# Approaches for Assessing Ground-Water Availability Under Competing Demands and Climate Change

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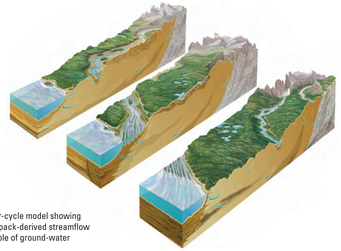
## Introduction:

Many areas of the American West struggle with the allocation of diminishing water supplies between growing municipal and agricultural demands. In the Pacific Northwest, surface-water supplies are additionally stressed by in-stream flow requirements mandated for the protection of endangered salmonid species. In the Yakima River Basin in Washington State, where river and stream flows primarily are derived from winter snowpack in the mountains, surface-water supplies are fully allocated in wet years and over-allocated in dry years. Tribal water rights from the1800s supersede irrigation or municipal rights in the basin, and ongoing litigation to discern the influence of ground-water pumping on surface-water flows led to U.S. Geological Survey involvement in a comprehensive assessment of ground water.

Location of Yakima River basin in Washington state



Water-cycle model showing snowpack-derived streamflow and role of ground-water

- Winter accumulation of mountain snowpack supplies streams and rivers in spring and summer
- A billion-dollar agricultural economy in the basin lowlands uses both surface and ground water for irrigation
- Minimum instream flows are legally protected for endangered salmonid species
- Ground-water pumping for irrigation and municipal supplies likely diminishes surface-water supplies

### A. Basin-Management Tools

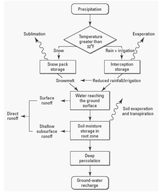
- Monthly Planning Model (Bureau of Reclamation)
- Watershed Models and Riverware Watershed and River System Management Program (WARSMP) (Bureau of Reclamation, USGS)
- Ecosystem Diagnostic and Treatment Model (EDT) (Bureau of Reclamation)
- HEC-RAS 1-D Hydraulic Model (Bureau of Reclamation)
- 2-D Hydraulic Model for 3 reaches (Bureau of Reclamation, USGS)

- Ecohydraulic models (USGS)
- Bioenergetic models (USGS)
- Stream Network Temperature Model (SNTEMP) for Yakima River Miles 36 to 116 (USGS)
- Sediment transport model (Bureau of Reclamation)
- Yakima River Decision Support System (YRDSS) (USGS)

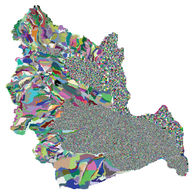
### B. Recharge

Aquifer recharge was estimated using process-based watershed models by calculating water balances for 81,367 Hydrologic Response Units (HRU). For each HRU, the models simulated snow accumulation and ablation interception of precipitaion and some irrigation of vegetation, evapotranspiration, surface runoff, infiltration, water storage in the root or soil zone, and recharge.

- Precipitation-Runoff Modeling System (PRMS)
- Deep Percolation Model (DPM)



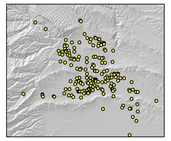
Precipitation-Runoff Modeling System flowchart



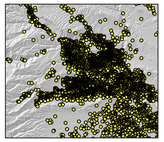
Map with 81,367 Hydrologic Response Units in the Yakima River Basin

### C. Pumpage

Between 1960 and 2001, 19,728 new wells were drilled in the Yakima River Basin, primarily for agricultural and domestic use.



1960 well locations and abundance

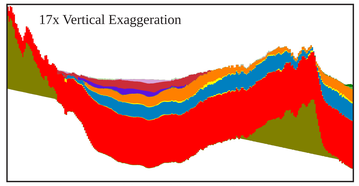


2001 well locations and abundance

### D. Ground-Water Model Construction

Discretization of subsurface hydrogeologic units was implemented using the Hydrologic Unit Flow (HUF) package of MODFLOW-2000, in which three-dimensional geologic structure is defined independently from model-layer geometry. Multi-flow basalt members were idealized as consisting of repeating sequences of hydraulically-conductive flow tops and low-conductivity columnar flow interiors.

- Modular three-dimensional finite-difference ground-water flow model (MODFLOW-2000)
- Constructed with HUF and Stream Flow Routing (SFR) packages
- 45 hydrogeolocic units represented by 600 x 600 x 24 cells

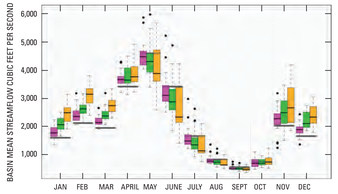



A hydrogeologic cross-sectional view through the Toppenish River basin demonstrates how the HUF package allows discretization of geologic structure into discontinuous units distinct and separate from the uniform model-grid.

## Yakima River Basin:

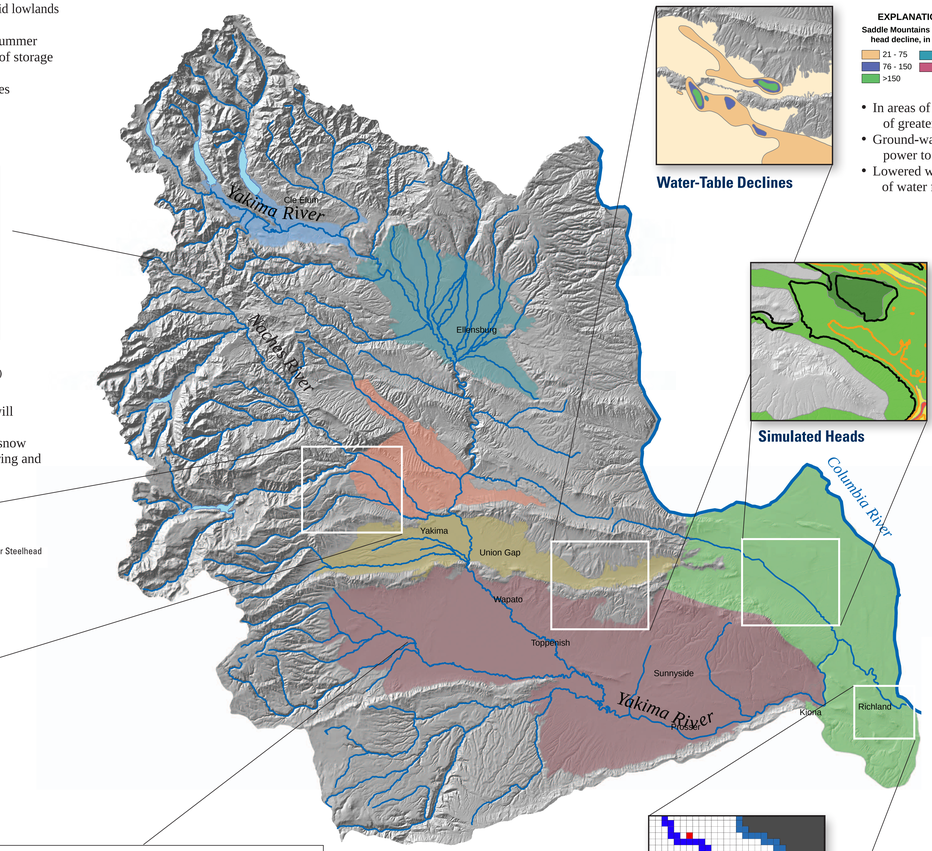
- Area of 6,200 square miles covering alpine mountains to arid lowlands
- Precipitation between 6 and 120 inches per year
- Snowpack-derived streamflow dominates in spring and summer
- Five major reservoirs with more than 1 million acre-feet of storage
- Three counties and the Yakama Nation Reservation
- Approximately 300,000 people and 600,000 irrigated acres

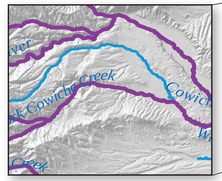
### Predicted Effects of Climate Change on Streamflow




NACHES RIVER BASIN, WASHINGTON
RANGE IN MEAN MONTHLY VALUES FOR: 2030 (red), 2060 (green), AND 2090 (yellow)

- Climate Models indicate warming temperatures, which will reduce recharge over the next 20, 50, and 80 years
- More precipitation will be in the form of rain rather that snow resulting in increased winter runoff and reduced late-spring and summer runoff

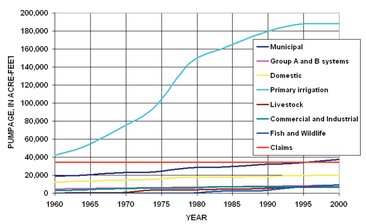


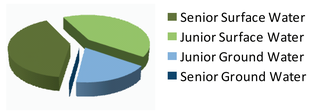

EXPLANATION
Stream with Summer Steelhead

Steelhead Distribution

- Endangered Species Act mandates protection of three listed salmonid species
- 2 species already extirpated from the basin
- Minimum flow requirements during spawning season conflict with irrigation season.




Water-Rights Allocation




- Senior surface-water rights (assigned prior to 1906) take precedence over Junior surface-water rights
- Junior surface-water users are typically curtailed during drought years
- Ground-water pumpers are predominantly Junior users, but are not curtailed like surface-water users
- The Yakama Nation is exercising its Senior Surface-water Treaty rights for the protection of endangered species



EXPLANATION
Saddle Mountains Basalt head decline, in feet
21 - 75
76 - 150
>150
stable
rise

Water-Table Declines

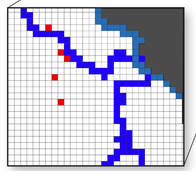
- In areas of heavy pumping, head declines of greater than 150 feet have been measured
- Ground-water users must pay for additional power to pump from greater depths
- Lowered water tables likely increase capture of water from streams



EXPLANATION
Depth-to-Water in feet
< 20
< 80
< 200
> 200
Contour, in feet
0
100
200

Simulated Heads

- Simulated heads and measured heads correspond in both magnitude and location



EXPLANATION
Well
Stream
GHB
No Flow
Cells are 1,000 feet by 1,000 feet

Ground-Water Model Discretization

EXPLANATION
Subbasins
ROSLYN
KITTITAS
SELAH
YAKIMA
TOPPENISH
BENTON

0 10 20 Miles

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