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FORECASTING RUNOFF IN WATERSHEDS WITH SEASONALLY FROZEN SOILS

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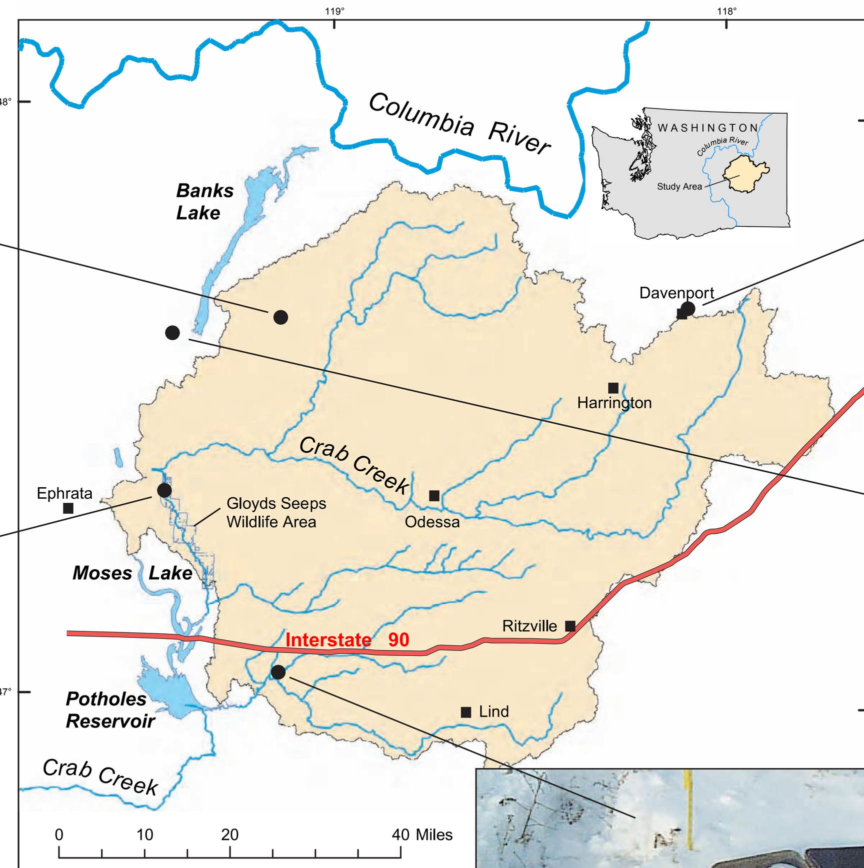
Peak snowmelt and rainfall runoff into Potholes Reservoir in Grant County, Washington, is strongly affected by seasonally frozen soils. When soils are fully or partially frozen, snowmelt and rainfall cannot infiltrate or, in the case of partially frozen soils, infiltration is greatly reduced. The reduced field capacity and infiltration rate of the soil profile affect the volume and timing of surface runoff and ground-water recharge.

STUDY AREA

Typical dry-land-farming land use on the Upper Columbia Plateau, south of Hartline

A joint Federal agency operation is temporarily halted by Crab Creek in the Gloyd Seeps Wildlife Area.

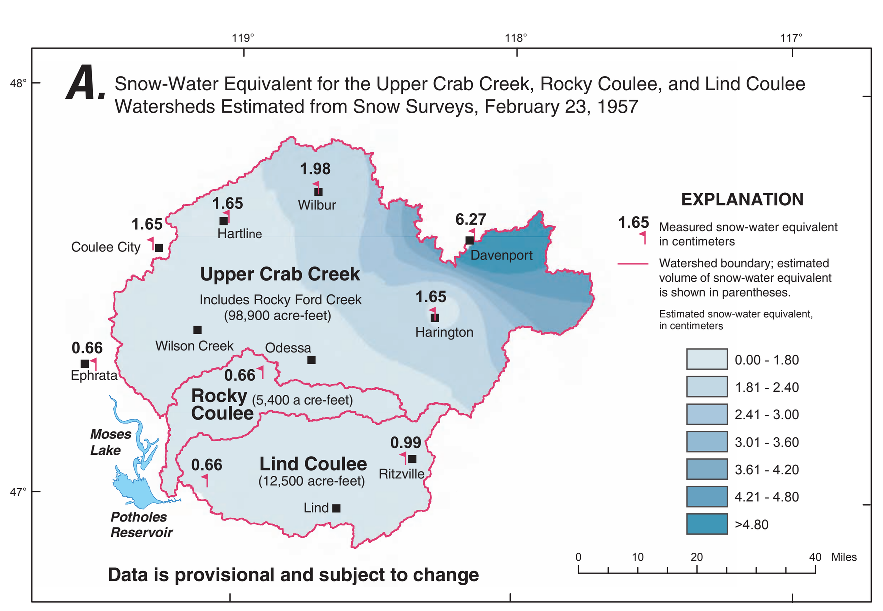


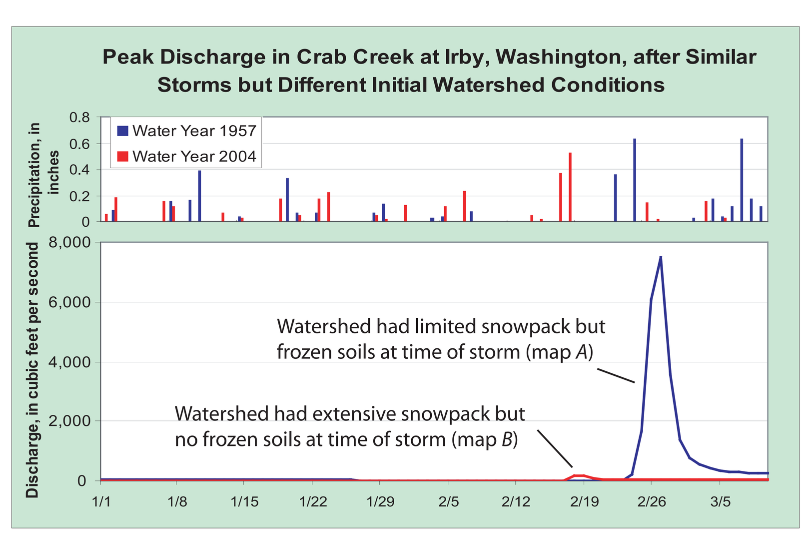
Snow properties measuring kit including scale, known-volume scoop, magnifying glass, and ruler

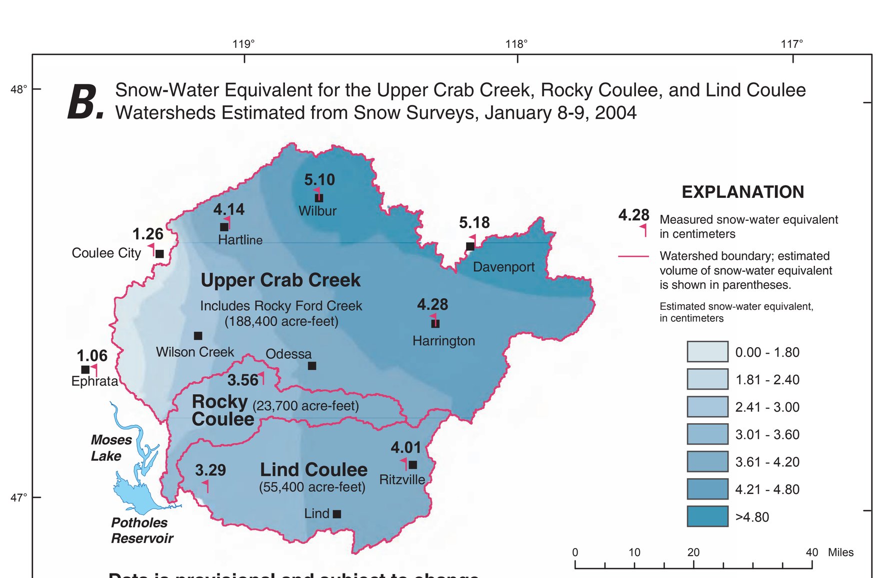
Snowpack in Davenport, January 9, 2004

Dry Falls, located just west of the Crab Creek Watershed

THE SURFACE-WATER RUNOFF RESPONSE IS DRAMATICALLY DIFFERENT IN WATERSHEDS WITH FROZEN SOILS

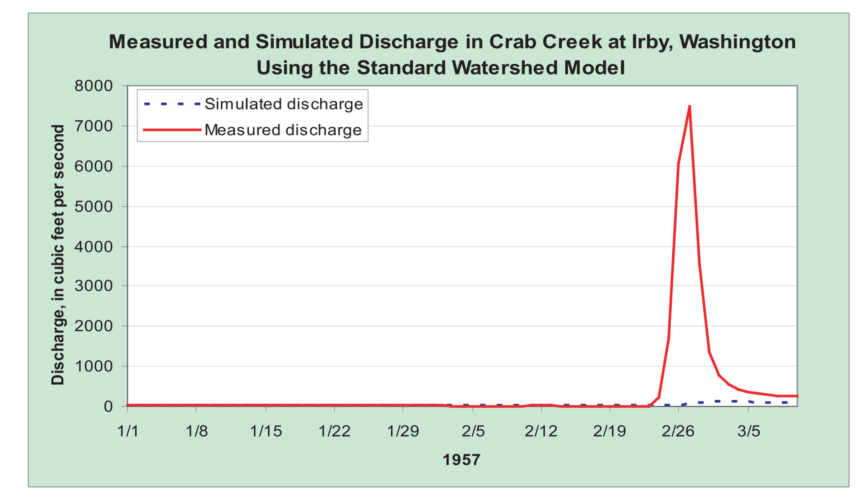


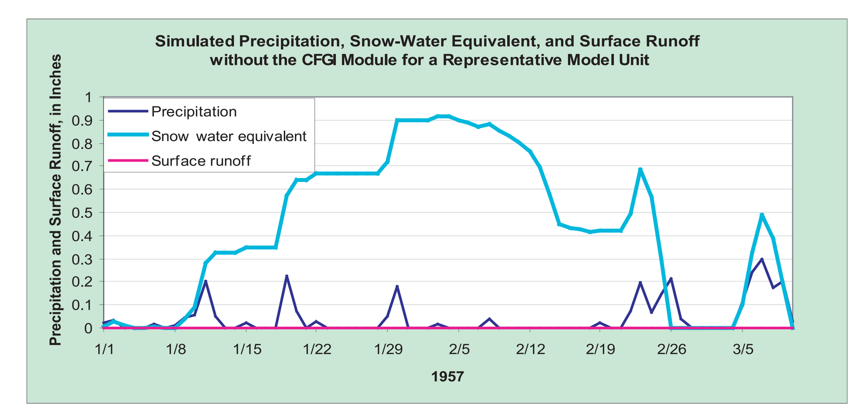


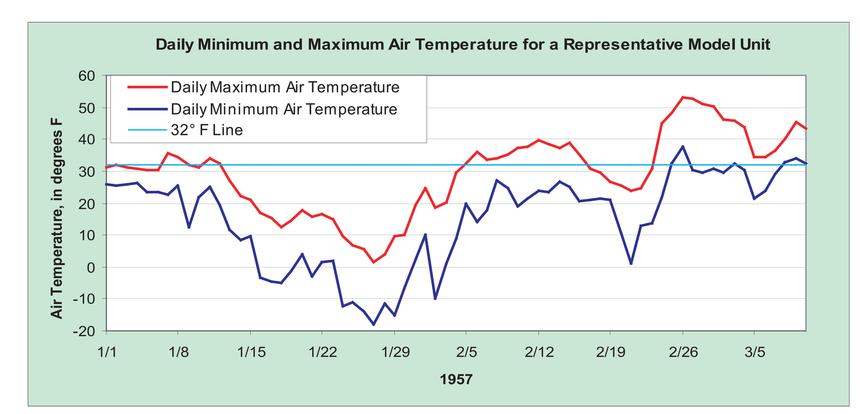


The peak discharge of record in Crab Creek at Irby, Washington, occurred after a 2-day rainstorm in February 1957. Watershed conditions prior to the storm included a limited snowpack (map *A*) and frozen soils. By comparison, in 2004 a rainstorm with similar 2-day precipitation generated a much smaller runoff response even though the snowpack water-equivalent in the basin was far greater than in 1957 (map *B*). The dramatic difference in runoff response between the 1957 and 2004 storms is explained by frozen-soil conditions.

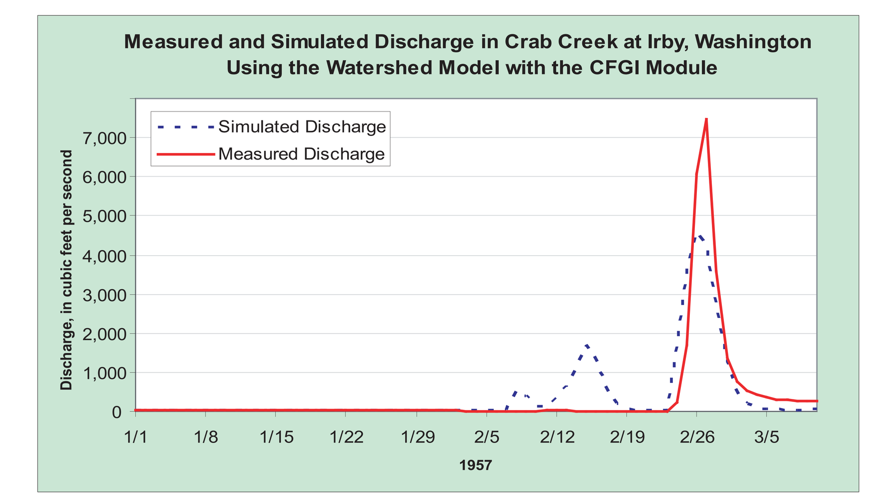
A STANDARD WATERSHED MODEL CANNOT SIMULATE FROZEN-SOILS CONDITIONS

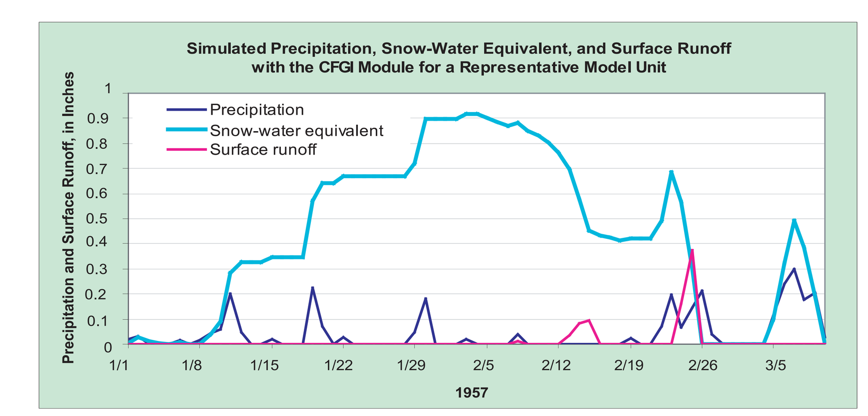


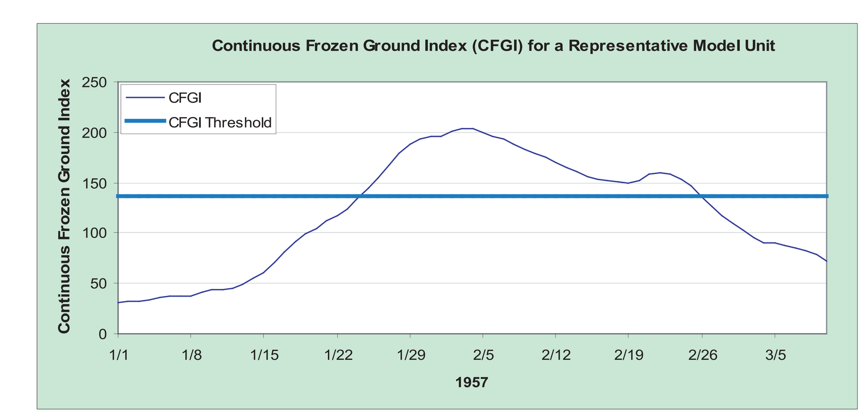




WATERSHED MODEL WITH CFGI MODULE SIMULATES FROZEN-SOILS CONDITIONS







Simulated runoff into Potholes Reservoir matches measured values better with use of the frozen-soils module.

THE CONTINUOUS FROZEN GROUND INDEX (CFGI) ALGORITHM IS INCORPORATED INTO A STANDARD WATERSHED MODEL

A previously developed frozen-soils algorithm that calculates a continuous frozen-soils index, called CFGI, was modularized and incorporated into a spatially distributed hydrologic model compiled with the U.S. Geological Survey's (USGS) Modular Modeling System (MMS). The algorithm was originally developed in 1978 by the National Weather Service, Northwest River Forecast Center and used with the Streamflow Synthesis and Reservoir Regulation (SSARR) model (Larson and others, 2002).

The CFGI algorithm computes an index that considers daily air temperature and snowpack. When the index is above a user-defined threshold, all simulated water at ground surface becomes surface runoff.

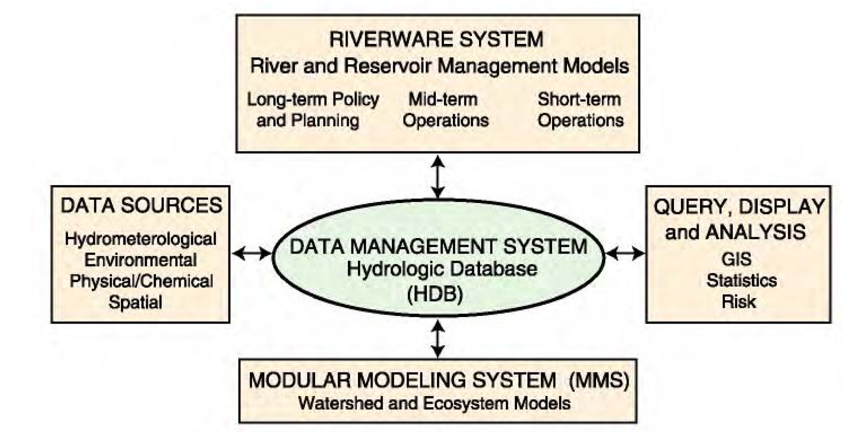
CFGI is computed according to

$$CFGI_i = A * CFGI_{i-1} - T * e^{(-4 * K * D)},$$

where
- i = current timestep (day)
- A = daily decay coefficient
- T = mean daily air temperature (degrees C)
- K = snow-reduction coefficient (0.5 centimeters^{-1} for T>0 and 0.08 centimeters^{-1} for T<0)
- D = depth of snowpack in centimeters

The new CFGI MMS module includes two calibration parameters: the CFGI threshold (137 in the current calibration) and the daily decay coefficient (0.97 in the current calibration).

ACCURATE FORECASTING OF WATERSHED RUNOFF ALLOWS EFFICIENT MANAGEMENT OF POTHOLES RESERVOIR



Schematic of the Decision Support System for the Watershed and River System Management Program (WARSMP)

Incorporation of the frozen soils module into MMS is part of the Watershed and River System Management Program (WARSMP), a collaborative effort between the USGS and U.S. Bureau of Reclamation (USBR). Under this program, the USGS develops hydrologic forecast tools, which the USBR incorporates into river-management models to efficiently distribute water to lakes, reservoirs, and irrigators for growing crops. A calibrated version of the hydrologic model that includes the frozen soils module will be used by the USBR to forecast the unregulated flows that serve as input into a river-management model, RiverWare, used to optimize reservoir operations in the Columbia Basin Irrigation Project.

A successful application of WARSMP was completed in the Yakima River Basin with the USBR and the program for the Crab Creek-Potholes Reservoir will follow a similar design for the decision support system (Mastin and Vacarro, 2002).

REFERENCES CITED

Larson, Emily, Wu, Joan, and McCool, Don, 2002, Continuous Frozen Ground Index (CFGI) as an indicator for high erosion frozen soil events: Washington State University, Center for Multiphase Environmental Research Technical Report, accessed October 2004 at http://www. cmer.wsu.edu/summer/larson.pdf.

Mastin, M.C. and Vaccaro, J.J. 2002, Watershed models for decision support in the Yakima River Basin, Washington: U.S. Geological Survey Open-File Report 02-404, 48 p.

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