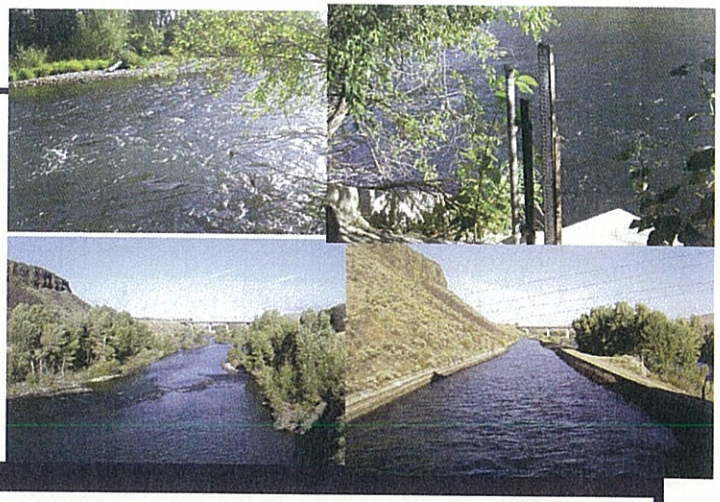
# Climate Variability Impact Studies in the Treasure Valley region



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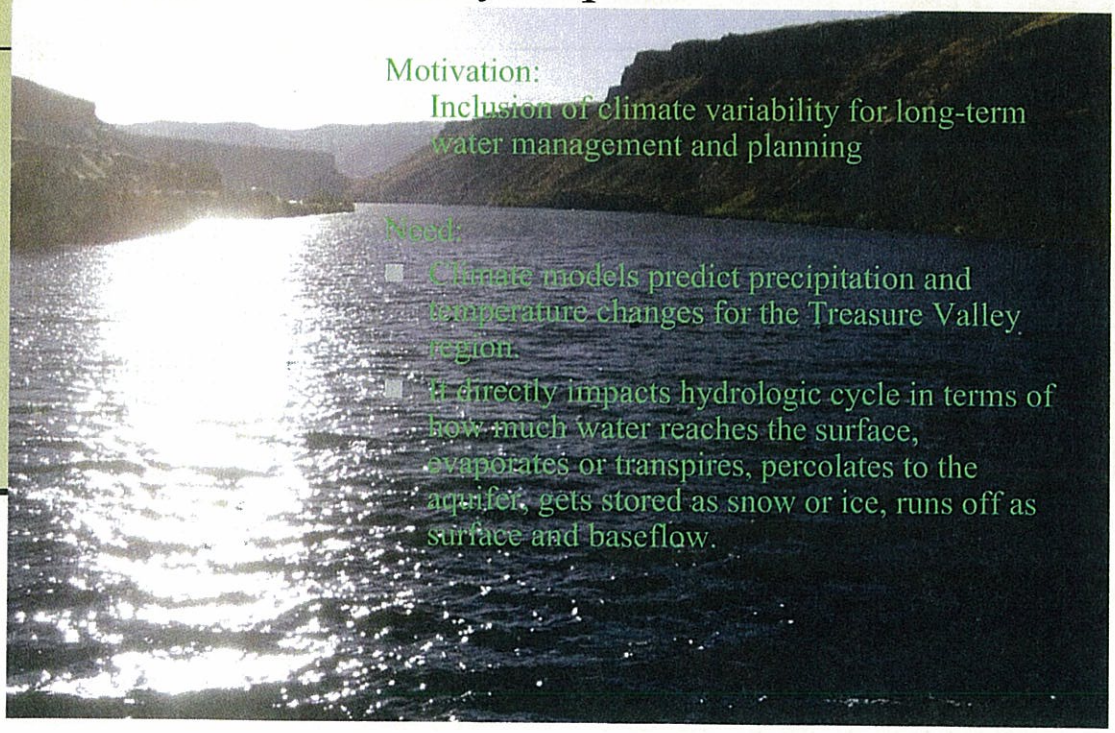
Team Members: Xin Jin, Postdoc
Civil Engineering, Boise State University, Boise, ID 83725
Nov 10, 2010

# Climate Variability Impact



Motivation:
Inclusion of climate variability for long-term water management and planning

Need:

- Climate models predict precipitation and temperature changes for the Treasure Valley region.
- It directly impacts hydrologic cycle in terms of how much water reaches the surface, evaporates or transpires, percolates to the aquifer, gets stored as snow or ice, runs off as surface and baseflow.

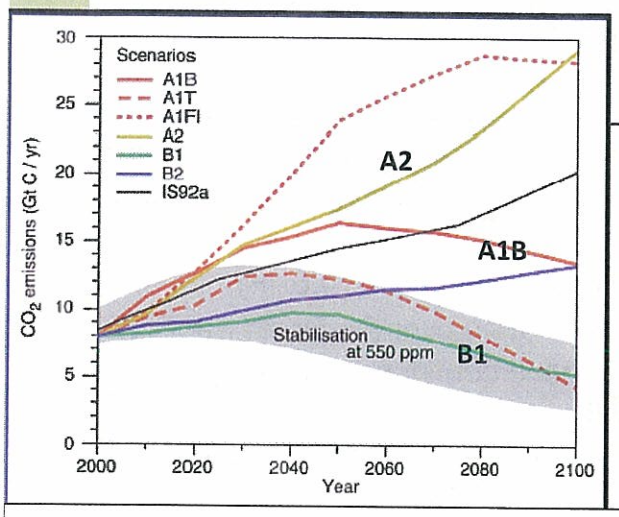
## Scope of the work

- Review of literature to understand changes in regional temperature and precipitation can impact the hydrology and water supply in the Treasure Valley basin
- Identify atleast three potential climate change scenarios from a suite of climate models and provide the rationale behind the choice of climate data and model
- Using Soil Water Assessment Tool (SWAT) to describe and quantify the possible impact of climate change on the water supply –for the Treasure Valley- amount of rainfall, timing and magnitude of snowmelt, interannual variability assessment in the streamflow and other water balance components including evapotranspiration, soil moisture and recharge.

## Intergovernmental Panel on Climate Change (IPCC)

- The leading body for the assessment of climate change
- Established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO)
- Provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences (*www.**ipcc**.ch/* ).

# IPCC Special Report on Emission Scenarios (SRES)




IPCC, 2007

http://www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf

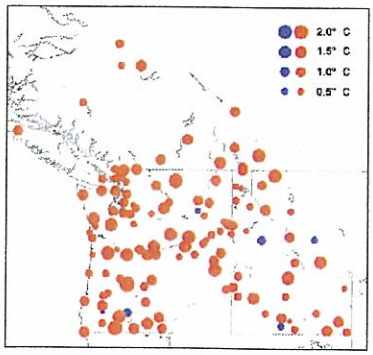
**Table 2.** The six SRES illustrative scenarios and the stabilisation scenarios (parts per million $CO_2$) they most resemble (based on Swart *et al.*, 2002).

| SRES illustrative scenario | Description of emissions | Surrogate stabilisation scenario |
|---|---|---|
| A1FI | High end of SRES range | Does not stabilise |
| A1B | Intermediate case | 750 ppm |
| A1T | Intermediate/low case | 650 ppm |
| A2 | High case | Does not stabilise |
| B1 | Low end of SRES range | 550 ppm |
| B2 | Intermediate/low case | 650 ppm |

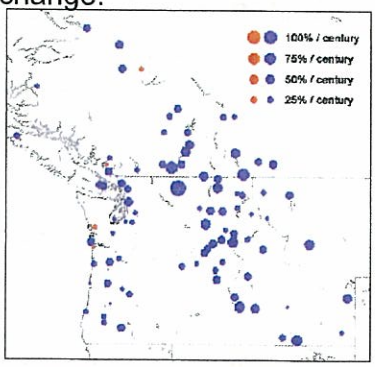
# Background: PNW

Source: Climate Impacts Group, UW; http://cses.washington.edu/cig/pnwc/pnwc.shtml

20th century trends in average annual temperature (1920-2000). Increases (decreases) are indicated with red (blue) dots. The size of the dot corresponds to the magnitude of change.




20th century trends in average annual precipitation (1920-2000). Increases (decreases) are indicated with red (blue) dots. The size of the dot corresponds to the magnitude of change.




Warming is expected to continue as a result of climate change, with a likely warming rate of about 0.5°F/decade. While future changes in precipitation are less certain, overall, precipitation is projected to increase in the PNW.

# Literature Summary

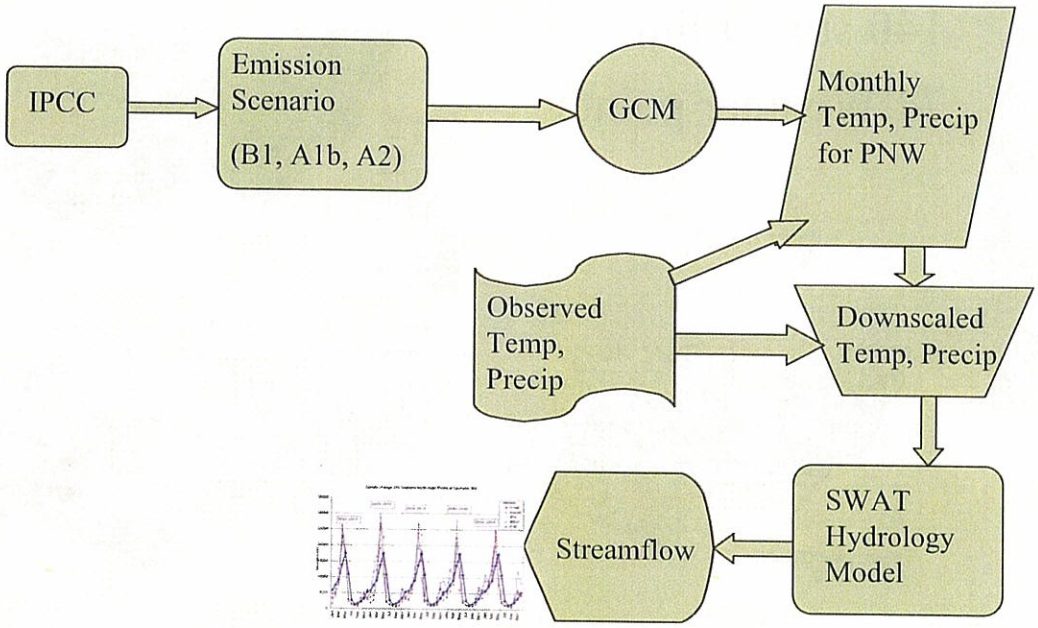
- Most GCMs reproduce key features (Mote and Salathe, 2009)
  - observed PNW climate including the sharp contrast between wet winters and dry summers
  - the 20th century warming of about 0.8°C (4.6 °F)
  - the mean atmospheric circulation over the North Pacific.
  - Hence, we can expect to have confidence in their projected changes in future climate.
- For the SRES scenarios examined here, all models produce annual mean warming of at least 0.1°C (3.3 °F)

# Choice of Global Climate Models

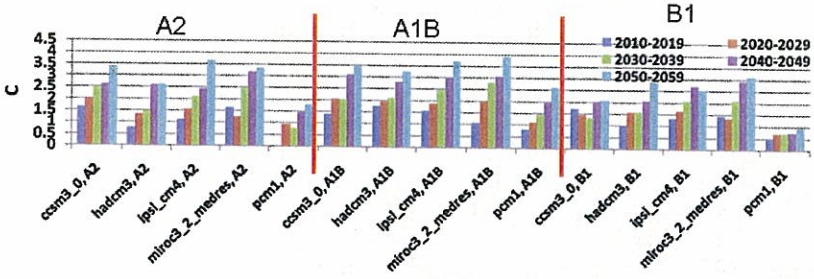
- CCSM3 (National Center for Atmospheric Research, USA)
- HADCM3 (Hadley Centre for Climate Prediction and Research/ Met Office, UK)
- IPSL-CM4 (Institut Pierre Simon Laplace, France)
- MIROC3.2 (medres)(Center for Climate System Research, Univ. of Tokyo, National Institute for Environmental Studies, and Frontier Research Center for Global Change, Japan)
- PCM (National Center for Atmospheric Research, USA)

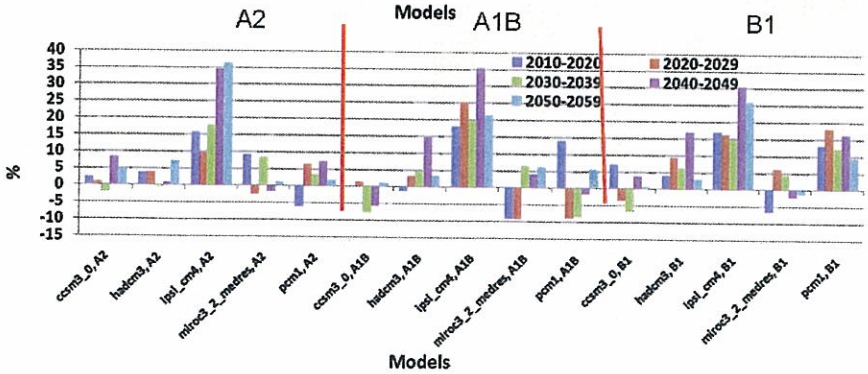
# Climate Model Downscaling Approach:

Steps to obtain precipitation and temperature data from global climate models to drive the hydrology model at the local scale




# Downscaled GCM Precipitation and Temperature for the Boise River Basin

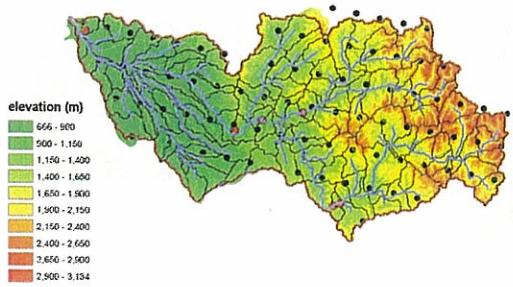


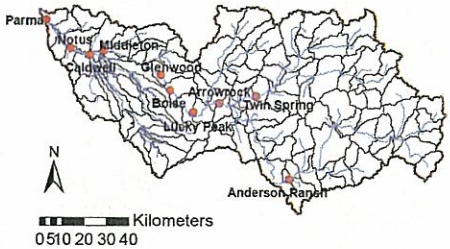



# Boise River Watershed

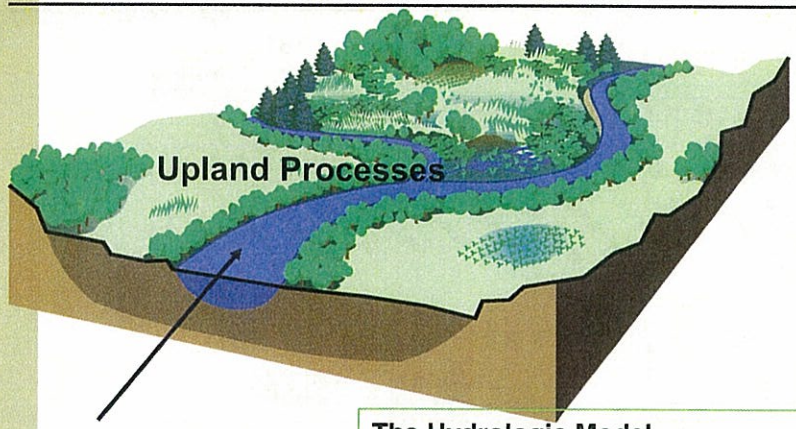
140 sub-basins

74 Weather points



# SWAT Watershed System




**Channel/Flood Plain Processes**

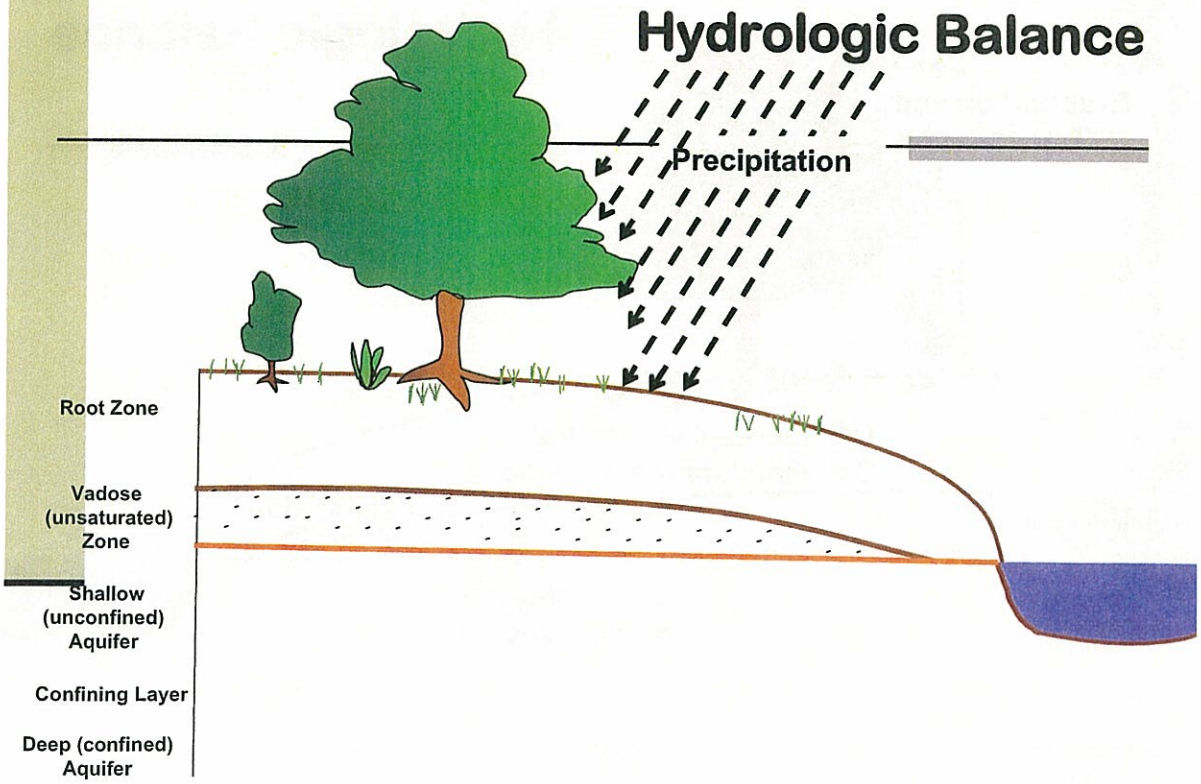
**The Hydrologic Model**

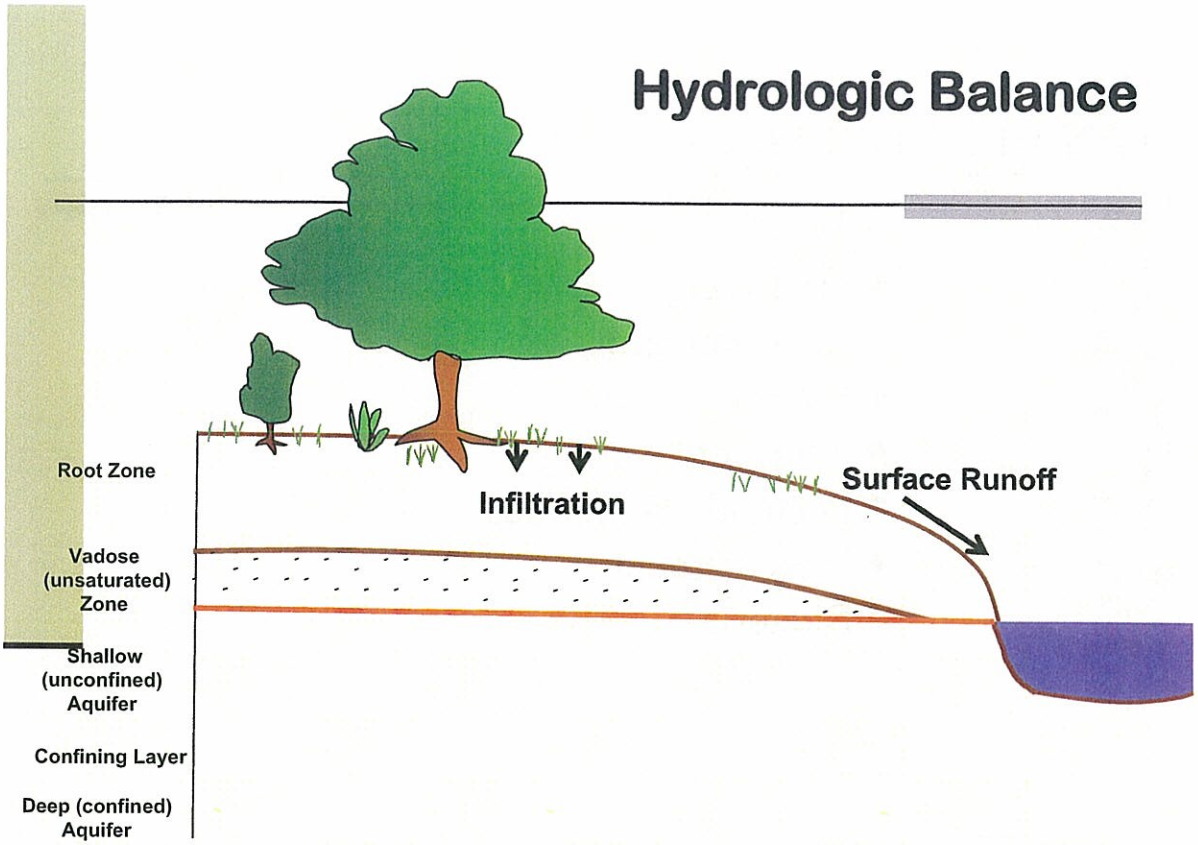
SWAT is a continuous simulation macroscale hydrologic model that operates on a daily time step and is designed to predict the impacts of land management on the water yield of large ungaged watersheds. The input requirements of the model are data describing a basin's weather, soil properties, topography, vegetation, and land management practices.

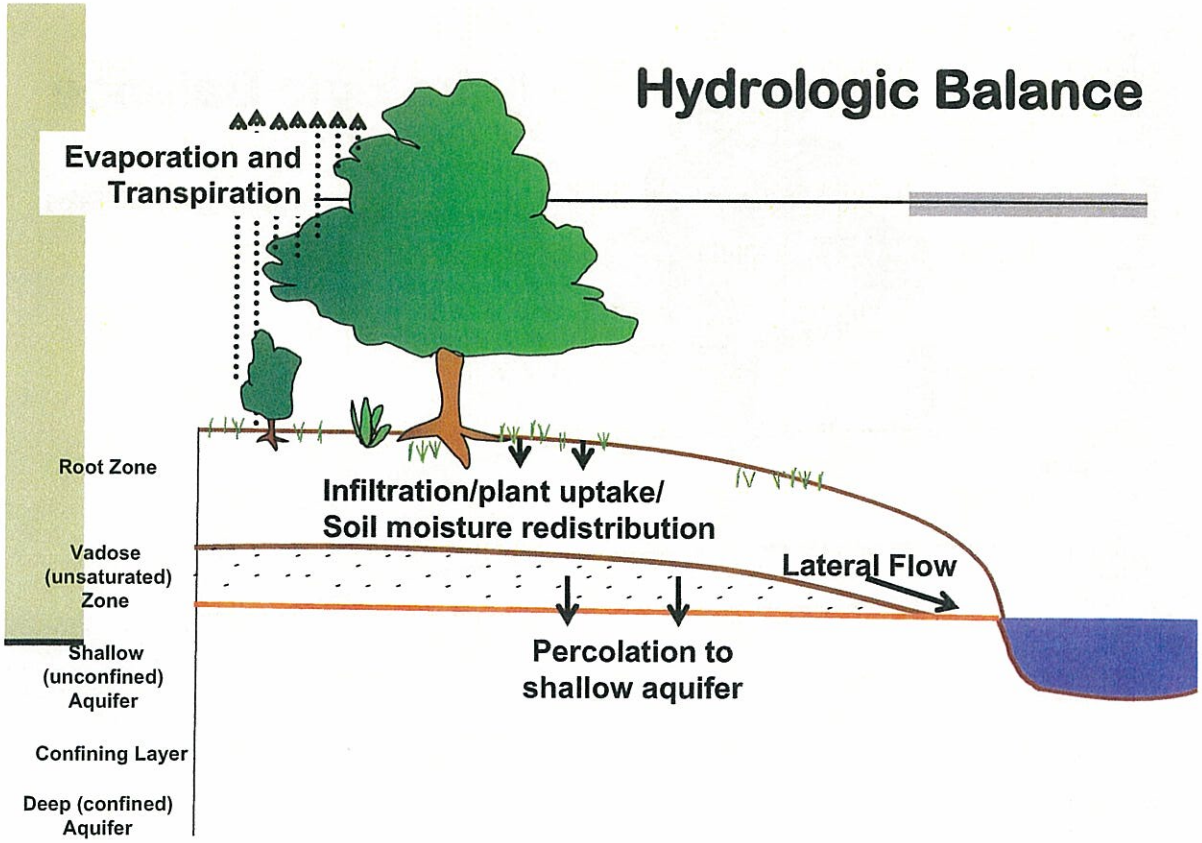
# Upland Processes

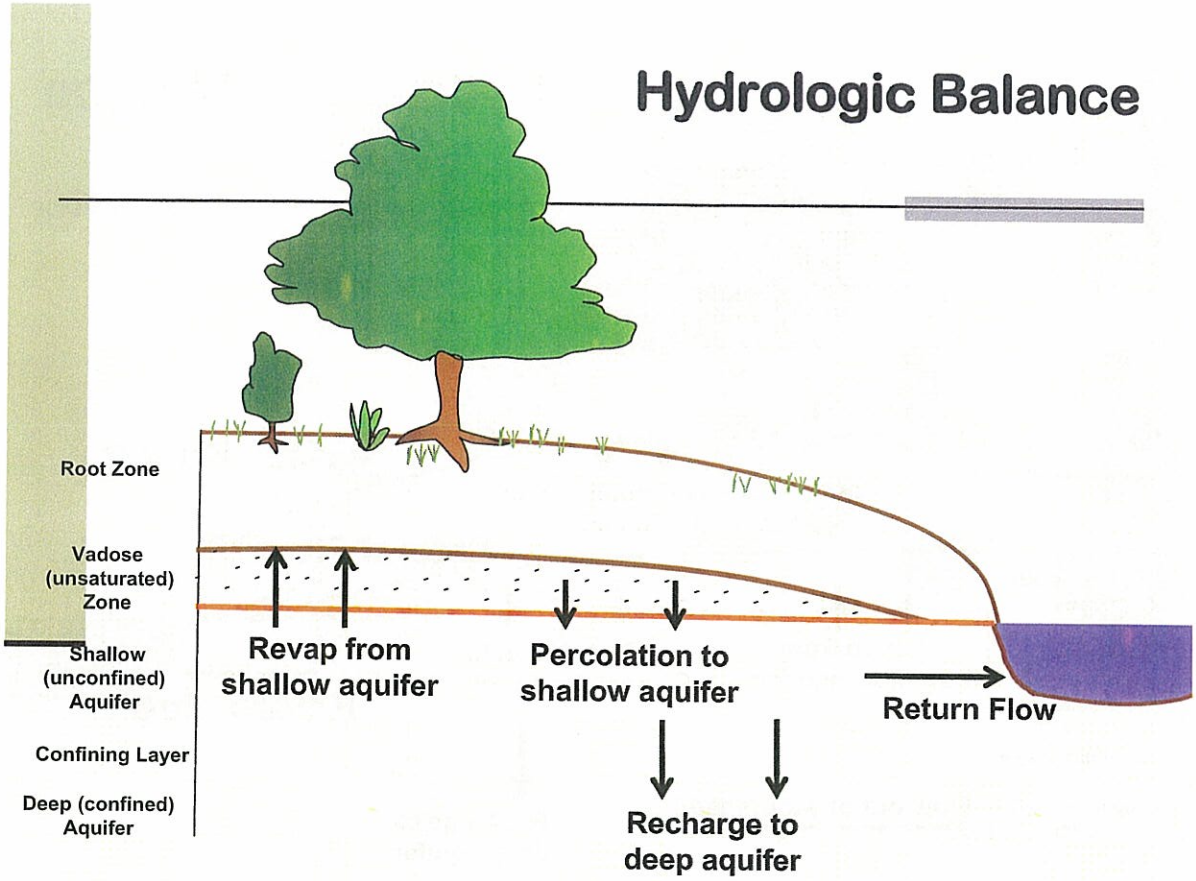
- Weather
- Hydrology
- Sedimentation
- Plant Growth
- Nutrient Cycling
- Pesticide Dynamics
- Management
- Bacteria

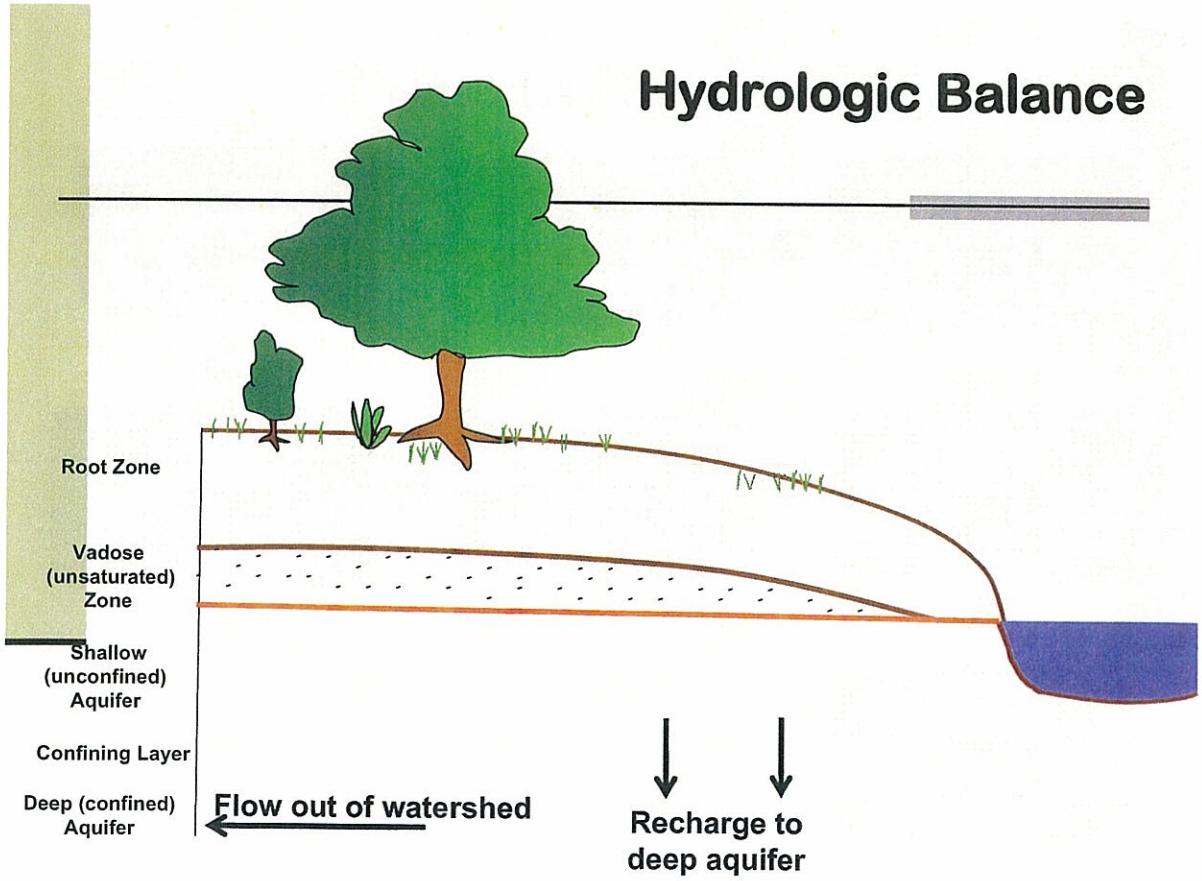
# Hydrologic Balance

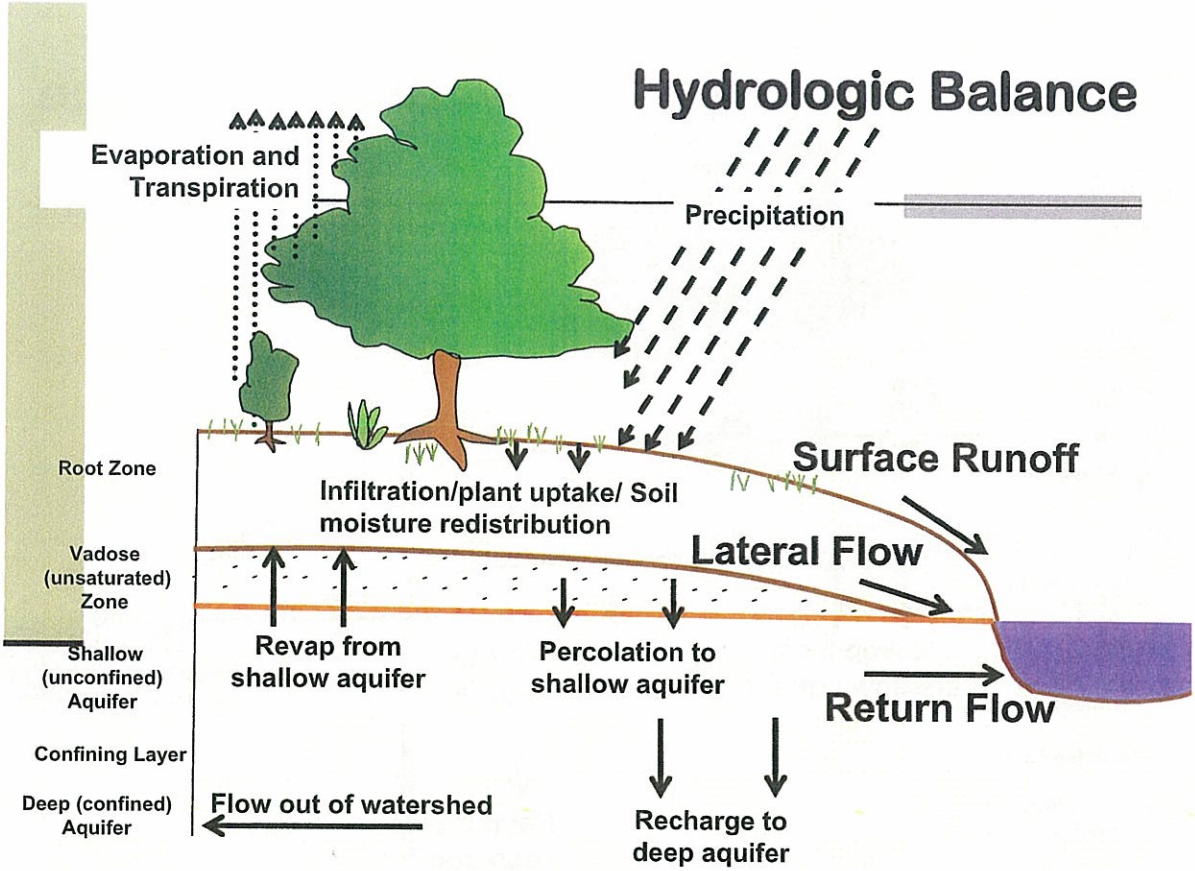


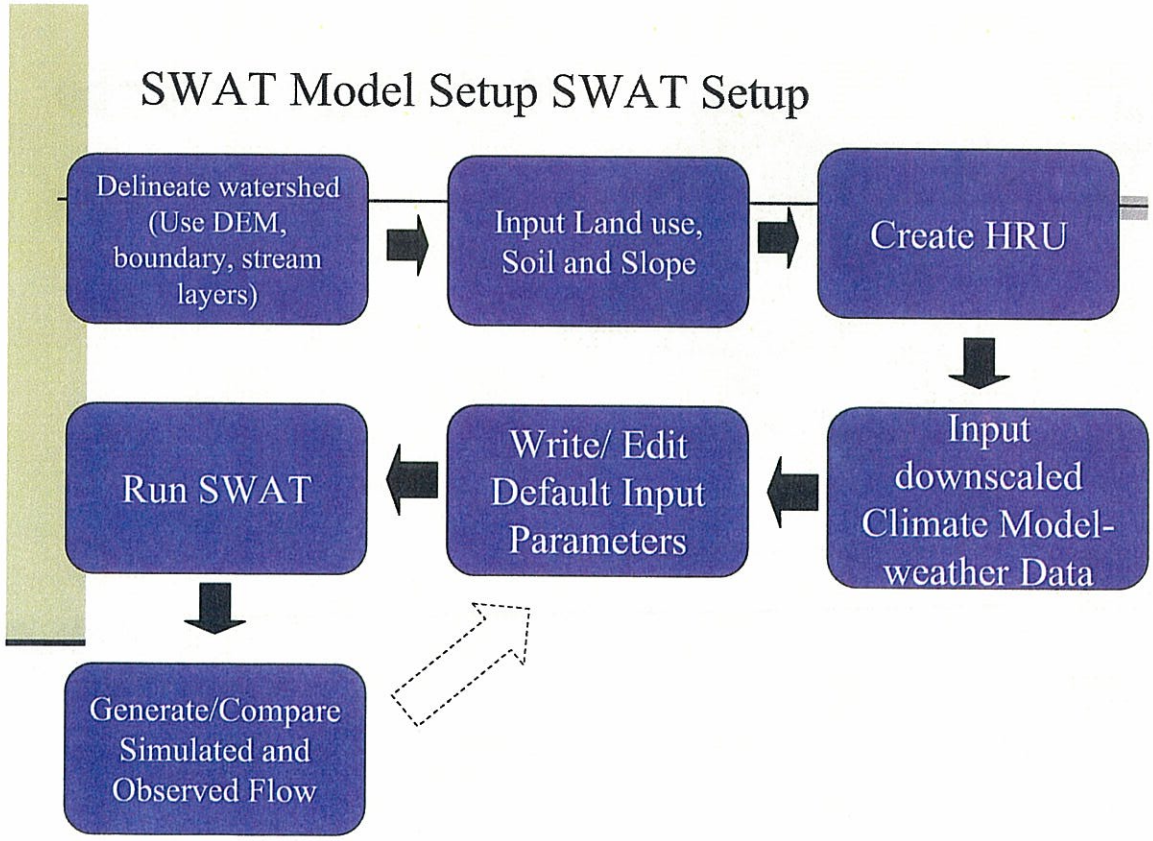

Hydrologic Balance
Root Zone
Infiltration
Surface Runoff
Vadose (unsaturated) Zone
Shallow (unconfined) Aquifer
Confining Layer
Deep (confined) Aquifer


Hydrologic Balance
Evaporation and Transpiration
Root Zone
Infiltration/plant uptake/
Soil moisture redistribution
Lateral Flow
Vadose (unsaturated) Zone
Percolation to shallow aquifer
Shallow (unconfined) Aquifer
Confining Layer
Deep (confined) Aquifer

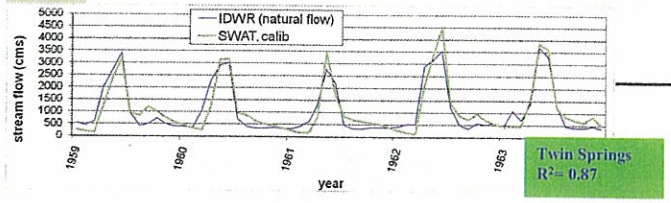

Hydrologic Balance
Root Zone
Vadose (unsaturated) Zone
Shallow (unconfined) Aquifer
Confining Layer
Deep (confined) Aquifer
Revap from shallow aquifer
Percolation to shallow aquifer
Return Flow
Recharge to deep aquifer

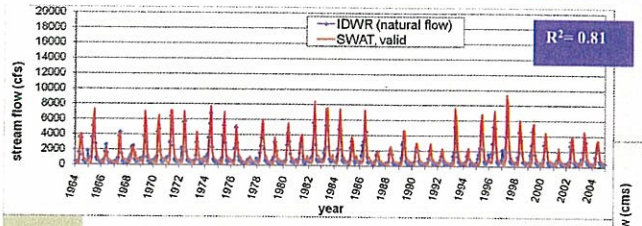

Hydrologic Balance
Root Zone
Vadose (unsaturated) Zone
Shallow (unconfined) Aquifer
Confining Layer
Deep (confined) Aquifer
Flow out of watershed
Recharge to deep aquifer

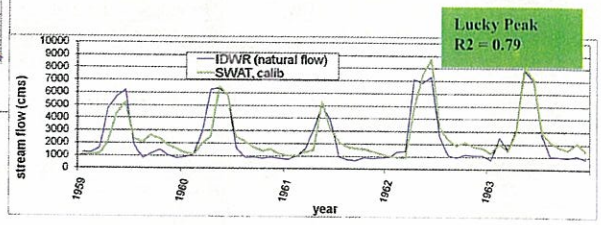

Hydrologic Balance
Evaporation and Transpiration
Precipitation
Root Zone
Infiltration/plant uptake/ Soil moisture redistribution
Surface Runoff
Vadose (unsaturated) Zone
Lateral Flow
Shallow (unconfined) Aquifer
Revap from shallow aquifer
Percolation to shallow aquifer
Return Flow
Confining Layer
Deep (confined) Aquifer
Flow out of watershed
Recharge to deep aquifer

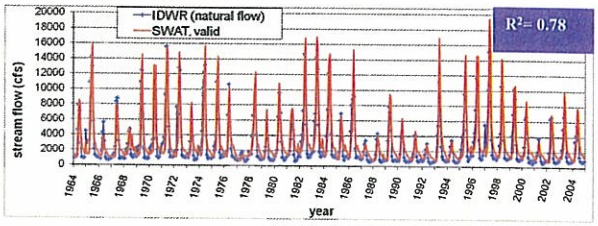

SWAT Model Setup SWAT Setup
Delineate watershed (Use DEM, boundary, stream layers)
Input Land use, Soil and Slope
Create HRU
Input downscaled Climate Model-weather Data
Write/ Edit Default Input Parameters
Run SWAT
Generate/Compare Simulated and Observed Flow

# Sequential Uncertainty Fitting (Sufi2) Calibration/Validation Result (Twin Springs and Lucky Peak)




# SWAT Calibration Parameters (Lucky Peak, Arrowrock, Twin Springs and Anderson Ranch)

| Parameter name | Parameter definition:Parma | low bound | up bound | imet | Calibration Sites: Lucky Peak | Arrowrock | Twin Springs | Anderson Ranch | scale level |
|---|---|---|---|---|---|---|---|---|---|
| Canmx | Maximum canopy storage (mm) | 0.816 | 9.802 | v | 4.344 | 3.109 | 2.508 | 8.351 | hru |
| Cn2 | Initial SCS CN II value | -34.77 | 37.44 | r | -32.5 | -21 | -32.9 | -21.68 | hru |
| Alpha_Bf | baseflow alpha factor (days) | 0 | 1 | v | | | | | hru |
| Epco | Plant uptake compensation factor | -50 | 50 | r | | | | | hru |
| Esco | Soil evaporation compensation factor | 0.95 | 1 | v | Default Parameters | | | | hru |
| Gw_Delay | Groundwater delay (days) | 0 | 192.3 | v | | | | | hru |
| Gw_Revap | Groundwater revap coefficient | 0.02 | 0.2 | v | | | | | hru |
| Revapmn | Threshold water depth in the shallow aquifer for "revap" (mm) | 0.01 | 500 | v | | | | | hru |
| Gwqmn | Threshold water depth in the shallow aquifer for flow (mm) | 0 | 673 | v | 572.2 | 422.3 | 535.5 | 75.5 | hru |
| Rchrg_Dp | Deep aquifer percolation fraction | 0 | 1 | v | 0.488 | 0.89 | 0.364 | 0.272 | hru |
| Ch_K2 | channel effective hydraulic conductivity (mm/hr) | 3.8 | 80.8 | v | 19.8 | 72.3 | 51.01 | 34.2 | subbasin |
| Sol_Awc | Available water capacity (mm H2O/mm soil) | -50 | 50 | r | 8.9 | 16.9 | 12.38 | 13.9 | hru |
| Sol_K | Saturated hydraulic conductivity (mm/hr) | 12.5 | 37.5 | r | | | | | hru |
| Surlag | surface runoff lag time (days) | 0 | 10 | v | 1.446 | | | | basin |
| Timp | Snow pack temperature lag factor | 0.001 | 1 | v | 0.0063 | | | | basin |
| Smtmp | snow melt base temperature (C) | 1.8 | 5.5 | v | 4.1 | | | | basin |
| | note: for imet, v - replacement, r - multiplying initial value by value (in percentage) | | | | | | | | |

# SWAT Calibration Parameters

(Parma)

| Parameter name | Parameter definition | low bound | up bound | imet | Parma Calibration values | scale level |
|---|---|---|---|---|---|---|
| Canmx | Maximum canopy storage (mm) | 0.816 | 9.802 | v | 1.705 | hru |
| Cn2 | Initial SCS CN II value | -34.77 | 37.44 | r | 23.6 | hru |
| Alpha_Bf | baseflow alpha factor (days) | 0 | 1 | v | 0.0601 | hru |
| Epco | Plant uptake compensation factor | -50 | 50 | r | 9.46 | hru |
| Esco | Soil evaporation compensation factor | 0.95 | 1 | v | 0.962 | hru |
| Gw_Delay | Groundwater delay (days) | 0 | 192.3 | v | 173.2 | hru |
| Gw_Revap | Groundwater revap coefficient | 0.02 | 0.2 | v | 0.191 | hru |
| Revapmn | Threshold water depth in the shallow aquifer for "revap" (mm) | 0.01 | 500 | v | 3.66 | hru |
| Gwqmn | Threshold water depth in the shallow aquifer for flow (mm) | 0 | 673 | v | 643.9 | hru |
| Rchrg_Dp | Deep aquifer percolation fraction | 0 | 1 | v | 0.252 | hru |
| Ch_K2 | channel effective hydraulic conductivity (mm/hr) | 3.8 | 80.8 | v | 13.36 | subbasin |
| Sol_Awc | Available water capacity (mm H2O/mm soil) | -50 | 50 | r | -28.88 | hru |
| Sol_K | Saturated hydraulic conductivity (mm/hr) | 12.5 | 37.5 | r | 36.73 | hru |
| Surlag | surface runoff lag time (days) | 0 | 10 | v | 1.446 | basin |
| Timp | Snow pack temperature lag factor | 0.001 | 1 | v | 0.0063 | basin |
| Smtmp | snow melt base temperature (C) | 1.8 | 5.5 | v | 4.1 | basin |
| | note: for imet, v - replacement, r - multiplying initial value by value (in percentage) | | | | | |

# SWAT Performance

| Subbasin | | $r^2$ | NSE |
|---|---|---|---|
| Parma | calibrated (1959 - 1963) | 0.81 | 0.75 |
| | validated (1964 - 2004) | 0.82 | 0.80 |
| Lucky Peak | calibrated (1959 - 1963) | 0.79 | 0.78 |
| | validated (1964 - 2004) | 0.78 | 0.73 |
| Arrow Rock | calibrated (1959 - 1963) | 0.75 | 0.75 |
| | validated (1964 - 2004) | 0.77 | 0.70 |
| Twin Spring | calibrated (1959 - 1963) | 0.87 | 0.85 |
| | validated (1964 - 2004) | 0.81 | 0.65 |
| Anderson Ranch | calibrated (1959 - 1963) | 0.87 | 0.70 |
| | validated (1964 - 2004) | 0.83 | 0.64 |

# Future Temperature and Precipitation Trends

A2

| | | P (%) | T (C°) |
|---|---|---|---|
| 2010-2019 | ccsm3_0 | 2.49 | 1.63 |
| | hadcm3 | 3.60 | 0.76 |
| | ipsl_cm4 | 15.71 | 1.11 |
| | miroc3_2_medres | 9.09 | 1.64 |
| | pcm1 | -6.02 | 0.02 |
| 2020-2029 | ccsm3_0 | 0.93 | 1.98 |
| | hadcm3 | 3.76 | 1.35 |
| | ipsl_cm4 | 9.72 | 1.53 |
| | miroc3_2_medres | -2.33 | 1.24 |
| | pcm1 | 6.36 | 0.93 |
| 2030-2039 | ccsm3_0 | -1.82 | 2.47 |
| | hadcm3 | -0.47 | 1.48 |
| | ipsl_cm4 | 17.66 | 2.11 |
| | miroc3_2_medres | 8.23 | 2.47 |
| | pcm1 | 3.33 | 0.77 |
| 2040-2049 | ccsm3_0 | 8.22 | 2.63 |
| | hadcm3 | 0.85 | 2.59 |
| | ipsl_cm4 | 34.37 | 2.43 |
| | miroc3_2_medres | -1.64 | 3.17 |
| | pcm1 | 7.15 | 1.47 |
| 2050-2059 | ccsm3_0 | 4.89 | 3.37 |
| | hadcm3 | 7.00 | 2.61 |
| | ipsl_cm4 | 36.28 | 3.61 |
| | miroc3_2_medres | 1.00 | 3.34 |
| | pcm1 | 1.69 | 1.77 |

A1B

| | | P (%) | T (C°) |
|---|---|---|---|
| 2010-2019 | ccsm3_0 | 0.18 | 1.38 |
| | hadcm3 | -1.19 | 1.76 |
| | ipsl_cm4 | 17.89 | 1.56 |
| | miroc3_2_medres | -9.11 | 1.07 |
| | pcm1 | 14.12 | 0.79 |
| 2020-2029 | ccsm3_0 | 1.45 | 2.05 |
| | hadcm3 | 3.20 | 1.96 |
| | ipsl_cm4 | 25.16 | 1.85 |
| | miroc3_2_medres | -9.06 | 1.98 |
| | pcm1 | -8.81 | 1.10 |
| 2030-2039 | ccsm3_0 | -7.66 | 2.02 |
| | hadcm3 | 4.58 | 2.10 |
| | ipsl_cm4 | 19.82 | 2.48 |
| | miroc3_2_medres | 6.40 | 2.78 |
| | pcm1 | -8.50 | 1.45 |
| 2040-2049 | ccsm3_0 | -5.62 | 3.08 |
| | hadcm3 | 14.86 | 2.80 |
| | ipsl_cm4 | 35.15 | 2.99 |
| | miroc3_2_medres | 4.06 | 3.06 |
| | pcm1 | -1.59 | 1.95 |
| 2050-2059 | ccsm3_0 | 1.06 | 3.44 |
| | hadcm3 | 3.15 | 3.22 |
| | ipsl_cm4 | 21.28 | 3.70 |
| | miroc3_2_medres | 6.05 | 3.91 |
| | pcm1 | 5.49 | 2.59 |

B1

| | | P (%) | T (C°) |
|---|---|---|---|
| 2010-2019 | ccsm3_0 | 7.02 | 1.690 |
| | hadcm3 | 3.79 | 1.005 |
| | ipsl_cm4 | 16.97 | 1.321 |
| | miroc3_2_medres | -6.58 | 1.418 |
| | pcm1 | 13.15 | 0.484 |
| 2020-2029 | ccsm3_0 | -3.45 | 1.470 |
| | hadcm3 | 9.17 | 1.567 |
| | ipsl_cm4 | 16.28 | 1.645 |
| | miroc3_2_medres | 6.10 | 1.345 |
| | pcm1 | 18.17 | 0.699 |
| 2030-2039 | ccsm3_0 | -6.72 | 1.302 |
| | hadcm3 | 6.21 | 1.587 |
| | ipsl_cm4 | 14.66 | 2.063 |
| | miroc3_2_medres | 4.37 | 2.101 |
| | pcm1 | 12.15 | 0.696 |
| 2040-2049 | ccsm3_0 | 3.62 | 2.003 |
| | hadcm3 | 16.88 | 2.067 |
| | ipsl_cm4 | 30.49 | 2.702 |
| | miroc3_2_medres | -2.24 | 2.907 |
| | pcm1 | 16.28 | 0.747 |
| 2050-2059 | ccsm3_0 | 0.46 | 2.068 |
| | hadcm3 | 2.89 | 2.865 |
| | ipsl_cm4 | 25.75 | 2.542 |
| | miroc3_2_medres | -1.17 | 3.092 |
| | pcm1 | 9.28 | 0.949 |

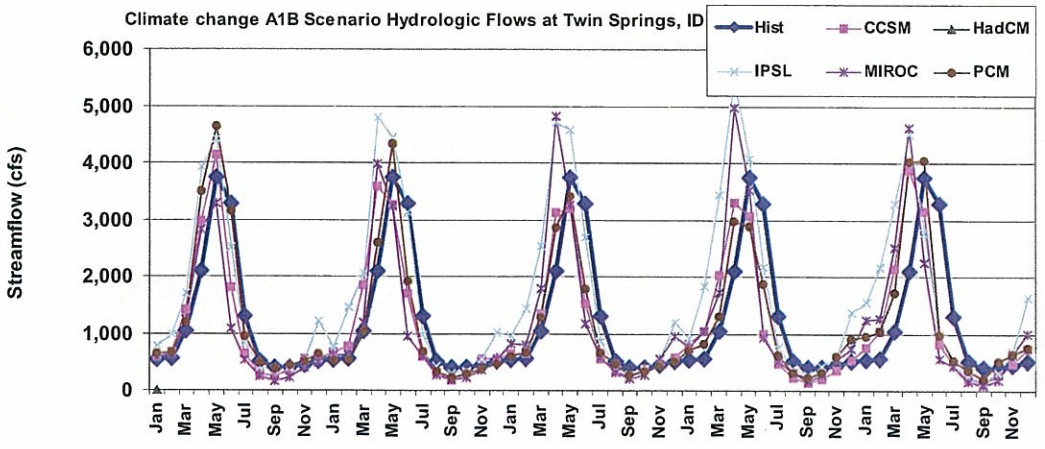
# Future Flow Trends in the Boise River Basin

| | Change (cfs) | | |
|---|---|---|---|
| Scenario | Peak flow Min | Peak flow Max | Peak flow Avg |
| A2 | -1223 | 4117 | 621 |
| A1B | -1693 | 3285 | 300 |
| B1 | -1366 | 3917 | 436 |
| | Low flow Min | Low flow Max | Low flow Avg |
| A2 | -622 | 195 | -281 |
| A1B | -662 | 77 | -303 |
| B1 | -607 | 336 | -328 |

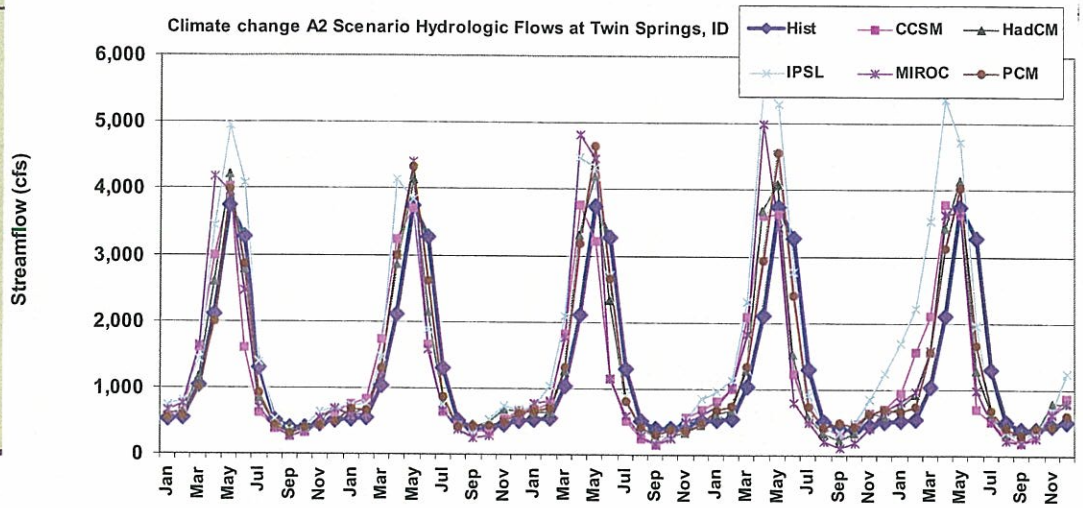
# Future Volume Trends in the Boise River Basin

| | Change in flow volume (ac-ft) | | |
|---|---|---|---|
| Decade | A2 | A1B | B1 |
| 2010-2019 | 200738 | 97195 | 184812 |
| 2020-2029 | 72193 | 78271 | 382690 |
| 2030-2039 | 191419 | 101483 | 174700 |
| 2040-2049 | 276108 | 218825 | 358348 |
| 2050-2059 | 269021 | 106963 | 226368 |
| Average | 201896 | 120547 | 265384 |
| | | Overall Avg | 195942 |

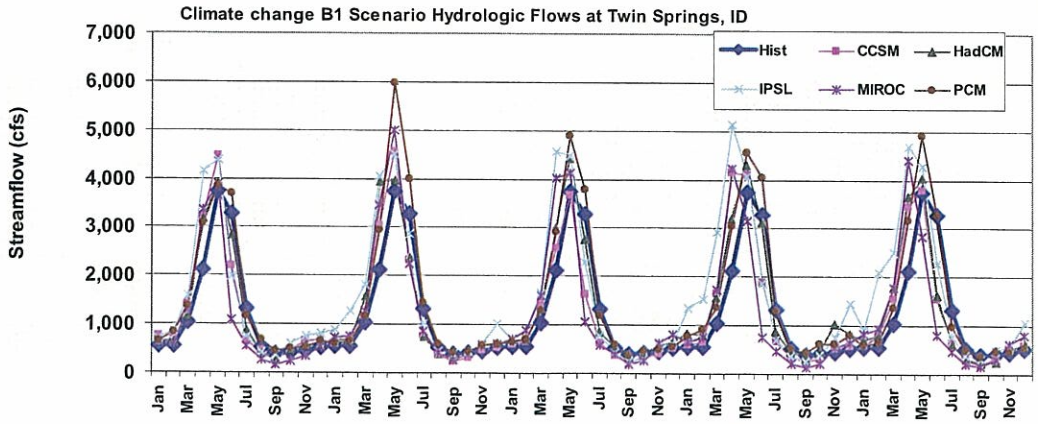
# Projected Streamflow – Twin Springs (A1B, 2010-2059)



# Projected Streamflow – Twin Springs (A2, 2010-2059)

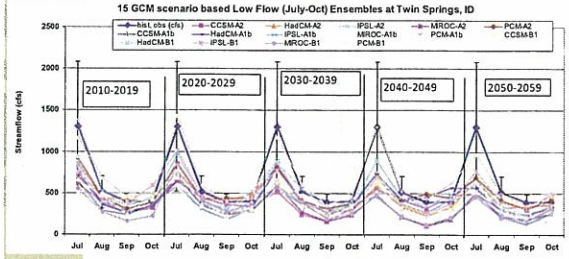



# Projected Streamflow – Twin Springs (B1, 2010-2059)

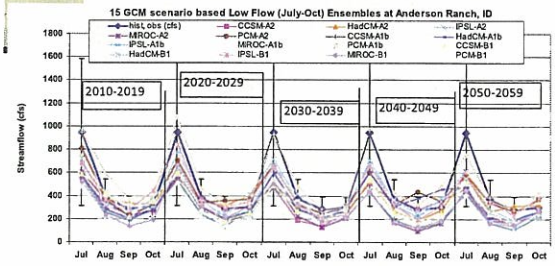


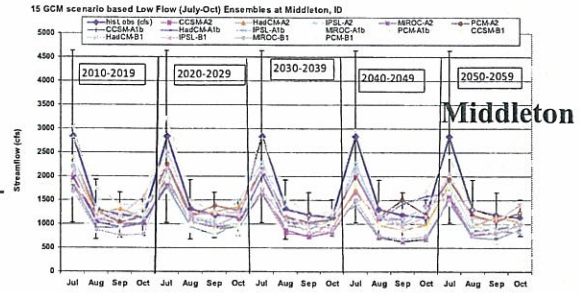
# Low Flows

## Twin Springs

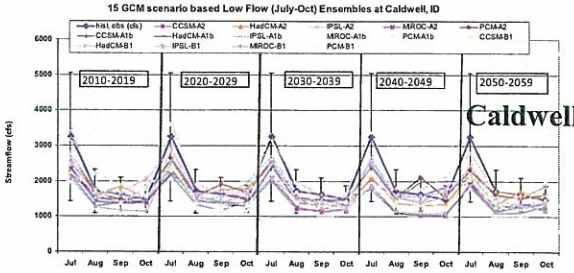



## Anderson Ranch



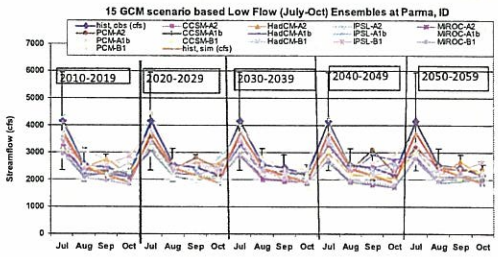




Middleton

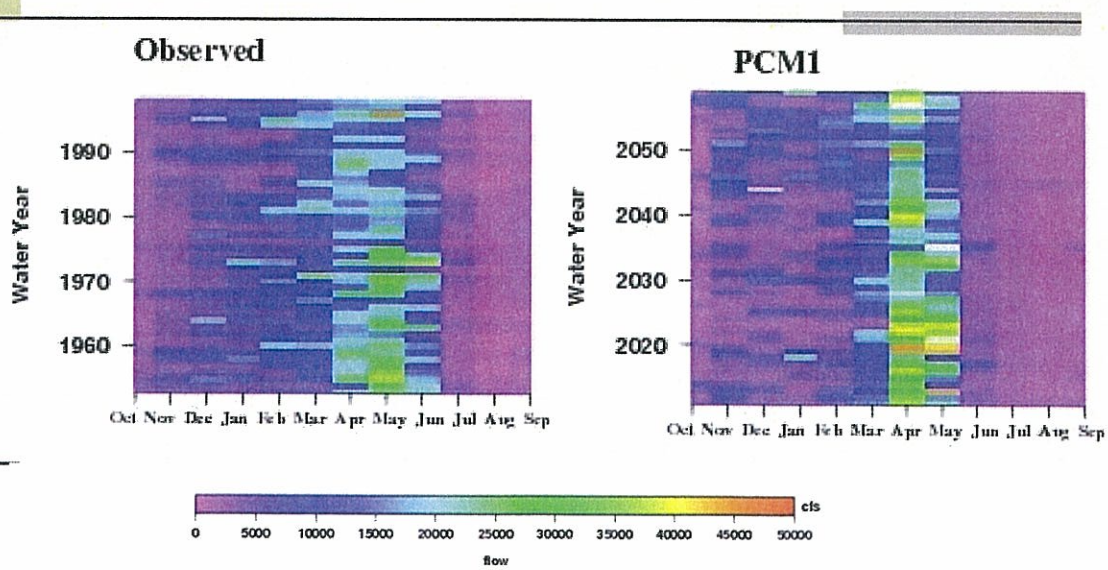



Caldwell

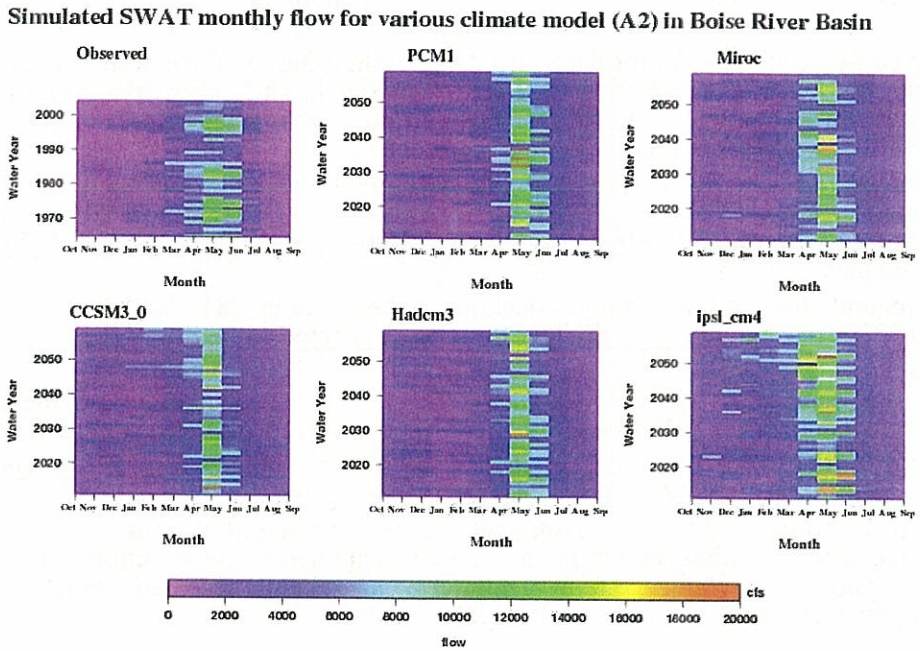
Parma



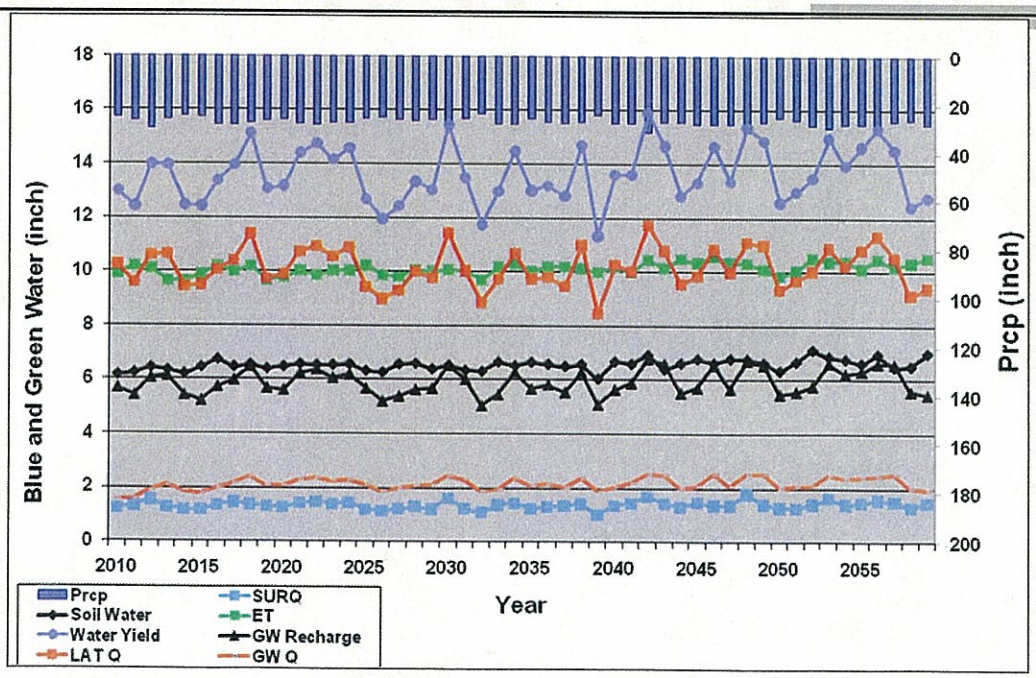

# Future Flows Time Map – Lucky Peak

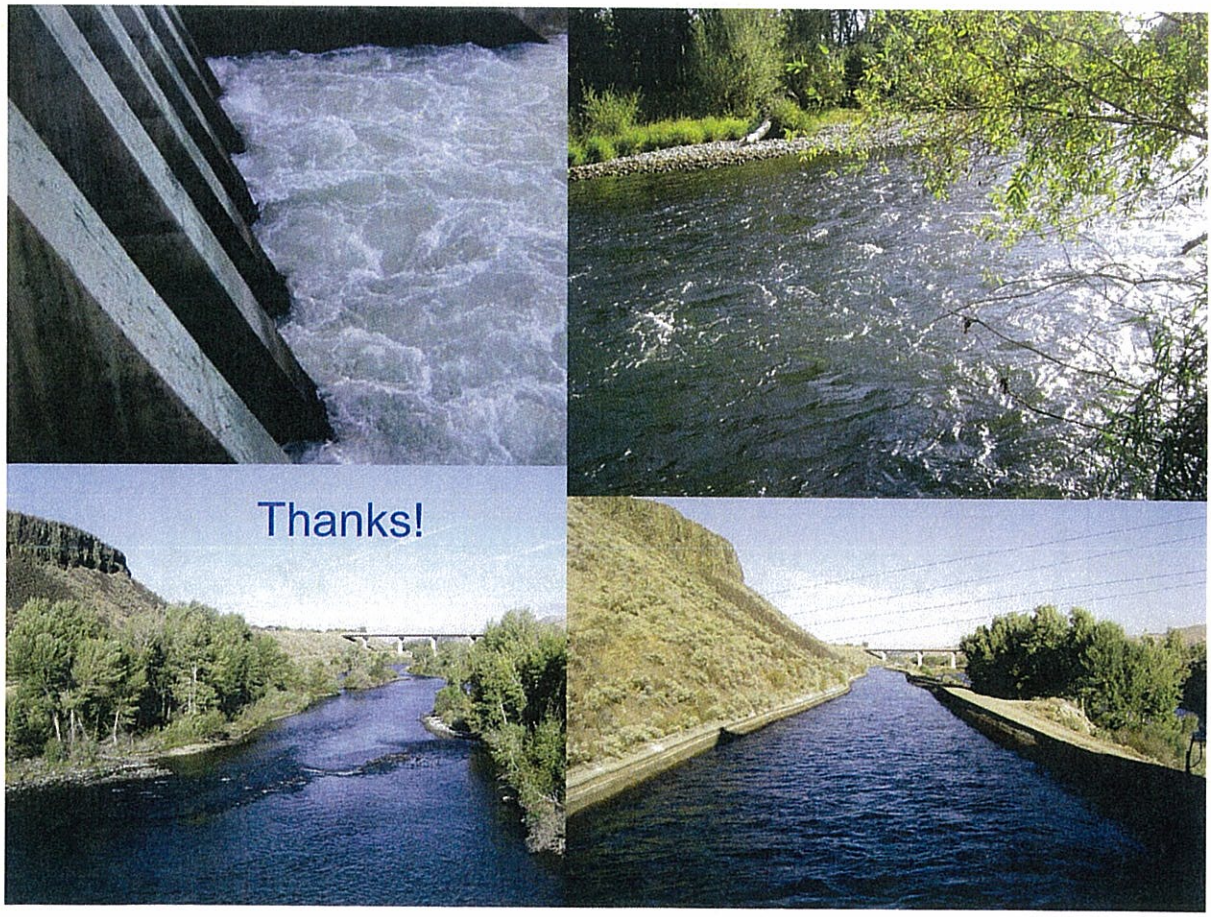


# Time Map – Lucky Peak, A2




# Annual water balance components



# Summary

- For the Treasure Valley region, changes in precipitation ranged between -3.8 % and 36%. Changes in temperature are expected to be between 0.02 and 3.9 °C.
- We calibrated the model for the Boise River basin using the flows from Parma, Lucky Peak, Arrowrock, Twin Springs and Anderson Ranch. This calibration exercise resulted in 16 parameters adjusted for various processes within the basin including snowmelt, vegetation, groundwater and surface runoff.
- On average, in the Boise River basin the peak flows (March through June) are expected to increase by 4117 cfs (A2), 3285 cfs (A1B) and 3917 cfs (B1). **Thus, the high flows in the future will probably be higher than historic high flows. The peak flows will be earlier.**
- In general, the low flow averages declined in the future by 281 cfs (A2), 303 cfs (A1B) and 328 cfs (B1). **Notably, the low flows are expected to be lower than historic low flows**.
- Translation of flows into volumes (integrating area under the hydrograph) the increase in flow volumes are 201896 ac-ft (A2), 120547 ac-ft (A1B) and 265384 ac-ft (B1).
- The overall average when combining all of these flow volumes results in **increasing flow volume by 195942 ac-ft over the next five decades**.
- There are some uncertainties in our estimates and that can be attributed to GCM-produced precipitation and temperature, model parameters and structure (for instance reach gain or loss, residence time of aquifer recharge) and measured regulated flow, computed natural flow and its year-to-year variability.