Modifications to DPM—A Deep Percolation Model for Estimating Groundwater Recharge

By John J. Vaccaro and Marijke van Heeswijk, U.S. Geological Survey, Washington Water Science Center, Tacoma, Washington

Introduction

The Deep Percolation Model (DPM) is a daily water-budget model developed by the U.S. Geological Survey for estimating groundwater recharge from precipitation and irrigation. Recharge is defined as the amount of water leaving either the active root zone (deep percolation) or, in the case of bare soils such as sand dunes, the mapped depth of the soil column. DPM is designed to create independent estimates of groundwater recharge for groundwater flow models and can be used at scales ranging from field plots to large regions with variations in climatic, soil, land-use, and land-cover conditions.

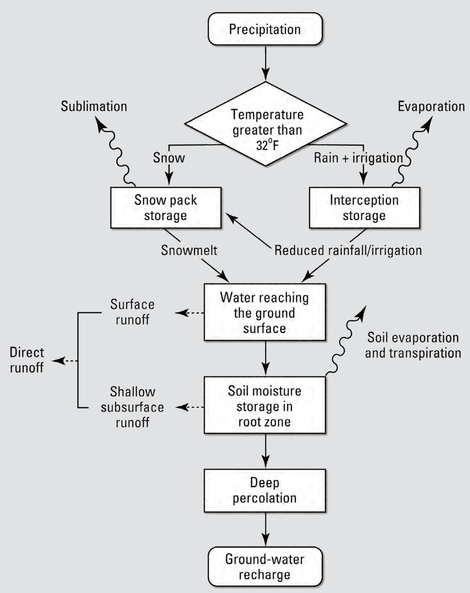
DPM includes energy and water-budget components that are represented as physical processes in DPM. The process components are represented in the following mass-balance equation:

$$R = P - SE - PT - SRO - EI - SUB - (\pm SNO \pm SM \pm IS) \pm DS ,$$

where

R	is recharge (deep percolation)	*SUB*	is snow sublimation
P	is precipitation	*±SNO*	is change in snowpack
SE	is soil evaporation	*±SM*	is change in soil water in the root or soil zone
PT	is plant transpiration	*±IS*	is change in intercepted moisture storage
SRO	is surface runoff	*±DS*	is deficit or surplus
EI	is evaporation of intercepted water		

Conceptual model of precipitation routing in DPM. Irrigation is added to either rain (above canopy) or to the ground (below canopy).



DPM Version History

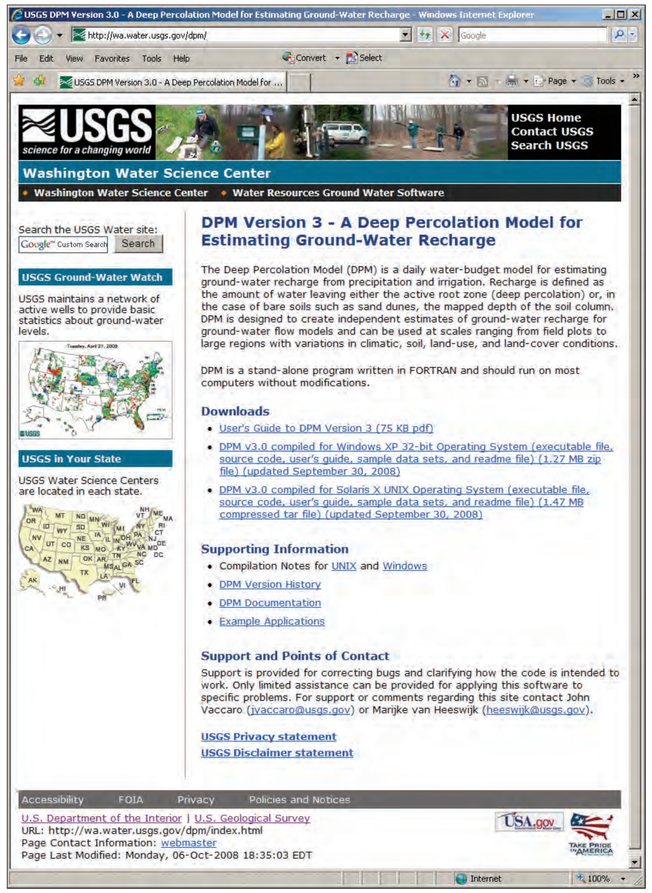
DPM Version 1 was released in 1987 (Bauer and Vaccaro, 1987) and Version 2 was released in 1997 (Bauer and Mastin, 1997). Version 2 eliminated the requirement for a quadrilateral model-grid system and allowed for soils in the root or soil zone to saturate. In addition, the method used to calculate surface runoff was changed to a combination of an approximation of Darcy flow for saturated soils and saturation excess, and the Priestly-Taylor potential evapotranspiration method was added for non-agricultural land-use/land-cover options. Agricultural land-use/land-cover options continued to use the original Jensen-Haise method of DPM Version 1. A revision to DPM Version 2 incorporated after 1997 included the option of specifying time-varying saturated vertical hydraulic conductivities—the limiting infiltration rate below the root zone. DPM Version 3, released in 2008, enhances Version 2 by making it consistent with a modularized version of DPM released in 2007 that is included in the U.S. Geological Survey's Modular Modeling System (MMS; Vaccaro, 2007).

The main differences between DPM Versions 1 and 3 in simulating physical processes that affect water-budget components are that in DPM Version 3

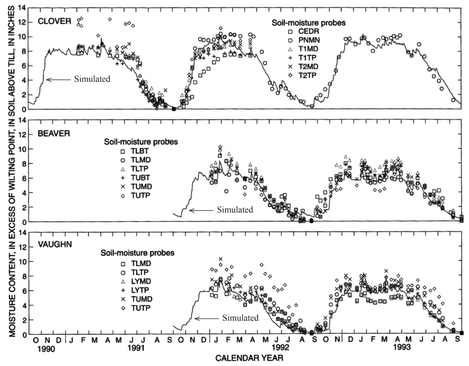
- Soils can saturate;
- Surface runoff for saturated soils is calculated using an approximation of Darcy flow that includes a joint calculation of lateral flow (runoff) and downward flow (recharge);
- Potential evapotranspiration for native plant cover is estimated using the Priestly-Taylor method;
- Snowmelt is computed as a function of wind speed during rain-on-snow events; and
- Measured throughfall is an optional model input.

Accessing DPM Version 3

DPM Version 3 may be downloaded from http://wa.water.usgs.gov/dpm and the equivalent MMS version of DPM may be downloaded from links provided in http://pubs.usgs.gov/sir/2006/5318/pdf/sir20065318.pdf.



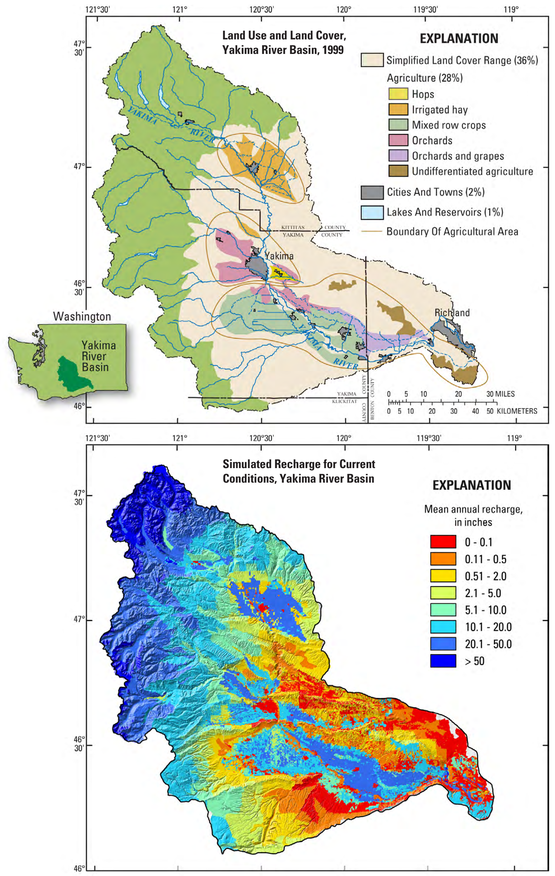
Application of DPM in the Puget Sound Lowlands, Washington, that shows a close match between measured and simulated soil moisture content (Bauer and Mastin, 1997)



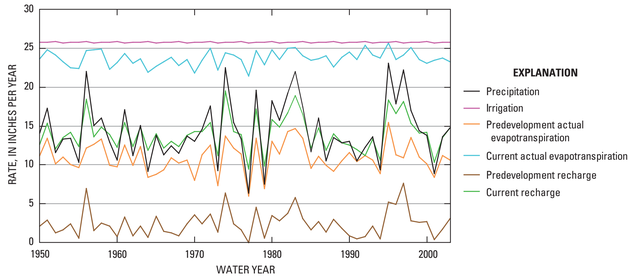
New Features of DPM Version 3

DPM Version 3 includes new land-use/land-cover options; simulation of snowmelt during rain-on-snow conditions as a function of wind speed; estimation of incoming solar radiation if no solar radiation data are available; optional application of irrigation above or below the vegetation canopy; optional areal distribution of precipitation using monthly instead of annual weighting factors; input and output file names read externally to the program; and arrays sized so that users will be less likely to need to recompile the program. DPM Version 3 is backward compatible with datasets created for Version 2, with one exception: the time series format of the optional file for specifying time-varying hydraulic conductivities has been made consistent with that of all other time series input files.

Application of DPM in the agricultural region of the Yakima River Basin, Washington (Vaccaro and Olsen, 2007)



Selected water-budget components in the Naches area of the Yakima River Basin for predevelopment (natural) and current land-use conditions



Land-use and land-cover options of DPM Version 3. New options (highlighted in light blue) were added so DPM can be used to simulate evapotranspiration for additional crop types throughout North America.

Cover type identifier	Cover type	Growing season*
1	Conifer forest	Full year
2**	Grass—native or irrigated; evapotranspiration estimated using Priestly-Taylor method	Full year
3	Sagebrush and associated scrub	Full year
4	Winter wheat—harvested in summer and planted in autumn, each year; larger maximum water demand than cover type identifier 204	September 4 to July 4
204	Winter wheat—harvested in summer and planted in autumn, each year; smaller maximum water demand than cover type identifier 4 based on more recent information	September 4 to July 4
5	Winter wheat, grown on 2-year cycle—second calendar year of cycle: harvested in summer, fallow in autumn; larger maximum water demand than cover type identifier 205	December 31 to July 4
205	Winter wheat, grown on 2-year cycle—second calendar year of cycle: harvested in summer, fallow in autumn; smaller maximum water demand than cover type identifier 5 based on more recent information	December 31 to July 4
6	Winter wheat, grown on 2-year cycle—first calendar year of cycle: fallow in summer, planted in autumn; larger maximum water demand than cover type identifier 206	September 14 to January 1
206	Winter wheat, grown on 2-year cycle—first calendar year of cycle: fallow in summer, planted in autumn; smaller maximum water demand than cover type identifier 6 based on more recent information	September 14 to January 1
7	Orchards (low-latitudes) or deciduous trees (mid-latitudes, with thick understory, such as in riparian areas)	Full year
8	Alfalfa	Full year
208	Alfalfa	February 28 to October 31
9**	Grass—native or irrigated; evapotranspiration estimated using Jensen-Haise method	Full year
209	Row crops (mid-latitudes)—undifferentiated; annual crop water use of about 28 inches. Can be used for multiple crops in a season or crops such as asparagus	February 28 to October 30
10	Water	—
11	Corn	May 5 to November 6
211	Corn	May 5 to September 21
12	Potato—larger maximum water demand than cover type identifier 212	June 12 to October 21
212	Potato—smaller maximum water demand than cover type identifier 12	April 19 to September 14
13	Barren soils—sand, sand dunes, and very permeable soil without vegetation	—
14	Lentil and/or Pea	April 30 to August 15
214	Lentil	April 30 to August 15
15	Spring wheat—planted in spring, harvested in autumn; larger maximum water demand than cover type identifier 215	March 30 to August 31
215	Spring wheat—planted in spring, harvested in autumn; smaller maximum water demand than cover type identifier 15 based on more recent information	March 30 to August 31
16	Impervious	—
17	Small vegetables (California) —carrots, lettuce, etc.	August 30 to January 20
18	Cotton (Texas)	March 30 to September 28
19	Mint	May 5 to August 20
20	Grape (California)	February 28 to September 23
21	Grape (Washington and Oregon)	March 30 to October 25
22	Hops (Washington, Idaho, and Oregon)	March 30 to September 6
23	Olive tree (California)	February 28 to December 3
24	Citrus	Full year
25	Soybeans (central United States)	May 5 to September 24
26	Apple and other orchards	February 28 to November 25
27	Sorghum	May 18 to October 6
28	Pasture (mid-latitudes)	February 28 to October 31
29	Bean	May 13 to August 23
30	Pea	April 13 to July 24
31	Asparagus	February 28 to October 31

* No transpiration simulated if air temperature is at or below freezing.
** Representative of shallow rooted grasses; root depth, interception capacity, and growing season would need to be adjusted for native tall grass.
— Not applicable

References Cited

Bauer, H.H., and Mastin, M.C., 1997, Recharge from precipitation in three small glacial-till-mantled catchments in the Puget Sound Lowland, Washington: U.S. Geological Survey Water-Resources Investigations Report 96-4219, 119 p.

Bauer, H.H., and Vaccaro, J.J., 1987, Documentation of a deep percolation model for estimating ground-water recharge: U.S. Geological Survey Open-File Report 86-536, 180 p.

Vaccaro, J.J., 2007, A deep percolation model for estimating ground-water recharge—documentation of modules for the modular modeling system of the U.S. Geological Survey: U.S. Geological Survey Scientific Investigations Report 2006-5318, 30 p.

Vaccaro, J.J., and Olsen, T.D., 2007, Estimates of ground-water recharge to the Yakima River Basin aquifer system, Washington, for predevelopment and current land-use and land-cover conditions: U.S. Geological Survey Scientific Investigations Report 2007-5007, 30 p.

Contacts

John Vaccaro, jvaccaro@usgs.gov, (253) 552-1620
Marijke van Heeswijk, heeswijk@usgs.gov, (253) 552-1625

U.S. Geological Survey, Washington Water Science Center,
Tacoma, Washington, 98402

U.S. Department of the Interior
U.S. Geological Survey

April 2009