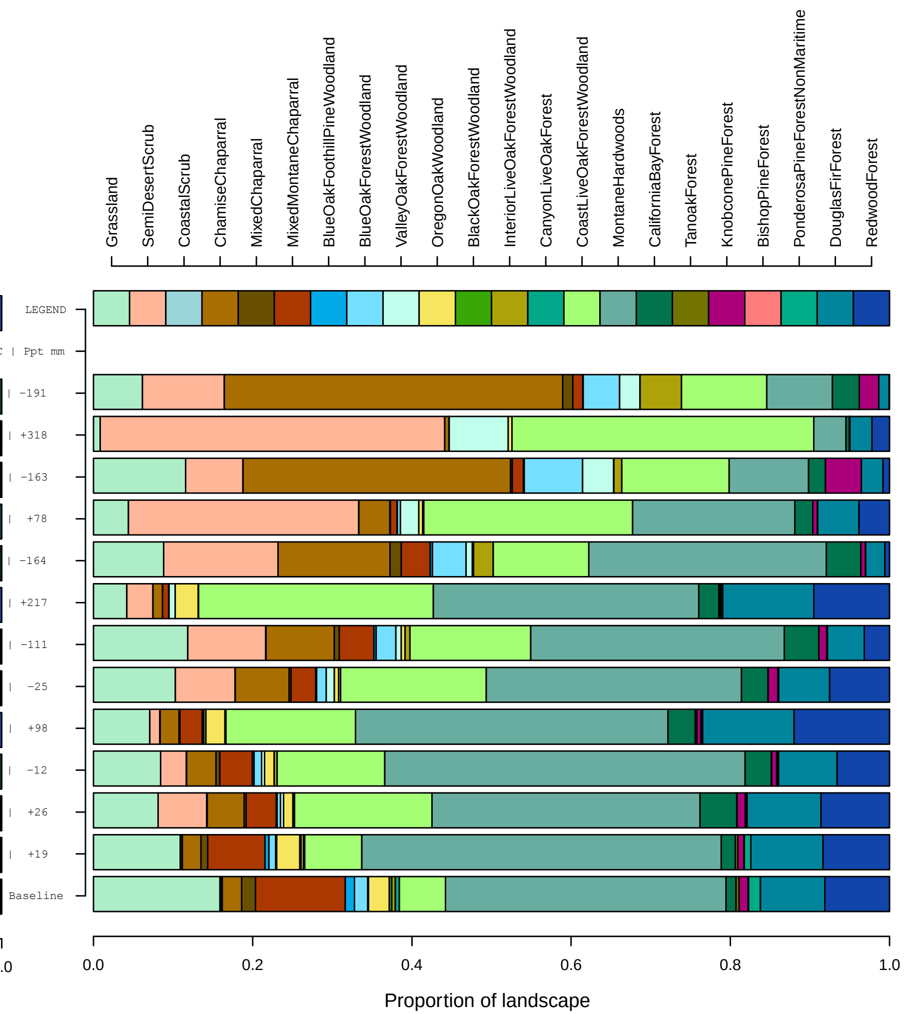
Grassland declining from 20% today → < 10% in late century

Mixed Montane Chaparral declining from ~10% → < 5% by mid century

Blue Ridge Berryessa



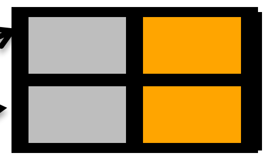
Southern Mayacamas Mountains



there can be significant differences between landscape units

Another way to look at the vegetation data: Four-square diagrams

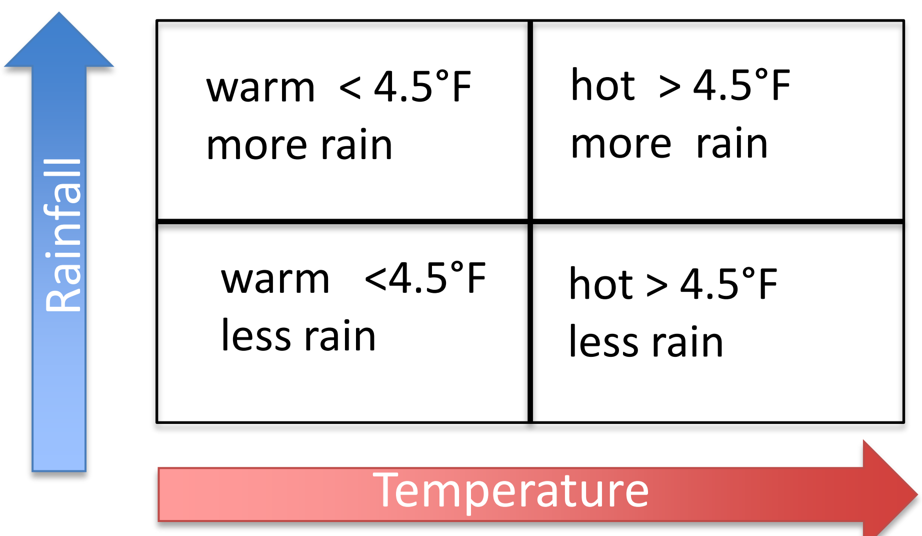
Example: *Redwood Forest is sensitive to temperature in Northern Mayacamas*



Rainfall does not have large effect

Significant declines emerge at hotter temperatures.

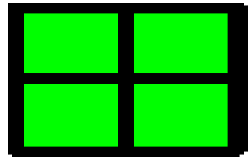
The position in the square reflects the temperature and rainfall of a scenario



Color-coding the square quadrants shows the direction of change in percent cover in suitable climate for veg type (current to 2050)

Red: Dramatic Decline	(<25% of current)
Orange: Moderate Decline	(25-75% of current)
Gray: Relative Stability	(75-125% of current)
Green: Increase	(>125% of current)

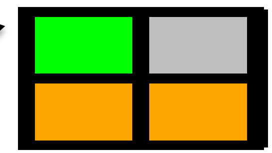
Example: California Bay Forest is not sensitive to temperature or rainfall



Does well in all future scenarios regardless of Warming magnitude and rainfall

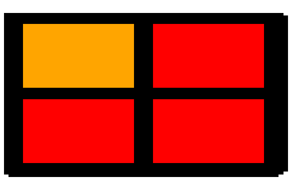
Example: Oregon Oak is sensitive to rainfall in Northern Mayacamas

Does well in high rainfall scenarios, but declines in low rainfall



Does worse in hotter scenarios, But impacts are not great.

Example: Canyon Live Oak is sensitive to rainfall and temperature in Northern Mayacamas



It shows declines in all scenarios

Four Square Diagrams: The prognosis for the 22 vegetation types in each landscape unit are shown below divided into 4 climate scenarios. Comparing the landscape units reveals differential vulnerability of vegetation across Napa County.

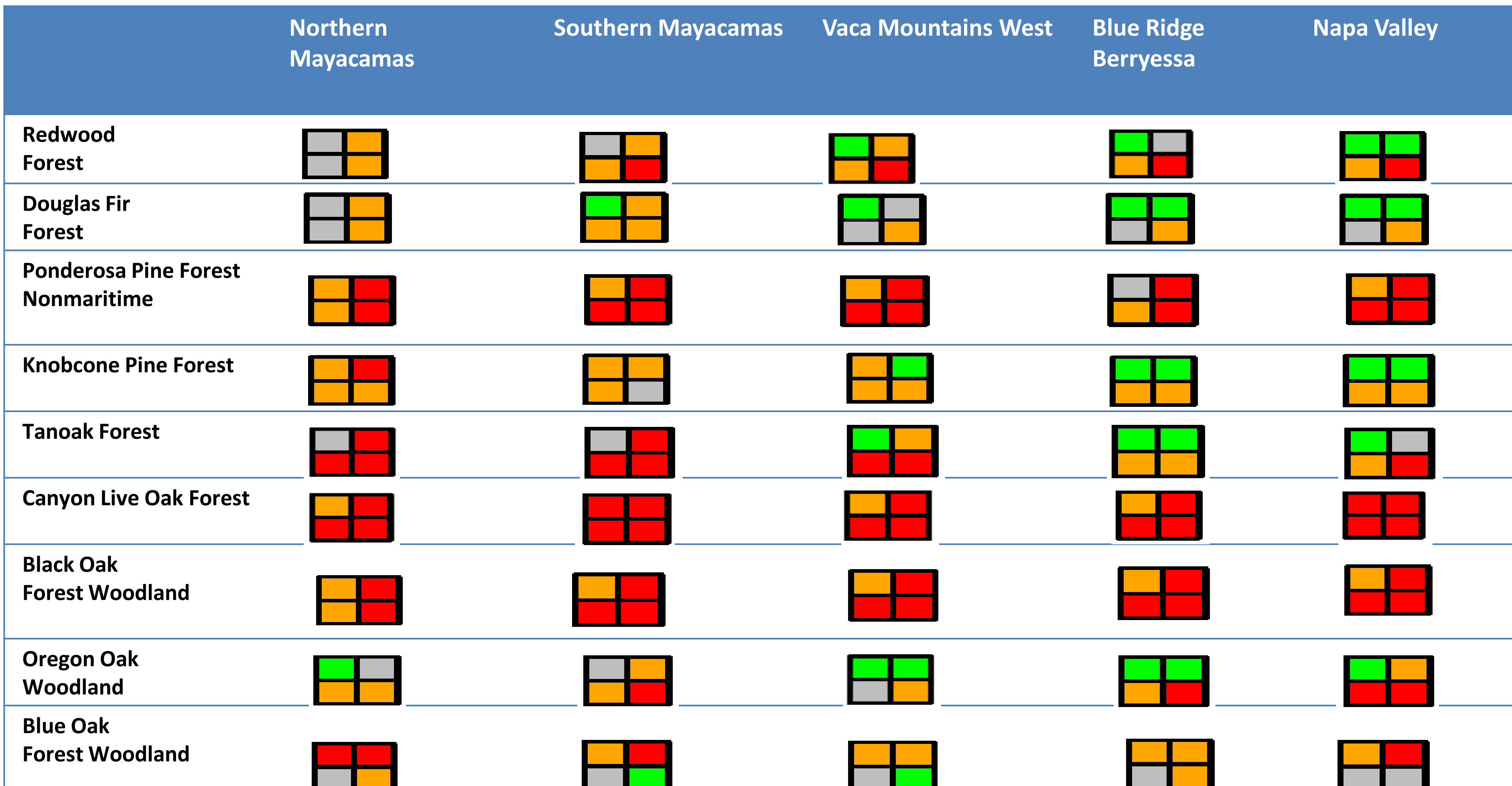
The color shows the direction of change in percent cover between current and 2050.

Red: Dramatic Decline	(<25% of current)
Orange: Moderate Decline	(25-75% of current)
Gray: Relative Stability	(75-125% of current)
Green: Increase	(>125% of current)

The position shows the scenario

Temperature

Rainfall		
	Warm < 4.5°F High rain	Hot > 4.5°F High rain
	Warm < 4.5°F Low rain	Hot > 4.5°F Low rain

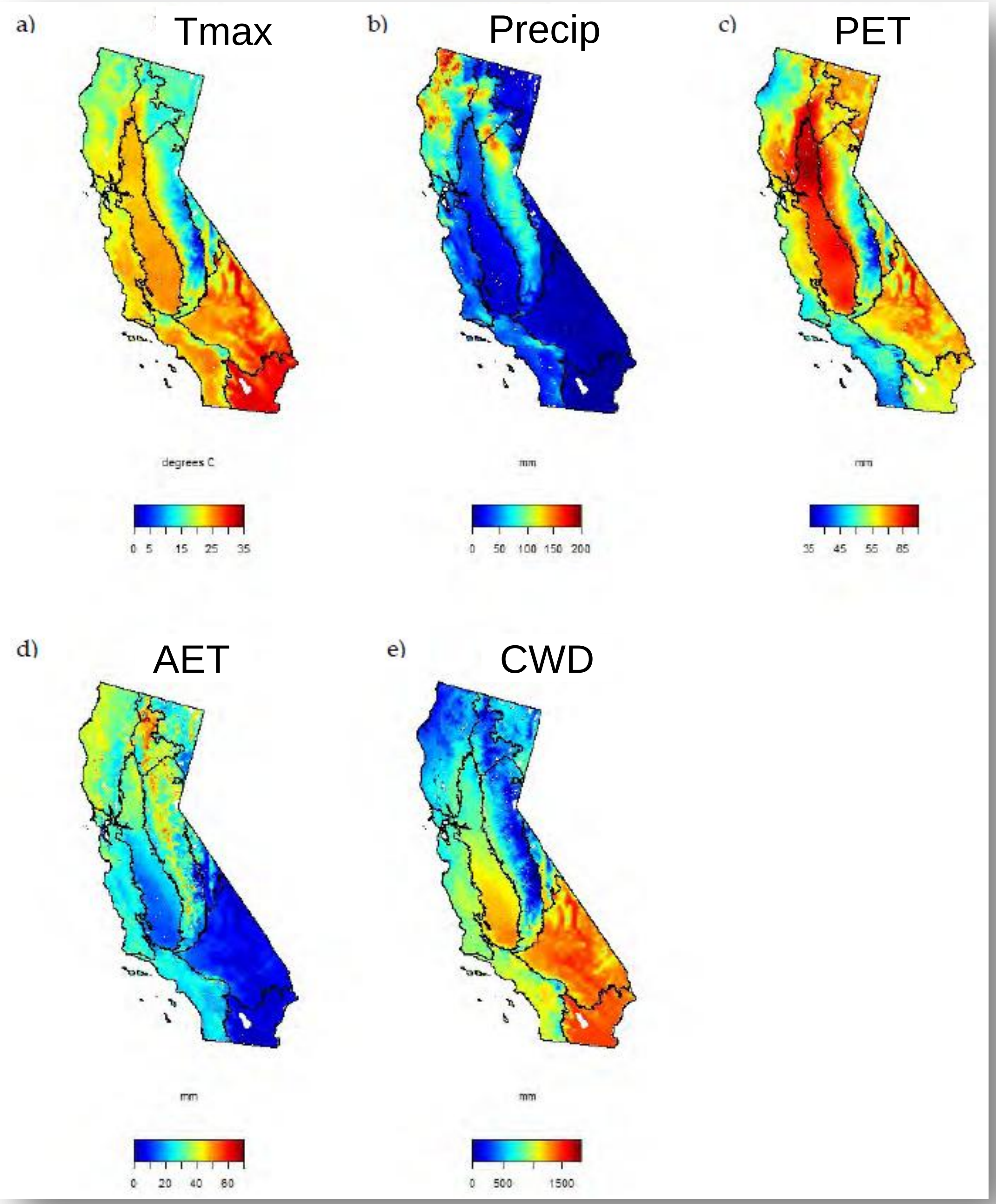


Modeled fire risks in Napa Valley

Management Question

What will be the impact of climate change on the potential fire frequencies in the Napa Valley?

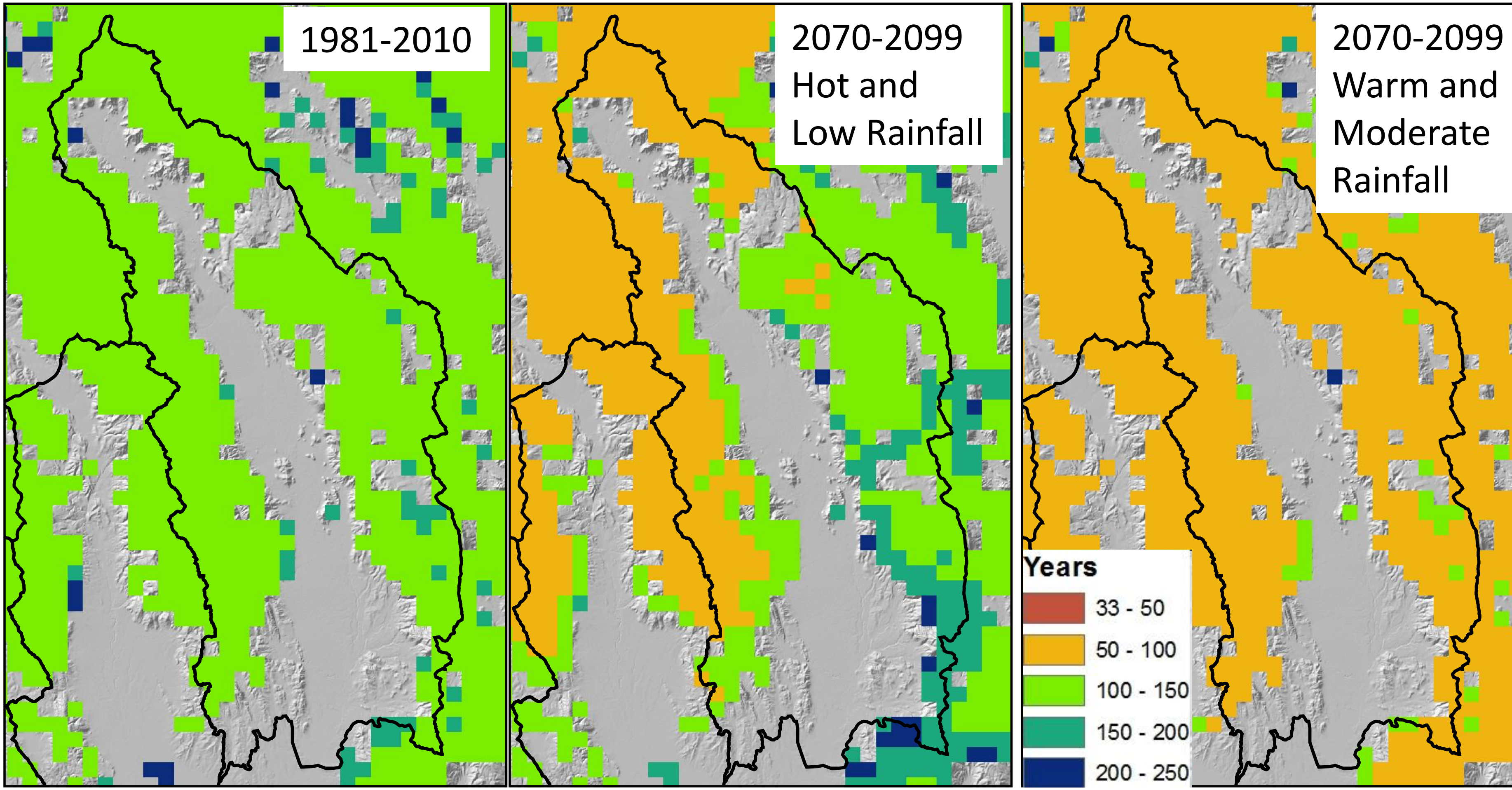
Statewide Fire Risk Model: BCM data inputs



Spatial Patterns in Explanatory Climate Variables 1971–2000

Krawchuk and Moritz 2012 PIER report

Change in Projected Probability of Burning One or More Times

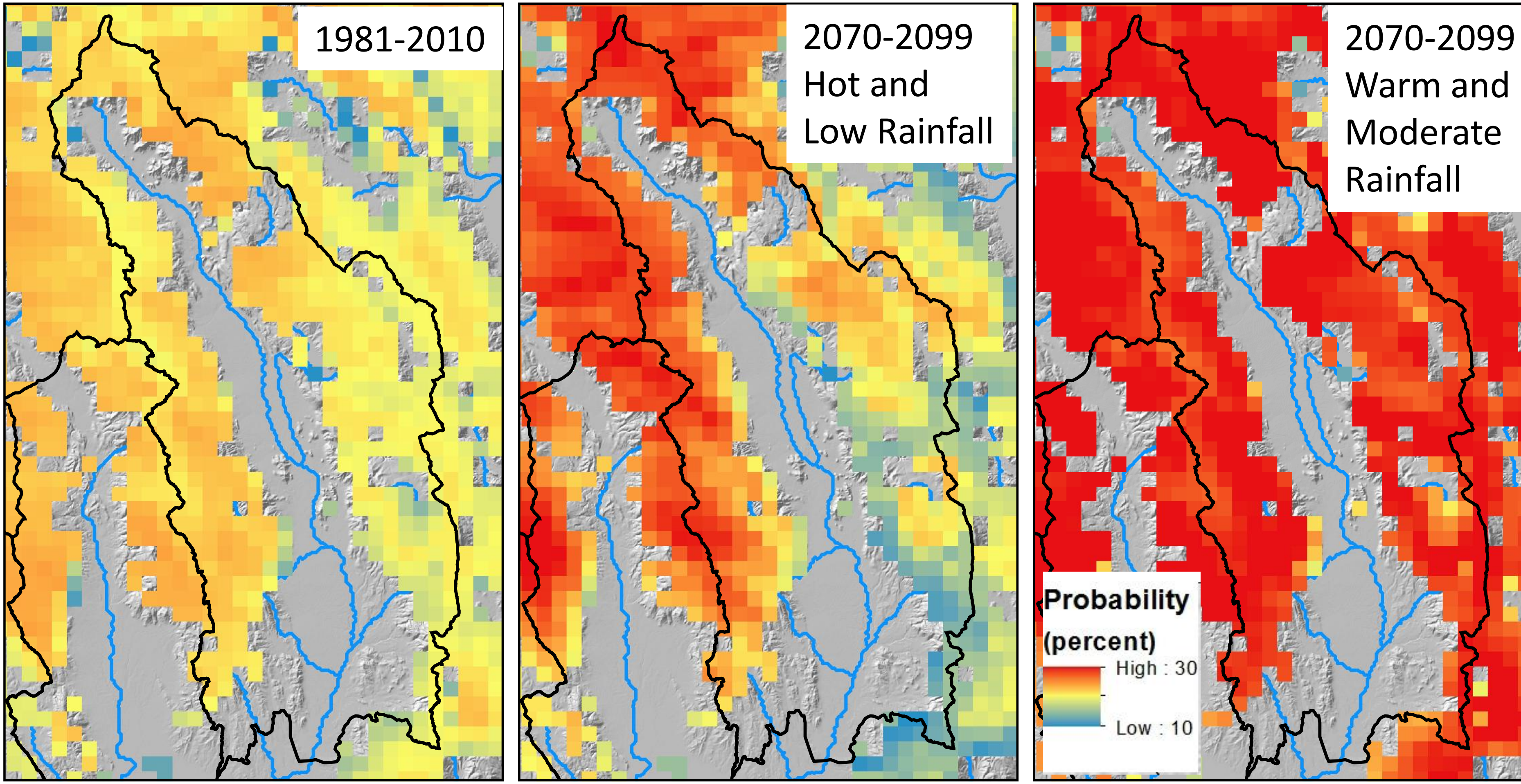


Fire return intervals cut by up to 30%

Urban and agricultural areas masked out

		Current	Hot, Low Rainfall	Moderate Rainfall
Variable	Units	1971-2000	2070-2099	2070-2099
Fire return interval	Years	129	119	87
	SD	19	36	13

Change in Projected Probability of Burning One or More Times



Probability of fire doubles in some locations

		Current	Hot, Low Rainfall	Moderate Rainfall
Variable	Units	1971-2000	2070-2099	2070-2099
Probability of burning 1 or more times	Percent	21%	22%	29%
	SD	2%	5%	3%

Urban and agricultural areas masked out