Water Supply and Hydroelectric Generation

-Potential Impacts of Climate Change

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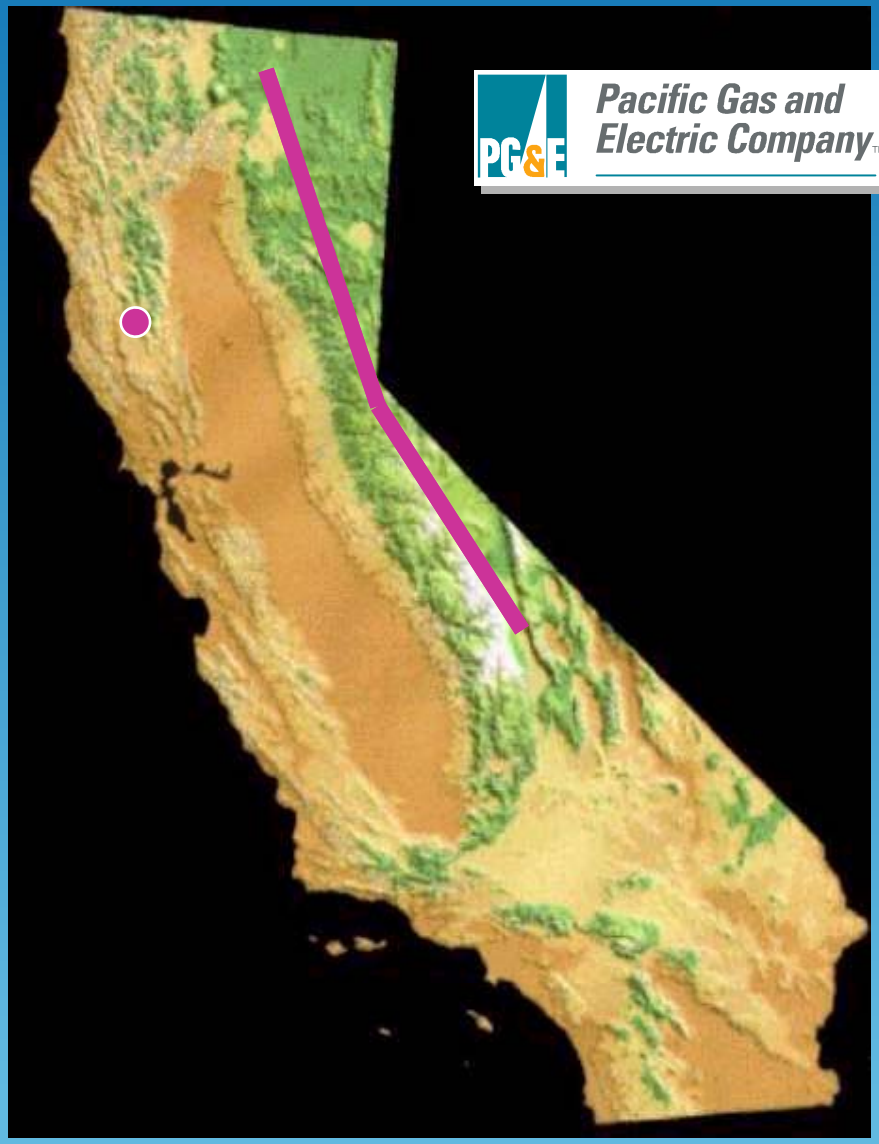
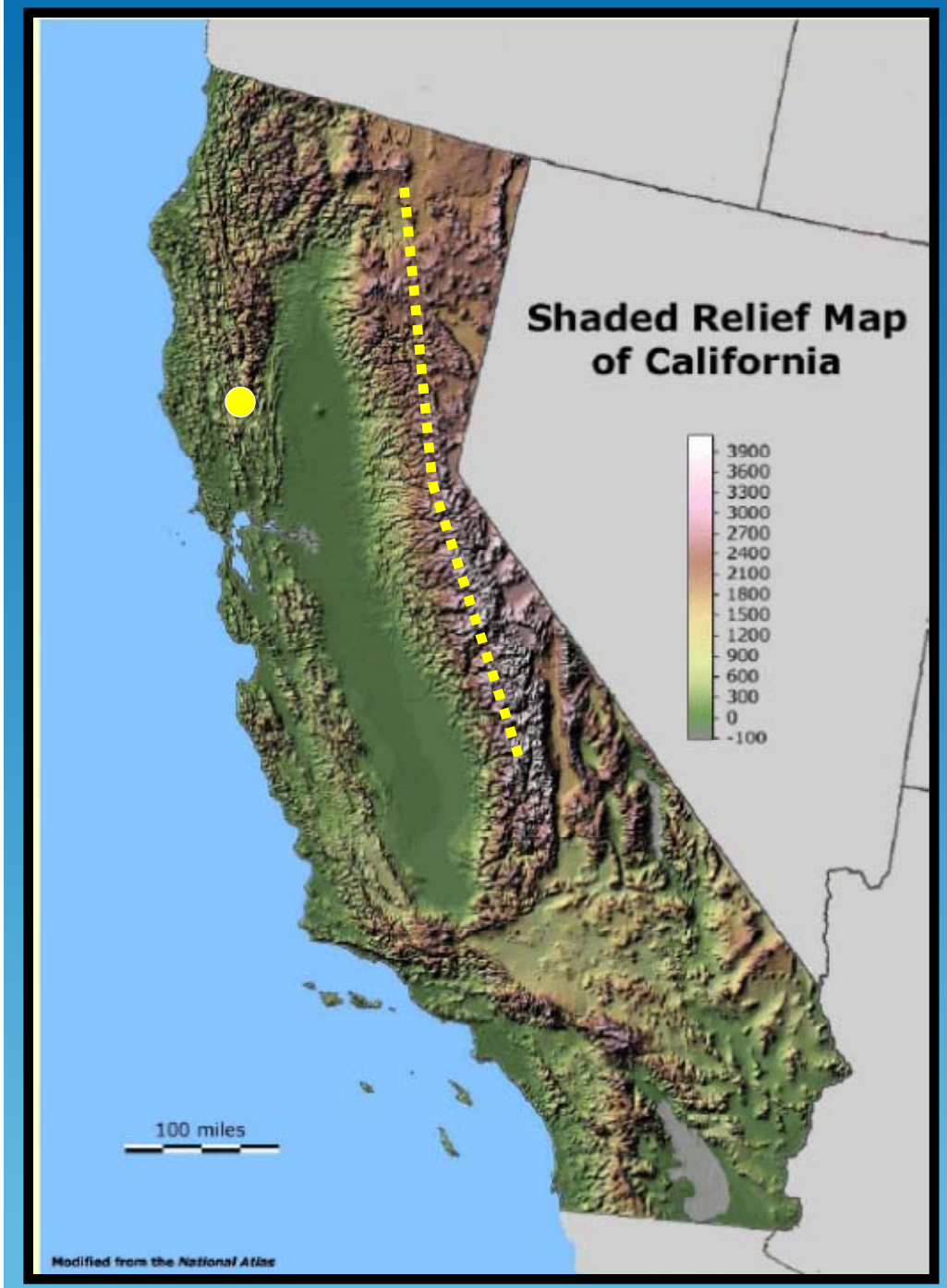
California Energy Commission

Sacramento, CA

The PG&E Hydroelectric System



- 68 Powerhouses; 110 Generating Units; Total Generation Capacity of 3,896 MW
- Approximately 2.3 Million acre-feet of Surface Reservoir Capacity
- 99 Reservoirs, 174 Dams
- 184 Miles of Canals; 44 Miles of Flumes; 135 Miles of Tunnels; 19 Miles of Pipe
- 140,000 Acres of Land
- 26 FERC Licenses; 3 Unlicensed Projects
- Hydroelectric System Extends 500 Miles from Mt Shasta to Bakersfield
- Provides about Five Percent of California's Electric Energy



- Elevation generally increases from north to south for PG&E's hydroelectric system.
- Regional geology, orographic/rain shadow effects, and elevation are essential when considering climate change for California's mountain areas.
- Feather River exists mostly on ancestral Sierra, mostly metamorphic and topographically complex with a few rain shadowed subbasins.
- Feather River cuts through the Sierra Crest into Basin & Range Geomorphic Provence

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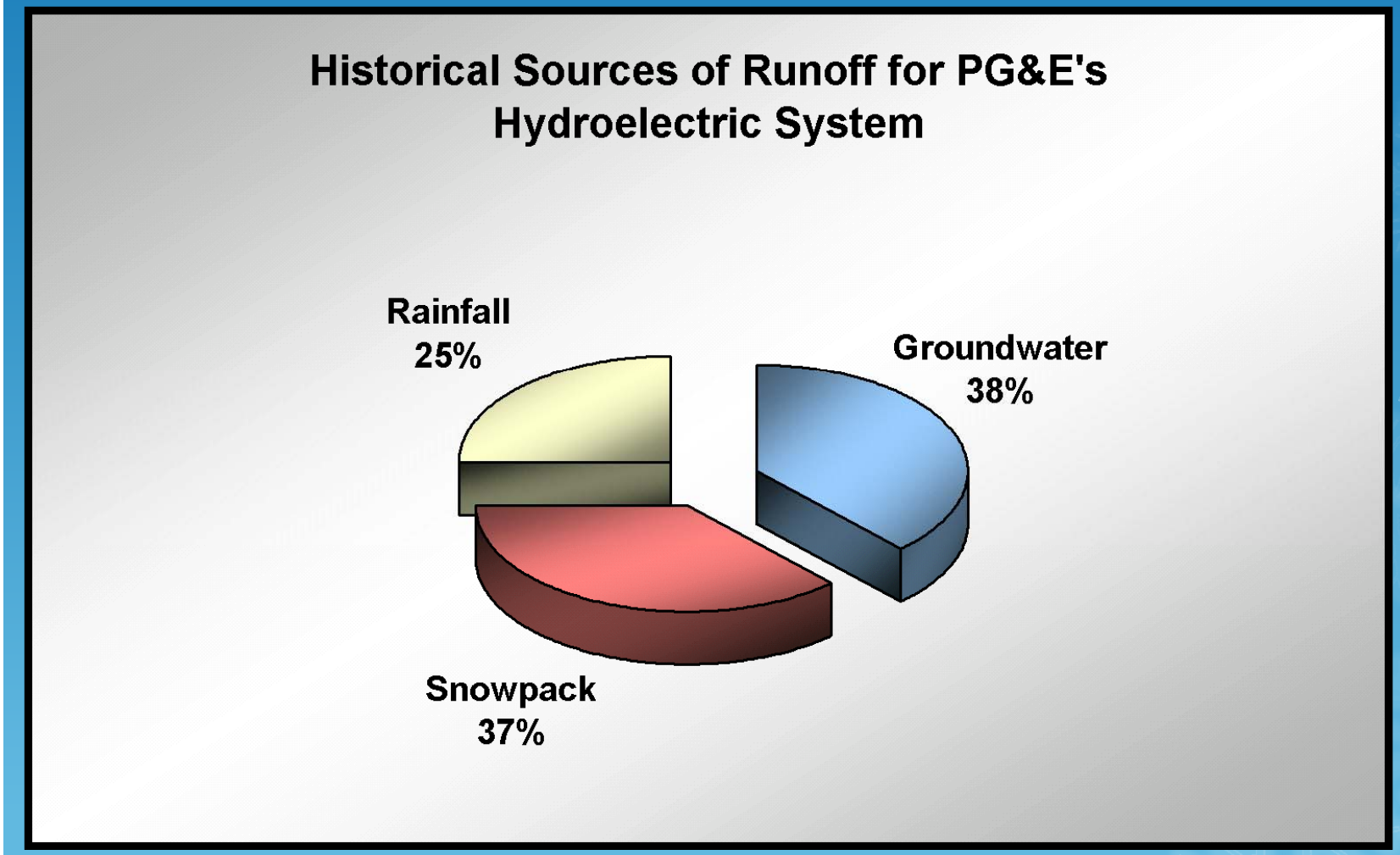
Historic Sources of Runoff for PG&E's Hydroelectric System



Assessing Hydroelectric System Impact

- Current approach has been to look at historical data comparison only.
- Benefit of having large hydroelectric operational data base automatic daily computation of gaged data into unimpaired subbasin and reach flows.
- Each of the operational subbasins are tracked for climate change. Creates close up focus with regard to elevation, to

What are We Seeing?

- Most change has occurred on the relatively lower elevation northern Sierra.
- Water Year runoff has declined for two Upper North Fork Feather River rain shadowed subbasins
- Lake Almanor subbasin (491 mi^2) and East Branch of NF Feather (1,025 mi^2) – Both are rain shadowed situations or topographically blocked by mountain ridges.
- Other North Fork Feather River subbasins w/strong orographic cooling show relatively little impact from climate change other than an increase in March runoff. Water Year runoff has remained unimpacted.

What are We Seeing? (*Cont.*)

- Average minimum January temperatures for the more recent of the two successive 35-year periods have risen approximately 5-6^{0}F around Lake Almanor and as much as 9^{0}F on the East Branch of the North Fork Feather River.
- There has been a large decline in the aquifer outflow of springs into Lake Almanor.
- The April 1 snowpack on the Feather River snow courses with the exception of Lower Lassen Peak (8,250' elevation) has declined in the more recent 35-year period.

April through June Runoff on the East Br of North Fork Feather – 40% Trend Decline since 1964

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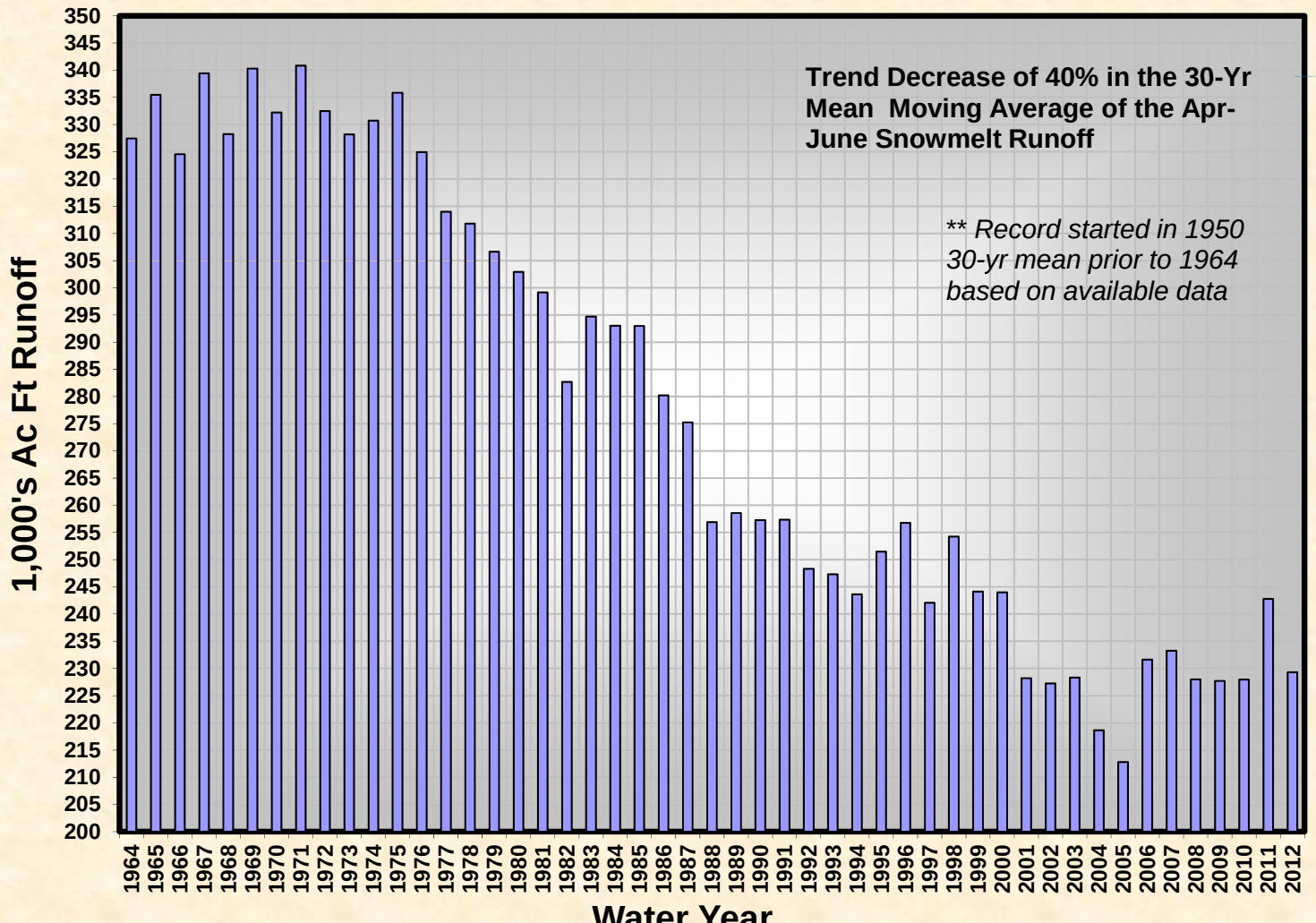
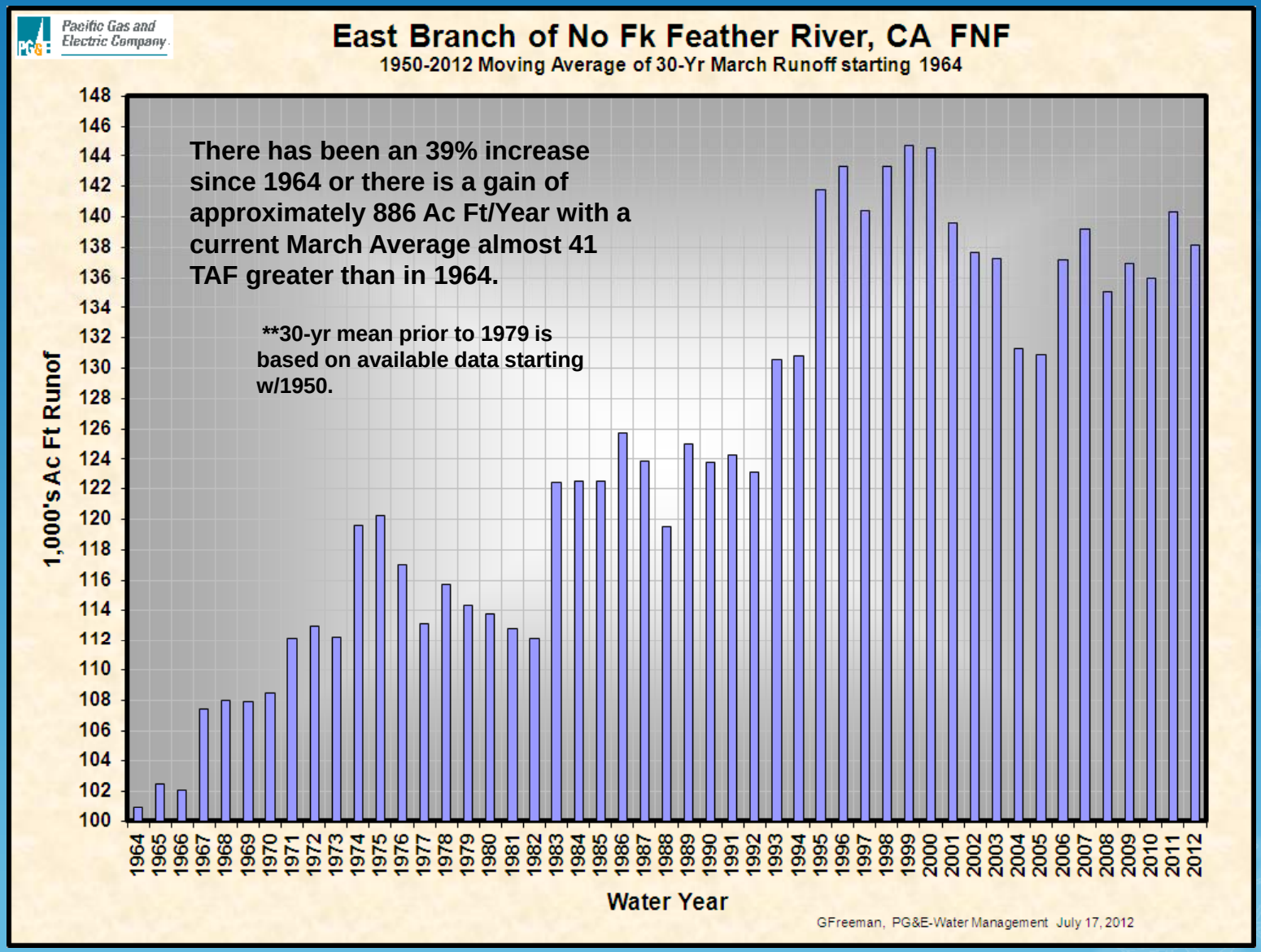
East Branch of No Fk Feather River, CA FNF

1935-2012 moving average of 30-yr April-June mean Roff starting 1964**

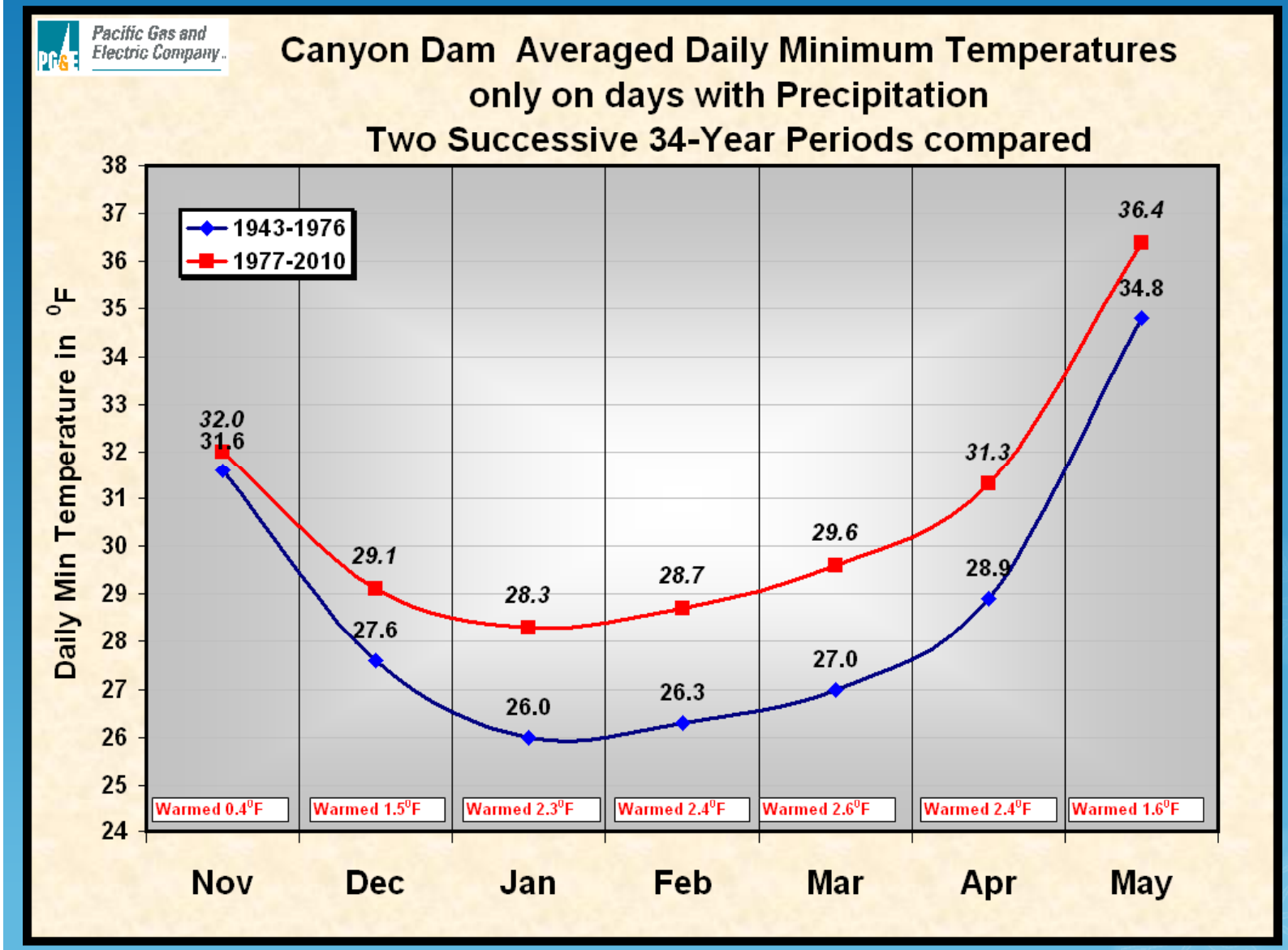


GFreeman, PG&E, Water Management July 17, 2012

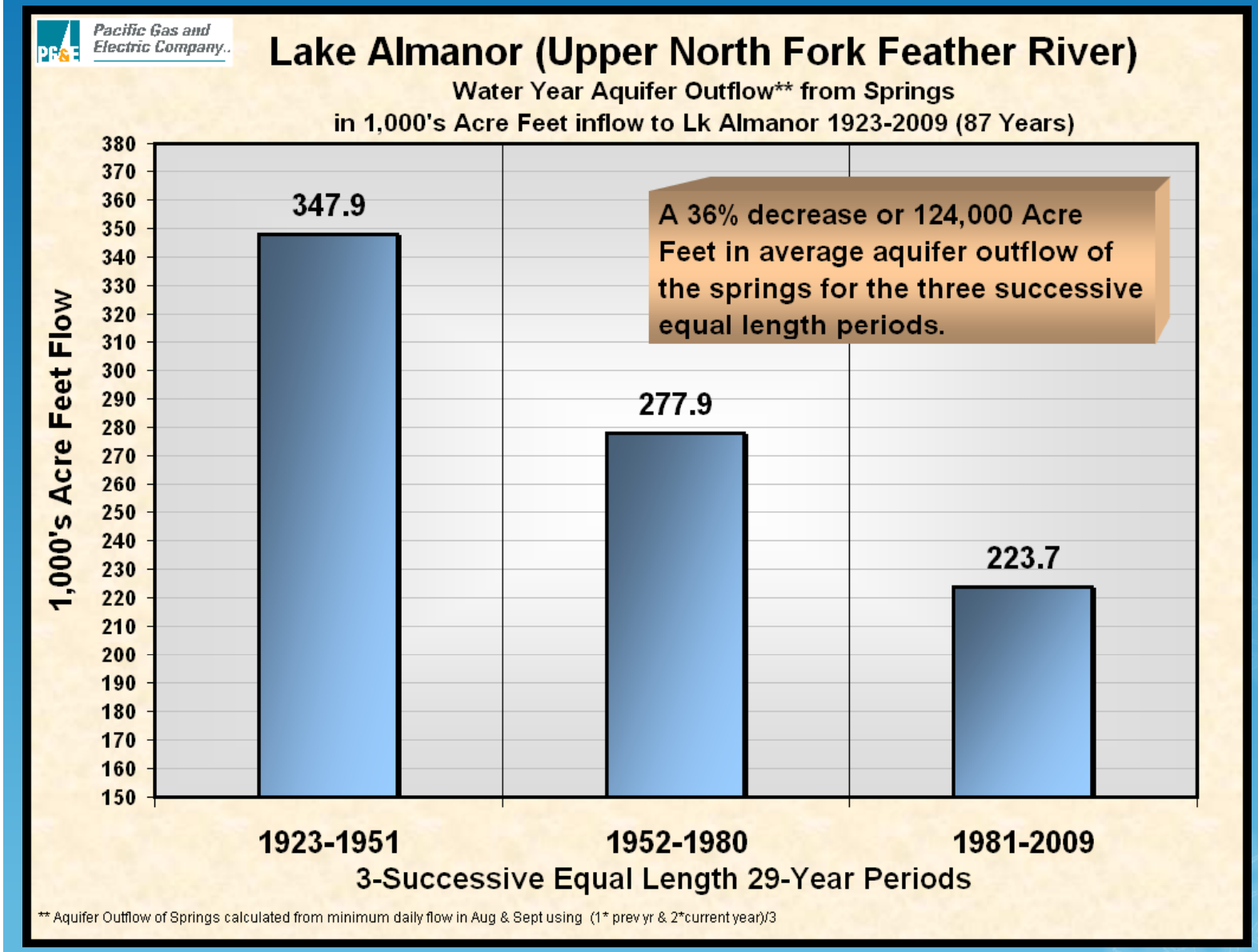
March Runoff on the East Br of North Fork Feather – 39% Trend Increase since 1964



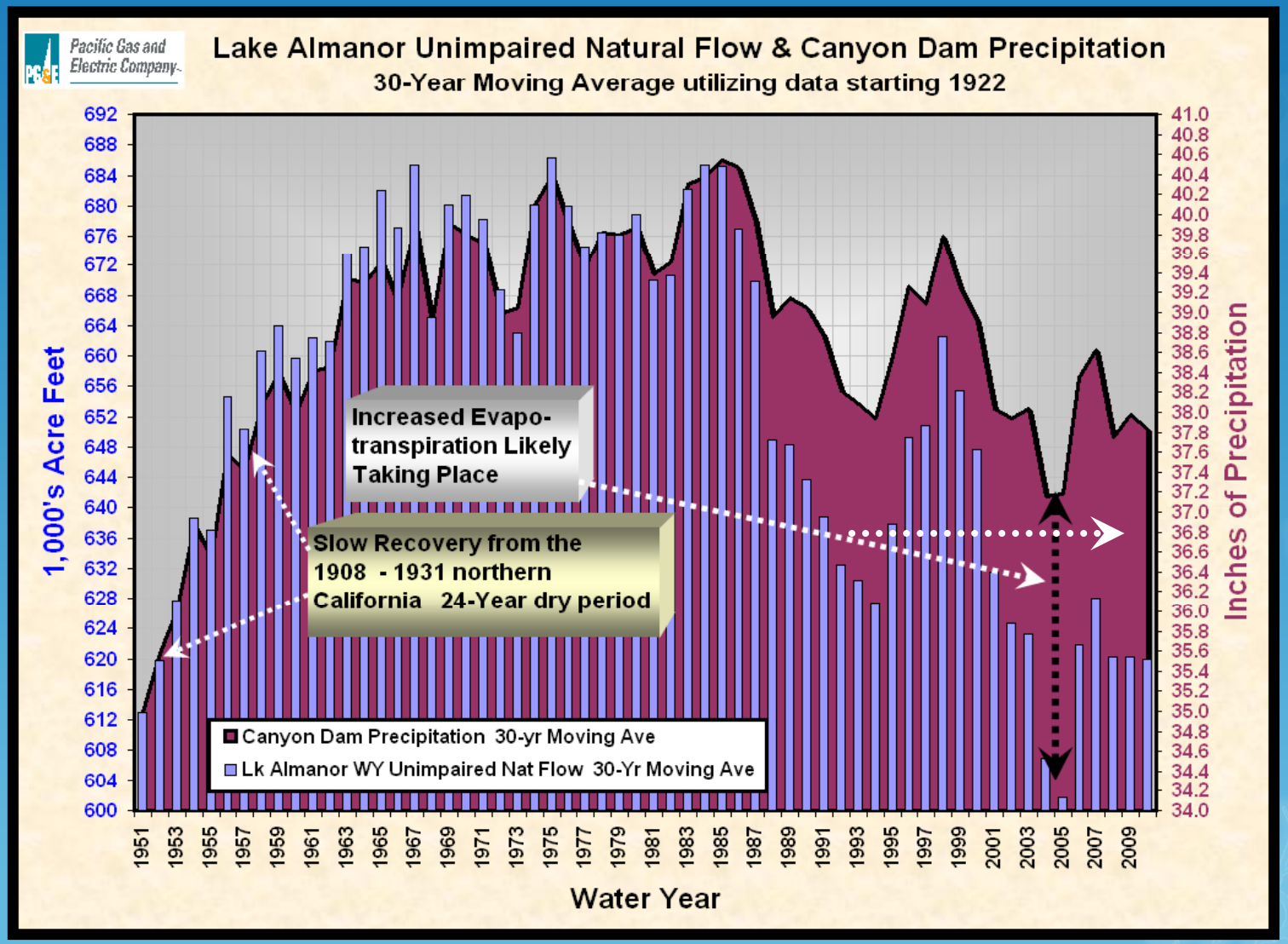
Canyon Dam Averaged Daily Minimum Temperatures in ^{0}F
Only for Storm Days with Precipitation
Two Successive 34-Year Periods Compared



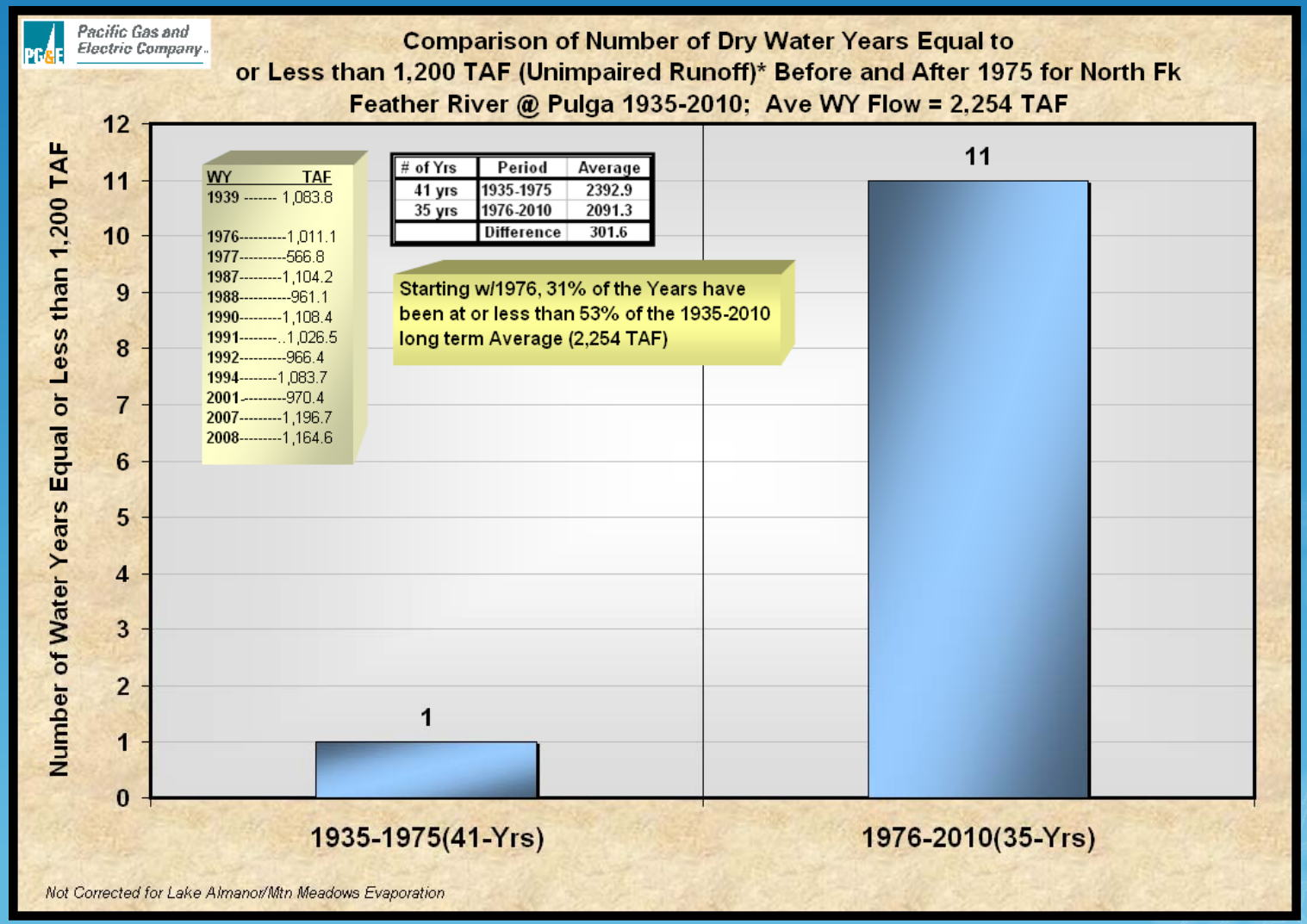
A Three Period 36% Decrease in Aquifer Outflow of the Springs since 1923



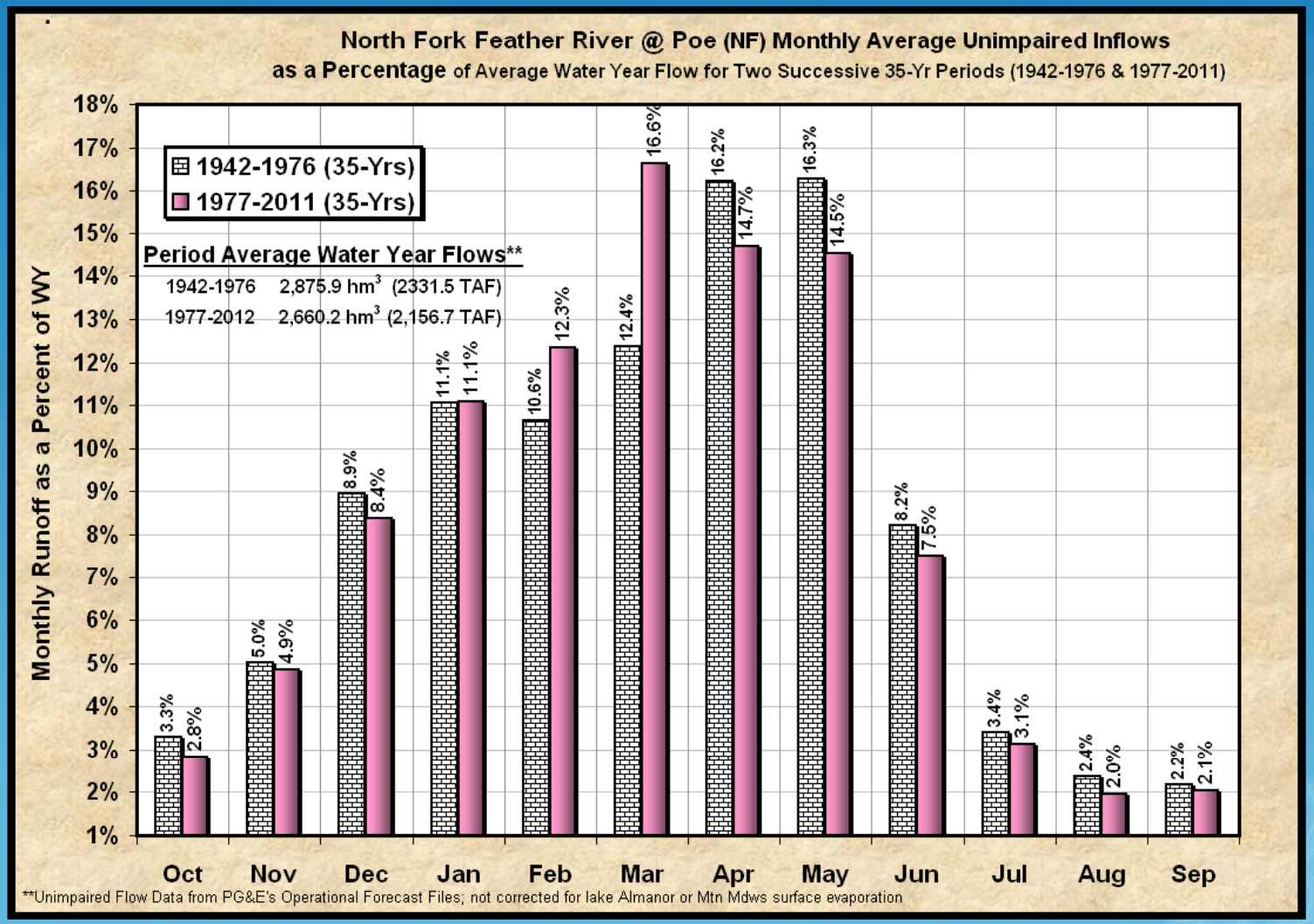
The Increasing Loss to Evapotranspiration in Recent Years for the Lake Almanor Subbasin



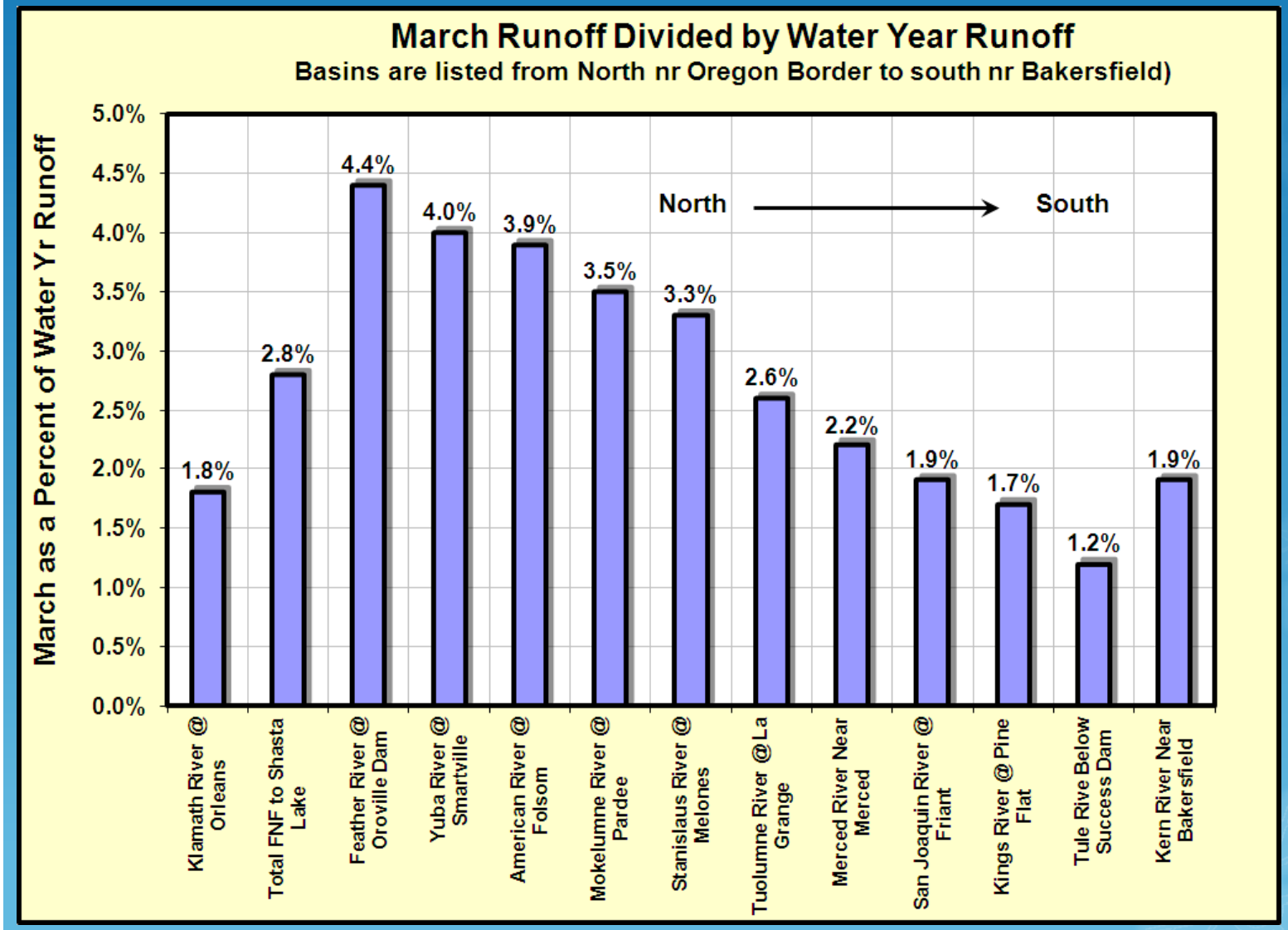
Recent Years Reveal an Increase in Number of Dry Years for North Fork Feather River



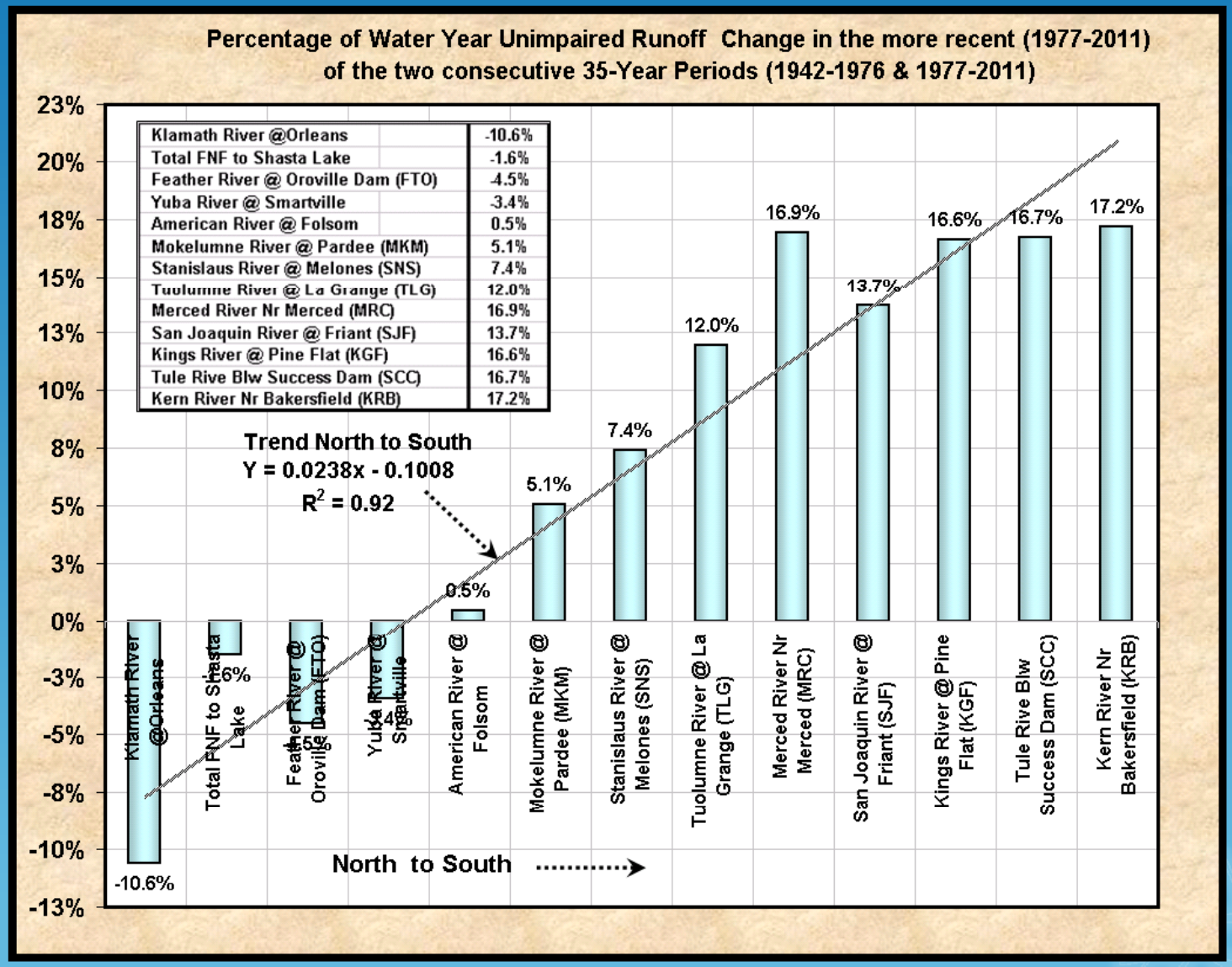
Monthly Comparison for Northern California's North Fork Feather River for two Successive 35-Year Periods



Percent Recent Period Increase in March / Water Year Runoff for 13 California Rivers Compared for two Successive 35-year Periods (1942-1976 & 1977-2011)



South of the Yuba River, Water Year Runoff has increased during the most recent 35-Year Period (1977-2011)



Climate Change Indices Based on 30-Yr Moving Average starting w/1964(Base Year for Change)

the following trended April through June percentage runoff change since 1964 seem appropriate for the initial tracking process.

Green light status: <20% April through June(July) runoff loss

Amber light status: 20%-40% April through June(July) runoff loss

Red light status: >40% April through June(July) runoff loss

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April through June for Mokelumne North

April through July for Stanislaus South (Due to high elevations for southern Sierra)

	Basin/Sub basin		2009	2025	2050	2075	2100
North	McCloud	MC	0%	0%	0%	0%	0%
North	Pit River	PH	0%	0%	0%	0%	0%
North	No Fork Feather @ Pulga	NF	-23%	-31%	-44%	-56%	-69%
North	Lk Almanor	NF901	-21%	-28%	-39%	-50%	-62%
North	Butt Vlly	NF902	0%	0%	0%	0%	0%
North	East Branch	NF903	-39%	-53%	-75%	-96%	-100%
North	Bucks Lake	NF904	-1.1%	-1.5%	-2.1%	-2.6%	-3.3%
North	Poe	NF905	-12%	-16%	-22%	-29%	-35%
North	So Fk Feather@ Ponderosa	SF	-5%	-7%	-9%	-12%	-15%
North	Little Grass Valley	SF901	-18%	-24%	-34%	-44%	-53%
North	SF Divsn Dam-SF902	SF902	-17%	-24%	-37%	-49%	-61%
North	Lost Crk Res	SF903	-38%	-52%	-73%	-93%	-100%
North	West Branch/Butte Crk	BW					
North	Butte Crk @ Butte Cnl Hddm	BW901	-29%	-39%	-56%	-71%	-87%
North	West Brnch Feather@BW8	BW902	-30%	-42%	-61%	-79%	-98%
Central	No Yuba River@Smartville	NY	-18%	-25%	-35%	-45%	-55%
Central	Slate Creek	NY901	-26%	-47%	-81%	-100%	-100%
Central	Oregon Crk	NY902	-5%	-7%	-10%	-12%	-15%
Central	Hour House	NY903	-16%	-34%	-47%	-59%	-71%
Central	Bullards Bar	NY904	-14%	-19%	-26%	-33%	-41%
Central	Narrows	NY905	-3%	-5%	-7%	-10%	-13%
Central	So Yuba River&Bear River	YB					
Central	Jackson Meadows	YB901	-3%	-5%	-8%	-11%	-13%
Central	Bowman	YB902	0%	0%	0%	0%	0%
Central	Lk Spaulding	YB903	-13%	-17%	-24%	-31%	-38%
Central	Rollins(Bear River)	YB904	-8%	-11%	-15%	-20%	-24%
Central	MiddleFk American & Rubicon	R					
Central	French Mdws	R901	4%	6%	8%	11%	13%
Central	Hell Hole	R902	-8%	-11%	-16%	-20%	-25%
Central	Mokelumne River Nr Mokelumne Hill	M	-9%	-12%	-17%	-22%	-28%
Central	Lower Bear	M901	-19%	-26%	-37%	-47%	-58%
Central	Salt Springs	M902	-10%	-13%	-19%	-24%	-29%
Central	Stanislaus River Nr Goodwin Dam	S	-9%	-12%	-16%	-21%	-25%
Central	Mid Fk Sstan@Beardsley	S902	-2%	-3%	-4%	-5%	-6%
Central	So FK Stan@Lyons	S903	+3	*linear extension not applicable*			
South	Merced River @ Exchequer	JM	+7%	*linear extension not applicable*			

Conclusions

- In terms of hydroelectric production, climate change is currently negatively impacting the relatively low elevation, topographically complex northern California watersheds such as the Feather River, Pit and McCloud Rivers more the than the higher southern Sierra Watersheds.
- March runoff has increased for all watersheds analyzed.
- Adaptation is an important management planning tool for helping to deal with the impacts of climate change.
- Water Year runoff has increased in the recent 35-years for watersheds south of the Yuba River and decreased for the Yuba River north.
- Conceptually if the current rate of change continues, for the PG&E hydroelectric system as a whole, annual hydroelectric production is anticipated to remain mostly unchanged from the impacts of climate change for the next 12-13 years. After which the impacts of snowpack decline and increased variance in runoff amount has potential to begin negatively impacting hydroelectric energy production.

Conclusions (Cont.)

- Aquifer outflow of the large volcanic springs in northern California is anticipated to continuously decline as the low elevation snowpack declines leading to an increasing loss of groundwater recharge opportunity.
- The increase in March runoff is currently greatest in the Feather River and declines to the north and south.
- January minimum air temperatures for rain shadowed subbasins have warmed at a much faster rate than for orographically cooled subbasins.
- Recent years reveal an increase in number of dry years for North Fork Feather River.
- PG&E will continue to track and evaluate the impact of climate change on its hydroelectric operation