ADVANCING KNOWLEDGE AND STEWARDSHIP OF FRESH WATER SYSTEMS THROUGH RESEARCH, EDUCATION, AND RESTORATION
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**
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
How do we achieve restoration?

Science

Natural River

Restored River

Driving Processes

Altered River

Restoration Solutions
Important to evaluate landscape to local scales

Beechie et al. 2010

Natural River

Driving Disturbance Agents

Altered River

Beechie et al. 2010
Reach Scale

Landscape Scale

Beechie et al. 2010
The Natural Stream Reference Condition
Forested Landscape
High Wood Loads
Beaver

Deep Pools, Abundant Gravels, Complex Channels
Shade and Cover, Cold Water, Moderated Flow Regime

Abundant Trout
Sea Runs of Shad
Freshwater Mussels
What’s wrong with our rivers?

Natural River

Fluvial Geomorphology

Altered River

Driving Processes
Human influences

Land uses alter inputs to rivers

Present day

Current landscape processes

Current habitat conditions

Current status of biota

Modification of river channels and flows

Removal or introductions of biota

Ag/Urban/Forest Remnants

Low Wood Loads

Absence of Beaver Dams

Altered River
Altered River

- Shallow Pools
- Limited Gravels
- Simple Channels
- Lack of Shade and Cover
- Warmer water
- Flashier Flow Regime
- Fragmentation
Watershed Hydrology
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.

Discharge

• volume of water passing point in channel per unit time

• $Q = A \times v$
  - $Q =$ discharge, $m^3/s$
  - $A =$ x-sectional area ($m^2$) = Depth * Width
  - $v =$ velocity (m/s)
Hydrograph

- **Rainfall Intensity (inches/hr)** vs. **Stream Discharge (cfs)**
- **Time of Rise**
- **Lag Time**
- **Rising Limb**
- **Recession Limb**
- **Stormflow**
- **Baseflow**

Fig. 1.14 A storm hydrograph. A hydrograph shows how long a storm takes to...
Stormflow
• Infiltration
  – Movement of water into soil pores

• Infiltration rate
  – Amount soaking in over time

• Infiltration capacity
  – Maximum rate water infiltrates a soil
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
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>
</tbody>
</table>
# Runoff Curve Numbers – developed urban lands

<table>
<thead>
<tr>
<th>Cover description</th>
<th>Curve numbers for hydrologic soil group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td><strong>Open space (lawns, parks, golf courses, cemeteries, etc.)</strong></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><strong>Impervious areas</strong></td>
<td></td>
</tr>
<tr>
<td>Paved parking lots, roofs, driveways, etc. (excluding right of way)</td>
<td>98</td>
</tr>
<tr>
<td><strong>Streets and roads</strong></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><strong>Western desert urban areas</strong></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><strong>Urban districts</strong></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><strong>Residential districts by average lot size</strong></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>
</tbody>
</table>
### Runoff Curve Numbers for agricultural lands

<table>
<thead>
<tr>
<th>Cover type</th>
<th>Cover description</th>
<th>Treatment</th>
<th>Hydrologic condition</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fallow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bare soil</td>
<td>—</td>
<td></td>
<td>77</td>
<td>86</td>
<td>91</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>Crop residue cover (CR)</td>
<td>Poor</td>
<td></td>
<td>76</td>
<td>85</td>
<td>90</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good</td>
<td></td>
<td>74</td>
<td>83</td>
<td>88</td>
<td>90</td>
</tr>
<tr>
<td><strong>Row crops</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Straight row (SR)</td>
<td>Poor</td>
<td></td>
<td>72</td>
<td>81</td>
<td>88</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good</td>
<td></td>
<td>67</td>
<td>78</td>
<td>85</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>SR + CR</td>
<td>Poor</td>
<td></td>
<td>71</td>
<td>80</td>
<td>87</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good</td>
<td></td>
<td>64</td>
<td>75</td>
<td>82</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Contoured (C)</td>
<td>Poor</td>
<td></td>
<td>70</td>
<td>79</td>
<td>84</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good</td>
<td></td>
<td>65</td>
<td>75</td>
<td>82</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>C + CR</td>
<td>Poor</td>
<td></td>
<td>69</td>
<td>78</td>
<td>83</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good</td>
<td></td>
<td>64</td>
<td>74</td>
<td>81</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Contoured &amp; terraced (C&amp;T)</td>
<td>Poor</td>
<td></td>
<td>66</td>
<td>74</td>
<td>80</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good</td>
<td></td>
<td>62</td>
<td>71</td>
<td>78</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>C&amp;T + R</td>
<td>Poor</td>
<td></td>
<td>65</td>
<td>73</td>
<td>79</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good</td>
<td></td>
<td>61</td>
<td>70</td>
<td>77</td>
<td>80</td>
</tr>
</tbody>
</table>
## Runoff Curve Numbers for agricultural lands

<table>
<thead>
<tr>
<th>Cover type</th>
<th>Hydrologic condition</th>
<th>Curve numbers for hydrologic soil group</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture, grassland, or range—continuous forage for grazing.</td>
<td>Poor</td>
<td>68</td>
<td>79</td>
<td>86</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>49</td>
<td>69</td>
<td>79</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>39</td>
<td>61</td>
<td>74</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Meadow—continuous grass, protected from grazing and generally mowed for hay.</td>
<td>—</td>
<td>30</td>
<td>58</td>
<td>71</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Brush—brush-weed-grass mixture with brush the major element.</td>
<td>Poor</td>
<td>48</td>
<td>67</td>
<td>77</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>35</td>
<td>56</td>
<td>70</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>30₃</td>
<td>48</td>
<td>65</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>Woods—grass combination (orchard or tree farm).</td>
<td>Poor</td>
<td>57</td>
<td>73</td>
<td>82</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>43</td>
<td>65</td>
<td>76</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>32</td>
<td>58</td>
<td>72</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Woods.</td>
<td>Poor</td>
<td>45</td>
<td>66</td>
<td>77</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>36</td>
<td>60</td>
<td>73</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>30</td>
<td>55</td>
<td>70</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>Farmsteads—buildings, lanes, driveways, and surrounding lots.</td>
<td>—</td>
<td>59</td>
<td>74</td>
<td>82</td>
<td>86</td>
<td></td>
</tr>
</tbody>
</table>
Natural, less developed, more forested, riparian buffers
Natural, less developed, more forested, riparian buffers
Near Surface Water Movement

• Forests moderate runoff

• Interception
  – Leaf shape & texture
  – Time of year
  – Vertical and horizontal density
  – Vegetation age
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.
Urban, developed, less vegetation, impervious surfaces
Urban, developed, less vegetation, impervious surfaces
Urban Watershed Restoration

- Stormwater management BEFORE stream restoration
Uncontrolled urban stormwater will destroy any in-channel restoration investment.
Agriculture, less developed, animals/crops, nutrients, and sediment
Agriculture, less developed, animals/crops, nutrients, and sediment
Natural versus Urban – Flow
Hydrologic Watershed Restoration for Flood Control

- *Increase infiltration*
- *Increase concentration time*
- *Increase baseflow (cools in summer, warms in winter)*
Case Study: How Farming Practices Can Alter Watershed Hydrology

Hydraulic Conductivity by Treatment

- **Geometric Avg**
- **Arithmetic Avg**

<table>
<thead>
<tr>
<th>Treatment Type</th>
<th>Hydraulic Conductivity (ksat) (in/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic No-Till</td>
<td>![Graph Bar]</td>
</tr>
<tr>
<td>Organic Till</td>
<td>![Graph Bar]</td>
</tr>
<tr>
<td>Conservation</td>
<td>![Graph Bar]</td>
</tr>
<tr>
<td>Conventional</td>
<td>![Graph Bar]</td>
</tr>
</tbody>
</table>
Case Study: Hydrologic Restoration of Agricultural Watershed

Hurricane Sandy Coastal Resiliency Competitive Grant Program

The Hurricane Sandy Coastal Resiliency Competitive Grant Program supports projects that reduce communities’ vulnerability to the growing risks from coastal storms, sea level rise, flooding,
White Clay Creek Watershed
Chester County, PA

**Total Area** 8 km²

Land cover distribution from National Land Cover Database (NLCD 2011)

- Open Water
- Perennial Ice/Snow
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land (Rock/Sand/Clay)
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub/Scrub
- Grassland/Herbaceous
- Pasture/Hay
- Cultivated Crops
- Woody Wetlands
- Emergent Herbaceous Wetlands

Coverage

STROUD™
Water Research Center
“Level-lip spreader” are shallow conservation swales built along the contour of the slope that collect surface runoff during rainstorms. With most storms the water that is collected will infiltrate into the ground, sediments settle out, and the water flows as groundwater to the stream. In big storms the water will flow over the level-lip evenly into the streamside forest before reaching the stream. Level-lip spreaders help reduce flooding and prevent nutrients and sediments from reaching the stream. These swales are being designed by Chester County Conservation District in partnership with the Stroud Center.
Level Lip Spreaders and Wetland storage > 10,000 m$^3$
(~25% of a 2 inch, 24 hour storm event)
Questions
Stream Geomorphology
The Master Variables: Water and Sediment

G.K. Gilbert, Mackin and others....

“Graded” river is just able to transport load supplied to it
Leopold and Bull (1979)....
Slope, width, depth, velocity, roughness, pattern and channel morphology mutually adjusted to provide the power and efficiency necessary to transport the load supplied from the drainage basin without aggradation or degradation of the channel.
Curve approaching equilibrium

Initiation of Disturbance

Sediment Load

Time

From Miller, 1997
Complex Response

Depositional Zones
Basin Outlet

Cross-Section

Time 0
Deposition

Time 1
Incision

Time 2
Re-incision

(Adapted from Schumm, 1973, 1977)
\[ \log Ca = -0.35 + (0.993) \log Wf + (0.052) \log Ad \]

- \( Ca \) = cross-sectional area of post-settlement alluvium
- \( Wf \) = floodplain width
- \( Ad \) = drainage area
Settlement, land clearing, poor farming practices

Soil Conservation Service, improved farming practices

Improved farming practices
Pre-settlement

riparian wet prairie / sedge meadow

Holocene alluvium

Late Wisconsin gravel

St. Peter sandstone

Post-settlement

cropland

box elder

dry

post-settlement alluvium

Holocene alluvium

Late Wisconsin gravel

St. Peter sandstone

pasture

wet
Habitat Units

Straight

pool

riffle

Sinuous

pool

riffle

thalweg line

or cross over
Step Pool Reach
The time factor...
Bank Erosion

- Normal, natural, important and expected process!
Channel Velocity

- Section C
- Section E
- Section G

Depth (feet)

Horizontal Distance (feet)

- High velocity
- Low velocity

Generalized Surface Streamlines

Generalized Velocity Distributions

Helical flow
Grass does little to protect banks – root depths too shallow
Vegetation bank stabilization
Restoration Should Focus On Process Instead Of Form

Why focus on process?

• Organisms are adapted to local/regional habitat conditions
• Habitats are by nature dynamic in both space and time and are controlled by physical stream processes
River Ecosystem Engineers
Restored River
Restored River

Deeper Pools
More Gravels
Increased Complexity, Shade and Cover
Cooler Water
Moderated Flow Regime
Re-Connected Habitats
ROOT WAD WITH FOOTER: SECTION

(Not to scale)

Log: 8'-12' Length
Diameter of Log 16 in. Minimum

Live Posts: roots should extend to dry season water level

Geotextile Fabric (Optional)

Root wad: if possible, partially embed root fan into river bottom

OHW, or Bankfull
Boulder: 1/2 times diameter of log

Base Flow

Streambed

Footer Log

Dry Season Water Level
Water Temperature

Water temperature

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

And more...
Water temperature

Influence on O₂ Concentration

O₂ concentration influences:
• chemical reactions, phosphate release
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 and exposed to air temps
- Groundwater inputs
  - Cooler in summer, warmer in winter
  - Can acts as a thermal refuge
- Water depth
Alkalinity

• capacity of water to resist changes in pH
• important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater
• derived from watershed geology and land use
Case Study: How Riparian Forest Restoration Transforms a Stream

Long-Term Research in Environmental Biology (LTREB): Trajectory for the Recovery of Stream Ecosystem Structure and Function during Reforestation
Restored Reach 1976 - 2015

3m over 39 years, or 8cm/yr
Restored Reach 2012 - 2019

0.6 m over 7 years, or 8 cm/yr
Meadow – Restored - Forest
Meadow – Restored - Forest
Shading

Incision

Widening

Infilling/Aggradation
QUESTIONS