Assessment of Restoration Activities at Indian Creek Watershed

Agreement No. 4600004703
CALFED Watershed Grant Program

Final report

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Introduction

University of California Davis Hydrologic Research Laboratory (HRL) and the Feather River Coordinated Resource Management (CRM) group performed an assessment of Restoration Activities at Indian Creek Watershed in Upper Feather River Basin in California. This project was carried out under a contract (4600004703) from the California Department of Water Resources (DWR) for the CALFED watershed program.

Meadowland restorations were performed at the upstream regions of Indian Creek watershed (Last Chance Creek, Red Clover Creek, Ward Creek, Hosselkus Creek, and Clarks Creek). Map of the Indian Creek watershed is shown in Figure 1. The goal of the project was the model-based evaluation of the impact of these restoration activities on the downstream sections of the watershed in terms of river flow and water temperature during the historical critical wet and dry periods by means of reconstructed hydroclimate input data. The Watershed Environmental Hydrology (WEHY) model (Kavvas et al. 2004), together with local monitoring, was utilized to assess the cumulative effects of localized restoration activities in Indian Creek watershed in the Upper Feather River Basin.

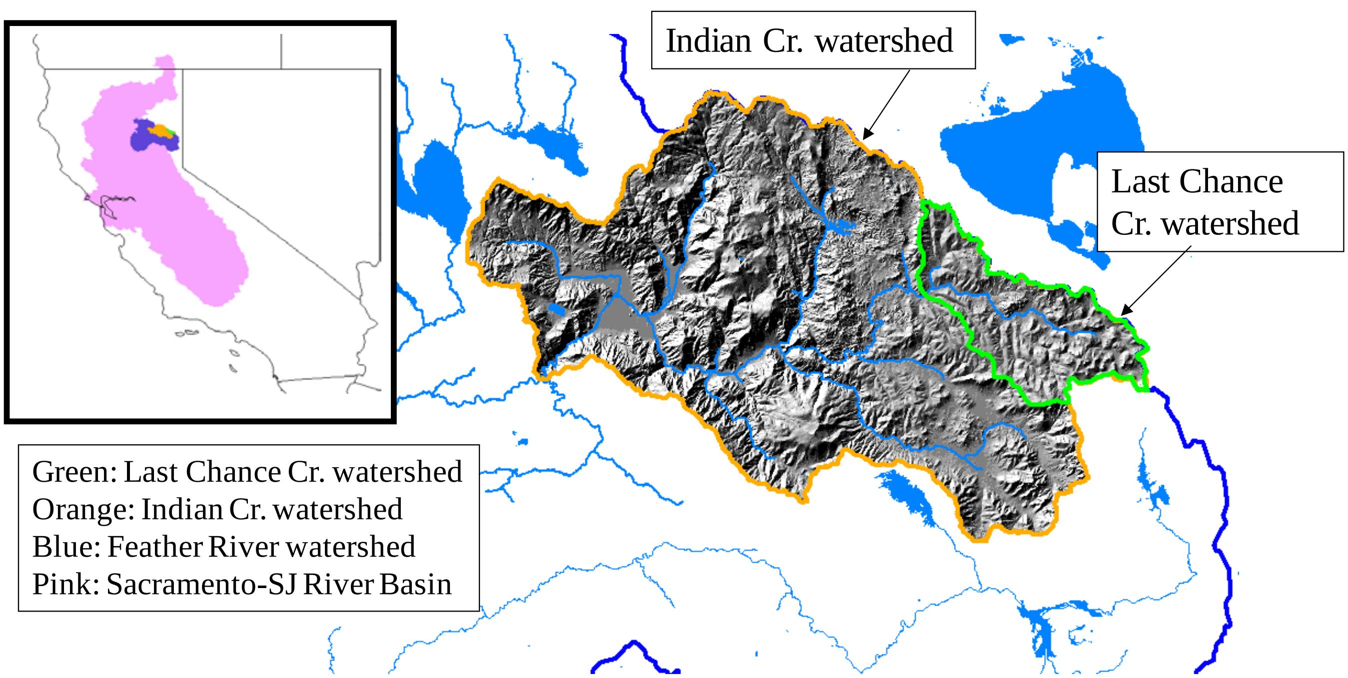

Figure 1 - Map of Indian Creek watershed

Field Monitoring

The field monitoring has been performed by the Feather River CRM (Plumas Corporation), subcontractor, Research Agreement #sub 0700076 between Feather River CRM and Regents of Univ. of Calif., Davis. During the project period, streamflow and stream temperature were continuously monitored at the following eight locations in Indian Creek watershed: Indian Creek at DWR weir, at Flournoy, and at Taylorsville, Last Chance Creek at Doyle crossing and at Million Dollar Bridge, Red Clover Creek at Notson Bridge, Lights Creek at Deadfall Bridge, and Wolf Creek at Greenville. Also, Feather River CRM installed seven additional monitoring wells for measuring groundwater levels as well as groundwater temperatures in Indian Valley in the lower part of Indian Creek watershed, as shown in Figure 2. Radiation, which is an important factor for the streamflow temperature, was measured by a hand-held radiation meter for various vegetation types at several locations in the watershed with monthly frequency. This information was used for energy balance of the land and water surfaces in the modeling effort.

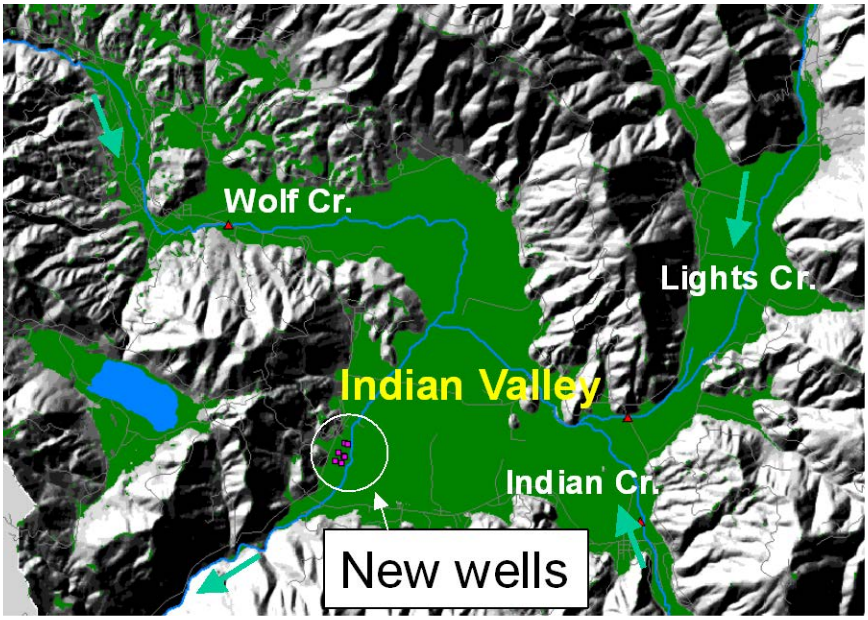

Figure 2 - Locations of the observation wells in the Indian Valley (lower part of Indian Creek watershed) over the shade map.

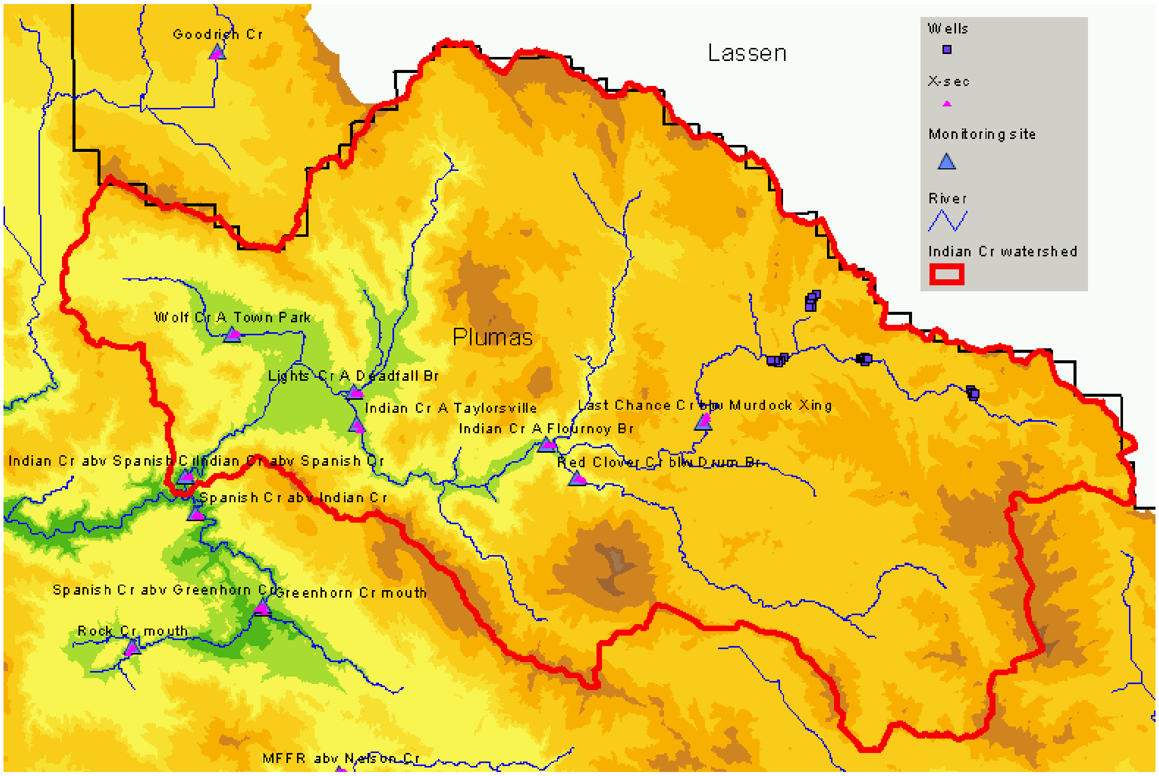

Figure 3 Locations of the field monitoring sites (flow stations, cross sections, wells) over the digital elevation map, DEM (NED).

GIS and Model Parameter Estimation

Hydrologic Research Laboratory (HRL) at UC Davis developed a GIS database over the Indian Creek watershed. The GIS database consists of the county-scale soil database, SSURGO, from California NRCS, Digital Elevation Model (DEM) from National Elevation Dataset (NED) at 1 arc second resolution in Geographic projection, National Land Cover Data (NLCD), river channel network and large watershed boundaries from National Hydrography Dataset (NDH), and road network, areal photos, county border, and other digital maps from California Spatial Information Library (CalSIL). The acquired spatial data were compiled in the ArcGIS and projected to the standard map projection (UTM zone 10). The existing monitoring site locations were plotted over the DEM, using their GPS coordinates, provided by Feather River CRM, as shown in Figure 3. Also, the compiled land cover/ land use information is shown in Figure 4. Several DEMs, such as SRTM (Shuttle Radar Topography Mission), NED 1/3 arc second and the NED 3 arc second datasets, were examined for the Indian Creek watershed project. It was found that the NED 1/3 arc second dataset was not appropriate for this project because it required more computational resources than what HRL had during the time of the project.

Also, the SRTM dataset could not be utilized due to some missing data in the watershed. Consequently, the DEM of NED 1 arc second was selected as the basic topographical information for this project, and its coordinate system became the standard for the rest of the watershed base maps.

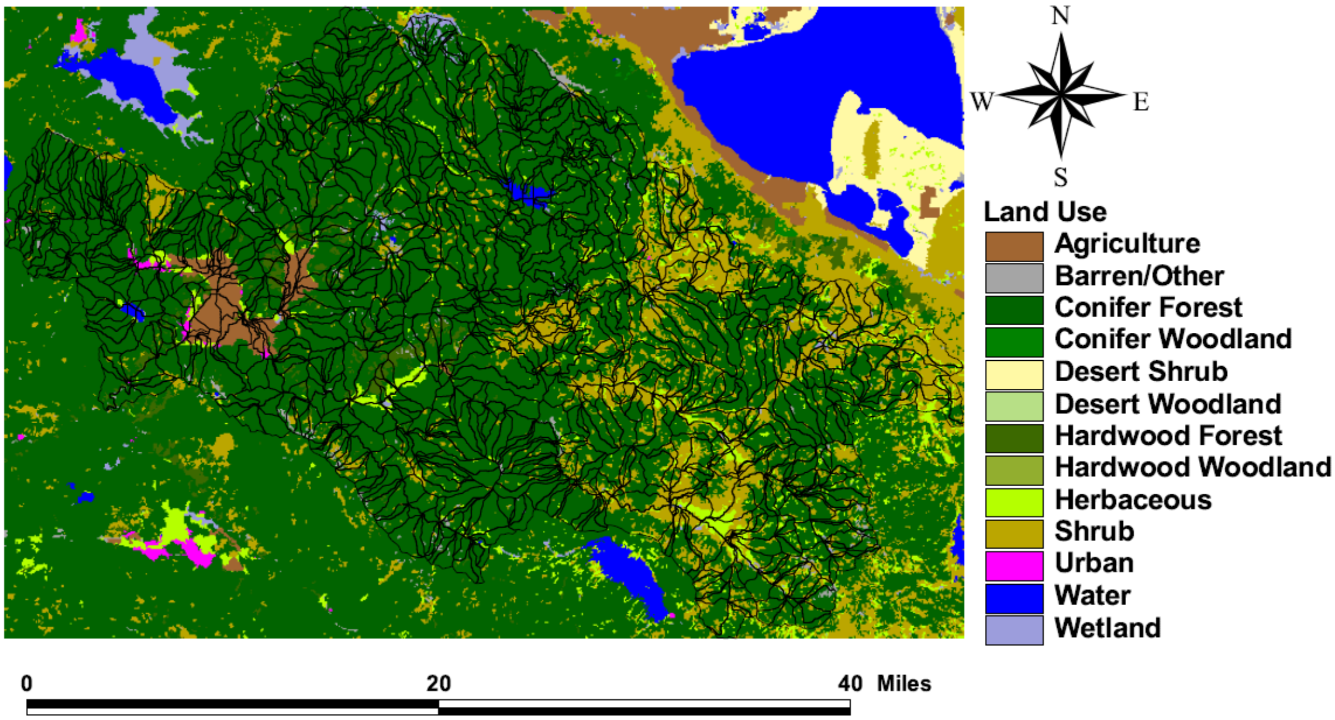

Figure 4 Land cover information from National Land Cover Data (NLCD)

The parameter maps were developed based on the GIS for the WEHY model implementation. The aspect map, slope map, river channel network, sub-watershed delineation, and model computational units (MCUs) were derived from the 1 arc second (NED) DEM as mentioned above. The derived MCU map for this project is shown in Figure 5. The SSURGO datasets were processed and analyzed for their soil physical parameters. The soil parameter maps for WEHY model, such as porosity of soil (Figure 6), hydraulic conductivity of soil (Figure 7), and root zone soil depth (Figure 8), have been developed based on SSURGO datasets. The other land surface parameters, such as surface roughness, were estimated from National Land Cover Data (NLCD). The detailed methodology for the physical parameter estimation is available in Chen et al. 2004a, and 2004b.

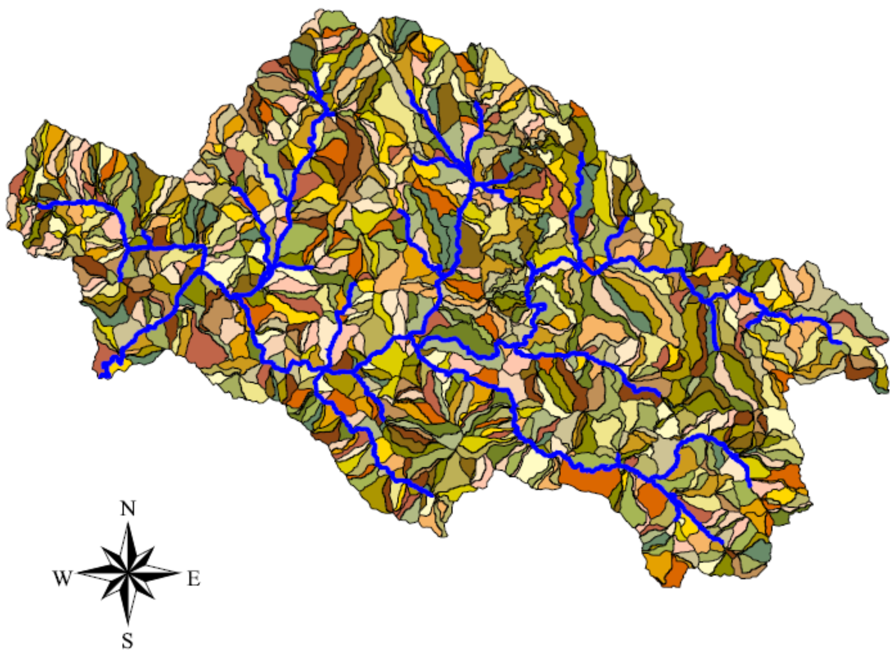

Figure 5 The derived MCUs based on subwatershed delineation and the channel network, using the selected DEM (1 arc second NED) in the Indian Creek watershed

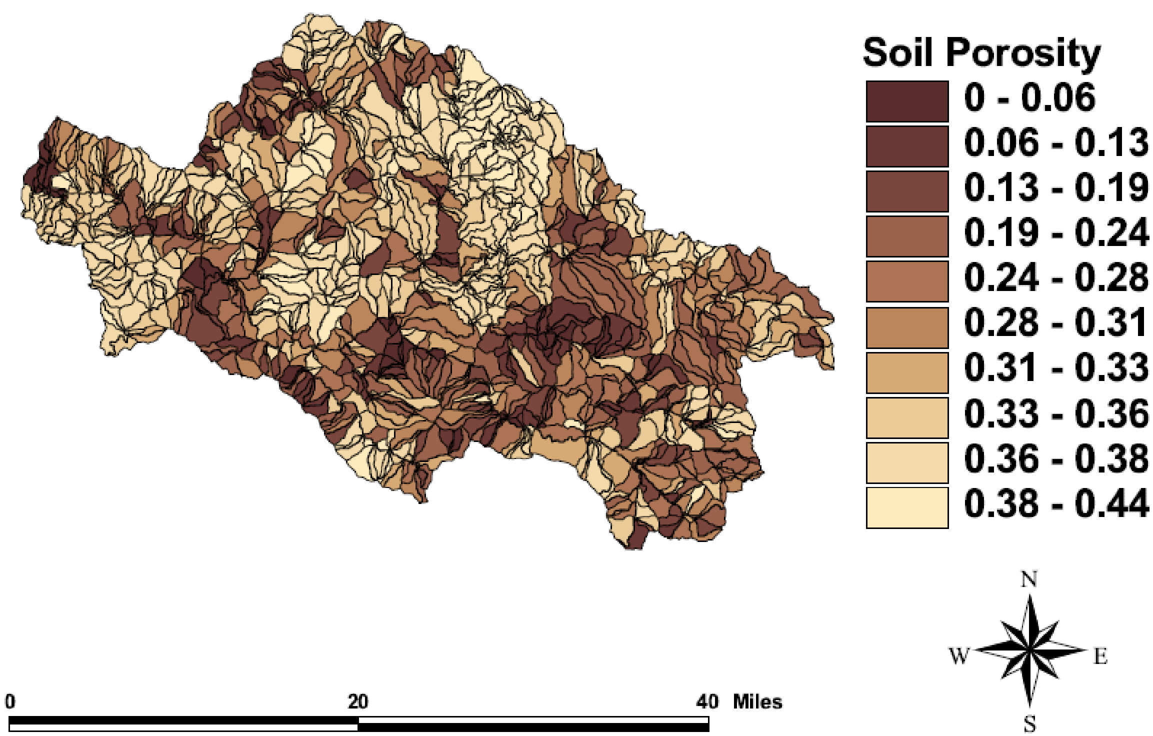

Figure 6 Derived soil porosity map of the Indian Creek watershed

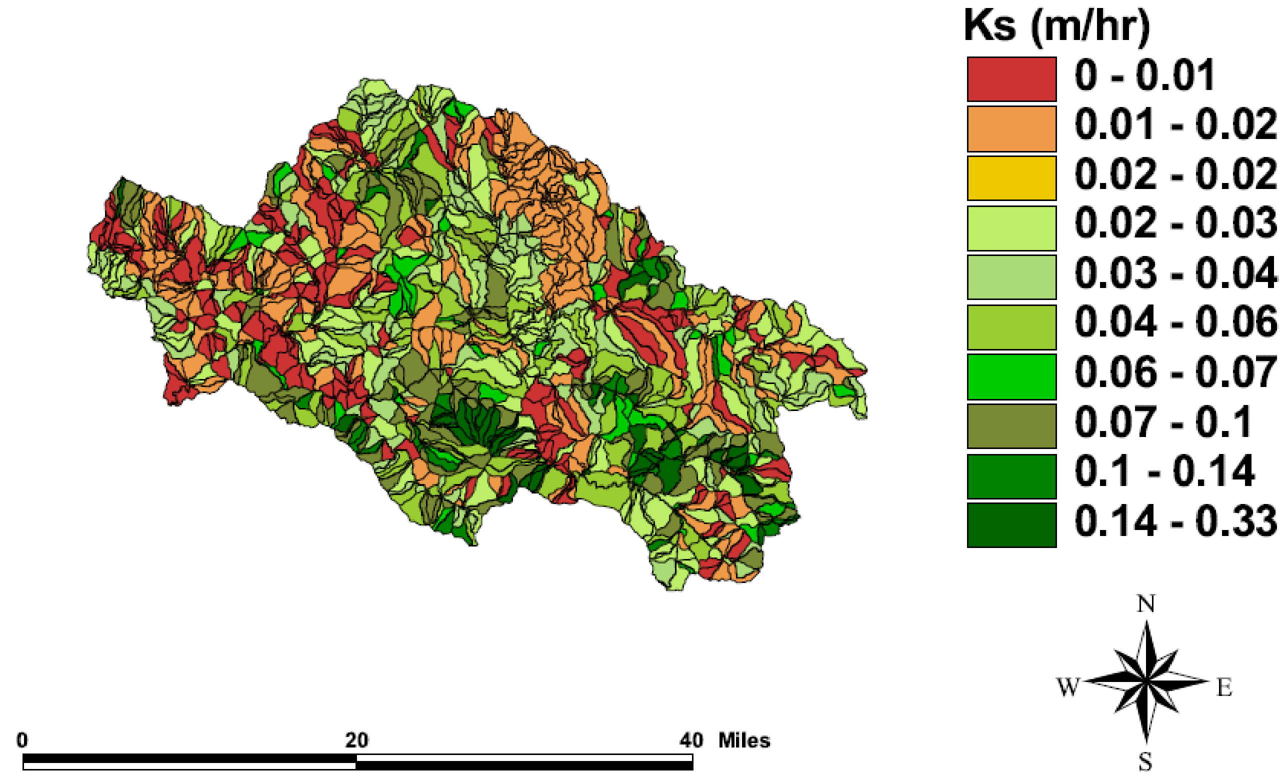

Figure 7 Derived mean saturated hydraulic conductivity map of the Indian Creek watershed

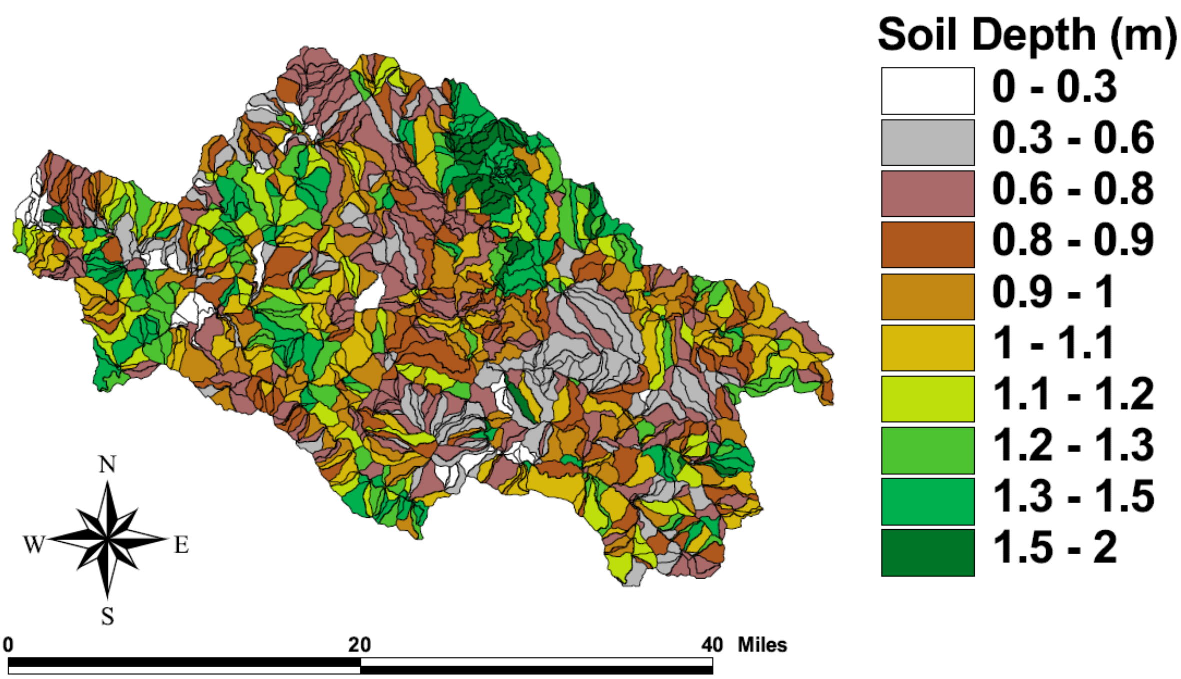

Figure 8 Derived soil depth map of the Indian Creek watershed

Model Implementation

Reconstruction of historical atmospheric conditions

It is important to perform the assessment of the restoration effect (i.e. comparing before and after the land management change) under an identical climate condition. Unfortunately, since the weather condition never repeats itself, it is impossible to compare the pre- and post restoration conditions solely by the field measurements. Furthermore, it is necessary to use a physically-based watershed model because the direct linkage between the land cover and the model physical parameters are explicitly expressed in the model. However, it is difficult to prepare the spatially-distributed atmospheric data at hourly time increments, which the physically-based model usually requires. In order to overcome this shortcoming, the historical atmospheric data were reconstructed by means of the numerical regional hydroclimate model (RegHCM) using the NCAR/NCEP reanalysis data. The upper atmospheric model component of the RegHCM is MM5 model (Mesoscale Model 5th generation, NCAR/NCEP). The model nesting domains of the MM5 are shown in Figure 9.

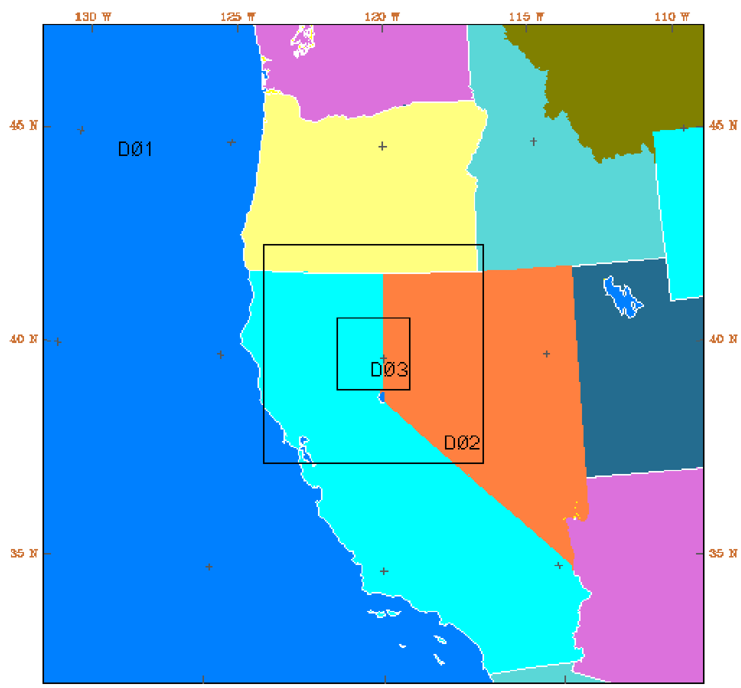

Figure 9 - MM5 Nesting Domains for Indian Creek Watershed Model

It is desirable that the restoration assessment period includes the critical dry and wet years. The critical wet and dry periods were identified by the analysis of the flow record at Pulga station, North Fork, Feather River. As shown in Figure 10, the historical period in 1983-1993 includes the critical wet and dry years in this basin.

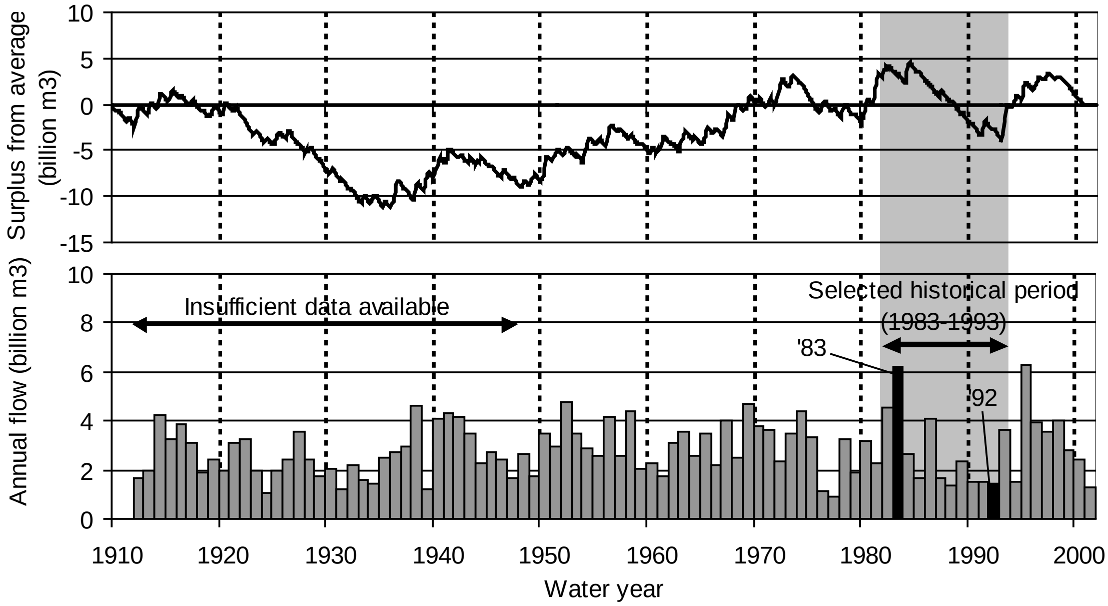

Figure 10 - Critical period analysis at Pulga station, North Fork, Feather River

The atmospheric conditions were reconstructed using RegHCM during the selected assessment period (1983-1993) based on the NCEP/NCAR reanalysis data. The reconstructed atmospheric data were validated using the ground observation record in terms of air-temperature and precipitation, as shown in Figures 11 and 12. The comparisons were made at the locations surrounding the Indian Creek watershed since there is no weather station in the watershed. It can be seen from these figures that the historical atmospheric conditions during the selected assessment period are successfully reconstructed. Also, it may be mentioned that the corresponding other important atmospheric variables, humidity, radiation, wind field etc., were also reconstructed in this process.

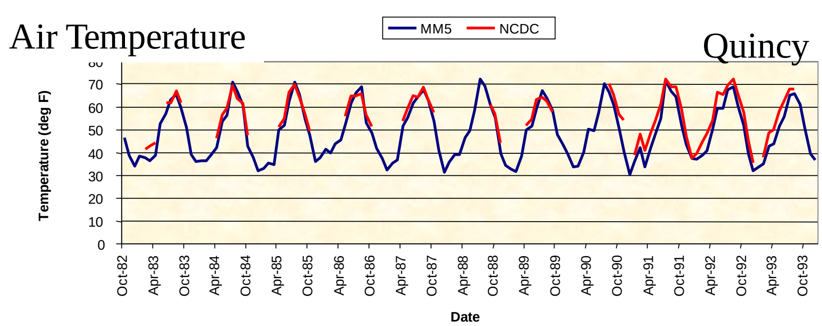

Figure 11 – Validation of the reconstructed air temperature data

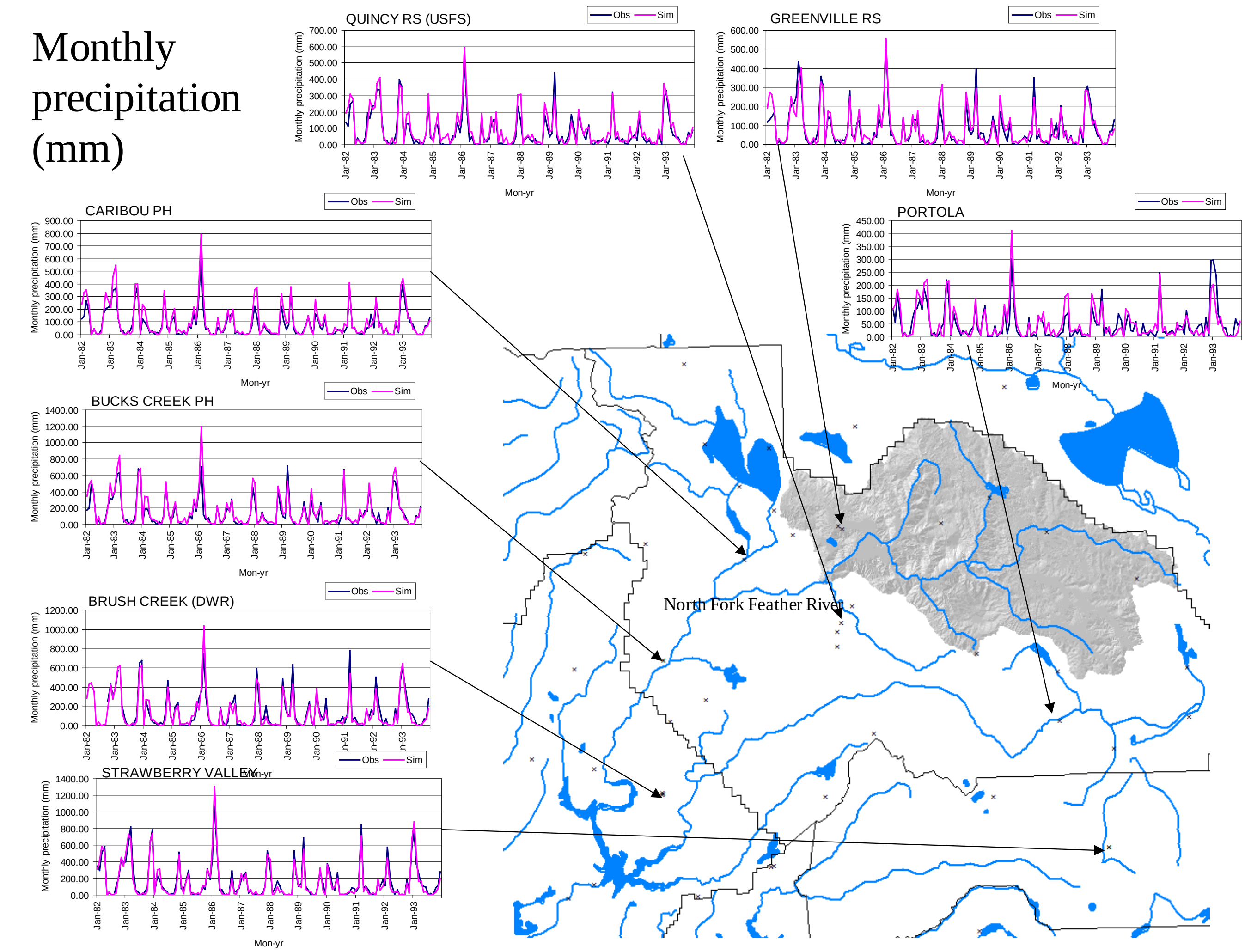

Figure 12- Validation of the reconstructed precipitation field.

Snow modeling

It is well recognized that snow plays an important role in the hydrologic regime in Upper Sierra Nevada. In this project, the snow condition in the watershed was modeled based on the energy balance framework (Ohara and Kavvas, 2006). In order to compute the snowmelt water in the Indian Creek watershed, information on various atmospheric variables including precipitation, temperature, humidity, radiation, and wind field need to be supplied to the snow model from the above described RegHCM. The snow model accounts for the canopy effect on the snow accumulation and melt processes explicitly. The vegetation parameters were estimated from information in the literature (Hedstrom and Pomeroy, 1998. and Link and Marks, 1999) and National Land Cover Data (NLCD). The snow simulation was accomplished using the reconstructed atmospheric conditions during 2000 through 2005 in order to calibrate and validate the snow model. The snow simulation results, in terms of snow water equivalent (SWE), were compared against the snow survey data at Grizzly Ridge (GRZ) station from CDEC in the Indian Creek watershed during the year 2004, as shown in Figure 13.

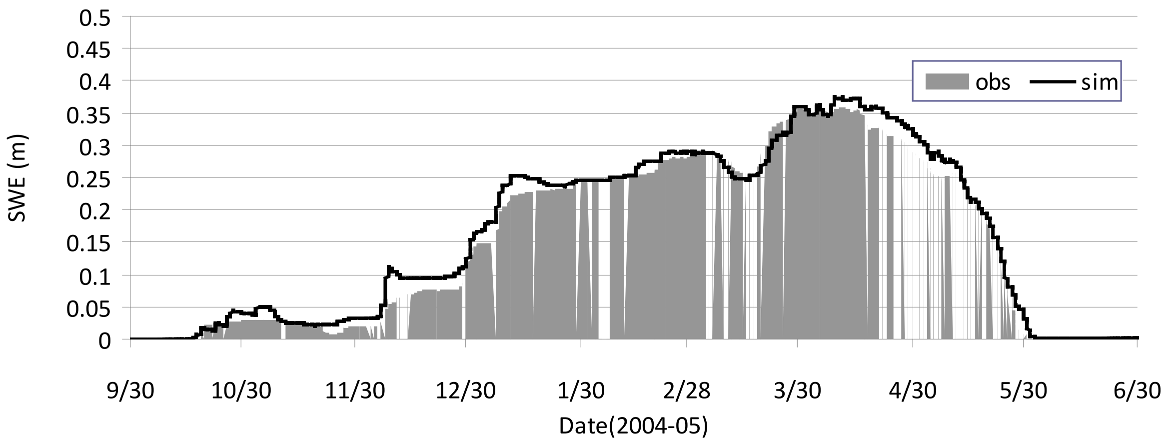

Figure 13 Validation of snow model by SWE comparison at Grizzly Ridge station (CDEC) during the year 2004-05. Note that the observed SWE, developed from the snow water content data, includes missing data.

The model-simulated snow distribution in the Indian Creek watershed on February 1, 2004, and the corresponding snow extent, observed by the satellite, Moderate Resolution Imaging Spectroradiometer (MODIS), is shown in Figure 14. Through the spatial comparison between the modeled snow distribution and the corresponding satellite-driven snow cover extent of MODIS, in addition to the time series comparison of SWE at the Grizzly Ridge station (CDEC), as shown in Figure 13 above, the model successfully reconstructed the snow conditions over the Indian Creek watershed.

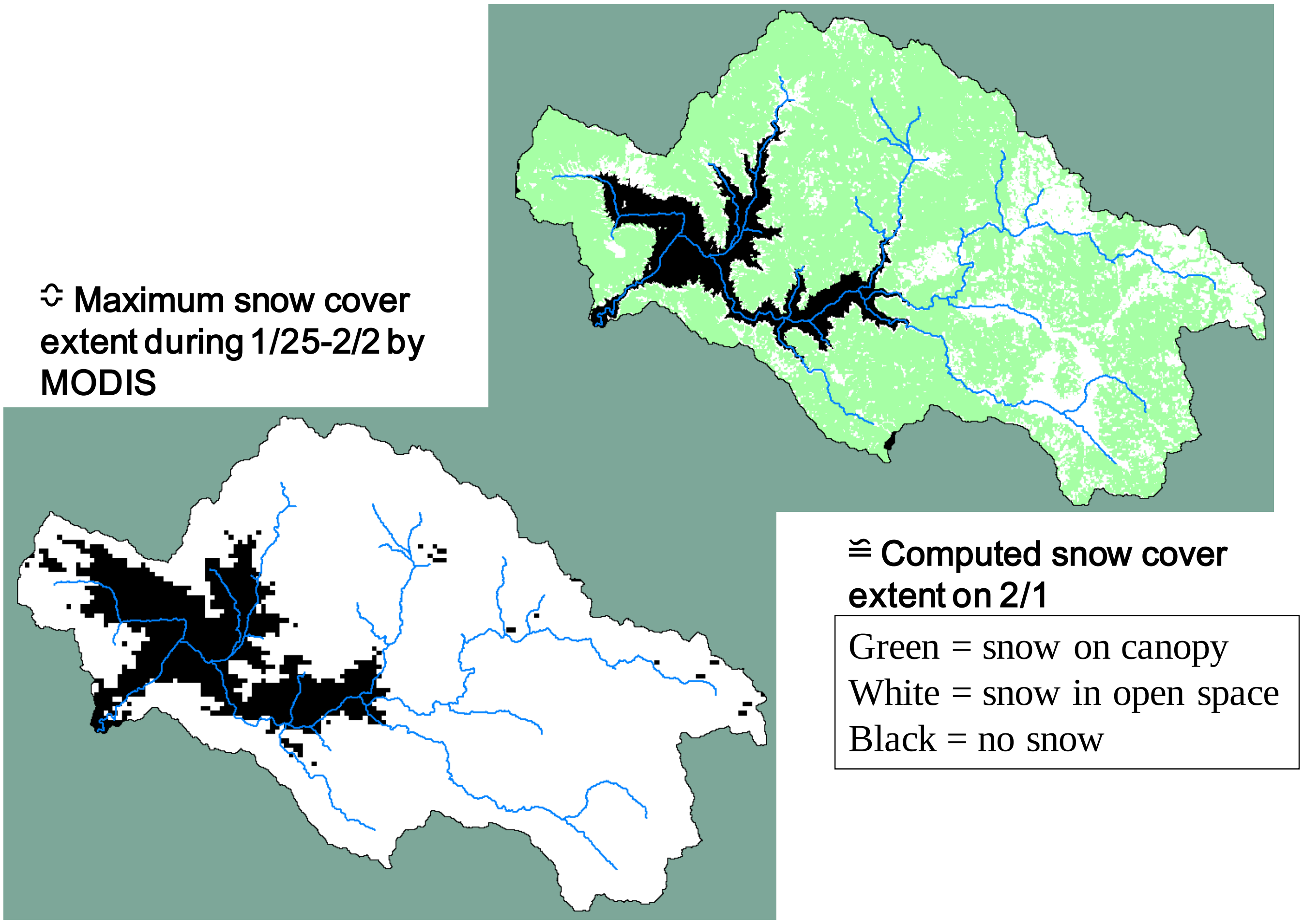

Figure 14 Computed snow distribution and observed maximum snow cover extent by MODIS in the Indian Creek watershed during February 1, 2004. White denotes the snow cover on the open space, and light green color denotes the snow storage on the canopy.

The module on the plant canopy effect on the snow accumulation and melt processes was also installed into the snow model component. In this process, the vegetation-related parameters that were derived from the literature (Hedstrom and Pomeroy, 1998. and Link and Marks, 1999) and National Land Cover Data (NLCD) were incorporated into the model. The area, affected by the canopy, is shown as light green color in Figure 14. The snow simulation was accomplished using the reconstructed atmospheric conditions during 2000 through 2005 for calibration and validation of the snow model due to the observation data availability. As the snow model was able to successfully reconstruct the snow conditions over the Indian Creek watershed, its snow simulation results were used in the hillslope runoff and channel flow routing models.

Implementation of the hydrology model

The WEHY model was applied to the Indian Creek watershed, including the unconfined aquifer beneath the meadowland of the watershed. The channel network was modeled by accounting for the interaction between the river flow and groundwater. The surface water temperature model was coupled to the channel network model.

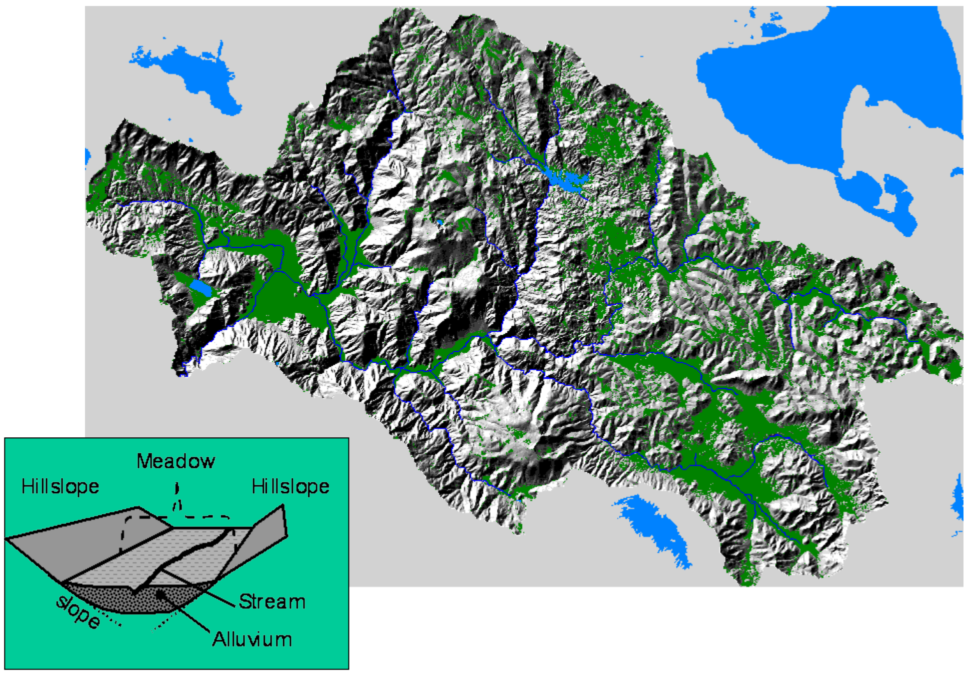

Figure 15 – Delineation of the meadowland and meadow aquifer

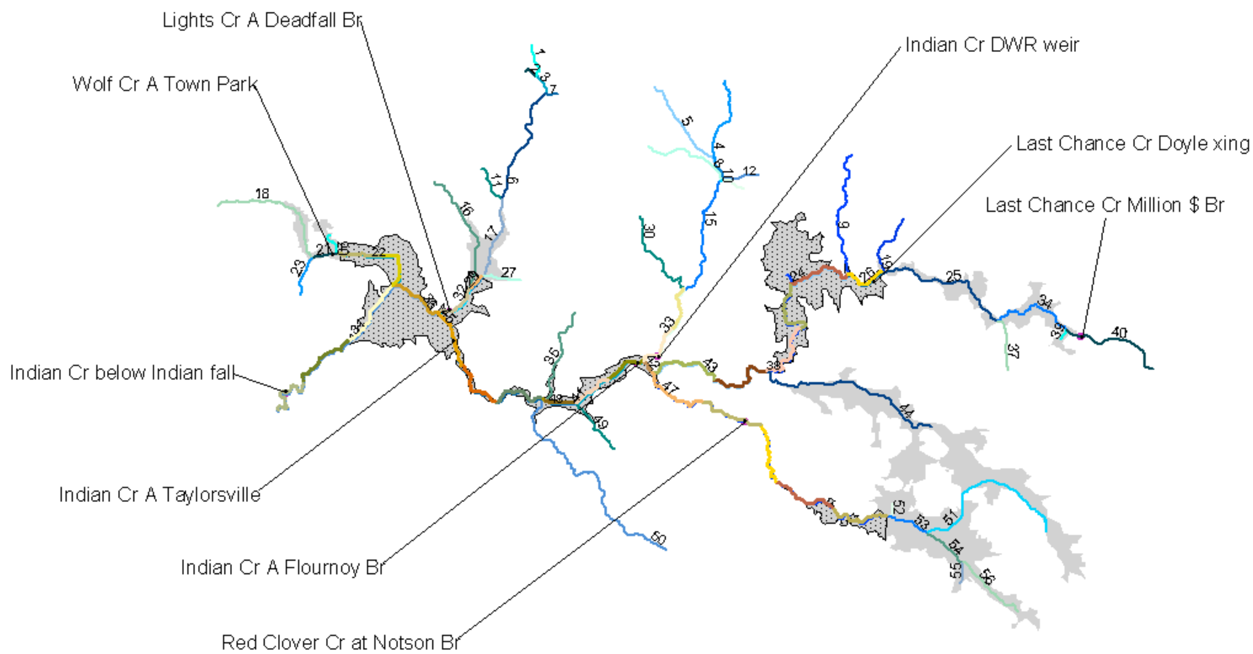

Figure 16 - The channel network and estimated meadow land extent (shaded area) of the Indian Creek in North Fork of Feather River

The modeled channel network and associated meadowland/groundwater domains are shown in Figures 15 and 16. In order to run the stream temperature model, the channel flow must be quantified beforehand. A coupled stream and groundwater flow model was applied to the Indian Creek watershed. The results of the calibrated flow simulation during the water year 2004 at several locations along the main stream are shown in Figures 17 through 24, and the corresponding validation results during the water year 2005 are shown in Figures 25 through 32.

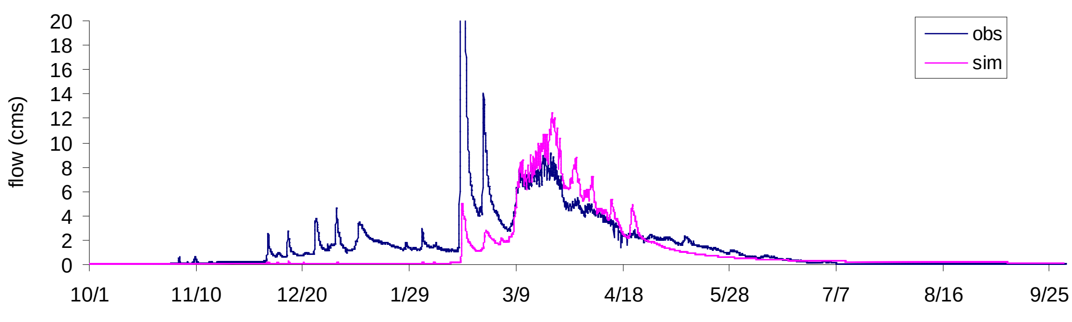

Figure 17 - Calibration results of the hydrology model of Lights Creek during the water year 2004

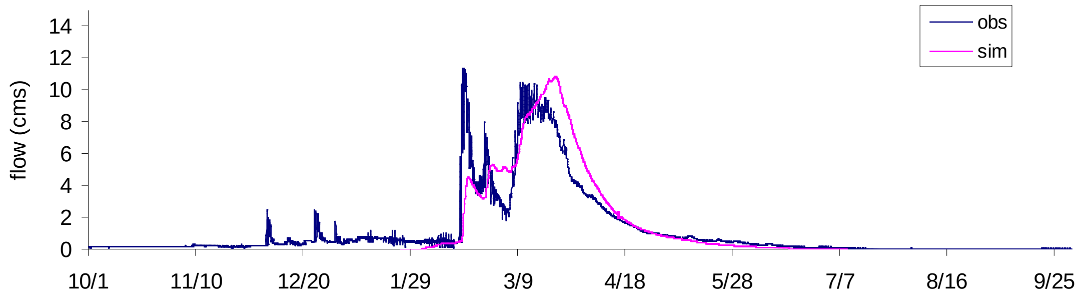

Figure 18 - Calibration results of the hydrology model of Red Clover Creek at Notson Bridge during the water year 2004

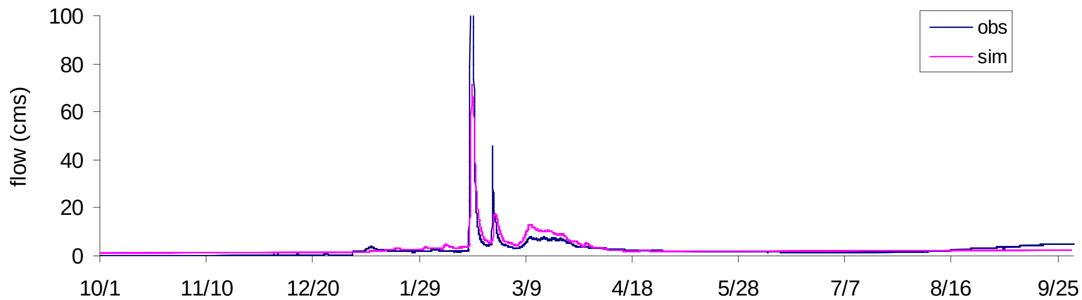

Figure 19 - Calibration results of the hydrology model of Wolf Creek during the water year 2004

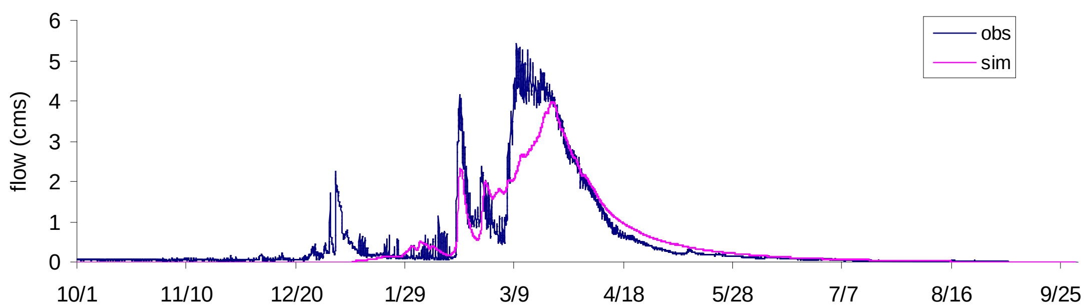

Figure 20 - Calibration results of the hydrology model of Last Chance Creek at Doyle Crossing during the water year 2004

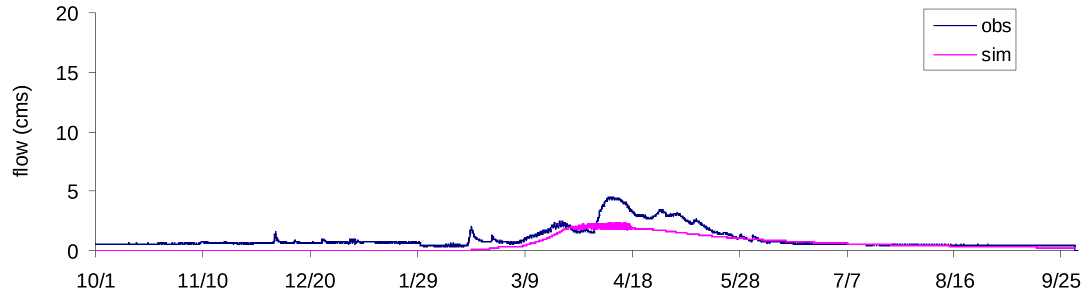

Figure 21 - Calibration results of the hydrology model of Indian Creek at DWR weir during the water year 2004

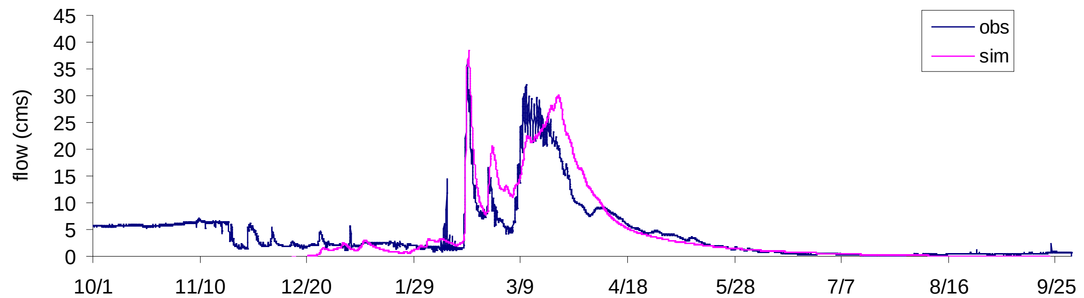

Figure 22 - Calibration results of the hydrology model of Indian Creek at Flournoy Bridge during the water year 2004

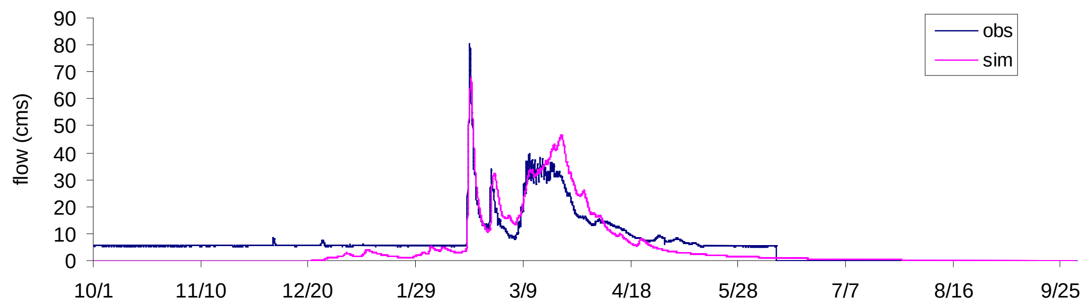

Figure 23 - Calibration results of the hydrology model of Indian Creek at Taylorsville during the water year 2004

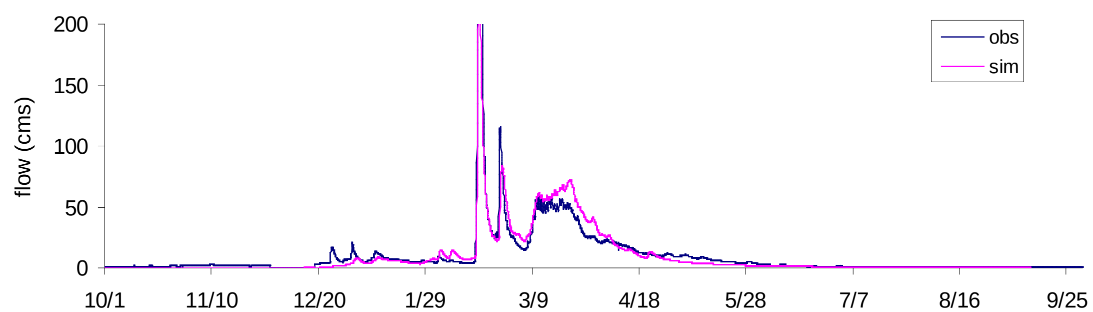

Figure 24 - Calibration results of the hydrology model of Indian Creek at Indian Fall during the water year 2004

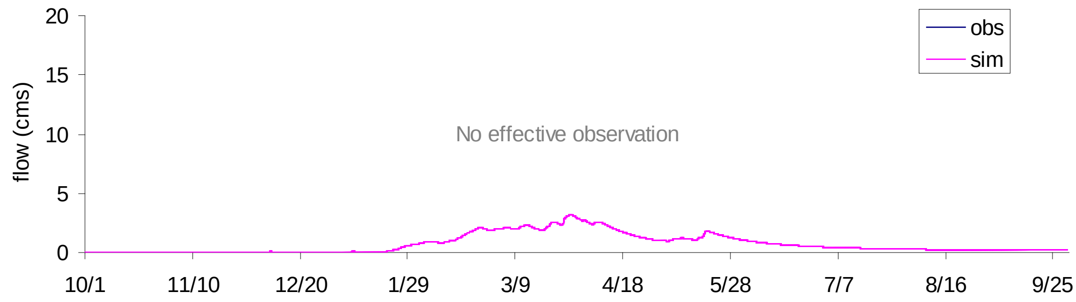

Figure 25 - Validation results of the hydrology model of Lights Creek during the water year 2005

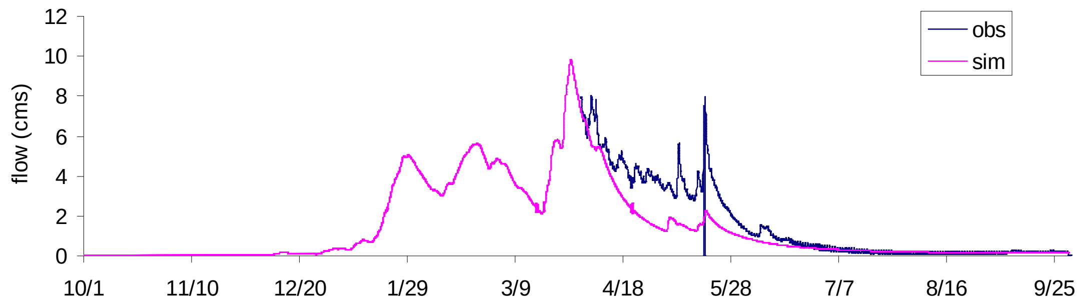

Figure 26 - Validation results of the hydrology model of Red Clover Creek at Notson Bridge during the water year 2005

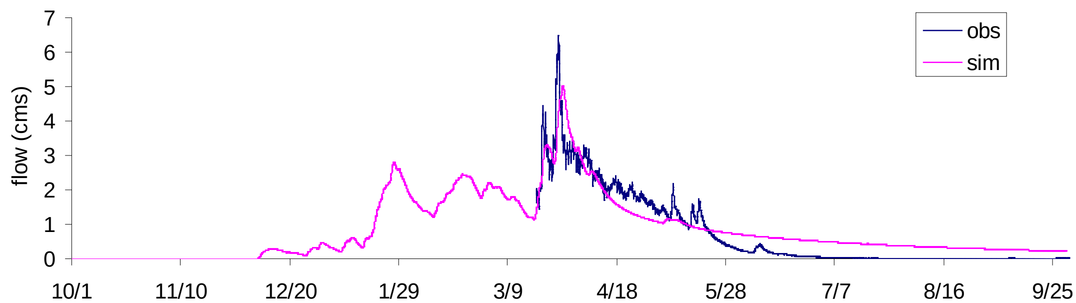

Figure 27 - Validation results of the hydrology model of Last Chance Creek at Doyle Crossing during the water year 2005

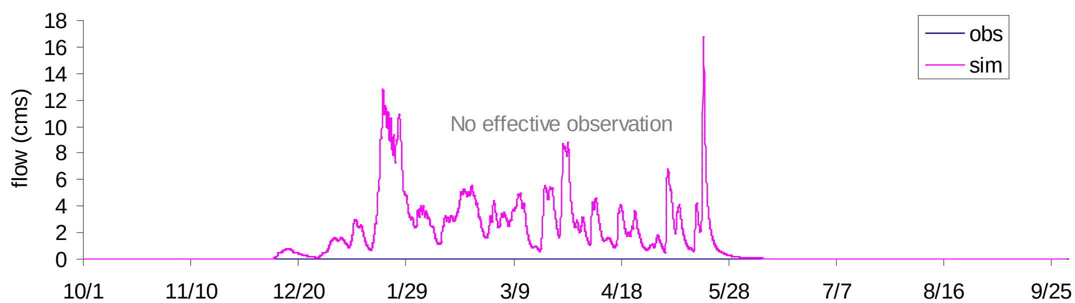

Figure 28 - Validation results of the hydrology model of Wolf Creek during the water year 2005

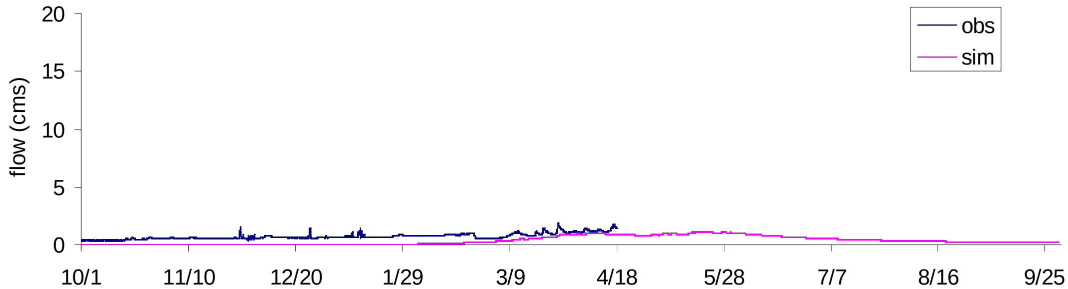

Figure 29 - Validation results of the hydrology model of Indian Creek at DWR weir during the water year 2005

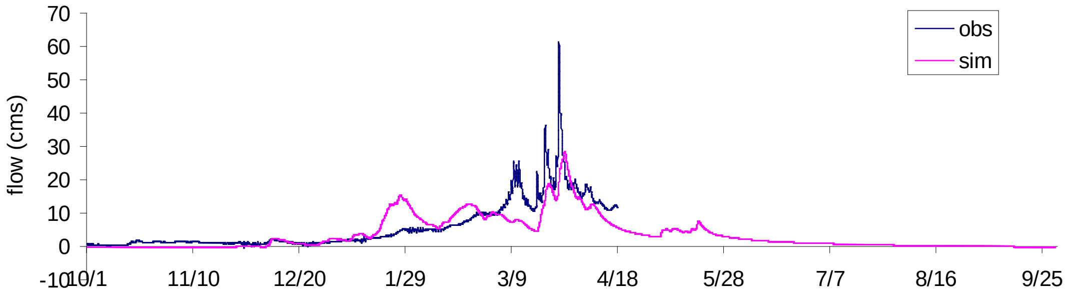

Figure 30 - Validation results of the hydrology model of Indian Creek at Flournoy Bridge during the water year 2005

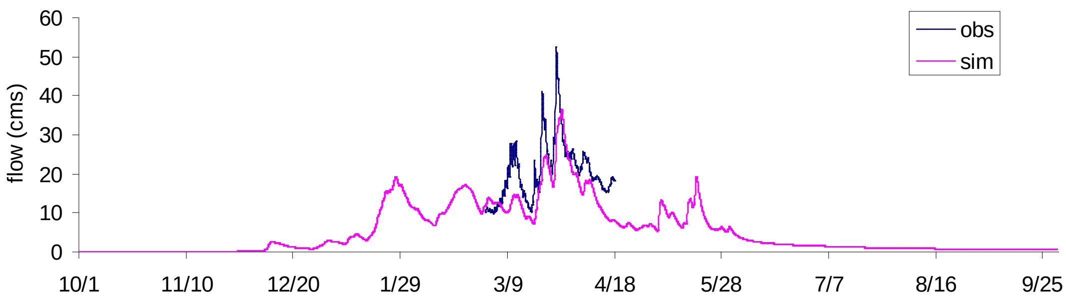

Figure 31 - Validation results of the hydrology model of Indian Creek at Taylorsville during the water year 2005

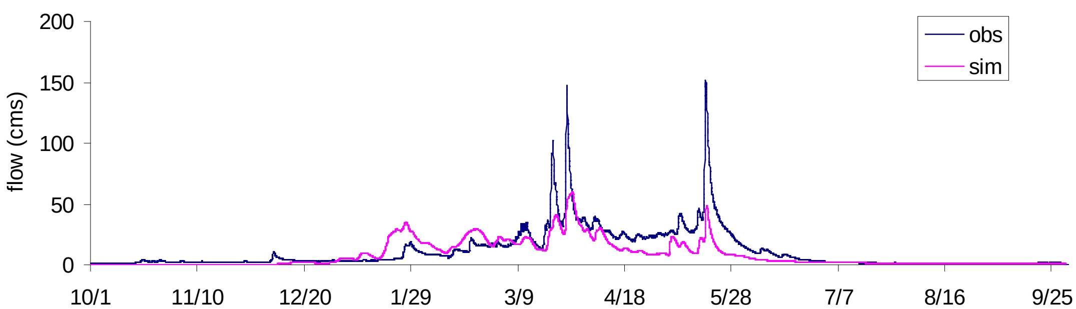

Figure 32 - Validation results of the hydrology model of Indian Creek at Indian Fall during the water year 2005

Implementation of the stream temperature model

Under the modeled flow conditions in Indian Creek watershed, the newly developed stream temperature model was applied and tested. The calibration results for the temperature model are shown in Figures 33 through 37. These results show clear diurnal oscillations of the stream temperatures at all locations. The corresponding validation results are shown in Figures 38 through 42. These figures indicate that the modeled hydrologic and thermal environment represents the reality fairly well.

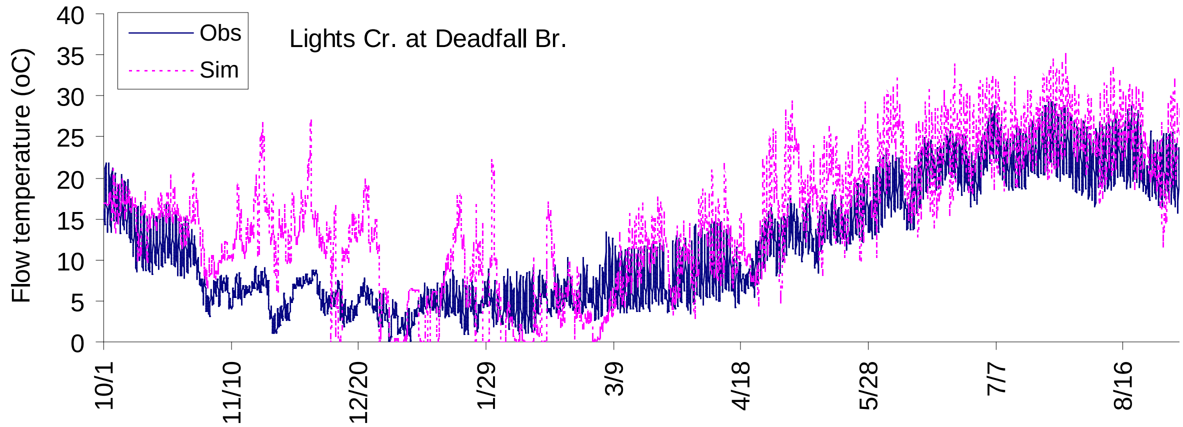

Figure 33 - Calibration results for the stream temperature model of Lights Creek at Deadfall Bridge during the water year 2004

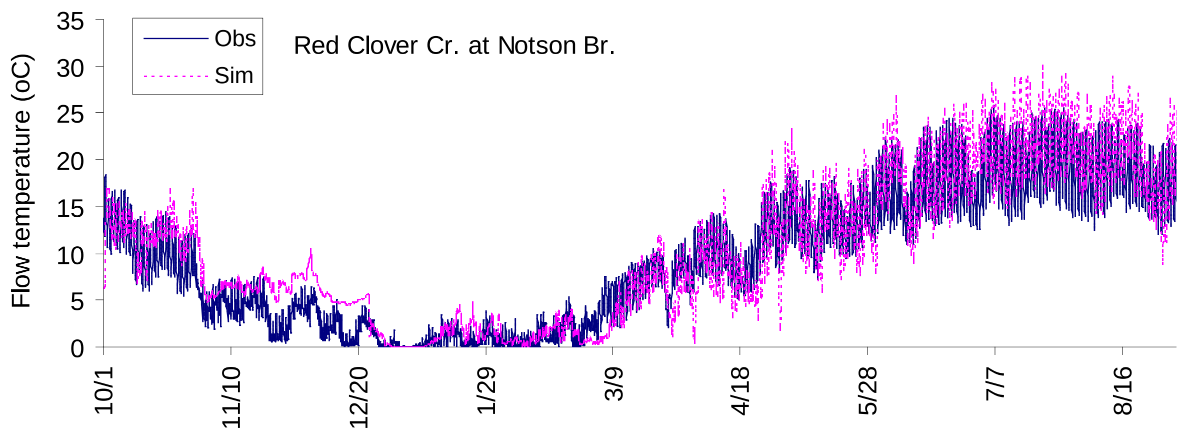

Figure 34 - Calibration results of the stream temperature model of Red Clover Creek at Notson Bridge during the water year 2004

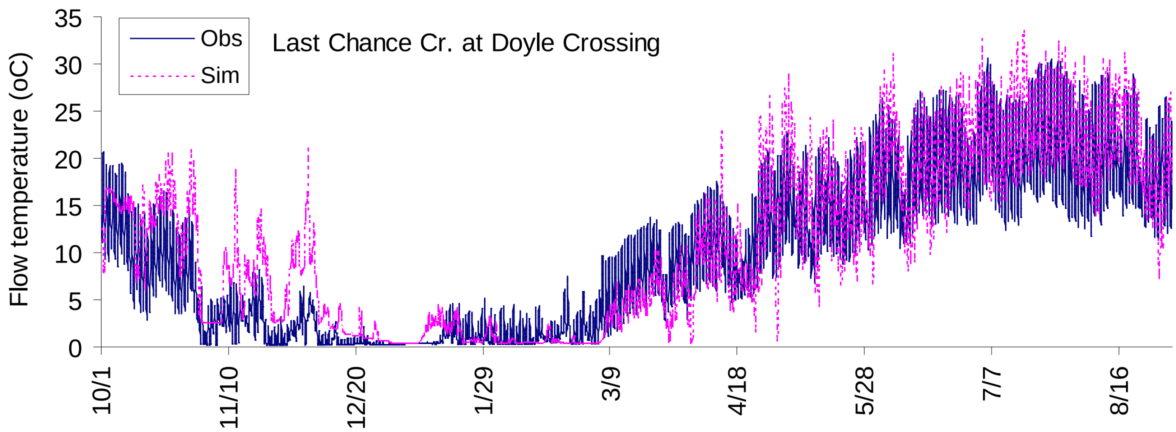

Figure 35 - Calibration results of the stream temperature model of Last Chance Creek at Doyle Crossing during the water year 2004

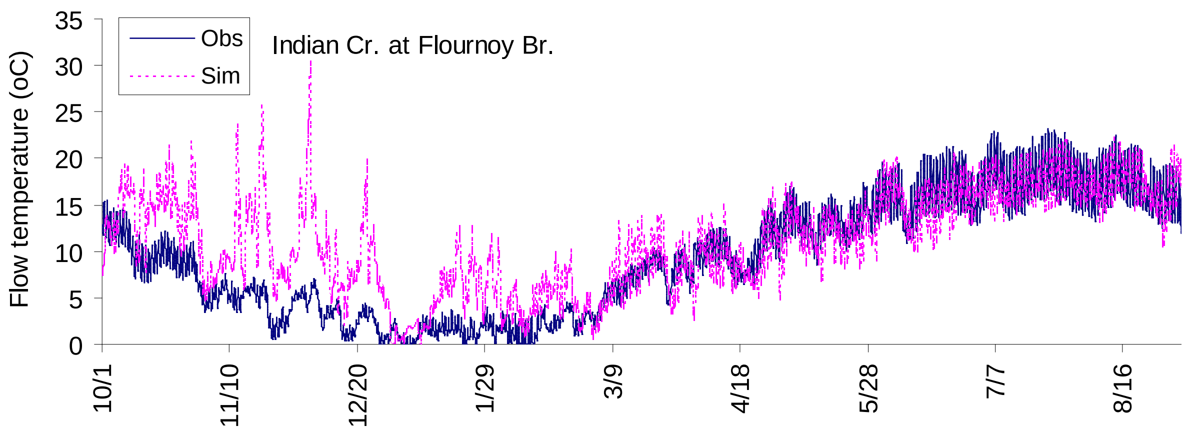

Figure 36 - Calibration results of the stream temperature model of Indian Creek at Flournoy Bridge during the water year 2004

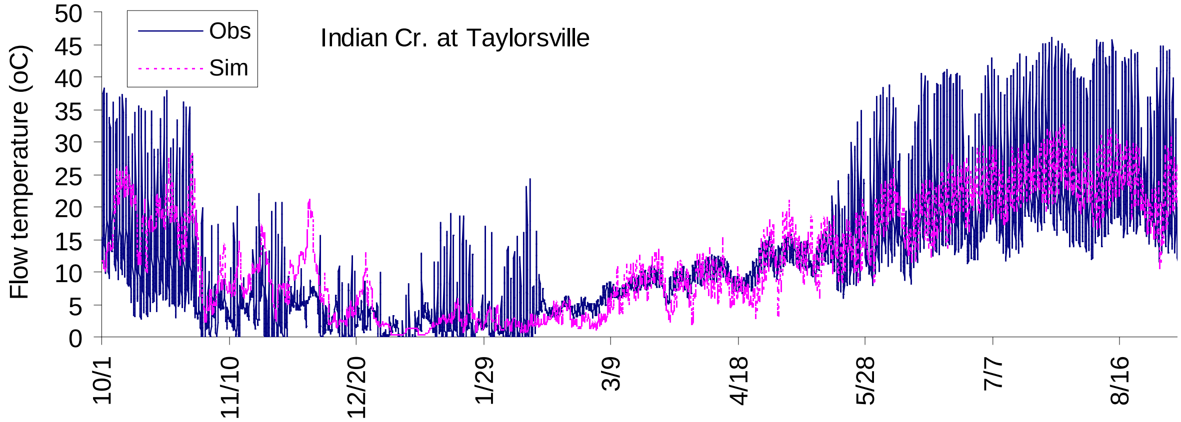

Figure 37 - Calibration results of the stream temperature model of Indian Creek at Taylorsville during the water year 2004

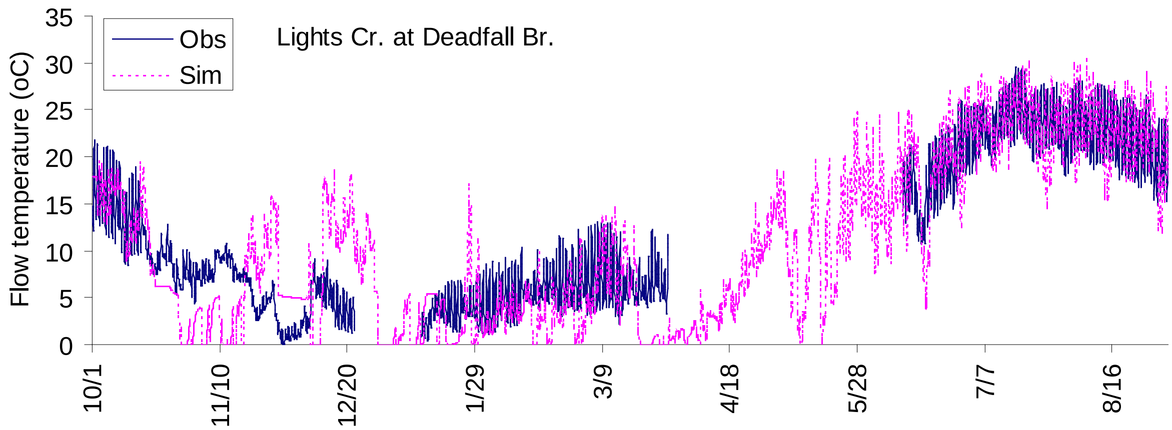

Figure 38 - Validation results of the hydrology model of Lights Creek at Deadfall Bridge during the water year 2005

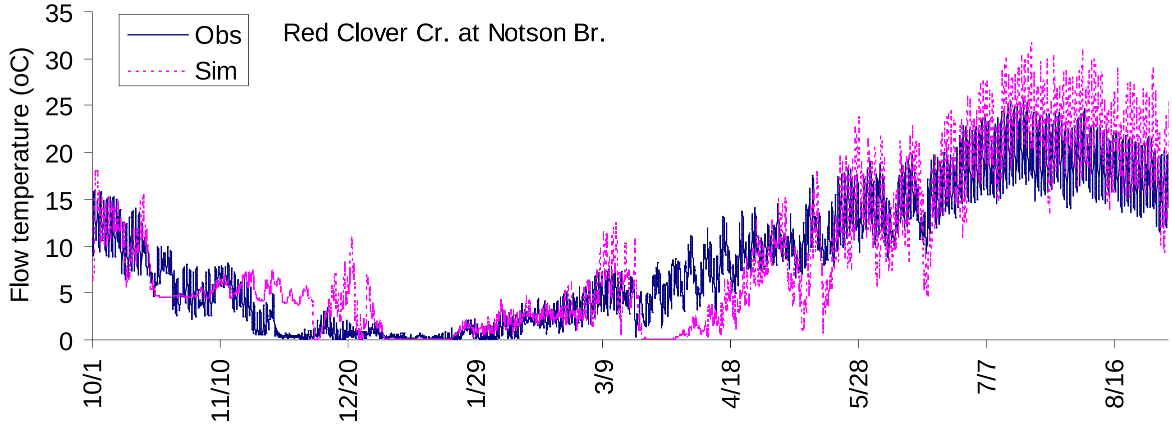

Figure 39 - Validation results of the hydrology model of Red Clover Creek at Notson Bridge during the water year 2005

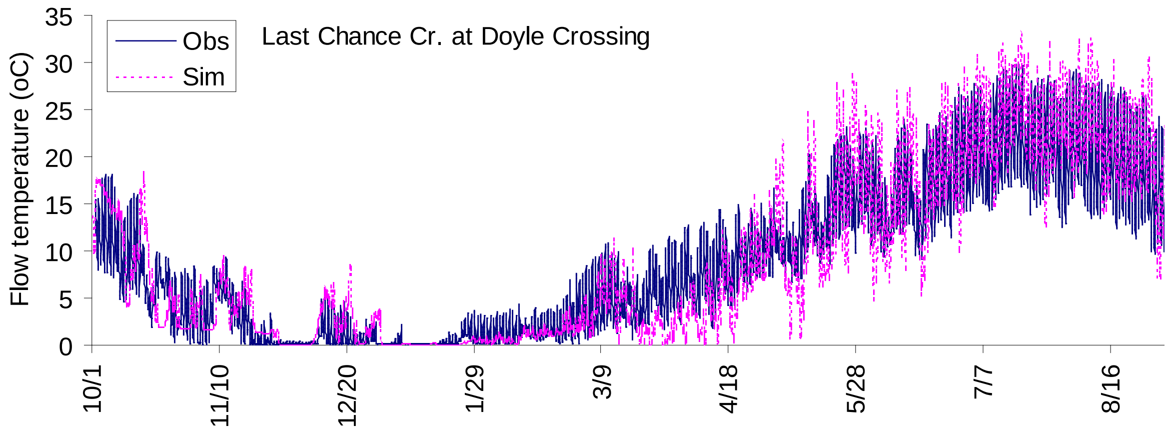

Figure 40 - Validation results of the hydrology model of Last Chance Creek at Doyle Crossing during the water year 2005

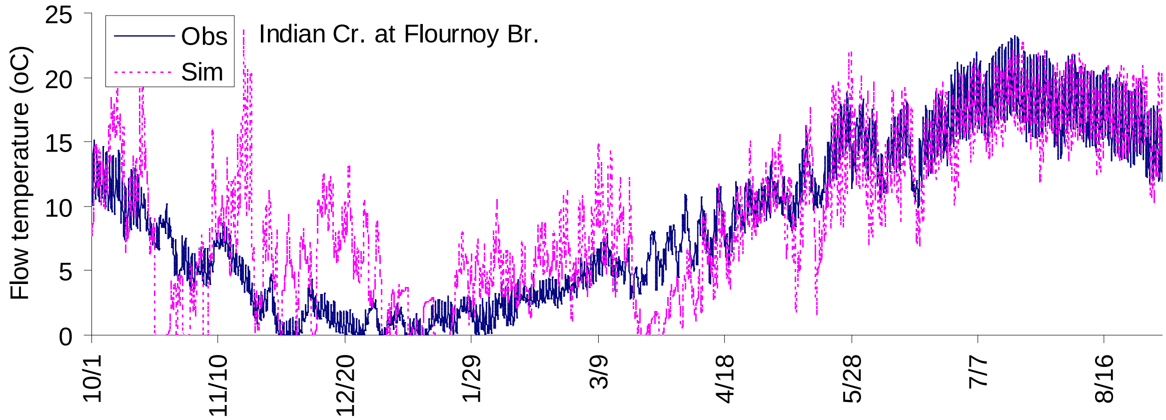

Figure 41 - Validation results of the stream temperature model of Indian Creek at Flournoy Bridge during the water year 2005

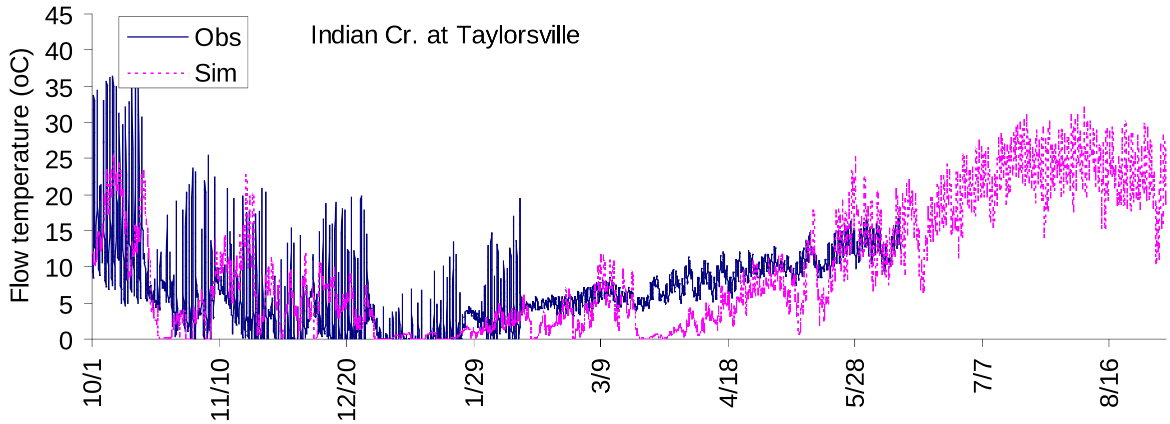

Figure 42 - Validation results of the hydrology model of Indian Creek at Taylorsville during the water year 2005

Scenario assessment of the impact of meadow restoration in terms of streamflow and temperature

The impact of meadow restoration was evaluated based on the calibrated and validated hydrological and water temperature models under the reconstructed historical climate conditions. One of the most important changes to meadowland hydrology due to meadow restoration is the rise in the groundwater table (Benoit and Wilcox, 1997, Hammersmark et al. 2008, Ohara et al. 2012). Once the groundwater table is raised by the pond and plug technique, the river bank storage will increase significantly, as sketched in Figure 43. In this study, one considers the scenario where the width of the meadow aquifer is increased by twenty percent in the post-restoration condition. Then, the change in the watershed response in hydrologic and the thermal conditions, brought about by this meadow restoration, are examined under the identical atmospheric and snow conditions.

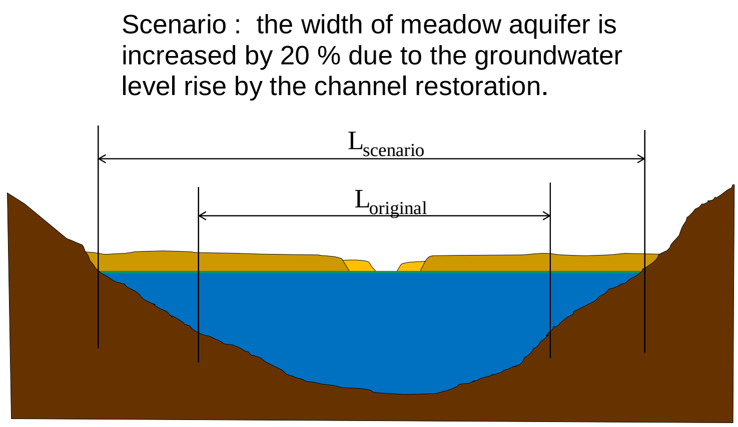

Figure 43 – The scenario for the meadow restoration

The assessment results at various locations within Indian Creek watershed over the 11-year period are shown in Figures 44 through 49. The top graphs show the monthly streamflow under the original and restoration scenario conditions (blue line graphs) and their percentage difference (blue bar graph). Meanwhile, the bottom graphs show the monthly mean stream temperature (red line graphs) and their difference (red bar graph). According to these figures, in general, the meadow restoration may reduce the wet season flow and increase the summer-time flow. The stream temperature may be cooled during the summer season and may be warmed in winter by the meadow restoration because the groundwater contribution to the stream flow is enhanced in the post restoration scenario.

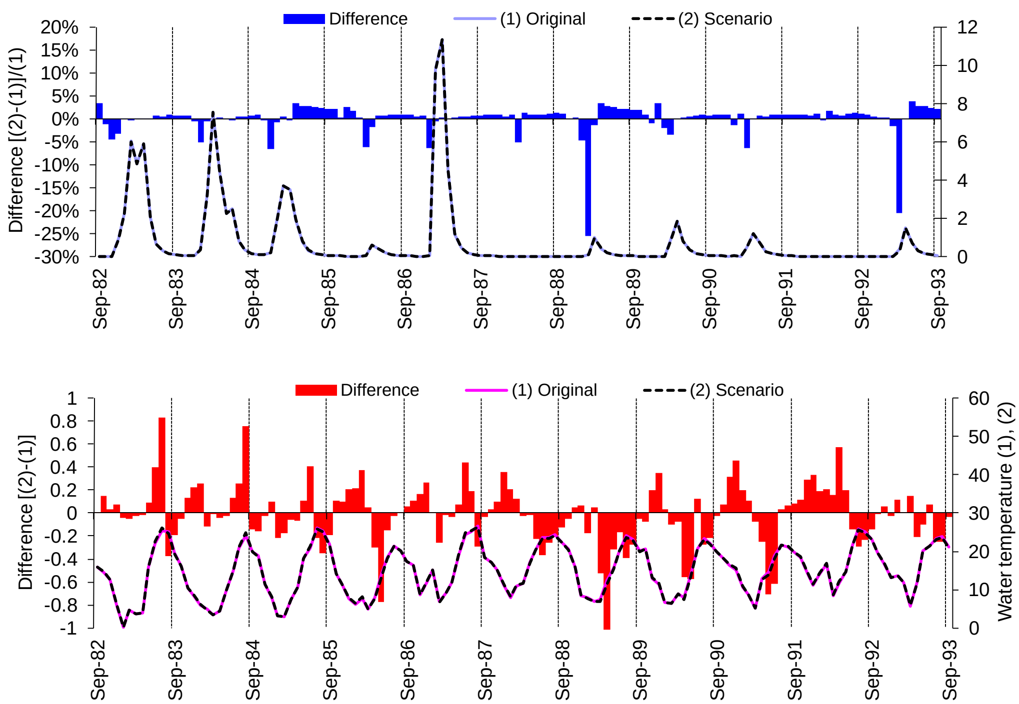

Figure 44 - Assessment of the impact of meadowland restoration in terms of streamflow and temperature at Lights Creek site

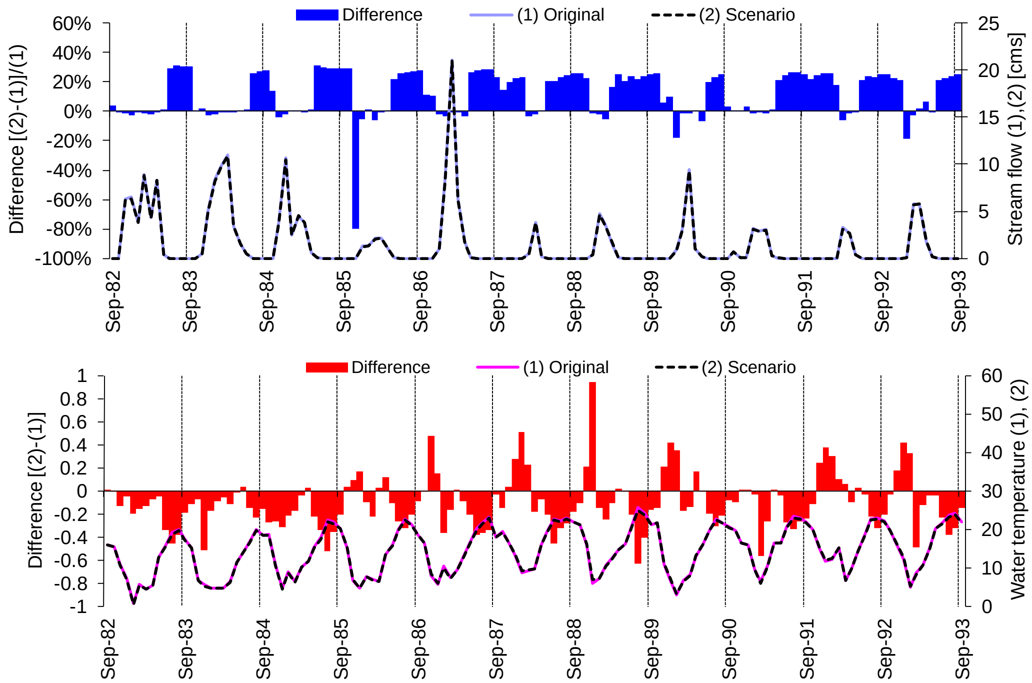

Figure 45 - Assessment of the impact of meadowland restoration in terms of streamflow and temperature at Wolf Creek site

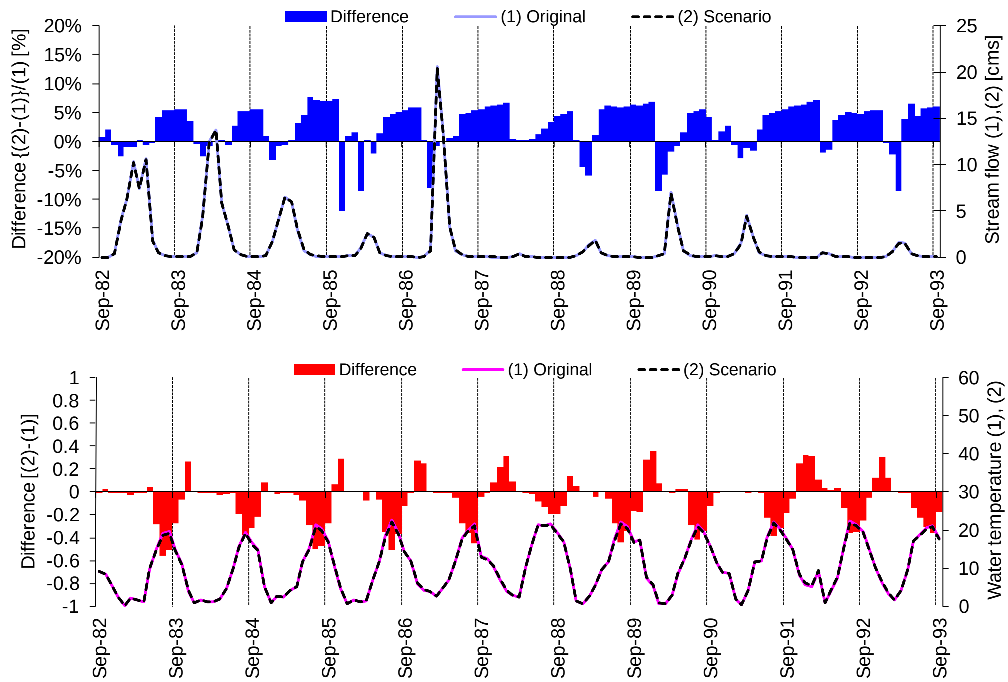

Figure 46 - Assessment of the impact of meadowland restoration in terms of streamflow and temperature at Red Clover Creek site

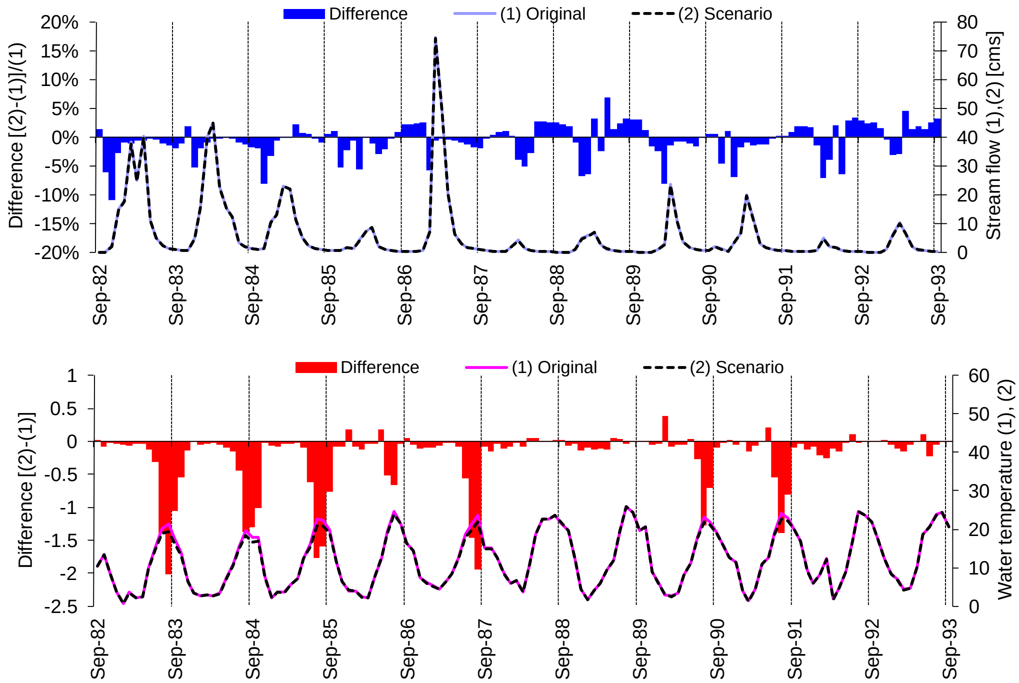

Figure 47 - Assessment of the impact of meadowland restoration in terms of streamflow and temperature at Taylorsville, Indian Cr.

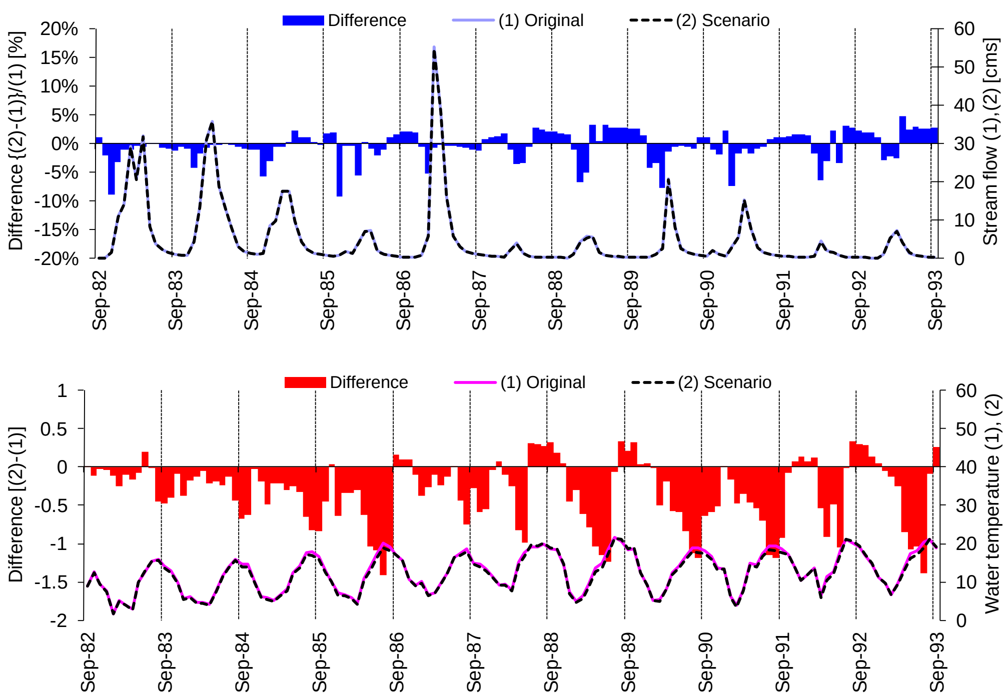

Figure 48 - Assessment of the impact of meadowland restoration in terms of streamflow and temperature at Flournoy, Indian Cr.

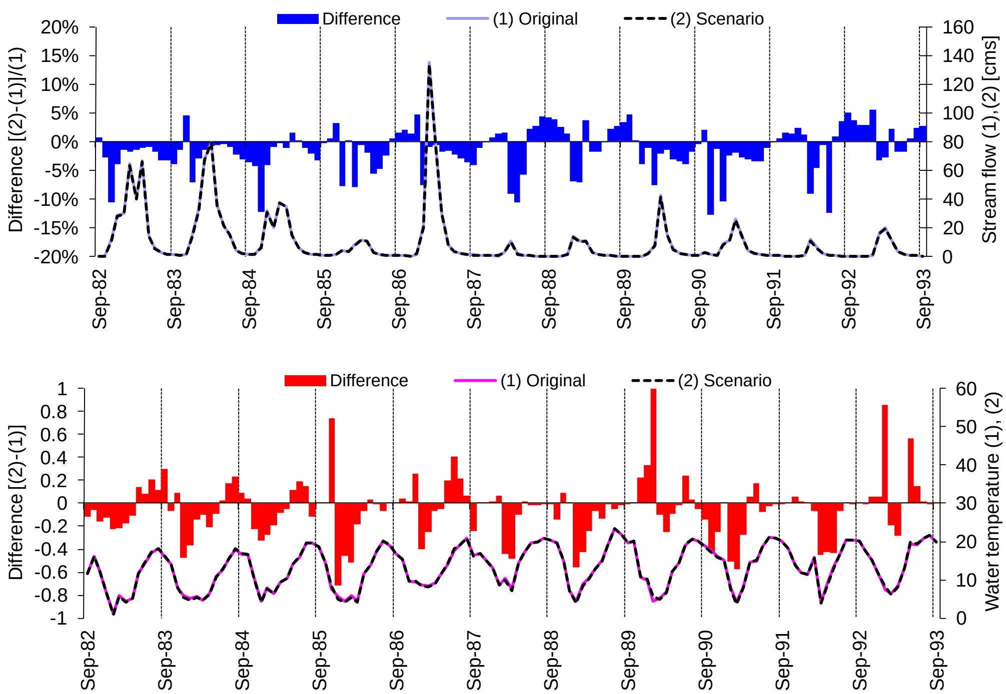

Figure 49 - Assessment of the impact of meadowland restoration in terms of streamflow and temperature at Below Indian Fall, Indian Creek

Summary

Evaluation of the effect of meadow restoration on the streamflow and stream temperature of a watershed solely by field observations is very difficult since the pre- and post-restoration conditions are not comparable under the evolving climatic and hydrologic conditions. Therefore, in this study, physically-based hydrologic and water temperature models were employed for the restored and un-restored meadow conditions in order to quantify the effect of land management change on river flow and environmental ecosystem. With a physically-based watershed environmental hydrology model it is possible to quantify the effect of meadow pre and post-restoration conditions on the hydrologic regime and ecology (in this study, in terms of water temperature) of a watershed under the same hydro-climatic conditions.

Watershed Environmental Hydrology (WEHY) model was successfully implemented at Indian Creek watershed to the simulation of hydrologic and water temperature conditions in the watershed. The hydrology module of WEHY requires input from snow simulation as well as from the reconstructed atmospheric data in order to compute the mass and heat balances over and under the land surface. Then the river routing module of WEHY, together with its groundwater module, need the computed surface and subsurface runoff water from every hillslope (MCU) within a watershed in order to route the surface and subsurface flows within the channel network region of the watershed toward the watershed outlet. The measured precipitation, air temperature, snow depth, snow extent, streamflow, groundwater level, and water temperature data were utilized for model calibration and validation. The environmental module of WEHY for water temperature (Kavvas et al. 2006), was applied to the Indian Creek watershed based on the reconstructed surface and subsurface hydrologic conditions that were calibrated and validated by the field observations.

In this study, for the assessment of the impact of meadow restoration, we focused on the water temperature as a proxy for the aquatic ecosystem conditions in the North Fork, Feather River. According to the analyses, the meadow restoration may cool the stream water during the summer season by increasing the groundwater contribution to the stream at most of the reaches in Indian Creek watershed. This reduction in summer streamflow (baseflow) temperature would help the spawning of coldwater fishes in the stream. The enhanced summer groundwater contribution to the streamflow may come from the stored water in the river banks due to the flooded water over the restored meadowland during the winter. As such, some flood mitigation effect by the meadow restoration was also observed in the model simulations.

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