AGU

Session H41A - 18

Impacts of Climate Change on the Hydrology of the Colorado River System

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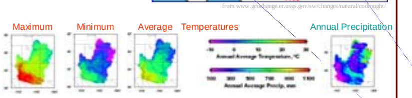
1 Colorado River

The Colorado River

The Colorado River Basin covers 630,000 km2 in seven states and part of Mexico. Precipitation ranges from over 1.1m in the mountainous headwaters to less than 0.1m in the desert. The annual natural flow at Lees Ferry, AZ, dividing the upper and lower basins, has ranged from 5.0 to 23.7 million acre-feet, with an average of 15 million acre-feet. The upper basin contributes approximately 90% of the annual runoff.

Eleven major storage projects provide approximately 61 million acre-feet of storage (four times the mean annual flow). These reservoirs are operated to provide flood control, hydropower generation, agricultural, industrial, and municipal water supply, fish and wildlife targets, and recreation.

from www.geochange.er.usgs.gov/sw/changes/natural/codrought/

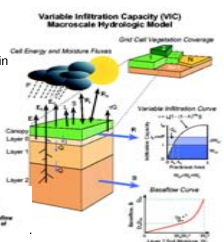


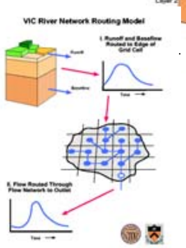
2 Hydrologic Model Implementation

The Hydrologic Model

The hydrologic model used is the VIC macroscale land surface model (see http://www.hydro.washington.edu/ for model details). The model was run in a 24 hour timestep Water Balance mode at 1/8° resolution. Forcing variables are daily precipitation, maximum and minimum temperatures (from NCDC cooperative observer stations), and wind from NCEP Reanalysis. Soil parameters are taken from the Penn State Soil Geographic Database (STATSGO) and land cover is from the University of Maryland 1-km Global Land Cover product (derived from AVHRR). Water Balance mode assumes that the soil surface temperature is equal to the air temperature for the current time step. The exception to this is that the snow algorithm still solves the surface energy balance at three hour timesteps to determine the fluxes needed to drive accumulation and ablation processes.

VIC Model Features:
- Multiple vegetation classes in each cell
- Sub-grid elevation band definition (for snow)
- 3 soil layers used
- Subgrid infiltration/runoff variability



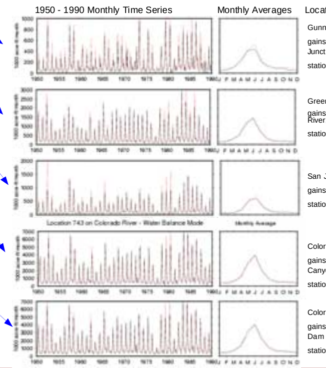


VIC Routing Features:
- all runoff exits cell in single flow direction
- Within Cell routing uses a Unit Hydrograph approach
- Channel routing uses linearized Saint-Venant equation

3 Validation of VIC Generated Streamflows

Validation of Runoff

The VIC model was calibrated by adjusting the soil depths, baseflow parameters, and infiltration capacity curve parameter to reproduce observed streamflow. Runoff from each 1/8 degree grid cell is routed to points with estimated naturalized flows where the hydrographs are compared. Gridded VIC forcing data is available for 1950 - 2000 and Colorado River naturalized flows exist for the period from 1906 - 1990.



4 General Circulation Models and Climate Scenarios

The DOE/NCAR PCM, Hadley Centre HadCM2, and Max Plank Institute's ECHAM4 climate models are used to represent possible future climate scenarios. These General Circulation Models(GCM) mathematically represent atmospheric, land surface, and atmosphere-ocean processes. The HadCM2 use a 1% equivalent CO_2 increase per year + sulfate aerosols (IS92a), the ECHAM4 uses the IS92a CO_2 + IS92a sulfate aerosols, and the PCM is forced by the IPCC 2001 Business As Usual(BAU) emission scenario of 1% annual increase in atmospheric CO_2 concentration + aerosol forcings. Plots below show regridded average annual temperature increase and relative precipitation % for transient runs versus their respective controls. Model information can be found at http://www.usgcrp.gov/usgcrp/nacc/background/scenarios/emissions.html

DOE/NCAR PCM

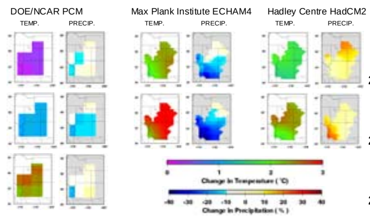
The model runs at the T42 resolution of 2.8 lat. x 2.8 long. It has 18 vertical layers in the atmospheric and 32 in the ocean. The model represents multiple greenhouse gasses and has a CO_2 doubling equilibrium of 2.0 'C.

Max Plank Inst. ECHAM4

Spatial resolution is 2.8 lat. x 2.8 long. There are 19 vertical layers in the atmosphere and 9 in the ocean. ECHAM4 does not represent multiple greenhouse gasses, is flux-adjusted, and has a CO_2 doubling equilibrium of 2.6 'C

Hadley Centre HadCM2

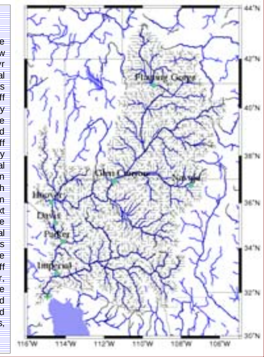
HadCM2 has 19 vertical layers in the atmosphere, 20 in the ocean, and a spatial resolution of 2.5' lat. x 3.75' long. The equilibrium climate sensitivity to a doubled atmospheric CO_2 concentration is approximately 2.6°C.



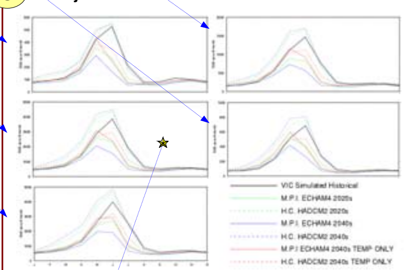
GCM output was retrieved from the IPCC DDC (http://www.usgcrp.gov/usgcrp/nacc/background/scenarios/emissions.html)

Abstract

The Colorado River system provides water supply to a large area of the interior west. It drains a mostly arid region, with naturalized flow (effects of reservoirs and diversions removed) averaging only 40 mm/yr over the 630,000 km2 drainage area at the mouth of the river. Total reservoir storage (mostly behind Hoover and Glen Canyon Dams) is equivalent to over four times the mean annual flow of the river. Runoff is heavily dominated by high elevation source areas in the Rocky Mountain headwaters, and the seasonal runoff pattern throughout the Colorado basin is strongly dominated by winter snow accumulation and spring melt. Because of the arid nature of the basin and the low runoff per unit area, performance of the reservoir system is potentially susceptible to changes in streamflow that would result from global warming, although those manifestations are somewhat different than elsewhere in the west where reservoir storage is relatively much smaller. We evaluate, using the macroscale Variable Infiltration Capacity (VIC) model, possible changes in streamflow over the next century using three 100-year ensemble climate simulations of the NCAR/DOE Parallel Climate Model corresponding to business-as-usual (BAU) future greenhouse gas emissions. Single ensemble simulations of the U.K. Hadley Center, and the Max Planck Institute, are considered as well. For most of the climate scenarios, the peak runoff shifts about one month earlier relative to the recent past. However, unlike reservoir systems elsewhere in the west, the effect of these timing shifts is largely mitigated by the size of the reservoir system, and changes in reservoir system reliability (for agricultural water supply and hydropower production) are dominated by streamflow volume shifts, which vary considerably across the climate scenarios.



5 Projected Streamflows 2020's & 2040's



Projected Climate Change Streamflows

HadCM2 and ECHAM4 projected streamflows for decades 2020 and 2040 are shown here. Solid lines are Max Plank, dashed Hadley Centre, green 2020s, and blue 2040s. In addition, red lines were generated by applying only GCM temperature signals(no precipitation scalars).

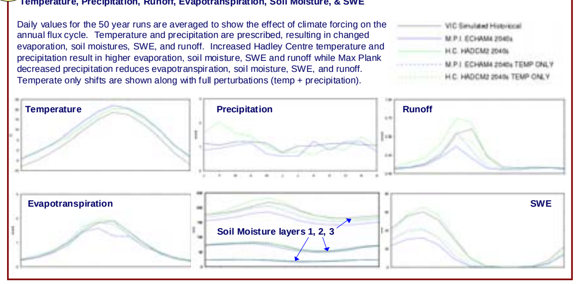
Method of Incorporating Climate Change Signal (Hadley Centre & Max Plank Institute)

Output from GCM control runs and transient simulations were regridded to the Colorado Basin at 1 degree resolution using the Symap algorithm. Temperature and precipitation changes are then calculated for each calendar month by comparing transient run 10 year average values, centered on 2025 and 2045, to the 240 year control run average values. These perturbations are then summed for precipitation and averaged for temperature. This results in each calendar month having a temperature shift value and precipitation scalar that the historic meteorological record (VIC input) for the entire basin is 'perturbed' by. The DOE/NCAR PCM is treated differently and is statistically bias corrected to map the control run back to historical climatology. PCM runs are not shown here.

6 Upper Basin 2040's flux parameters

Temperature, Precipitation, Runoff, Evapotranspiration, Soil Moisture, & SWE

Daily values for the 50 year runs are averaged to show the effect of climate forcing on the annual flux cycle. Temperature and precipitation are prescribed, resulting in changed evaporation, soil moistures, SWE, and runoff. Increased Hadley Centre temperature and precipitation result in higher evaporation, soil moisture, SWE and runoff while Max Plank decreased precipitation reduces evapotranspiration, soil moisture, SWE, and runoff. Temperate only shifts are shown along with full perturbations (temp + precipitation).



7 Overview of Reservoir Model

Colorado River Reservoir Model(CRRM)

A monthly timestep reservoir model is being created in Stella to represent the major storage projects of the physical system and their current operating policies. Storage of the 11 major reservoirs have been aggregated into Flaming Gorge, Navajo, Lake Powell, and Lake Mead. Hydropower simulations take place at these dams (except Navajo) as well as at Davis and Parker.

CRRM's objectives are:

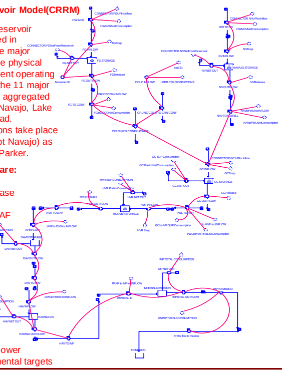
Minimum annual release from Lake Powell of 8.23 MAF & 1.5 MAF to Mexico

EOWY equalization of Lake Powell and Lake Mead

Variable demands

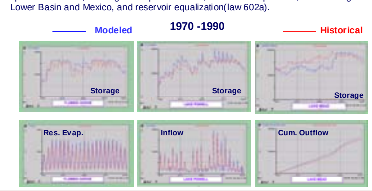
Shortage & surplus releases

Flood control, hydropower simulation, environmental targets



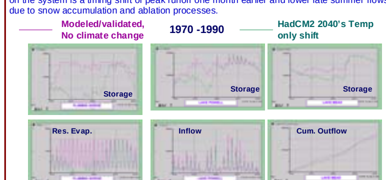
8 Validation of Reservoir Model

CRRM is still in the early stages of development. Nonetheless, before calibration or alteration of operating policies to take into account the spatial and temporal aggregation, the model performs reasonably well. Modeled (with naturalized historical inflows as input) versus historical storage is shown below for the largest three reservoirs in the system. A sample of other metrics used (evaporation, timeseries of inflows, & cumulative outflows) are also shown for modeled versus historical. **CRRM** will also be calibrated and validated on its ability to recreate hydropower generation, flood control space evacuation, shortage & surplus releases, reservoir evaporation, release targets to Lower Basin and Mexico, and reservoir equalization(law 602a).



9 Preliminary Results and Future Research

Although **CRRM** is still in the early stages of development, VIC generated flows for the Hadley Centre HadCM2 2040's temperature only shift run were inputted into the reservoir model. Results will change with further development of **CRRM**, however it is apparent that the smaller reservoirs are not as resilient to climate change as Lake Powell and Lake Mead. Flaming Gorge reservoir unrealistically dries out due to **CRRM** not modeling Fontenelle upstream or having shortage operating policies. Besides the streamflow volume reduction of the Max Plank model and temperature change only runs, the major effect of climate change on the system is a timing shift of peak runoff one month earlier and lower late summer flows due to snow accumulation and ablation processes.



CRRM will soon be operational in accessing the implications of climate change on hydropower, flood control, municipal & agricultural demands, environmental flow targets, reservoir evaporation, altered operating policies to reflect earlier snow melt, recreation reservoir levels, and the ability of the basin to meet objective storage and minimum releases.

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