H43G-1453: The Hydrodynamics of Natural and Incised Mountain Meadows

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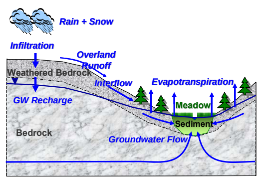
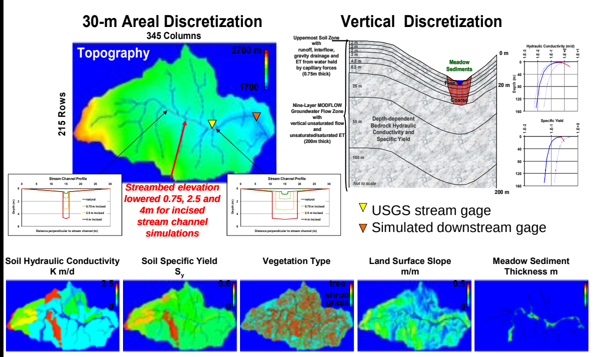
Historical grazing and land development have caused channel incision and streambed lowering in a large fraction of Sierra Nevada meadows. This has resulted in lowering of groundwater tables and changes in the magnitude and timing of watershed and meadow fluxes. The hydrodynamics of mountain meadows under natural and incised conditions has been investigated using numerical simulation. The net effect of stream incision on flow from the meadow to the stream is complex. In general, incision causes a slight increase in baseflow, decrease in ET, and loss of watershed GW water storage. The relative magnitude of these changes is dependent on the hydrologic properties of the bedrock and meadow sediments. Meadows are not isolated hydrologic systems and must be studied within the context of the encompassing watershed to fully understand their hydrodynamics.

1 Model Approach and Framework

The hydrodynamics of mountain meadows under natural and incised stream channel conditions has been investigated using the U.S. Geological Survey (USGS) coupled surface water – groundwater flow model GSFLOW (Markstrom et al., 2008). Processes represented in this model include daily: rain, snowfall and snowmelt; streamflow, overland runoff, interflow and infiltration; near-surface soil-zone storage and evapotranspiration (ET); and subsurface unsaturated/saturated groundwater (GW) flow and ET.

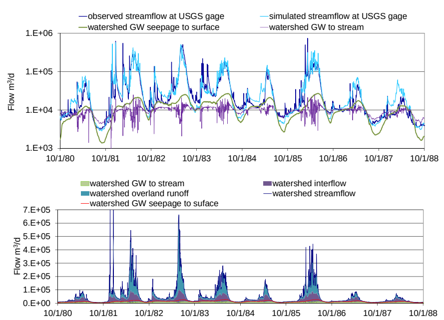


The Sagehen Creek watershed, located in the northern Sierra Nevada near Truckee, California, USA, was used as the basis for watershed topography, hydrography, vegetation and soil properties to ensure realistic watershed representation. Depth-dependent bedrock and meadow hydraulic properties were varied in model simulations to represent meadow hydrodynamics for a range of hydrologic conditions.



Simulations were conducted for water years 1980-1988 using daily temperature and precipitation records. Initial conditions were determined by a steady-state time step with elevation-dependent average recharge. This was then followed by a nine-year daily-time-step transient simulation.

2 Reference Case Simulation Results



References:

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW—Coupled ground-water and surface-water flow model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods 6-D1, 240 p.

Acknowledgments:

This work has been supported by the CA Department of Water Resources and the U.S. Geological Survey. We thank Liza Hoos (graduate student, Duke University) for her assistance with GIS analysis, and Andrew Manning (USGS) for providing well information.

3 Comparison of Natural and Incised Stream Channel Results for Water Years 1986 (wet), 1987 (dry), and 1988 (dry)

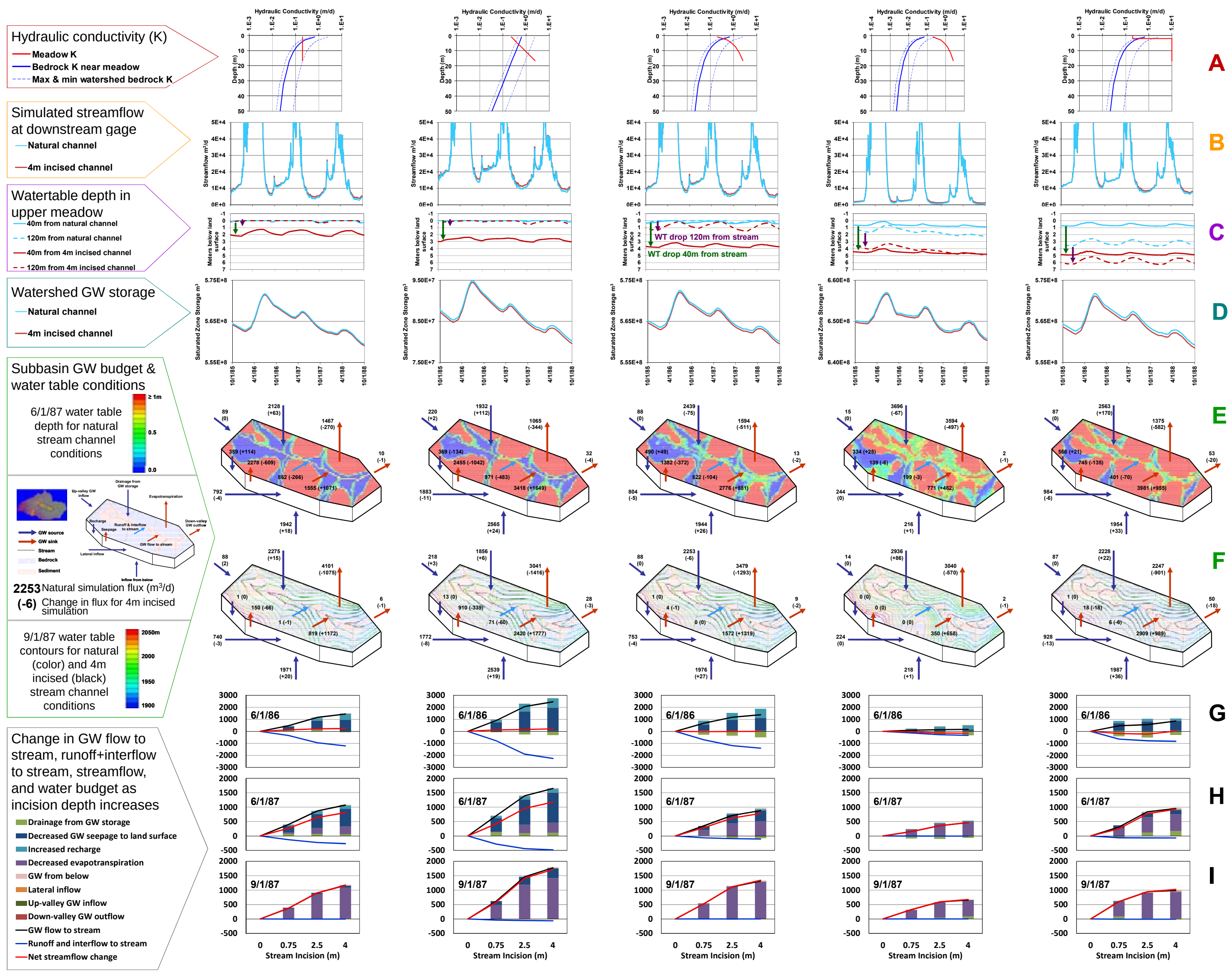
M- — **Decreased Meadow K**: constant meadow K equal to upper 2m meadow layer in RC

BR+ — **Increased Bedrock K**: exponential depth-dependent bedrock K results in more gradual K decrease with depth

RC — **Reference Case**: power law depth-dependent K, bedrock K decreases with depth, meadow K increases with depth

BR- — **Decreased Bedrock K**: bedrock K decreased by a factor of ten

M+ — **Increased Meadow K**: upper 2m meadow layer unchanged, lower meadow layers increased by a factor of ~5



4 Long-term RC Simulation Results

A long-term simulation with RC properties, 1985 climate conditions, 5 years of natural stream channel conditions followed by 4m stream incision was conducted to examine the long-term effect of incision on baseflow and GW storage.

5 Conclusions

- **Summer stream baseflow** (see row B in section 3 results):
  - -Increases when bedrock or meadow K is increased (BR+, M+).
  - -Increases slightly for all 4m incised simulations, with a greater increase when bedrock or meadow K is increased (BR+, M+).
- **Meadow extent & water table depth** (see rows C, E & F in section 3):
  - -Wet meadow conditions develop when bedrock transmits GW flows to the meadows at a rate sufficient to maintain high water tables in the meadow sediments (BR+, M-). Meadow areas (E) extend from the bedrock/meadow sediment contact to the stream.
  - -Water tables become deeper and meadow extent decreases when bedrock K decreases (BR-) and less water flows into meadow areas, or meadow K increases((M+) resulting in a flatter water table in the meadow sediments. Meadow areas (E) are restricted to areas adjacent to the stream.
  - -Meadows with low permeability sediments (RC, M-) and/or large bedrock GW inflows (BR+) sustain longer wet-condition seasons and do not dry out as quickly (C).
  - -In wet meadows (M-, BR+, RC) stream-incision water table drop is limited to the area adjacent to the stream (C, F), however, in drier meadows (BR-, M+) the water table drop extends to the bedrock/meadow sediment contact.
- **Watershed GW storage** (see row D in section 3 results):
  - -Seasonal change in GW storage is proportional to bedrock K (BR+,BR-)
  - -Stream incision results in a loss of GW storage due to water table drop
  - -The loss of GW storage due to stream incision is larger when bedrock K is greater (BR+) or meadow K is greater (M+).
- **Sub-basin water budget** (see rows E, F & G in section 3 results):
  - -Increasing bedrock K (BR+) and/or increasing meadow K (M+) results in increased bedrock GW flux to meadow zone and decreased ET.
  - -Stream incision results in decreased overland flow and interflow, and increased groundwater discharge from the meadow to the stream. During the wet spring season when groundwater storage is replenished (especially during wet years) surface runoff and interflow decrease with incision depth more rapidly than groundwater discharge increases, resulting in a net decline in meadow flow to the stream. However, meadow flow to the stream increases with incision depth during dry conditions when there is no surface runoff or interflow and only groundwater flow from the meadow to the stream.
  - -The source of increased groundwater discharge due to stream incision is mainly from decreased groundwater seepage to the meadow surface and induced recharge during wet conditions, and from decreased groundwater evapotranspiration and storage loss during dry conditions.
  - -In dry conditions, the rate of streamflow increase as a result of incision tapers off as incision depth increases because less GW flow can be captured (no GW seepage, water table drops below the ET extinction depth).
- **Long-term effect of incision** (see section 4 results):
  - -Baseflow increase was greatest in the first year of incision and then gradually dropped off as the watershed approached equilibrium with the new stream channel configuration.