RECLAMATION

Managing Water in the West

Santa Ana River Watershed

Hydrology Projections

February 2, 2012, Fountain Valley, CA

Water Resources Planning and Operations Support Group
Technical Service Center, Denver, Colorado

U.S. Department of the Interior
Bureau of Reclamation

Hydrology Projections Outline

1. Background. Acronyms , definitions, assumptions, and hydrology model overview.

2. How were the hydrologic projections developed for the Santa Ana Watershed? Detailed description of the hydrologic projections development process, specifically streamflow.

3. What analysis was done using the hydrology projections? Detailed description of analysis of change and statistics used.

4. Results. All results are preliminary and draft.

5. Example analysis. Change in runoff using the hydrologic projections website hosted at Lawrence Livermore National Lab (LLNL).

6. Summary

7. Next Steps

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BACKGROUND

Acronyms

- VIC – Variable Infiltration Capacity Model. Hydrology model.
- BCSD – Bias Corrected and Spatially Downscaled. Statistical method of developing hydrology model inputs (precipitation and temperature) from global climate model (GCM) runs.
- CMIP-3 – Coupled Model Intercomparison Project, Phase 3. Most current global climate model runs.
- WWCRA – West-Wide Climate Risk Assessments (an activity under Reclamation's WaterSMART program). First SECURE Water Act report - West-wide effort to develop gridded hydrology.

Definitions

- Bias - statistical term meaning a systematic (not random) deviation from the true value.
- Ensemble – set of model (e.g., climate or hydrology) runs based on different initial conditions, forcings, and model physics. The result of each model run is called an Ensemble member.
- Median - the median is the value that has just as many values above it as below it (50^{th} percentile). Measure of central tendency.
- Runoff – for a gridded hydrology model, is the surface flow (surface runoff) or base flow (sub-surface runoff). Total runoff is the sum of surface and sub-surface runoff.
- Streamflow – cumulative runoff at a gage location derived by routing water through a channel network.
- Ensemble Median – median calculated from all the individual ensemble members.
- Re-sampling – replicating sample data based on a specified pattern.

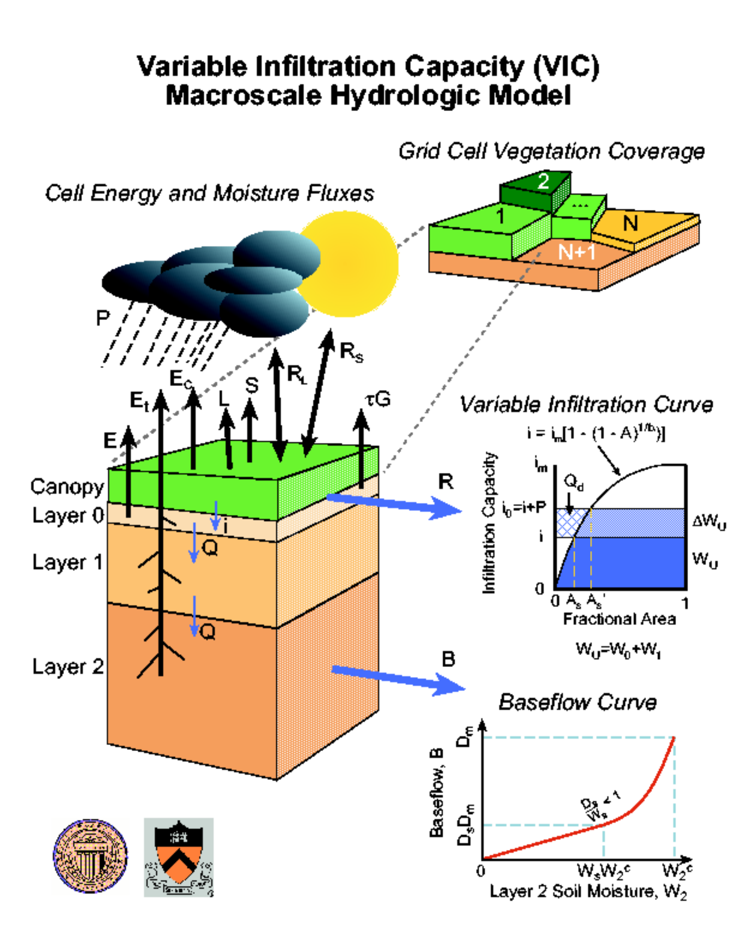
Assumptions

- 10-year base or reference hydrology period, water years 1990-1999. 1990s.

- Three (3) future look ahead periods:
  - water years 2020-2029. 2020s.
  - water years 2050-2059. 2050s.
  - water years 2070-2079. 2070s.

Background Information – Hydrology Model

- Gridded macro-scale (grid size, > 1 km) hydrology model, VIC (Variable Infiltration Capacity)
- VIC model version 4.0.7
- VIC model overview, http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml



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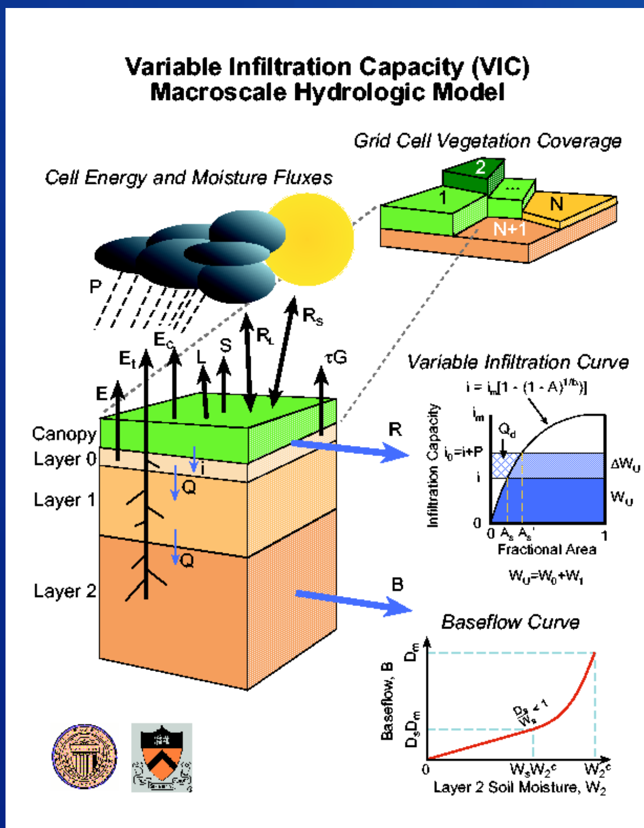
Hydrologic Modeling – VIC Setup, 2 Steps

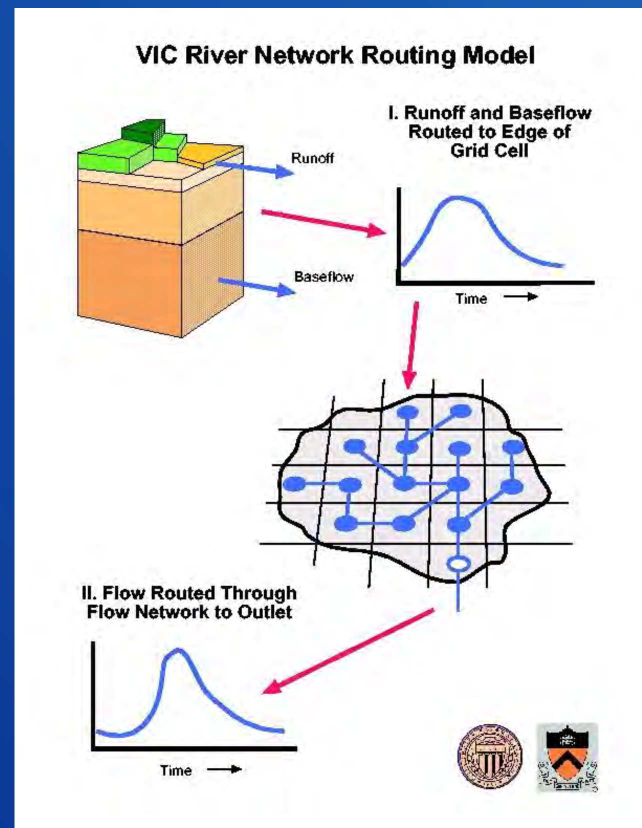
1.Land Surface Simulation

- simulate runoff (and other fluxes) at each grid cell



2. Streamflow Routing

- transport runoff from grid cell to outlet



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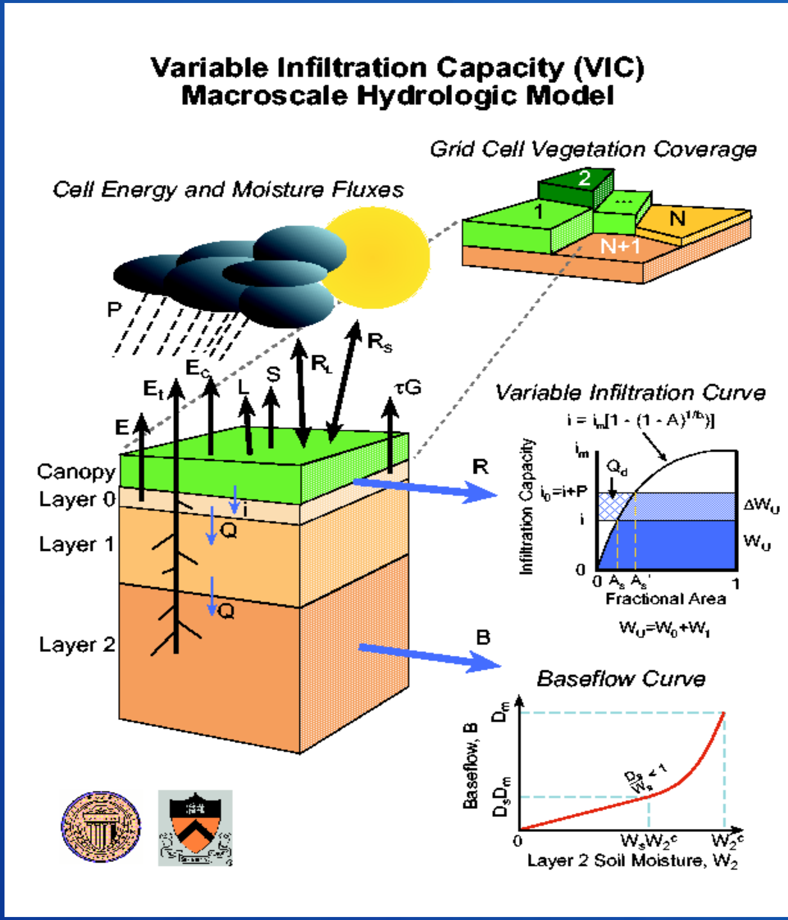
What happens next - Step 1?

STEP 1

- For each grid cell VIC simulates daily fluxes:
  - surface runoff
  - baseflow
  - evapotranspiration
  - etc.



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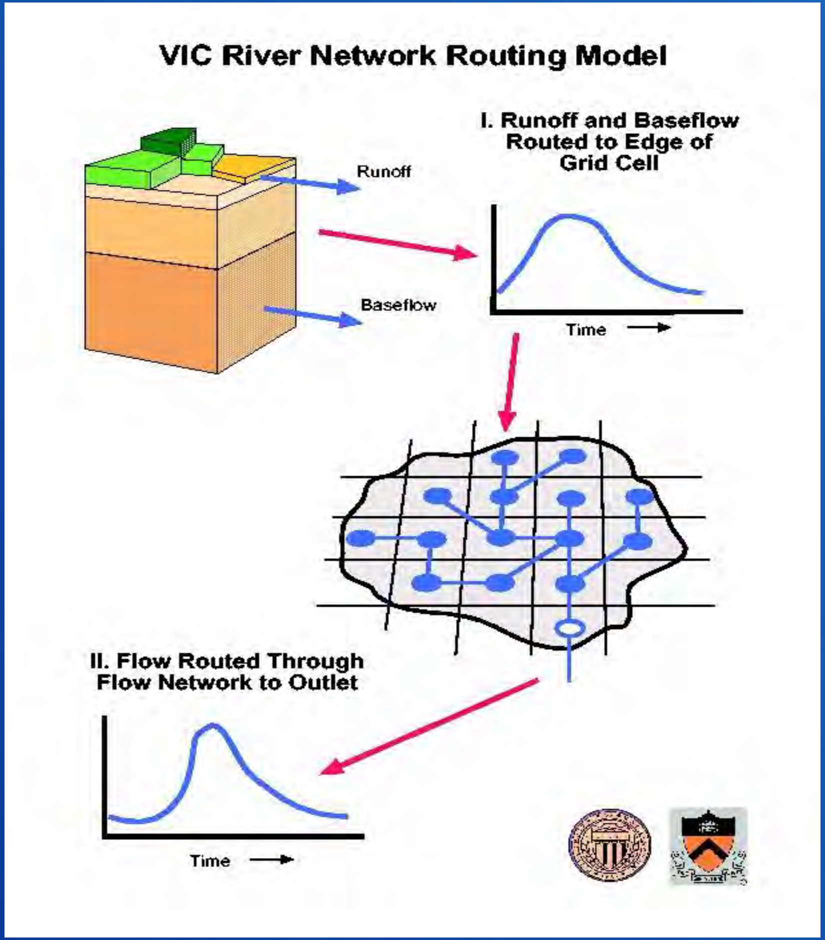
What happens next – Step 2?

STEP 2

- **Transport runoff (surface runoff and baseflow) - move water from the grid cells through the flow network to the outlet or routing locations of interest**



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Hydrologic Modeling - VIC

- **Calibrated to reproduce monthly to annual runoff in large sub-basins.**

- **These models have *biases.***

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HOW WERE THE HYDROLOGIC PROJECTIONS DEVELOPED FOR THE SANTA ANA WATERSHED?

How were the hydrologic projections developed for the Santa Ana Watershed?

- Steps in the hydrology projections development process.
  1. Development of VIC input datasets from the BCSD-CMIP-3 archive
  2. Identification of key locations in the Basin, sub-basins
  3. Sub-basin delineation
  4. Developing the VIC routing models
  5. Flow routing using WWCRA gridded runoff

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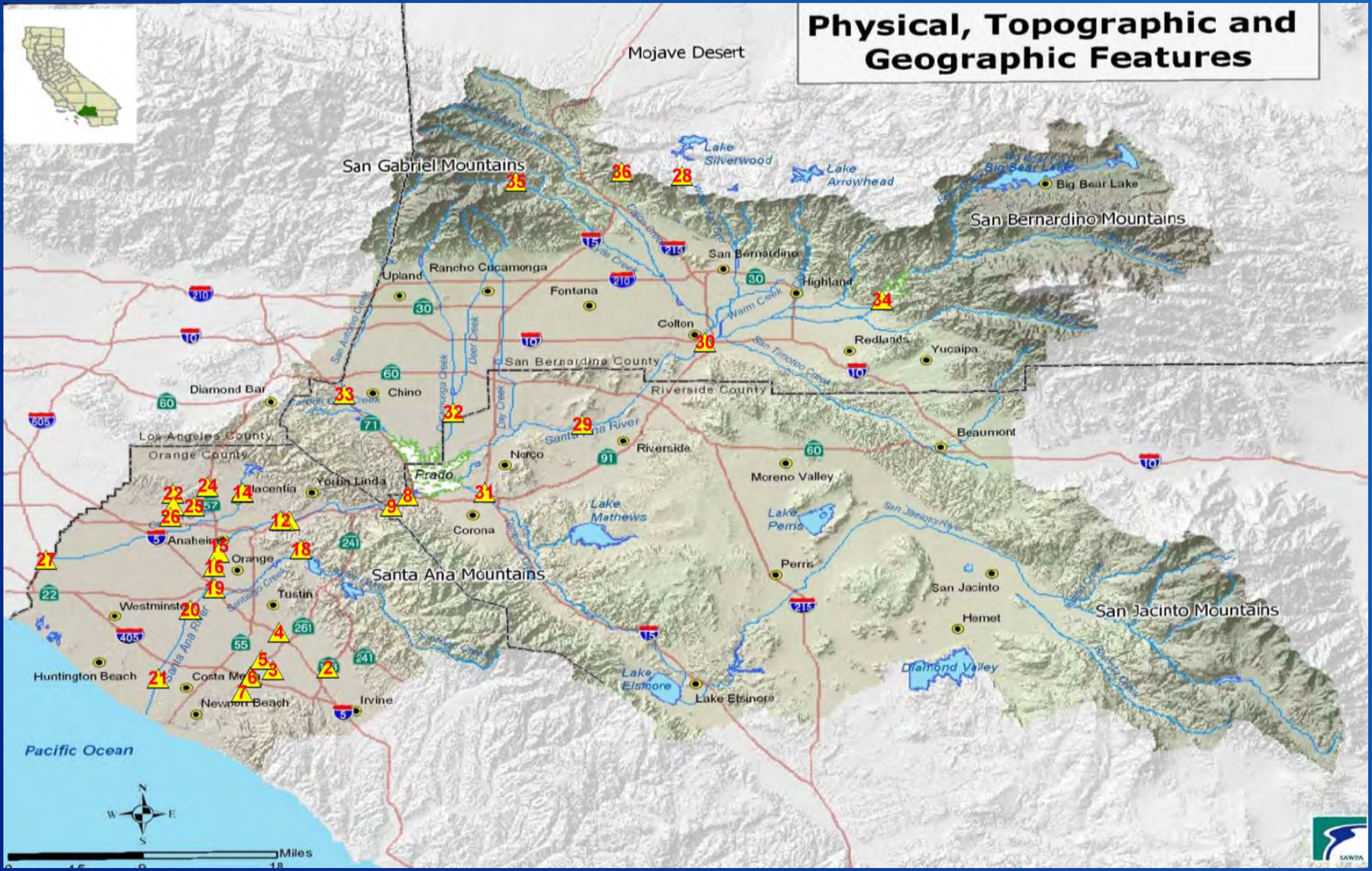
Step 1: Development of VIC input datasets from the BCSD-CMIP-3 archive

1. Daily precipitation (PRCP), minimum temperature (TMIN), maximum temperature (TMAX), and wind speed (WIND) – daily forcings

2. Source of historical daily forcings (PRCP, TMIN, TMAX, WIND) data - *Maurer et al. (2002)* [1950-1999], and subsequent extensions.

3. For each grid cell daily forcing starting on January 1, 1950, and going out to December 31, 2099 developed based on re-sampling of BCSD-CMIP-3 projections from historical daily forcings data (Step 2, above).

Step 2: Identification of key locations in the Basin



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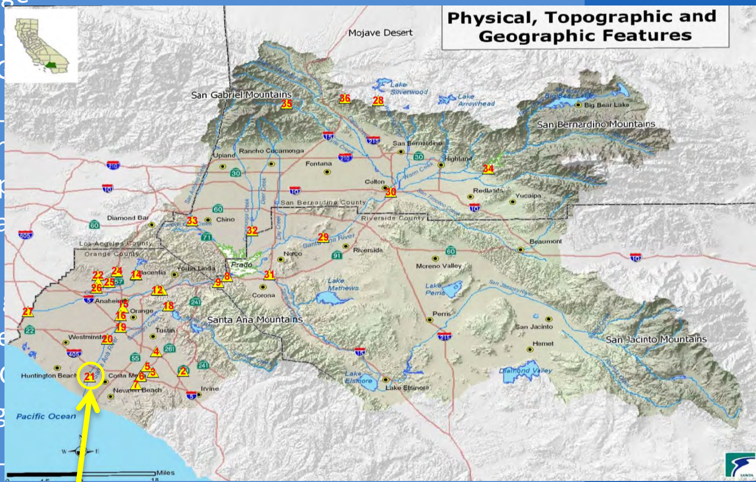
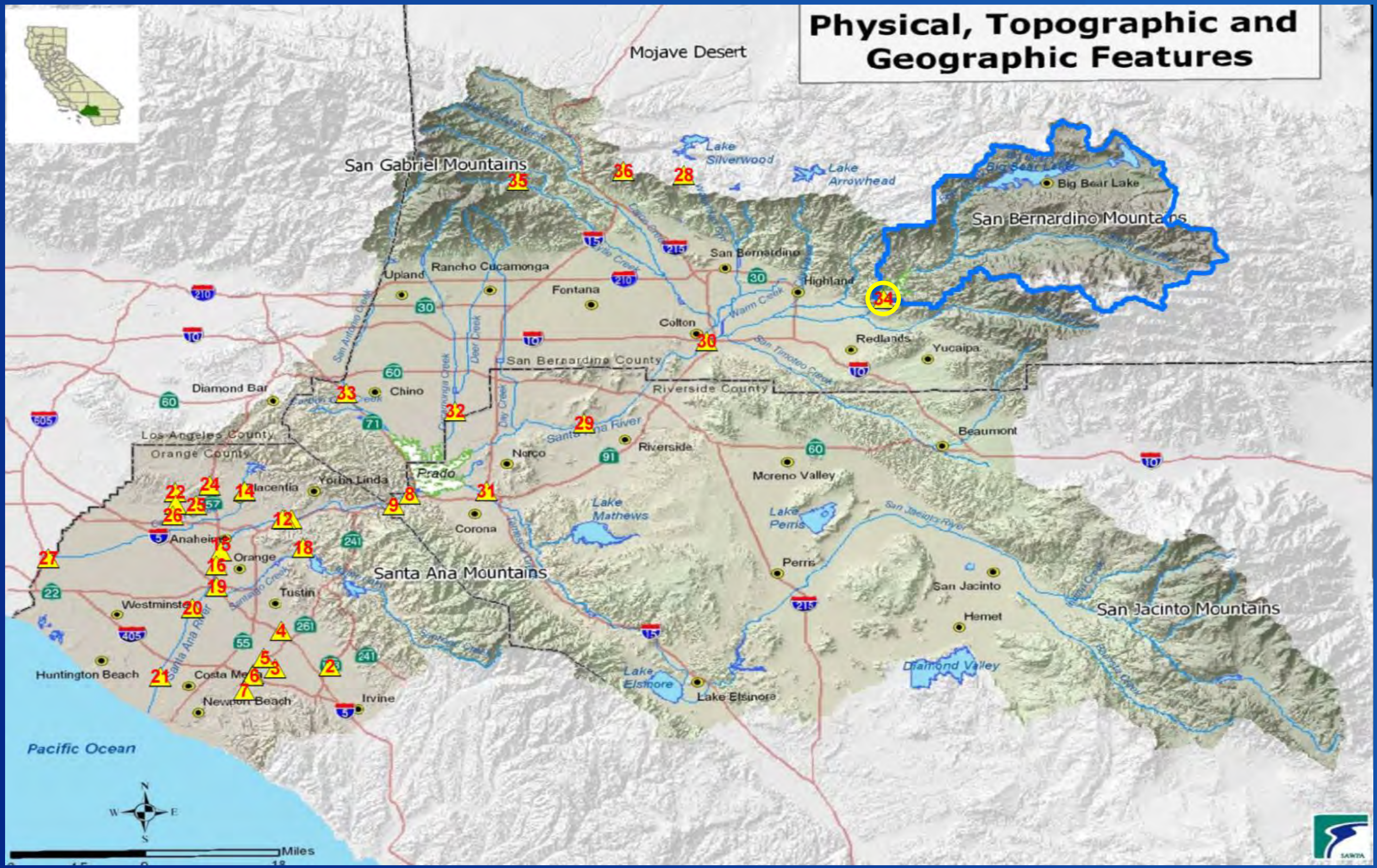
ID	Lat	Lon	Site Description
1	33.675020160	-117.835611000	Peters_Canyon_Wash_Tustin_Gage
2	33.683909460	-117.745330710	Marshburn_Channel_Gage
3	33.681686820	-117.809499150	San_Diego_Creek_Myford_Rd_Gage
4	33.725442191	-117.802408768	El_Modina-Irvine_Channel_Gage
5	33.693809460	-117.823037908	Peters_Canyon_Wash_Irvine_Gage
6	33.672798000	-117.835888800	San_Diego_Creek_Lane_Rd_Gage
7	33.655576290	-117.845611300	San_Diego_Creek_Campus_Dr_
8	33.885294816	-117.651816486	Santa_Ana_River_Prado_Dam_
9	33.872738742	-117.670852174	Santa_Ana_River_County_Line_
10	33.856404490	-117.790611220	Santa_Ana_River_Imperial_High
11	33.855848910	-117.797555880	Santa_Ana_River_AB_SPRD_Imp
12	33.856404440	-117.800889300	Santa_Ana_River_SPRD_Imperia
13	33.888903530	-117.845335820	Carbon_Creek_Olinda_Gage
14	33.889459080	-117.845335830	Carbon_Creek_Yorba_Linda_Ga
15	33.818812586	-117.873013779	Santa_Ana_River_Ball_Rd_Gage
16	33.802238450	-117.878390750	Santa_Ana_River_Katella_Ave_
17	33.822794190	-117.776721310	Santiago_Creek_Villa_Park_Gag
18	33.822794190	-117.776721310	Santiago_Creek_Div_Villa_Park_
19	33.777261477	-117.878057039	Santiago_Creek_Santa_Ana_Gage
20	33.752045602	-117.906379262	Santa_Ana_River_Santa_Ana_Gage
21	**33.672033347**	**-117.943733939**	**Santa_Ana_River_Adams_St_Gage**
22	33.887792060	-117.926449600	Brea_Channel_Brea_Dam_Gage
23	33.873625670	-117.925893710	Brea_Channel_Fullerton_Gage
24	33.895847650	-117.886170600	Fullteron_Channel_Fullerton_Dam_Gage
25	33.872875108	-117.902127395	Fullerton_Channel_Fullerton_Gage
26	33.860696271	-117.929366516	Fullerton_Channel_Richman_Ave_Gage
27	33.810571570	-118.075342080	Coyote_Creek_Los_Alamitos_Gage
28	34.259256110	-117.330684440	Devils_Canyon
29	33.968611110	-117.447500000	Santa_Ana_River_AT_Metropolitan_Water_District_Crossing_NR_Arlington
30	34.064688346	-117.303911477	Santa_Ana_River_AT_E_Street_NR_San_Bernardino
31	33.889166670	-117.561944440	Temescal_Creek_AB_Main_Street_AT_Corona
32	33.982777780	-117.598611110	Cucamonga_Creek_NR_Mira_Loma
33	34.003888890	-117.726111110	Chino_Creek_AT_Schaefer_Avenue_NR_Chino
34	34.114206940	-117.096661940	Seven_Oaks_Dam_Outlet
35	34.252500000	-117.525277780	Middle_Fork_Lytle_Creek_Gage
36	34.263888890	-117.401388890	Ridge_Top_Gage_NR_Devore



Step 3: Sub-basin delineation Seven Oaks Dam Outlet



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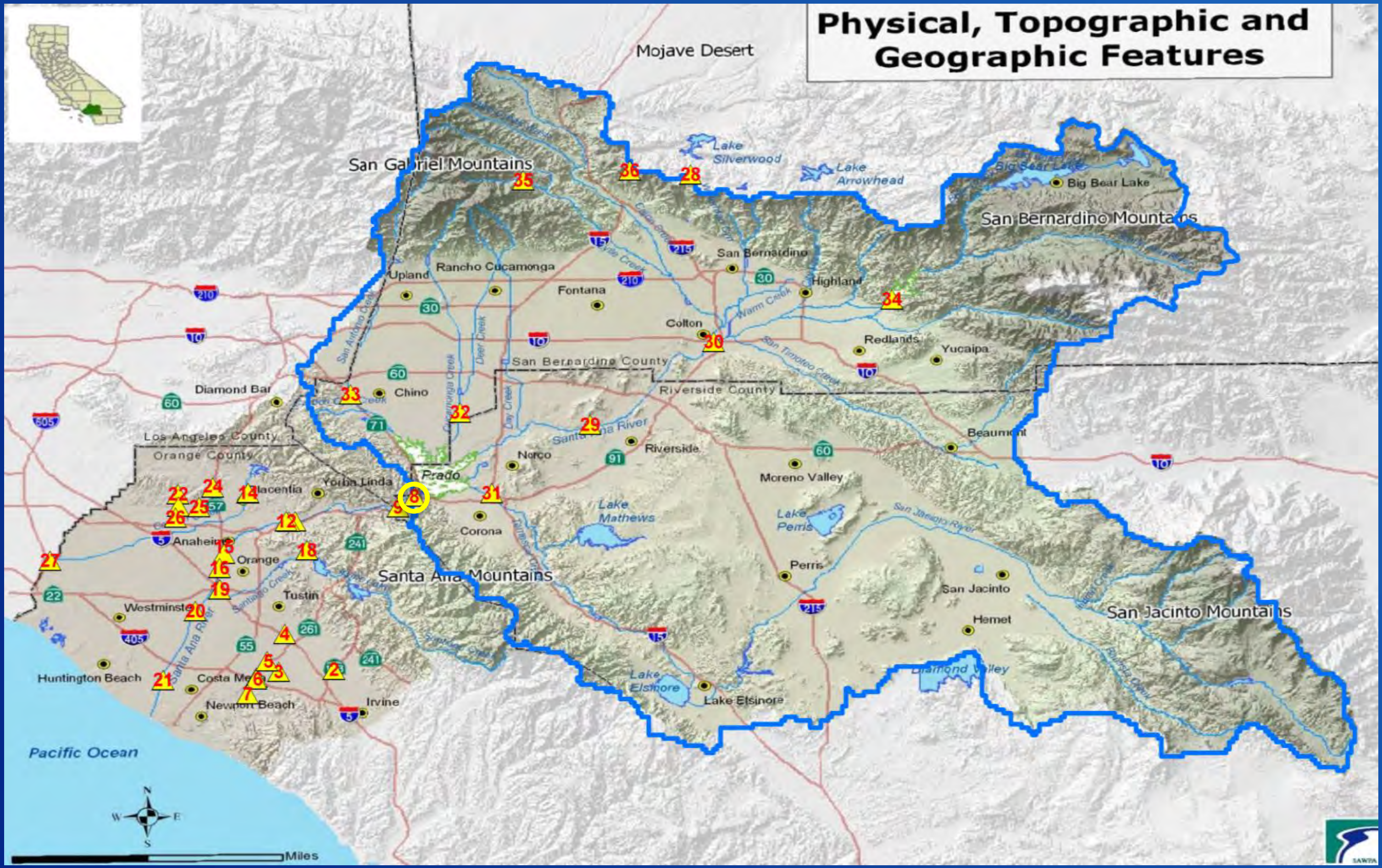
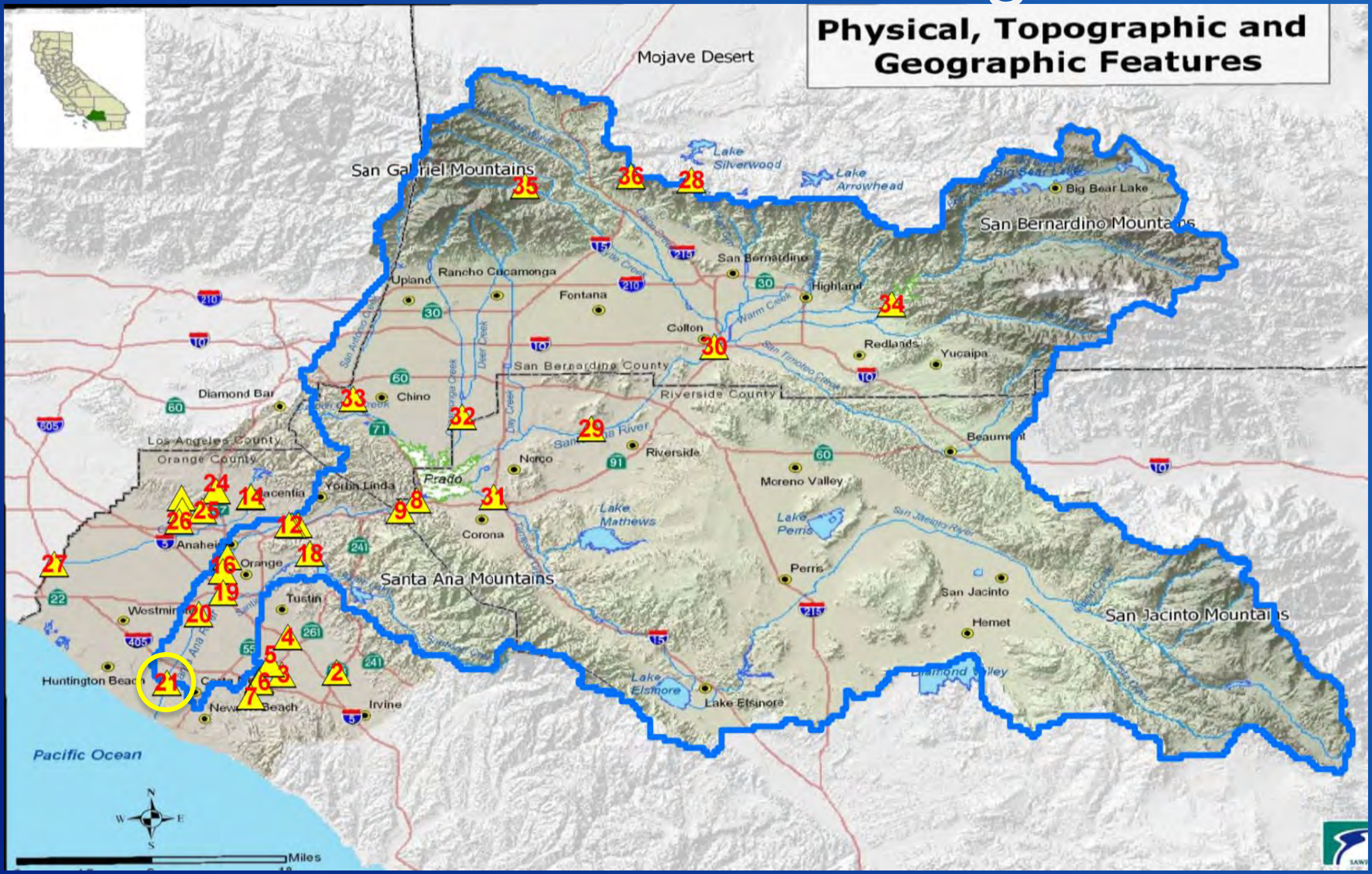
Step 3: Sub-basin delineation Prado Dam Gage



Step 3: Sub-basin delineation Adams Street Gage



Step 4: Developing the VIC routing models

Consists of two parts

1. Developing flow direction files - represent the flow network

2. Developing flow fraction files – fraction of grid cell covered by the sub-basin

Use Santa Ana River Adams Street Gage as the example

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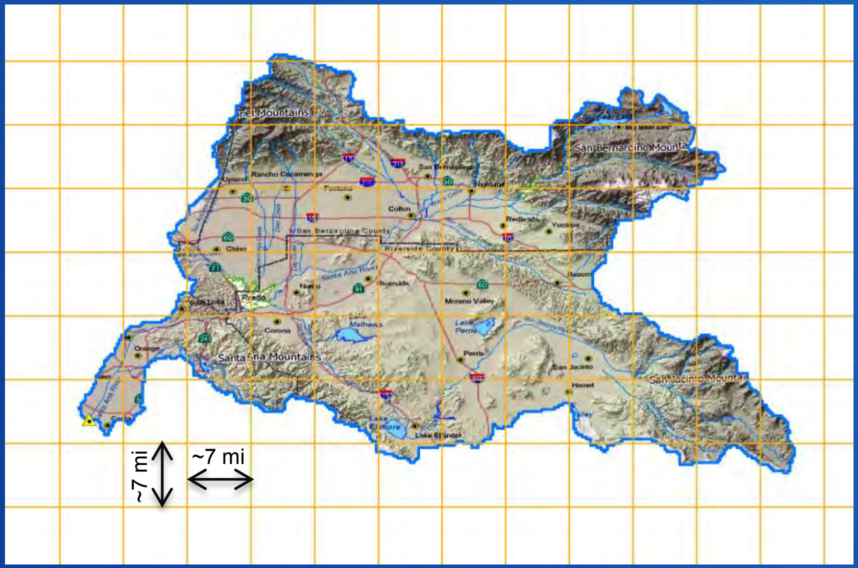
Step 4: Developing the VIC routing models Adams Street Gage

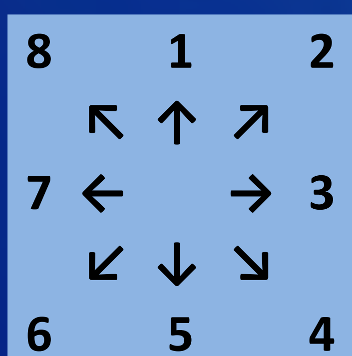
- Developing flow direction files - represent the flow network

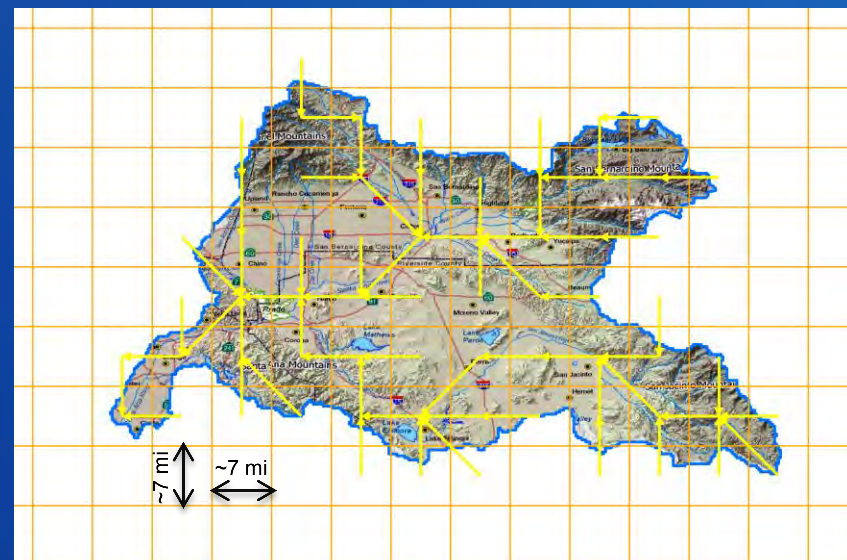
- Model grid, 1/8th degree x 1/8th degree (lat x lon) ~7 mi x 7 mi or ~ 12 km x 12 km



Step 4: Developing the VIC routing models Adams Street Gage

- Developing flow direction files - represent the flow network
- Model grid, $1/8^{th}$ degree x $1/8^{th}$ degree (lat x lon) ~7 mi x 7 mi or ~ 12 km x 12 km
- One of eight (8) flow direction assigned to each grid, USGS HydroSHEDS data, http://hydrosheds.cr.usgs.gov/





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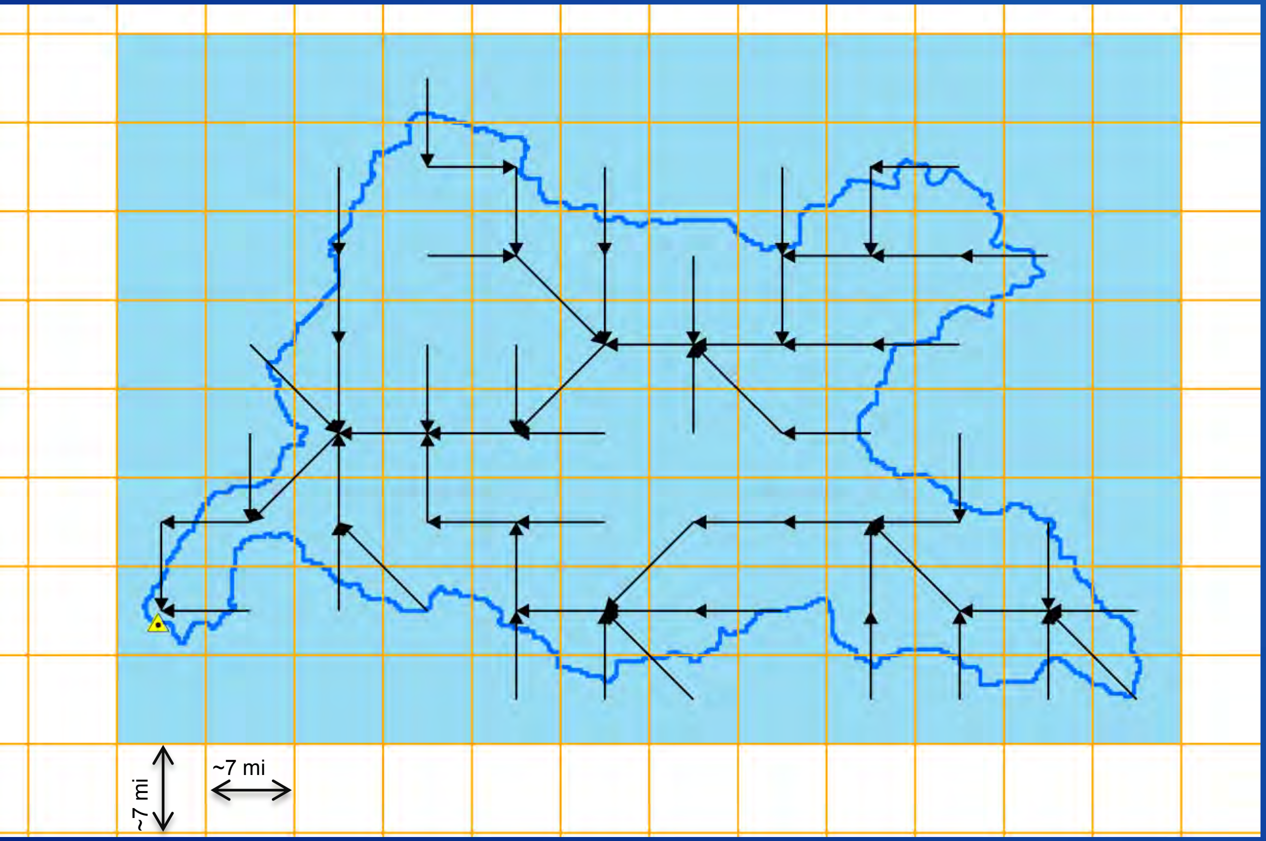
Step 4: Developing the VIC routing models
Adams Street Gage




```
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nrows          8
xllcorner      -118.0
yllcorner      33.5
cellsize       0.125
NODATA_value   0
0 0 0 5 0 0 0 0 0 0 0 0
0 0 5 3 5 5 0 5 5 7 0 0
0 0 5 3 4 5 5 5 7 7 7 0
0 4 5 5 5 6 7 7 7 7 0 0
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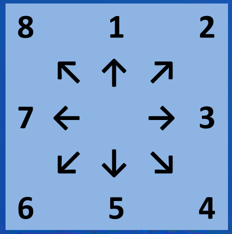
5 7 1 1 7 7 6 7 7 7 5 0
-9 7 1 8 1 7 7 7 1 8 7 7
0 0 0 0 1 1 8 0 1 1 1 8
```



Basin outlet represented by -9

Similar flow direction files were developed for all the 36 sites in the Santa Ana River Basin

Step 4: Developing the VIC routing models

Consists of two parts

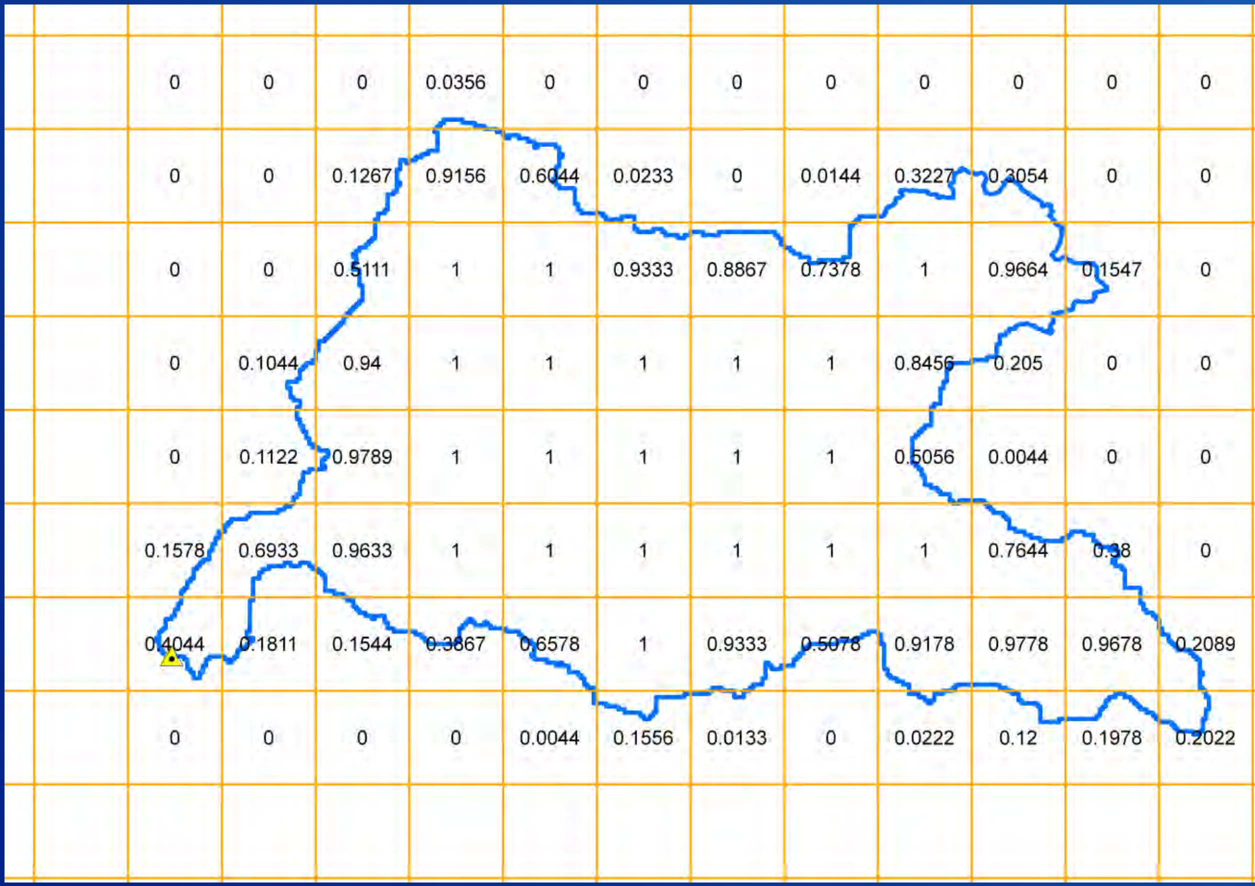
1. Developing flow direction files - represent the flow network

2. Developing flow fraction files – fraction of grid cell covered by the sub-basin

Use Santa Ana River Adams Street Gage as the example

Step 4: Developing the VIC routing models Adams Street Gage

Fraction of grid cell covered by the sub-basin, total = 40.2063




```
ncols         12
nrows         8
xllcorner     -118.0
yllcorner     33.5
cellsize      0.125
NODATA_value  0
0 0 0 0.0356 0 0 0 0 0 0 0 0
0 0 0.1267 0.9156 0.6044 0.0233 0 0.0144 0.3227 0.3054 0 0
0 0 0.5111 1.0 1.0 0.9333 0.8867 0.7378 1.0 0.9664 0.1547 0
0 0.1044 0.94 1.0 1.0 1.0 1.0 1.0 0.8456 0.205 0 0
0 0.1122 0.9789 1.0 1.0 1.0 1.0 1.0 0.5056 0.0044 0 0
0.1578 0.6933 0.9633 1.0 1.0 1.0 1.0 1.0 1.0 0.7644 0.38 0
0.4044 0.1811 0.1544 0.3867 0.6578 1.0 0.9333 0.5078 0.9178 0.9778 0.9678 0.2089
0 0 0 0 0.0044 0.1556 0.0133 0 0.0222 0.12 0.1978 0.2022
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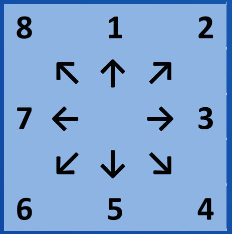
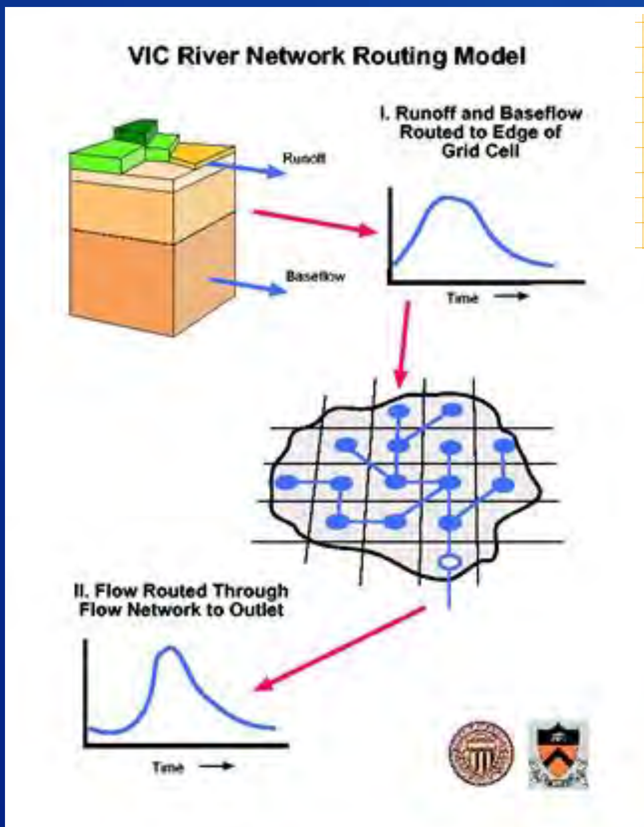
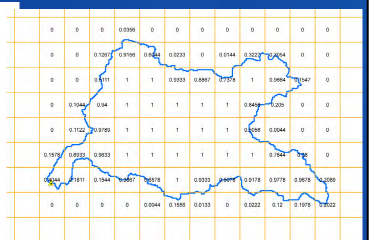


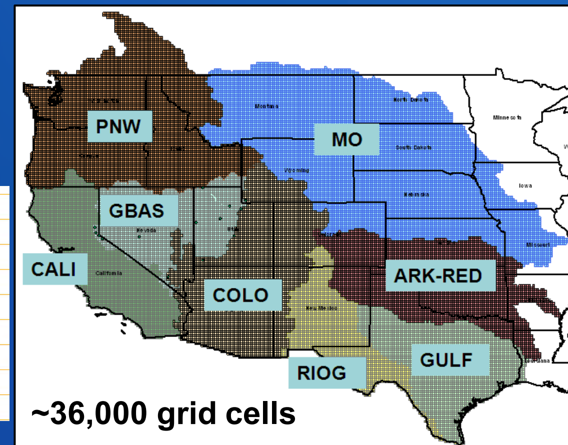
Similar flow fraction files were developed for all the 36 sites in the Santa Ana Basin

Step 5: Flow routing using the WWCRA gridded runoff

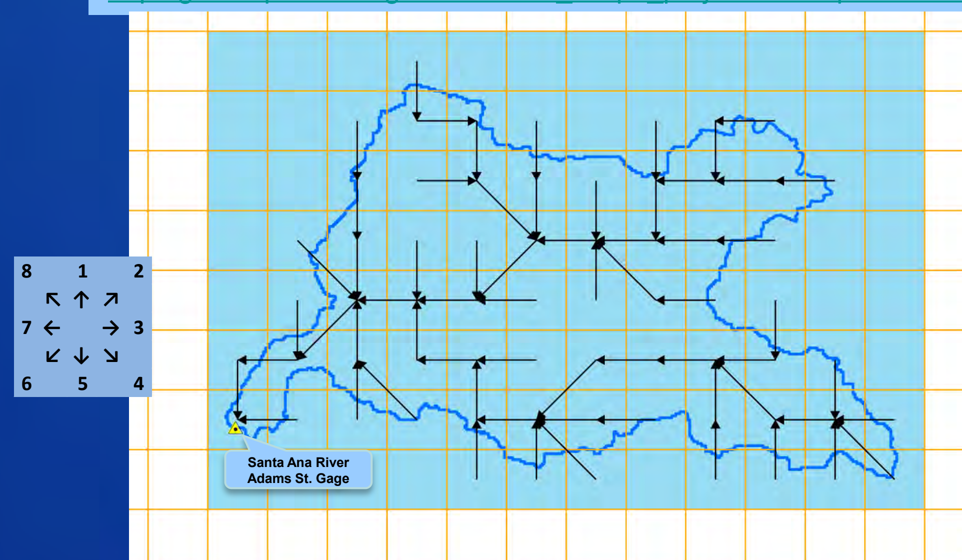
VIC Routing Model







BCSD Climate and Hydrology Projections Website
http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html



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WHAT ANALYSIS WAS DONE USING THE HYDROLOGY PROJECTIONS?

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Assumptions

- 10-year base or reference hydrology period, water years 1990-1999. 1990s.
- Three (3) future look ahead periods:
  - water years 2020-2029. 2020s.
  - water years 2050-2059. 2050s.
  - water years 2070-2079. 2070s.
- All analysis are made using modeled data from 112 BCSD CMIP-3 projections and VIC simulations.

Hydrology Projections Analysis

- Change analysis between the base period (1990s) and future period (2020s, 2050s, 2070s), how were the changes calculated?

- Precipitation – percentage (%) change. Steps - for example to estimate change in the 2020s from the 1990s. For a given grid cell in the Basin, and given projection [iproj] (recall, total number of projections is 112)

1. Calculate decade mean total precipitation (P) for the two decades 1990s (water years 1990-1999, iper=1) and 2020s (water years 2020-2029, iper=2).

2. Next , calculate percentage change (pchange) of projection iproj,

   pchange[iproj]=100((P[iproj, 2] - P[iproj,1])/P[iproj,1])*

3. Finally, calculate the median change from all the 112 projections - ensemble median change.

4. Repeat Steps 1 through 3 for all the grid cells in the Basin.

Hydrology Projections Analysis

- Change analysis between the base period (1990s) and future period (2020s, 2050s, 2070s), how were the changes calculated?

- Snow Water Equivalent (SWE) – calculations similar to precipitation.

- Temperature (T) – steps similar to precipitation but not percentage change,
  1. Calculate decade mean temperature (T) for the two decades 1990s (water years 1990-1999, iper=1) and 2020s (water years 2020-2029, iper=2).

  2. Next , calculate change in decade mean temperature value for projection iproj,

     change = (T[iproj, 2] - T[iproj,1])

  3. Finally, calculate the median change from all the 112 projections - ensemble median change.

  4. Repeat Steps 1 through 3 for all the grid cells in the Basin.

- More details/examples during presentation of results in subsequent slides. …

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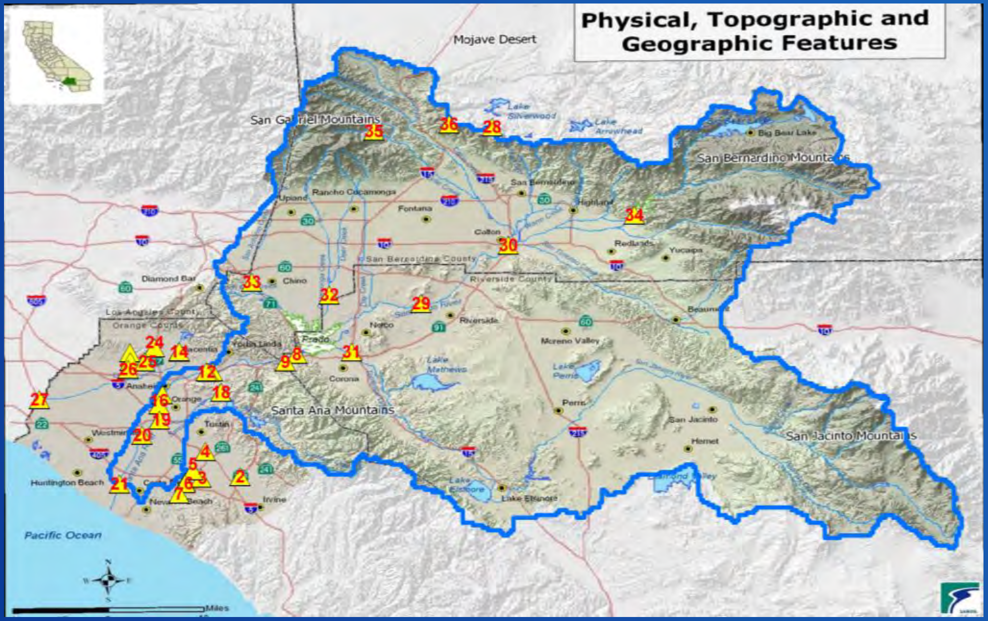
Hydrology Projections Results

- Change analysis between the base/reference period (1990s) and three future periods (2020s, 2050s, 2070s)
  1. Precipitation
  2. Temperature
  3. April 1st SWE
  4. Flow

- Spatial distribution and temporal trends

- Santa Ana R. Adams St. Gage



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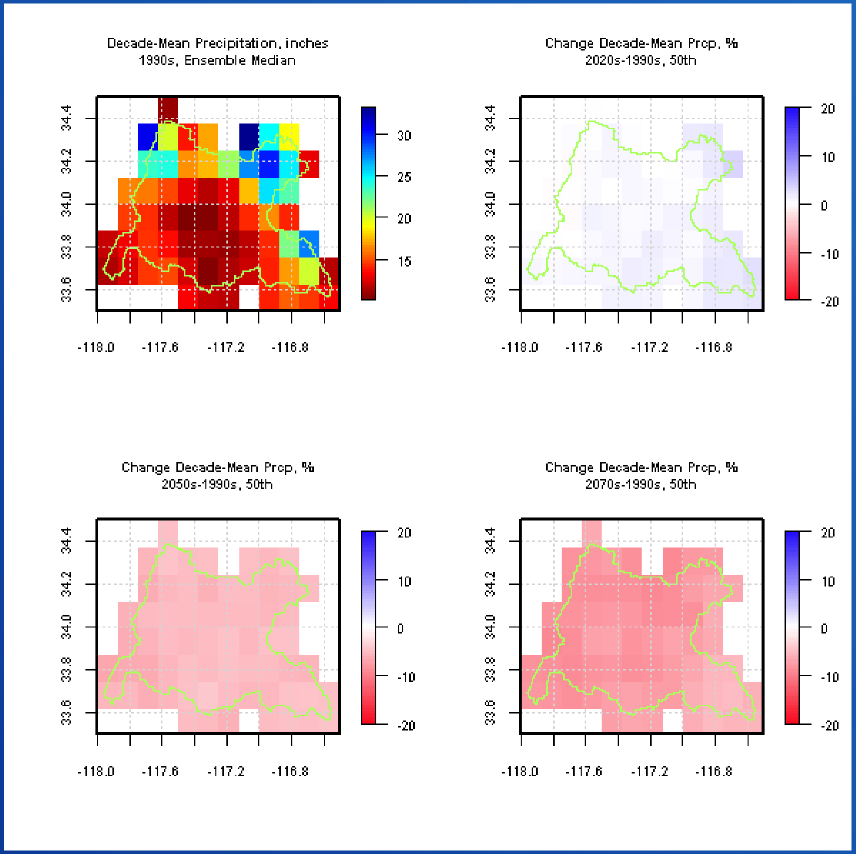
Hydrology Projections
Spatial Distribution of Precipitation (P)

- The ensemble- median change shows some increase in prcp over the basin during the 2020s’ decade from the 1990s’ reference.
- By the 2050s there is decline in prcp from the 1990s reference decade.
- Increased decline in prcp continues through to the 2070s decade from the 1990s reference decade.



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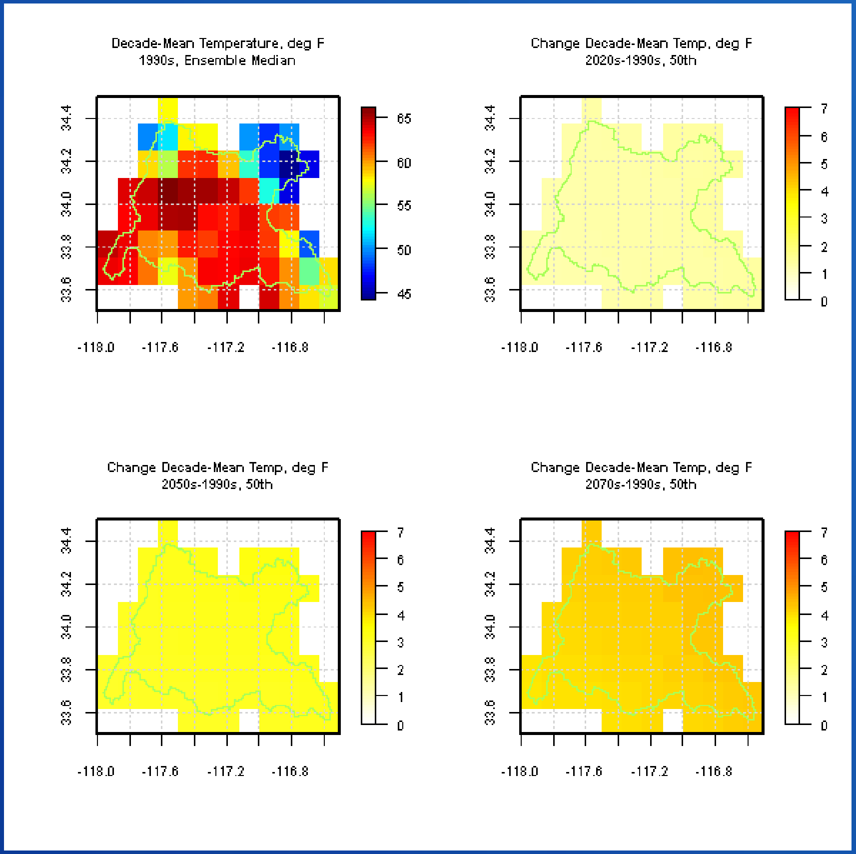
Hydrology Projections
Spatial Distribution of Temperature (T)

- The ensemble median change for the 2020s', 2050s', and 2070s' decades relative to the 1990s shows an increasing temperature value throughout the Basin.



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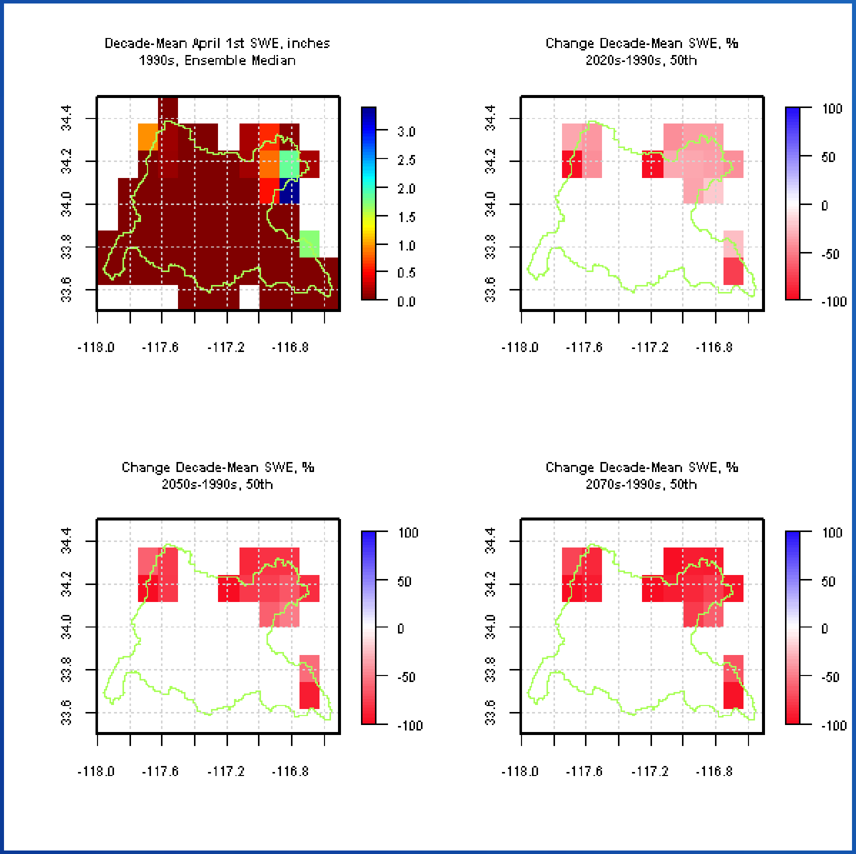
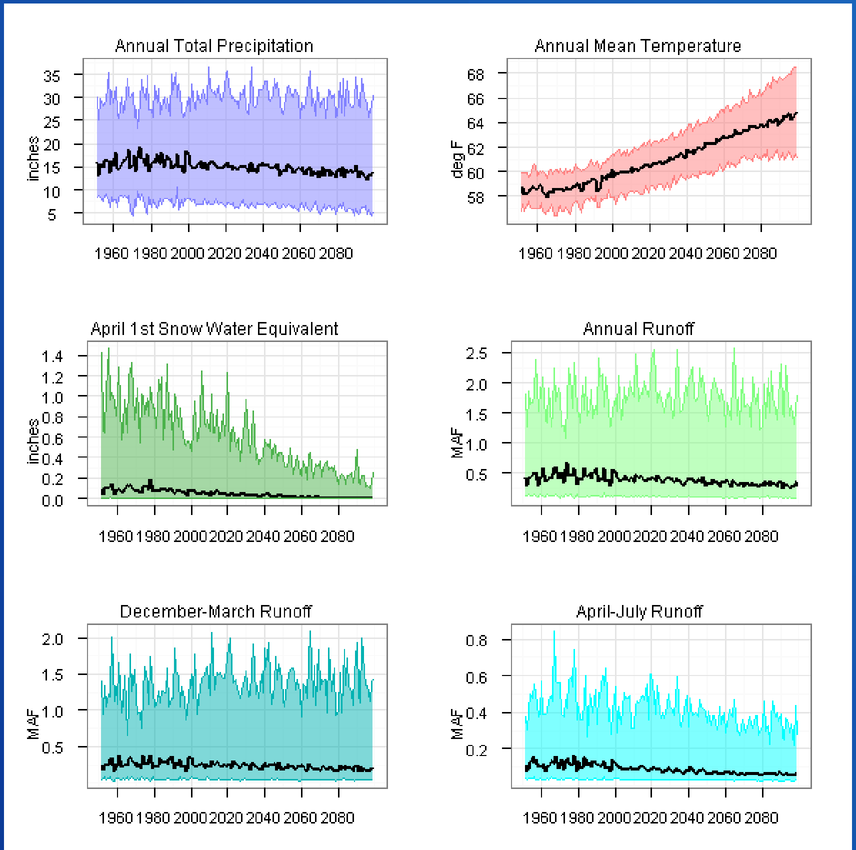
Hydrology Projections
Snow Water Equivalent (SWE)

- Spatial distribution of April 1st SWE – persistent decline through the future decades (2020s, 2050s, 2070s) from the 1990s' distribution.



Hydrology Projections
P, T, SWE, Flow

- Temporal trends – solid line is the median, 5th and 95th percentile bounds.
- P – longer-term decreasing trend
- T- increasing trend
- SWE - decreasing trend
- Flow – longer-term decreasing trend



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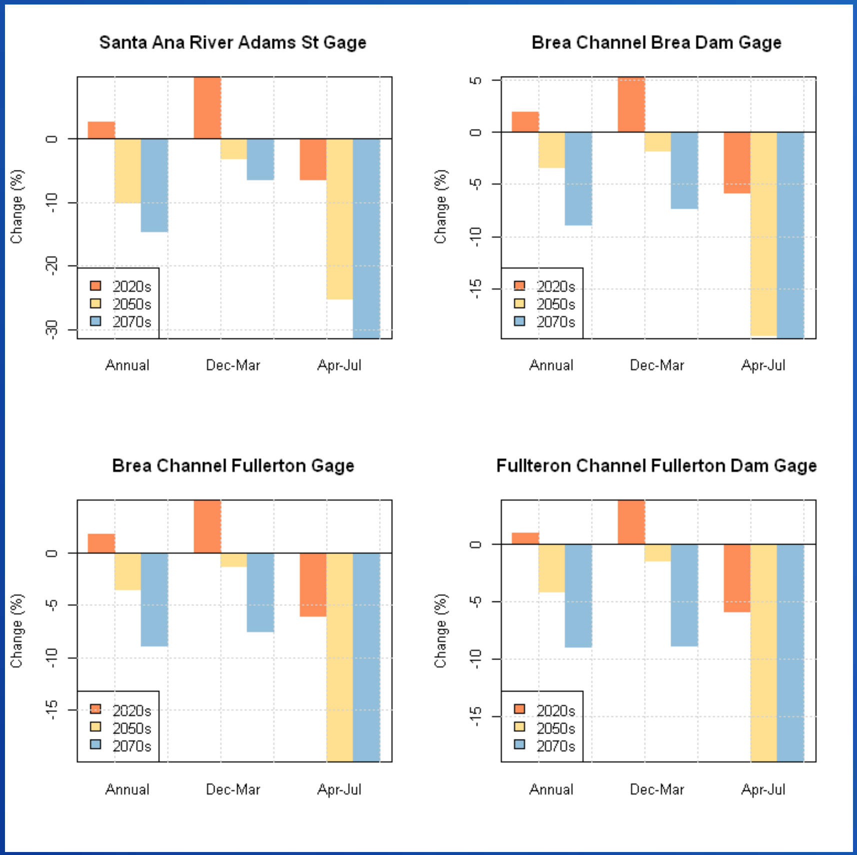
Hydrology Projections
Flow Impacts

- Annual and seasonal streamflow impacts
- 2020s – increase in annual runoff and winter (Dec-Mar) runoff, decrease in spring-summer (Apr-Jul) runoff from the 1990s reference
- 2050s – decrease in annual, winter, spring-summer runoff from the 1990s reference
- 2070s - decrease in annual, winter, spring-summer runoff from the 1990s reference



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Summary of Impacts
Santa Ana River Adams St. Gage

Hydroclimate Metric (change from 1990s)	2020s	2050s	2070s
Precipitation (%)	0.67	-5.41	-8.09
Mean Temperature (deg F)	1.22	3.11	4.10
April 1st SWE (%)	-38.93	-80.40	-93.07
Annual Runoff (%)	2.60	-10.08	-14.61
Dec-Mar Runoff (%)	9.82	-3.01	-6.38
Apr-Jul runoff (%)	-6.35	-25.24	-31.39

Similar analysis was done for all the 36 sites in the Santa Ana Basin

1. Background. Acronyms , definitions, assumptions, and hydrology model overview.

2. How were the hydrologic projections developed for the Santa Ana Watershed? Detailed description of the hydrologic projections development process, specifically streamflow.

3. What analysis was done using the hydrology projections? Detailed description of analysis of change and statistics used.

4. Results. All results are preliminary and draft.

5. Example analysis. Change in runoff using the hydrologic projections website hosted at Lawrence Livermore National Lab (LLNL).

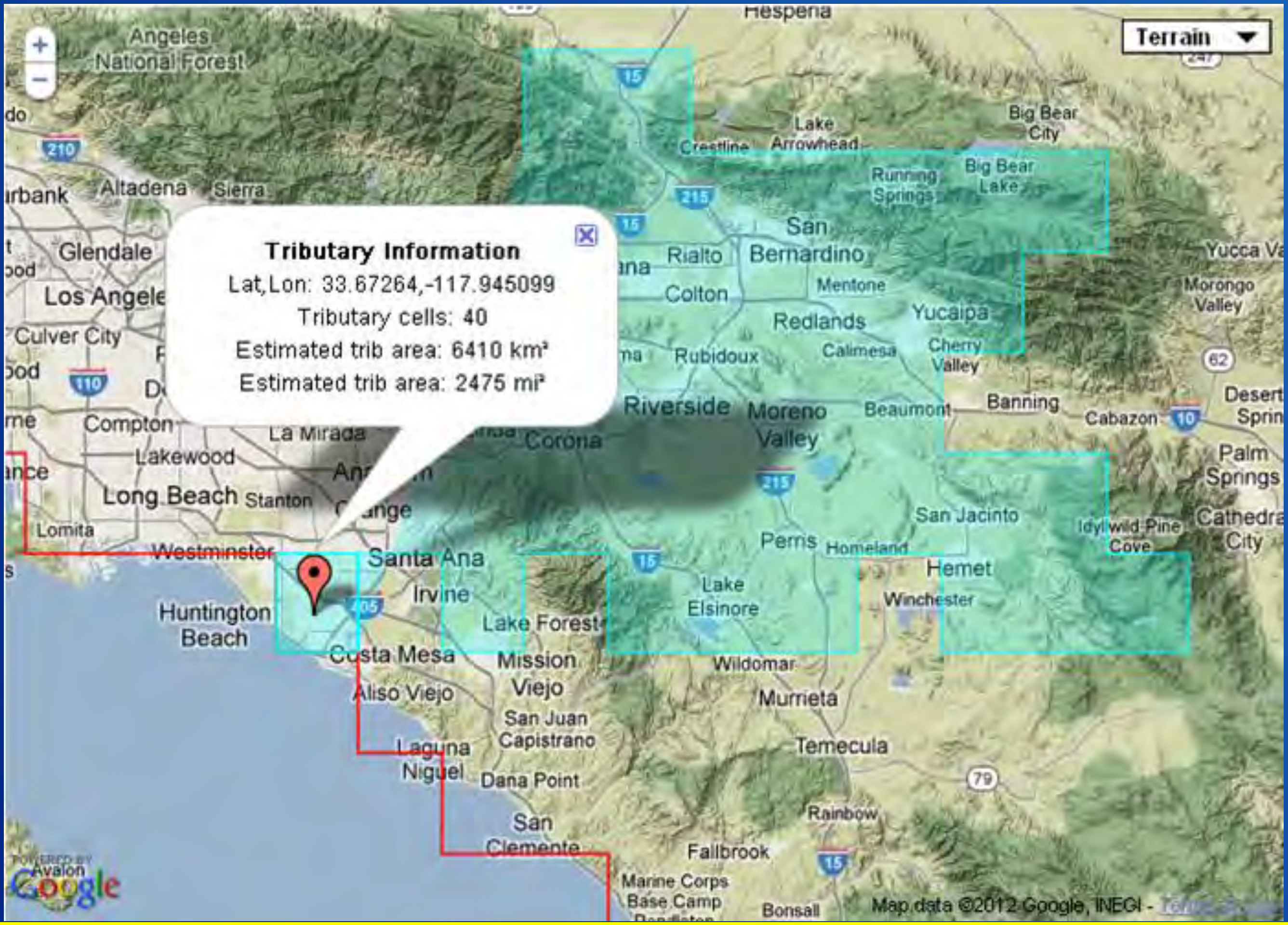
6. Summary

7. Next Steps

EXAMPLE ANALYSIS

RECLAMATION

Example: Runoff Impact
Santa Ana R. Adams St. Gage



http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html

RECLAMATION

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SUMMARY

Summary

- Developed hydrologic projections from climate change projections for the Santa Ana Watershed. 36 sites across the Santa Ana Basin.

- Analyzed the hydrologic projections to support updating of the IRWMP plan, i.e. OWOW 2.0.

- Example analysis on how runoff impacts can be calculated from the WWCRA gridded hydrology.

1. Background. Acronyms , definitions, assumptions, and hydrology model overview.

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NEXT STEPS

RECLAMATION

Next Steps

- Documenting all the analysis.
- Performing “as-needed” additional analysis.
- Developing decision support tools.