Physical Properties of Watersheds

Hydrology
Fluvial Geomorphology
Water Temperature
Watershed Influence on Stream Ecosystems

- Climate
  - Geology
  - Land Cover
    - Hydrologic Response
    - Sediment Load
    - Water Quality
      - Biological Communities and Ecosystem Services
Learning Objectives

Understand what a watershed is and how water moves from watershed hillslopes into streams and rivers
Be able to relate human and natural land use/land covers to a watershed’s hydrologic response
Understand the nature and sources of sediment loads in streams
Understand how scientists measure stream water and sediment discharge
Understand how restoration measures can address altered hydrologic and sediment regimes
Understand effective means of monitoring watershed hydrology, sediment loads, and physical habitat quality
Definitions

- **Hydrology** - science that encompasses the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment
- **Fluvial** – processes associated with rivers and streams
- **Geomorphology** - the study of the physical features of the surface of the earth and their relation to its geological structures
- **Fluvial Geomorphology**
Learning objectives:

Understand what a watershed is and how water moves from watershed hillslopes into streams and rivers

Be able to relate human and natural land use/land covers to a watershed’s hydrologic response
Watershed Hydrology

• Study of the spatial and temporal movement of water within a watershed
  - Includes delivery of water to and movement of water through a river or stream
Hydrologic Cycle

Fig. 2.2 – The hydrologic cycle. The transfer of water from precipitation to surface water and ground water, to storage and runoff, and eventually back to the atmosphere is an ongoing cycle.

Interagency Stream Restoration Working Group (15 federal agencies)(FISRWG).
Movement of all of this water

Stormflow

Baseflow
The Watershed

- Water-receiving area that drains into a stream
- All of the precipitation that falls into a watershed flows into that watershed’s stream
Watershed Boundary
(Drainage Divide)

- The line separating one watershed from another
Watershed Boundaries

Figure 14.4
The conceptual watershed

All land is in one watershed or another
Stormflow

- Direct Interception
- Throughfall
- Seep
- Overland
- Subsurface Storm Flow
- Groundwater
Infiltration

- **Infiltration**
  - Movement of water into soil pores
- **Infiltration rate**
  - Amount soaking in over time
- **Infiltration capacity**
  - Maximum rate water infiltrates a soil
- **Macropores (>75μm)**
- **Gravity**
- **Capillary action**

*Figure 2.5: Soil profile. Water is drawn into the pores in soil by gravity and capillary action.*
Infiltration and Runoff

- No Runoff if Rainfall Rate < Infiltration Rate
- If Rainfall Rate > Infiltration Rate
  - Water stands in small depressions
  - Travels down slope as Surface Runoff
Infiltration Rate of a Soil

- Determined by
  - Ease of entry through soil surface
  - Storage capacity of soil
  - Transmission rate through soil
Runoff

• If Rainfall Rate > Infiltration Rate = runoff and standing depressions
• Overland flow
Subsurface Flow

- Subsurface flow mixes with baseflow and increases ground water discharge to the channel.
Saturated Overland Flow

- Ground water breaks out of soil and travels to stream as overland flow or *quick return flow*.
- Rainfall becomes > infiltration rate, and all rainfall flows downslope as overland runoff.
- Combination of direct precipitation and quick return flow is called *saturated overland flow*.

*Figure 2.10: Flow paths of water over a surface. The portion of precipitation that runs off or infiltrates to the ground water table depends on the soil’s permeability rate; surface roughness; and the amount, duration, and intensity of precipitation.*
Primary Factors Influencing Runoff

- Land use/land cover
- Hydrologic soil groups
- Precipitation intensity
- Topography
- Antecedent watershed conditions
  - Saturated soils
  - Frozen soils/snowcover

Table 1 HSG based on USDA soil classification

<table>
<thead>
<tr>
<th>HSG</th>
<th>Soil Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Sand, loamy sand or sandy loam</td>
</tr>
<tr>
<td>B</td>
<td>Silt or loam</td>
</tr>
<tr>
<td>C</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td>D</td>
<td>Clay loam, silt clay loam, sandy clay, silty clay, or clay</td>
</tr>
<tr>
<td>Cover description</td>
<td>Curve numbers for hydrologic soil group</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Open space (lawns, parks, golf courses, cemeteries, etc.)</td>
<td></td>
</tr>
<tr>
<td>Poor condition (grass cover &lt;50%)</td>
<td>68</td>
</tr>
<tr>
<td>Fair condition (grass cover 50 to 75%)</td>
<td>49</td>
</tr>
<tr>
<td>Good condition (grass cover &gt;75%)</td>
<td>39</td>
</tr>
<tr>
<td>Impervious areas</td>
<td></td>
</tr>
<tr>
<td>Paved parking lots, roofs, driveways, etc. (excluding right-of-way)</td>
<td>98</td>
</tr>
<tr>
<td>Streets and roads</td>
<td></td>
</tr>
<tr>
<td>Paved; curbs and storm sewers (excluding right-of-way)</td>
<td>98</td>
</tr>
<tr>
<td>Paved; open ditches (including right-of-way)</td>
<td>83</td>
</tr>
<tr>
<td>Gravel (including right of way)</td>
<td>76</td>
</tr>
<tr>
<td>Dirt (including right-of-way)</td>
<td>72</td>
</tr>
<tr>
<td>Western desert urban areas</td>
<td></td>
</tr>
<tr>
<td>Natural desert landscaping (pervious area only)</td>
<td>63</td>
</tr>
<tr>
<td>Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)</td>
<td>96</td>
</tr>
<tr>
<td>Urban districts</td>
<td></td>
</tr>
<tr>
<td>Commercial and business (85% imp.)</td>
<td>89</td>
</tr>
<tr>
<td>Industrial (72% imp.)</td>
<td>81</td>
</tr>
<tr>
<td>Residential districts by average lot size</td>
<td></td>
</tr>
<tr>
<td>1⁄8 acre or less (town houses) (65% imp.)</td>
<td>77</td>
</tr>
<tr>
<td>1⁄4 acre (38% imp.)</td>
<td>61</td>
</tr>
<tr>
<td>1⁄3 acre (30% imp.)</td>
<td>57</td>
</tr>
<tr>
<td>1⁄2 acre (25% imp.)</td>
<td>54</td>
</tr>
<tr>
<td>1 acre (20% imp.)</td>
<td>51</td>
</tr>
<tr>
<td>2 acres (12% imp.)</td>
<td>46</td>
</tr>
<tr>
<td>Cover type</td>
<td>Treatment</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Fallow</td>
<td>Bare soil</td>
</tr>
<tr>
<td></td>
<td>Crop residue cover (CR)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Row crops</td>
<td>Straight row (SR)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SR + CR</td>
</tr>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contoured (C)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C + CR</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contoured &amp; terraced (C&amp;T)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C&amp;T + R</td>
</tr>
<tr>
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<td></td>
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</tbody>
</table>
### Runoff Curve Numbers for agricultural lands

<table>
<thead>
<tr>
<th>Cover description</th>
<th>Cover type</th>
<th>Hydrologic condition</th>
<th>Curve numbers for hydrologic soil group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Pasture, grassland, or range—continuous forage for grazing.</td>
<td>Poor</td>
<td>68</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>49</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>39</td>
<td>61</td>
</tr>
<tr>
<td>Meadow—continuous grass, protected from grazing and generally mowed for hay.</td>
<td>Poor</td>
<td>—</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>48</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>35</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>65</td>
</tr>
<tr>
<td>Brush—brush-weed-grass mixture with brush the major element.</td>
<td>Poor</td>
<td>57</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>43</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>32</td>
<td>58</td>
</tr>
<tr>
<td>Woods—grass combination (orchard or tree farm).</td>
<td>Poor</td>
<td>45</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>36</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>30</td>
<td>55</td>
</tr>
<tr>
<td>Woods.</td>
<td>Poor</td>
<td>—</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Farmsteads—buildings, lanes, driveways, and surrounding lots.</td>
<td>Poor</td>
<td>—</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
Near Surface Water Movement

- Forests moderate runoff
- Interception
  - Leaf shape & texture
  - Time of year
  - Vertical and horizontal density
  - Vegetation age
- Throughfall
- Stemflow
Ecological Infiltration Benefits

- Supports stream flow during dry weather periods
- Water is cleaned of pollutants and nutrients by soil organisms and plant roots
Stream Flow

- **Perennial** – permanently flowing (precip or groundwater abundant)
- **Ephemeral** – flow only during or immediately after precipitation (runoff dominated)
- **Intermittent** – flow only during certain times of the year (typically seasonal groundwater table intersecting channel)
  - Seasonal and typically flowing >30 days/yr
River Stage – What is it?

• Water level at some arbitrary reference point
  - Usually with zero being near streambed but also could be referenced to actual elevation above sea level
  - Historically measured with graduated staff gage - but pressure transducers now in addition
Measurement of Discharge

- Discharge – volume of water passing point in channel per unit time
- Channelized Streamflow - $Q = A \cdot v$
  
  $Q =$ discharge, m$^3$/s
  
  $A =$ x-sectional area
  
  (m$^2$) = Depth $\times$ Width
  
  $v =$ velocity (m/s)
Rating Curves

Change in Cross-Sectional Flow Area as Stream Stage Changes

$A_1 > A_2$

Stream
Flow or
Discharge
(cfs)

Stage (ft)

* Measurement of stream stage and flow
Rating curves

- Plot of river stage vs. discharge
- Based on cross-sectional area

Example of a typical stage-discharge relation; here, the discharge of the river is 40 cubic feet per second (ft³/s) when the stage is 3.30 feet (ft). The dots on the curve represent concurrent measurement of stage and discharge.

http://water.usgs.gov/edu/streamflow3.html
Anatomy of the Hydrograph

Fig. 1.14 – A storm hydrograph. A hydrograph shows how long a stream takes to rise from baseflow to maximum discharge and then return to baseflow conditions. In Stream Corridor Restoration: Principles, Processes, and Practices (1999). Interagency Stream Restoration Working Group (15 federal agencies)/FIS/RWG.
Watershed Land Use Change

Before development, rainfall followed a more convoluted path through the landscape - held in detention storage by pit and mound topography, infiltrating into organic-rich forest soil and moving slowly to the channel. The infiltrating water fed baseflow during times when it was not raining. Flood peaks were lower and came later.

After urbanization, rainfall moves rapidly to the channel with little chance to infiltrate during storms, thus baseflow is reduced. Flowing directly off impervious surfaces such as parking lots, runoff enters streams quickly raising their level. Flood peaks now come sooner and are higher, increasing flood hazards and the tempo of geomorphic change. For example, the natural 25 yr flow becomes the much more frequent 2 year flow.
Anthropogenic Extensions of the Stream Network
Baseflow

Early Stormflow

Peak Stormflow
Stream Channel Geometry

- Cross-Sectional Area \( A = W \times D \)
- Wetted Perimeter \( WP = W + 2D \)
- Hydraulic Radius \( R = \frac{A}{WP} \)
Current Velocity (V)

- Perhaps most significant characteristic affecting the biology in streams
- Mean V related to Q, D, W, and bed roughness
Current Velocity

- Near bed velocity depends on bed roughness
- Drag from Banks and air-water interface

![Diagram showing velocity and depth relationship]

- Mean velocity (also mean of 0.2 and 0.8)
- Boundary Layer
Channel Velocity

Section C

Section E

Section G

Horizontal Distance (feet)

Depth (feet)

high velocity

low velocity
Learning objectives:

Understand the nature and sources of sediment loads in streams

Understand how scientists measure stream water and sediment discharge
Watershed’s location and condition - determines the physical, chemical (and biological) conditions of the ecosystem

- **Topography** (mountains, valley, ridges, slopes) - determines climate, flow direction and speed
- **Climate** - determines precipitation, temperature, and humidity
- **Geology** (soils, bedrock) - water chemistry, water inputs to streams
- **Vegetation** - Influences organic and water inputs, water chemistry, temperature, shading
Longitudinal Trends

- Slope
- Bed material grain size
- Discharge
- Channel width and depth
- Mean flow velocity
- Relative volume of stored alluvium
Longitudinal Profile Zones

Zone 1 – Headwaters
Mountain headwater streams flow swiftly down steep slopes and cut a deep V-shaped valley. Rapids and waterfalls are common.

Zone 2 – Transfer Zone
Low-elevation streams merge and flow down gentler slopes. The valley broadens and the river begins to meander.

Zone 3 – Depositional Zone
At an even lower elevation a river wanders and meanders slowly across a broad, nearly flat valley. At its mouth it may divide into many separate channels as it flows across a delta built up of river-born sediments and into the sea.

Figure 1.27: Three longitudinal profile zones. Channel and floodplain characteristics change as rivers travel from headwaters to mouth.
Stream order
How Do We Study Streams?

Catchment System

Stream Segment

Segment System

Reach System

“Pool/Ripple” System

Microhabitat System

- leaf and stick detritus in margin
- sand-silt over cobbles
- transverse bar over cobbles
- moss on boulder
- fine gravel patch

debris dam

boulder cascade
Stream features

Important to evaluate landscape to local scales

Beechie et al. 2010

Natural River

Driving Disturbance Agents

Altered River

Beechie et al. 2010
Sediment Transport

• Basic process-form link in fluvial geomorphology
• Intermediate step linking flow to form of channel
• Channel change achieved through erosion, transport and deposition of sediment
Flowing water carries load

- Dissolved Load
- Suspended load
- Bed Load
Suspended Load

- Wash Load
  - Very fine particles (clay, silt) that are suspended in the flow
  - Essentially independent of hydraulic conditions
Suspended Load

- Little or no energy needed to keep fines suspended
- Rate of transport depends on...
  - stream capacity (Q)
  - supply of fines
  - Variable source area concept
Bedload

- Course particles that roll, bounce, or saltate along the bed of the stream
- Strongly dependent on hydraulic conditions
- Major role in channel formation and change

Bedload on White River, OR, after Nov. 2006 floods
Bed Material Load

- Bedload transport
  - At lower flows: sand transported over stable gravel armor layers
  - At higher flows: armor layer is destroyed releasing more sediment
  - Two phase flow
Getting Bedload Moving: Entrainment

- Position of particle relative to surrounding particles

Armor Layer

Shadowing & Imbrication

Sorting

- Sorting diagrams with $S_{FW}$ values 0.35, 0.50, 1.00, and 2.00

[Diagram showing flow direction and particle movement]
Sediment Yield & Large Animals
ATV Access
Figure 2.15: Particle transport. A stream’s total sediment load is the total of all sediment particles moving past a defined cross section over a specified time period. Transport rates vary according to the mechanism of transport.
Sediment Discharge Relations

• Complicated
  - Sediment waves move more slowly than flood waves
  - Exhaustion of sediment supply may occur
  - Seasonality of variability
  - Differences between rising and falling limbs of hydrographs
Components:

• Soil erosion
  - Rainfall detachment
  - Freeze/thaw
  - Overland flow

• Landslides

• Stream bank erosion

• Dust/deposition
Land Use Change
Response to Change

- Change in sediment size, sediment quantity, discharge, or slope will result in a change in at least one of the other variables, and that aggradation and degradation depend on the proportionality of sediment supply and transport capacity.

\[ Q_s \cdot D_{50} \propto Q_w \cdot S \]
Unit Stream Power

• $\omega = \gamma(QS)/w$
  
  $w = \text{width}$
  $Q = \text{discharge}$
  $S = \text{slope}$

• Rate of potential energy expenditure over unit length of channel

• Rate of doing work
Potential for Geomorphic Response

• High:
  - High stream power
  - High hydrologic variability
  - Course bed material
  - Low bank resistance
Potential for Geomorphic Response

- Low:
  - Low stream power
  - Low hydrologic variability
  - Fine bed material
  - High bank resistance
Learning Objectives

• Understand how restoration measures can address altered hydrologic and sediment regimes
• Understand effective means of monitoring watershed hydrology, sediment loads, and physical habitat quality
Settlement, land clearing, poor farming practices

Soil Conservation Service, improved farming practices

Improved farming practices
Concern about the contributions that legacy sediments may make to sediment and nutrient pollution of modern streams

James, L.A. 2013.

post-settlement alluvium

organic buried soil

sub-soil
Planform

• Influences distribution of energy across and along the channel
  - Controls sediment transport rates and patterns
• Pattern controlling process:

Pattern $\rightarrow$ Sinuosity $\rightarrow$ Stream Power $\rightarrow$ Sediment Load
Channel Sinuosity

- Channel length/straight line valley length
Rivers are dynamic, not static or “stable”
Bank Erosion

- Normal, expected process
- Wet banks are more easily eroded
  - Repeated wetting and drying
  - Frost action
- Summer flows may be less effective than frequent winter flows
- Multi-peaked flows may be more effective
- Local site characteristics are important
  - Bank material composition, flow asymmetry, and channel geometry
Highly susceptible vertical bank
Grass does little to protect banks – root depths too shallow
Vegetation bank stabilization
Water temperature

- Water quality
- Diversity + distribution + invasive species
- Habitat availability + connectivity
- Growth, reproduction, life cycle
- Environmental stressors + pathogens, disease, etc.

And more...
Influence on O₂ Concentration

O₂ concentration influences:
• chemical reactions, phosphate release
Nearly all organisms require DO for respiration

Large variation in adaptations and responses to low DO

Water temperature

Water quality

Indices of Biological or Biotic Integrity (IBIs)
Drivers of the temperature regime:

- Exposure
  - Lack of riparian shading
- Turbidity
  - Suspended solids which absorb and scatter light
- Reach volume to surface area
  - Shallow water is usually more dynamic: warming and cooling processes
- Groundwater
  - Cooler in summer, warmer in winter
  - Can acts as a thermal refuge
Learning objective:

• Understand effective means of monitoring watershed hydrology, sediment loads, and physical habitat quality
Turbidity

- Fine sediment transport (suspended load)
- Cloudiness or haziness of a fluid caused by large numbers of individual particles that are generally invisible to the naked eye, similar to smoke in air.

Mississippi River at its confluence with the St. Croix
Turbidity

- Measured by shining a light through the water and is reported in nephelometric turbidity units (NTU)
\[ \text{TSS (mg L}^{-1}\text{)} = 0.3068 \times \text{Turbidity} + 2.6961 \]

\[ R^2 = 0.9876 \]
Turbidity

- Affects light penetration and productivity, recreational values, and habitat quality, and cause lakes to fill in faster.
Turbidity

- Affects light penetration and productivity, recreational values, and habitat quality, and cause lakes to fill in faster.
Turbidity

• Increases sedimentation and siltation, resulting in harm to habitat areas for fish and other aquatic life
• Particles also provide attachment places for other pollutants and pathogens (e.g. metals and bacteria)
Turbidity

- Substrate Embeddedness
  - Smothering gravels
  - Eliminates invert and fish habitats

http://www.dep.wv.gov/WWE/getinvolved/sos/Pages/SOPhabitat.aspx
Turbidity

- Pool infilling ($V^*$ metric)

Figure 1. Representative pool in Three Creeks, a tributary to Willow Creek in Six Rivers National Forest

Many streams have USGS gages to measure stage and flow. This information is sometimes needed on at a specific location on a stream and/or on streams without a USGS gage. Monitoring the velocity/stage/flow in a stream can give us information about variations in inputs to streams.
Method Selection based on Physical Setting

- 3 factors to consider: physical setting, velocity, water depth
- Small channel – flume/v-notch weir or salt dilution method
- Medium – velocity profile via wading rod/current meter
- Large – velocity profile from bridge or tethered profiler (ADCP)
Measurement of Discharge

- Velocity profiling method
Velocity Measurements

- 0.6 method (60% below surface)
- Also, need average of velocity (20-40s)

**Measurement depth = 0.4 * depth**
Current meter set-up showing position of the tape and depth/velocity stations

Shows the 0.8 and 0.2 method

Gordon et al., 2004
Advantages of Continuous Data Collection

• Can adjust for seasonal impacts on sediment transport