Hydrologic Modeling with the Distributed-Hydrology-Soils-Vegetation Model (DHSVM)

DHSVM was developed by researchers at the University of Washington and the Pacific Northwest National Lab.

GIS grid-based representation (30 m x 30 m)

Simulated versus Measured Discharge
Each 30 x 30 meter grid contains information about the

- over-story vegetation
- under-story vegetation
- multi-layer soil properties
- saturated subsurface flow
- stream network
- UTM location
- slope, aspect and elevation
Thesis results of Katie Kelleher, Geology (2006)
DHSVM Modeling Inputs and Outputs

**GIS Preprocessing**

- Digital Topographic Data
- Digital Land Surface Data
- Time Series of Meteorological Data

- DEM
- Channel Network
- Vegetation Layer
- Soil Type
- Soil Thickness
- Meteorological Data
- Initial Conditions

**DHSVM**

- Stream Flow
- Snow & Snow Melt
- Soil Moisture
- Evapotranspiration
- Precipitation
DHSVM calculates a water and energy budget on each grid cell for each time step.

Inputs - Outputs = Change in Storage
Inputs - Outputs = Change in Storage

\[ P - E_{io} - E_{iu} - E_s - E_{to} - E_{lu} - Q_s = \Delta S_{i} + \Delta S_{s} + \Delta S_{io} + \Delta S_{iu} + \Delta W \]

\( P \) = Precipitation
North Shore Meteorological (MET) Station

[Map showing locations of various creeks and the North Shore Meteorological Station]
Brannian Creek Rain Gauge
Rainfall (or snow) is distributed over the DEM

Point Measurements → inverse distance elevation lapse rate → Distributed Rainfall (162,669 grid cells)

- Rain Gauge

Elevation (meters)
- High: 1024
- Low: 93
Inputs - Outputs = Change in Storage

\[ P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W \]

\( E_{io} \) = overstory evaporation
\( E_{to} \) = overstory transpiration
Inputs - Outputs = Change in Storage

\[ P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W \]

- \( E_{io} \) = overstory evaporation
- \( E_{to} \) = overstory transpiration

- \( E_{iu} \) = understory evaporation
- \( E_{tu} \) = understory transpiration
Inputs - Outputs = Change in Storage

\[ P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W \]

- \( E_{io} \) = overstory evaporation
- \( E_{to} \) = overstory transpiration

- \( E_{iu} \) = understory evaporation
- \( E_{tu} \) = understory transpiration
- \( E_s \) = soil evaporation
1 Evergreen Needleleaf
2 Evergreen Broadleaf
3 Deciduous Needleleaf
4 Deciduous Broadleaf
5 Mixed Forest
6 Woodland
7 Wooded Grassland
8 Closed Shrub
9 Open Shrub
10 Grassland
11 Cropland
12 Bare
13 Urban
14 Water
15 Coastal Conifer Forest
16 Xeric Conif Forest (Dry)
17 Mesic Conif Forest (Wet)
18 Subalpine Conif Forest
19 Alpine Meadow
20 Ice
21 Wetland
<table>
<thead>
<tr>
<th>Vegetation Description</th>
<th>15 = <strong>Coastal Conifer Forest</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Impervious Fraction</td>
<td>15 = 0.0</td>
</tr>
<tr>
<td>Overstory Present</td>
<td>15 = TRUE</td>
</tr>
<tr>
<td>Understory Present</td>
<td>15 = TRUE</td>
</tr>
<tr>
<td>Fractional Coverage</td>
<td>15 = 0.9</td>
</tr>
<tr>
<td>Hemi Fract Coverage</td>
<td>15 = 0.9</td>
</tr>
<tr>
<td>Trunk Space</td>
<td>15 = .5</td>
</tr>
<tr>
<td>Aerodynamic Attenuation</td>
<td>15 = 2.0</td>
</tr>
<tr>
<td>Radiation Attenuation</td>
<td>15 = 0.15</td>
</tr>
<tr>
<td>Max Snow Int Capacity</td>
<td>15 = 0.040</td>
</tr>
<tr>
<td>Snow Interception Eff</td>
<td>15 = 0.6</td>
</tr>
<tr>
<td>Mass Release Drip Ratio</td>
<td>15 = 0.4</td>
</tr>
<tr>
<td>Height</td>
<td>15 = 50.0 0.5</td>
</tr>
<tr>
<td>Overstory Monthly LAI</td>
<td>15 = 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0</td>
</tr>
<tr>
<td>Understory Monthly LAI</td>
<td>15 = 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0</td>
</tr>
<tr>
<td>Maximum Resistance</td>
<td>15 = 5000.0 3000.0</td>
</tr>
<tr>
<td>Minimum Resistance</td>
<td>15 = 666.6 200.0</td>
</tr>
<tr>
<td>Moisture Threshold</td>
<td>15 = 0.33 0.13</td>
</tr>
<tr>
<td>Vapor Pressure Deficit</td>
<td>15 = 4000 4000</td>
</tr>
<tr>
<td>Rpc</td>
<td>15 = .108 .108</td>
</tr>
<tr>
<td>Overstory Monthly Alb</td>
<td>15 = 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18</td>
</tr>
<tr>
<td>Understory Monthly Alb</td>
<td>15 = 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18</td>
</tr>
<tr>
<td>Number of Root Zones</td>
<td>15 = 15</td>
</tr>
<tr>
<td>Root Zone Depths</td>
<td>15 = 0.10 0.25 0.40</td>
</tr>
<tr>
<td>Overstory Root Fraction</td>
<td>15 = 0.20 0.40 0.40</td>
</tr>
<tr>
<td>Understory Root Fraction</td>
<td>15 = 0.40 0.60 0.00</td>
</tr>
</tbody>
</table>
Inputs - Outputs = Change in Storage

\[ P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W \]

\( \Delta S_{io} \) = change in overstory interception storage

\( \Delta S_{iu} \) = change in understory interception storage
Inputs - Outputs = Change in Storage

\[ P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W \]

\( \Delta S_{io} = \text{change in overstory interception storage} \)

\( \Delta S_{iu} = \text{change in understory interception storage} \)

\( \Delta W = \text{change in snow-water equivalent} \)
Inputs - Outputs = Change in Storage

\[ P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W \]

- \( Q_s \) = discharge leaving the lower soil
- \( \Delta S_{s1} \) = change in upper soil storage
- \( \Delta S_{s2} \) = change in lower soil storage
Soil Coverage (USDA)
Soil Depth (estimated)
USDA Soil Classifications

1 = SAND
2 = LOAMY SAND
3 = SANDY LOAM
4 = SILTY LOAM
5 = SILT
6 = LOAM
7 = SANDY CLAY LOAM
8 = SILTY CLAY LOAM
9 = CLAY LOAM
10 = SANDY CLAY
11 = SILTY CLAY
12 = CLAY
13 = ORGANIC (as loam)
14 = WATER (as clay)
15 = BEDROCK
16 = OTHER (as SCL)
17 = MUCK
18 = TALUS
### SOIL 6

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Description</td>
<td>LOAM</td>
</tr>
<tr>
<td>Lateral Conductivity</td>
<td>0.01</td>
</tr>
<tr>
<td>Exponential Decrease</td>
<td>3.0</td>
</tr>
<tr>
<td>Maximum Infiltration</td>
<td>1e-5</td>
</tr>
<tr>
<td>Surface Albedo</td>
<td>0.1</td>
</tr>
<tr>
<td>Number of Soil Layers</td>
<td>3</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.43</td>
</tr>
<tr>
<td>Pore Size Distribution</td>
<td>0.19</td>
</tr>
<tr>
<td>Bubbling Pressure</td>
<td>0.11</td>
</tr>
<tr>
<td>Field Capacity</td>
<td>0.29</td>
</tr>
<tr>
<td>Wilting Point</td>
<td>0.14</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>1485.</td>
</tr>
<tr>
<td>Vertical Conductivity</td>
<td>0.01</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>7.114</td>
</tr>
<tr>
<td>Thermal Capacity</td>
<td>1.4e6</td>
</tr>
</tbody>
</table>
Surface and Subsurface Flow
DHSVM Modeling Inputs and Outputs

Digital Topographic Data

Digital Land Surface Data

Time Series of Meteorological Data

Precipitation
Humidity
Temperature
Wind Speed
Shortwave Radiation
Longwave Radiation

GIS Preprocessing

DEM
Channel Network
Vegetation Layer
Soil Type
Soil Thickness
Meteorological Data
Initial Conditions

DHSVM

Streamflow
Snow & Snow Melt
Soil Moisture
Evapotranspiration
Precipitation
DHSVM Modeling Inputs and Outputs

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Initial Conditions

DHSVM
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- Snow & Snow Melt
- Soil Moisture
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- Precipitation
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- Initial Conditions

DHSVM

- Streamflow
- Snow & Snow Melt
- Soil Moisture
- Evapotranspiration
- Precipitation
Modeling Methods

- Collect and format MET and spatial data
- Calibrate the model to recorded streamflow
- Validate the model
Modeling Assumptions

• Recorded streamflow adequately captures actual streamflow.

• Recorded MET data provide an adequate representation of MET conditions in the basin.

• Model parameters, other than calibration parameters, provide an acceptable physical representation of the basin.

Simulations were performed on a Dell Precision having two, 3-GHz processors, 2 GB of RAM and a Linux platform.
Model Calibration

Alter model parameters until there is a sufficient match between the simulated streamflow and recorded streamflow. The most influential parameters are the:

- precipitation lapse rate
- soil thicknesses
- lateral hydraulic conductivity
Runoff Estimate: Lake Whatcom Water Budget Method

inputs - outputs = change in storage
Rating curve generated from the lake level-capacity data developed by Ferrari and Nuanes (2001)
Water Budget Runoff Estimate

inputs – outputs = change in storage

<table>
<thead>
<tr>
<th>Water Budget for water year (WY) 2003-2004</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
</tr>
<tr>
<td>Volume (MG)</td>
</tr>
<tr>
<td>Direct Precipitation</td>
</tr>
<tr>
<td>Diversion</td>
</tr>
<tr>
<td>Runoff</td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
</tr>
<tr>
<td>Volume (MG)</td>
</tr>
<tr>
<td>Whatcom Creek</td>
</tr>
<tr>
<td>Hatchery</td>
</tr>
<tr>
<td>Georgia Pacific</td>
</tr>
<tr>
<td>City of Bellingham</td>
</tr>
<tr>
<td>Water District 10</td>
</tr>
<tr>
<td>Evaporation</td>
</tr>
<tr>
<td>Change in Storage</td>
</tr>
</tbody>
</table>
**Water Budget Runoff Estimate**

Runoff = change in storage + outputs – direct precipitation – diversion flow

<table>
<thead>
<tr>
<th>Water Budget for water year (WY) 2003-2004</th>
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<tr>
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<tr>
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</tr>
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</tr>
</tbody>
</table>
Simulated Whatcom Creek Outflow
Runoff: Water Budget versus Simulated

- Water Budget
- Simulated

Millions of Gallons

10/1/03
11/1/03
12/2/03
1/2/04
2/2/04
3/4/04
4/4/04
5/5/04
6/5/04
7/6/04
8/6/04
9/6/04

1/3/04
2/3/04
3/3/04
4/3/04
5/3/04
6/3/04
7/3/04
8/3/04
9/3/04

-200
0
200
400
600
800
1000
1200
1400
1600
1800

2003
2004

Runoff: Water Budget versus Simulated
Model Validation

If the model is calibrated, it should adequately simulate streamflow for a different water year (e.g., different MET and recorded streamflow).
Runoff into Lake Whatcom (WY2001 to 2005)

- DHSVM (modeled)
- Water Budget Estimate

Millions of Gallons

10/1/01 2/1/02 6/1/02 10/1/02 2/1/03 6/1/03 10/1/03 2/1/04 6/1/04 10/1/04 2/1/05 6/1/05
What next?

- Constant model refinement.
- Determine the groundwater input to the lake.
- Focus on specific basins and include the effect of roads and impervious services.
- Examine sediment inputs to streams.
- Model the effect of glacial recession on diversion magnitudes.
- Simulate drought influences.
Austin Creek Stream Gauge (IWS)
Austin Creek Streamflow: WY 2004

Discharge (CFS)

- Simulated
- Recorded (IWS)

Oct Sept Mar
Rainfall (inches)

- **WY2004 (63.5 inches total)**
- **Drought (29.8 inches total)**
Deming glacier is shrinking!

Photo by Joe Wood
Geology graduate student Carrie Donnell is using DHSVM to predict how Deming glacier recession changes Middle Fork streamflow.
Middle Fork Nooksack calibration results: 2005 water year
Questions?

Lake Whatcom looking west toward the Puget Sound

Photo by Margaret Landis
Brannian Creek Stream Gauge (USGS)
Anderson Creek Stream Gauge (IWS)
Smith Creek Stream Gauge (IWS)
Olsen Creek Stream Gauge (USGS)
Major causes for water degradation in Washington

Development of the Lake Whatcom TMDL

The objectives of Ecology and researchers at Portland State are to:

1) Develop and calibrate a hydrodynamic and water quality model of Lake Whatcom using CE-QUAL-W2

2) Use the model to evaluate strategies for water quality improvement

http://www.ce.pdx.edu/w2/projects_lake_whatcom.html
Development of the Lake Whatcom TMDL

The objectives of Ecology and researchers at Portland State are to:

1) Develop and calibrate a hydrodynamic and water quality model of Lake Whatcom using CE-QUAL-W2

2) Use the model to evaluate strategies for water quality improvement

*runoff magnitudes are required inputs to the model*

http://www.ce.pdx.edu/w2/projects_lake_whatcom.html
Diversion Off

Diversion On (max of 65 cfs)
Diversion Flow into Mirror Lake

Anderson Creek Basin

Mirror Lake
Recorded Streamflow

Anderson Creek Basin

Anderson Creek Stream Gauge

Anderson Creek Rating Curve

\[ y = 5.4587x - 0.5524 \]

\[ R^2 = 0.9924 \]
Motivation

1) The lake serves as Bellingham’s drinking water supply.
2) Runoff is the largest input to the lake.

Runoff = streamflow and groundwater discharge to the lake

20 to 30% of the total runoff is groundwater (Pitz, 2005)