Effects of land-cover changes on the hydrological response of interior Columbia River basin forested catchments

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Purpose of Hydrologic Analysis

• To Evaluate the reliability of extending sub-basin macro model (VIC), to the catchment basin micro level DHSM model.
• To compare the two models using vegetation land cover data from 1900-1990, and calibrate them to previously recorded data.

Description of Models

• The VIC or (Variable Infiltration Capacity) is a macro scale model that solves the full water and energy balances.
• Soils are partitioned into a variable number of soil layers.
• Infiltration into the topsoil and base-flow variable curves are used to calculate runoff production in a basin.
• The grid cell method at a resolution of 1/8 to 2 degrees latitude by longitude is then used to route precipitation runoff in the basin or catchment.

Model - Distributed hydrology-soil-vegetation model (DHSVM)

• The DHSVM is a physically based spatially distributed hydrological model, with a resolution of 30m to 200m, making this a microscale model.
• The model describes the effects of soil, vegetation and topography on the movement of water at and near the land surface.
• Primary precipitation, temperature, solar and long-wave radiation, relative humidity and wind.
• This model solves the water and energy balance at each pixel for multiple soil layers, and then uses a downslope/down-gradient algorithm and vegetation canopy submodels to represent the attenuation of wind, solar radiation, interception to route linear catchment outlet.

Model Implementation

• Using the VIC model to study the Columbia River basin and create a historical (1900) land-cover vegetation model was implemented at the 1/8 resolution.
• This resolution is then compatible with the Country wide Land Data System.
• The DHSVM is used to complete a separate analysis using the models several variables.

Study Catchments

• Four catchments in the Columbia River basin were the focus of the study
• Mores Creek, Entiat River, Swan River, Mica Creek, where used throughout the study
• Topographical and hydrometerological data was used for implementation of the DHSVM. Giving us,(next slide)
Four Catchment Basins

Surface Characteristic Inputs to Models
- All elevation data was derived from USGS DEM’s or (digital elevation models) and aggregated for each catchment. This could be represented with roughly 100,000 pixels.
- This results in a pixel size of 120m for Mores catchment, 90m for Entiat, 60m for Swan, and 30m for the Mica catchment.

Surface Vegetation
- Current vegetation data was extracted from classified satellite imagery. This included 30 land-cover classification.
- This imagery was produced by the Landsat Thematic Mapper at approximately a 30m resolution.
- The U.S. Forest Service provided record of proprietary landowners, vegetation height, and leaf area index (LAI).

Soils
- The primary source of soils data was the US Department of Agriculture-National Resource Conservation Services (NRCS).
- Forest road locations from the Forest service where then used along with topographic data to calculate culvert locations and densities.

Climatological and Hydrological data
- Climatological and stream discharge data were taken from the National Climatic Data Center (NCDC) and the USGS.
- Stream flow, precipitation, temperature, and a temporal framework where incorporated with winds, long-wave radiation, humidity, short-wave radiation.
- This establishes the framework for which both models can estimate land cover change effects.

Parameter Estimation (Model Calibration)
- Parameters were estimated from the gathered information, and were adjusted via trial and error to obtain observed and predicted stream flow.
- Precipitation climatologies for the four catchments were produced using the precipitation regression on independent slopes method (PRISM).
- This allows precipitation estimations to be evenly distributed throughout the catchment.
- By comparing observed and predicted values it is possible to calibrate the complex number of factor used in the models making them more accurate.
Vegetation Scenarios

- After our models have been calibrated it is possible to study vegetation changes over time, and the effect of land cover on catchments stream flow.
- Two vegetation scenarios were used, one representing 1990, and the second the historical conditions in 1900.
- No historical fine resolution images exist, so they were inferred by current and historical images at 1km resolution.
- This is based on two fundamental assumptions.
  - 1st the current fine resolution image represents the current vegetation coverage correctly, with regards to vegetation types and distribution.
  - 2nd the difference between the two course resolution vegetation images describes the change in the vegetation’s age and LAI within each 1km course resolution grid cell.
- Lastly all hydrologic and physical aspects of the land surface were used in estimating vegetation types and ages.

Predicted Hydrologic effects of Historical land cover changes

- The model prediction of annual water balance for each catchment area is directly related to historical land cover changes.
- There are two cases, 1. conifers at the middle growth stage, or 2. Conifers at early growth stage.
- When LIA decreases there is a direct increase in runoff.
- When LIA is highest, especially when soil moisture is not limiting, then evapotranspiration generally is higher.
- The resulting changes in stream flow and evapotranspiration associated with land-cover changes from historical conditions were compared using both models. The conclusion is that the VIC is less sensitive to LAI than is the DHSVM, and is mainly due to elevation.

Comparison to VIC model results

- The resulting changes in stream flow and evapotranspiration associated with land-cover changes from historical conditions were compared with the results from the DHSVM.
- The course resolution of the VIC cause inconsistencies between the two models LAI and meteorological factors and mean elevation in the catchments.
- When the two methods were implemented to one catchment the inconsistencies also showed that soils and vegetation parameters along with rooting depths, decreased when using the VIC model.
- The resulting snow water equivalent, stream flow and evapotranspiration for the two models are however reasonable similar.
- With the exception that simulated snow water equivalent is somewhat higher in the VIC than the DHSVM.
Conclusion

- Predicted model effects of historical land-cover changes in the basin using the DHSVM, indicate that lower LIA has led to increased snow accumulation, increased stream flow, and reduced evapotranspiration.
- These factors are all controlled by seasonal changes in turbulent and radioactive fluxes and soil moisture over the year.
- The uniform vegetation study of the four catchments predicts the same general trend in the hydrological responses to leaf area, and supports the results from the historical land-cover change study.
- Comparing the two methods shows that the trend in hydrological processes is similar for both models.
- Yet the DHSVM is more sensitive to land-cover change than the VIC model, which is attributed to longer periods of soil moisture in the VIC.
- The more explicit representation of saturation excess in DHSVM creates differences in net radiation.
- The VIC use of architectural resistance in the evapotranspiration calculations lead to the higher DHSVM sensitivity of runoff to LAI changes.

Discussion

Roads

- The authors present a lot of information about how the DHSVM model is able to account for changes that may occur due to the presence of roads. Why then do they exclude roads from the simulation?

- To make the DHSVM model more equivalent with the VIC model? Which is more important: Data accurate to

Discussion

Spatial problems

- The authors found that low LAI increased runoff and that it increased snow sublimation on the ground. They also found that high LAI increased snow sublimation in the canopy. By changing vegetation types, precipitation is not affected but where that precipitation is held, how it runs off and how it evaporates will change. What can happen to snowmelt runoff when LAI has been increased? What can happen when LAI has decreased?

Temporal problems

- In the Swan River and Mica Creek catchments runoff actually increased when the LAI increased. The authors gave various explanations for this noting in particular that snowmelt runoff was higher toward the end of winter than normal and that ET was higher in early summer but lower at the end of summer because more water had run off and more had evaporated than historical data had showed. Basically, the soil was very dry by the end of summer because of early runoff and early increased ET. The total flow was relatively unchanged but the time of the flow changed. How does this affect the catchment’s hydrograph?

- How could this affect water management decisions?