Trick or Treat: Does NCD work to improve stream ecological function?
Limiting Factors & Ecological Function

- Biology
- Physicochemical
- Geomorphology
- Hydraulics
- Hydrology

Courtesy  Will Harmon, USFWS
Fish populations = Ecological Indicator

Colden et al. 2005
How do you improve a fish population?

Stocking
How do you improve a fish population?

Stocking

Regulations
How do you improve a fish population?

Stocking

Regulations

Habitat
Basics of Stream Habitat

Modified from Schlosser and Angermeier 1995
Basics of Stream Habitat

Modified from Schlosser and Angermeier 1995
Basics of Stream Habitat

Modified from Schlosser and Angermeier 1995
Fish move:
- Daily
- Seasonally
- In stochastic events

Movement frequency and distance is affected by:
- Species
- Resource availability
- Age

Habitats can be miles apart

Modified from Schlosser and Angermeier 1995
Scale

Fausch et al. 2002
Scale

Fausch et al. 2002
Aquatic Habitats in Colorado

Eastern Plains Rivers and Streams

Mountain Streams

Colorado Plateau/Wyoming Basins Rivers and Streams

Transition Zone Streams

Rio Grande Rivers and Streams

Aquatic Zones:
- Eastern Plains
- Mountain Streams
- Rio Grande
- Transition Zone
- Wyoming Basin/Colorado Plateau
Critical Trout Habitat Functions

1) Salmonid Forage Production Areas
2) High Flow Refugia
3) Low Flow & Winter Refugia
4) Spawning Habitat
5) Rearing Habitat
6) Overhead Cover
7) Instream Cover
8) Connectivity

Courtesy Dave Rosgen, Wildland Hydrology
Departure from Natural Forms:

- Channelization
- Loss of Floodplain Connectivity
- Removal of Wood
- Habitat Fragmentation
- Altered Hydraulic Conditions
The Flood...
- Boulder Creek – 25 year event
- Poudre River – 50 year event
- Big Thompson – 100 year event
- St. Vrain Creeks – 500 year event
Benefits from Flood?

• Physical Habitat
  – Recruitment of large wood
Benefits from Flood?

- Physical Habitat
  - Recruitment of large wood
  - Geomorphic benefits to habitat and channel stability
South Fork St Vrain Creek
Bohn Park
Pre-flood, April 2012
South Fork St Vrain Creek
Bohn Park
Post-flood, October 2013
Benefits from Flood?

• Physical Habitat
  – Recruitment of large wood
  – Geomorphic benefits to habitat and channel stability
  – Recruitment of inchannel boulders
Benefits from Flood?

• Physical Habitat
  – Recruitment of large wood
  – Geomorphic benefits to habitat and channel stability
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• Biological
  – Disturbance and re-setting vegetative communities
Benefits from Flood?

• Physical Habitat
  – Recruitment of large wood
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• Biological
  – Disturbance and re-setting vegetative communities
  – Improve connectivity at damaged and destroyed diversions/dams
Benefits from Flood?

• Physical Habitat
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  – Geomorphic benefits to habitat and channel stability
  – Recruitment of inchannel boulders

• Biological
  – Disturbance and re-setting vegetative communities
  – Improve connectivity at damaged and destroyed diversions/dams
  – Fish populations
What impact did the flood have on trout populations?

- Post-flood fish surveys conducted at multiples sites in severely impacted locations

- Trout abundance variable ranging from 58% decline to 89% increase over pre-flood population estimates
North Fork St. Vrain Creek
Meadow Park
Post-flood, February 2014
Post-Flood Fishery Assessment: St. Vrain Creek

Trout Abundance (#/mile)

- Rainbow Trout
- Brown Trout

Pre-flood
- 2009
- Post-flood
- 2013
- Post-flood
- 2014
What impact did the post-reconstruction have on trout populations?

• Post-flood reconstruction sites surveyed after construction activities had ceased

• Trout population abundance declined on average 95% after post-flood reconstruction

• Populations still below pre-flood 3 years after impact from post-flood reconstruction
South Fork St Vrain Creek
Bohn Park
Post-flood, February 2014
Post-Flood Fishery Assessment: St. Vrain Creek

![Graph showing trout abundance pre- and post-flood and post-channelization.]

- Rainbow Trout
- Brown Trout

**Trout Abundance (#/mile)**

- **Pre-flood**
  - 2005
  - 2013

- **Post-flood**
  - 2014
  - Post-channelization
The Culprits:

• Channelization
• Armoring
Multi-Stage Channel Design

• **Stage 1** – The low flow or inner berm channel
• **Stage 2** – The bankfull stage channel
• **Stage 3** – The active floodplain at the incipient point of flooding
• **Stage 4** – The infrequent but highest flood-level stage

(Used with permission from D.L. Rosgen)
Trapezoidal Channels

- Bank Vegetation
- Fish Habitat
- Sediment Transport
- Flood Stage
- Functional Floodplain
- Aesthetics
Big Thompson River
Below Olympus Dam
1995
Big Thompson River
Below Olympus Dam
September 2013
Brown Trout : Big Thompson Canyon

Brown Trout (#/mile)

Below Olympus Dam  | Chuck's Place  | Bridge at Glen Comfort  | Handicap Ramp  | Waltonia  | Drake  | Idlewilde  | Indian Meadows  | Viestenz-Smith Park

Pre-flood
Brown Trout: Big Thompson Canyon

Pre-flood vs. Post-flood, 2013:
- Channelized & Armored: 95% decline in abundance
- Upstream Sites: 13% increase in abundance

Channelized & Armored
Brown Trout : Big Thompson Canyon

- Pre-flood
- Post-flood, 2013
- Post-flood, 2014

Channelized & Armored sites show a 95% decline in abundance compared to pre-flood levels.

Upstream Sites: 13% increase in abundance

Channelized & Armored: 95% decline in abundance
Big Thompson River
Drake
11/19/2013
Big Thompson River
Near Drake
Post-flood, August 2014
Big Thompson River
Near Drake
Post-flood, August 2015
North Fork Big Thompson River
Near Drake
Pre-flood, August 2014
Brown Trout: Big Thompson Canyon

Upstream Sites: 13% increase in abundance
Channelized & Armored: 95% decline in abundance
Brown Trout : Big Thompson Canyon

Upstream Sites: 13% increase in abundance
Channelized & Armored: 95% decline in abundance
What is a Whitewater Park?
Typical WWP Structures

Chute

Hole
WWP Geomorphic Locations

- 21 <2% Riffle/Pool (Rosgen C or F)
- 3 Unknown
- 1 >2% Step/Pool (Rosgen A, B, or G)
Are WWPs Good Fish Habitat?
Natural Pools

Volume = 3474 ft$^3$
Max. Depth = 3.31 ft
Volume = 3697 ft$^3$
Max. Depth = 7.01 ft
Fluid dynamics model: FLOW-3D®

Whitewater park drop structure as modeled in FLOW-3D and the actual structure flowing at 173 cfs
Hydraulics: WWP vs Natural Pools

Depth ×2

Velocity ×3

Turbulence ×6

Vorticity ×2

Surging ×40
Results - Riffles
Longitudinal Profiles

WWP reach

Upper Pool
Middle Pool
Lower Pool

Water surface

Channel bottom

Natural reach

Upper Pool
Middle Pool
Lower Pool
What happens when riffles are removed?

Nov. 2012: Brown Trout Biomass

- Upstream: 333 lbs/acre
- Downstream: 133 lbs/acre
- Further downstream: 94 lbs/acre

FLOW
Habitat Suitability Criteria

- Depth (ft)
  - Juveniles: Raleigh et al. 1986

The graph illustrates the suitability of depth for juveniles and adults based on the studies mentioned.
Adult Rainbow Trout

t-test and Wilcoxon test:
$p < 0.05$
Brown Trout

Predicted

Observed

Adult Brown Trout Habitat

Brown Trout Biomass (lbs/acre)

Percent Good Habitat

Flow (cfs)

Natural

WWP
Rainbow Trout

Predicted vs. Observed Rainbow Trout Biomass (lbs/acre)

- Adult Rainbow Trout Habitat
- Flow (cfs)
- Percent Good Habitat

Observed Rainbow Trout Biomass:
- Natural
- WWP
Restoration of Natural Forms:

Conversion of single-stage to multi-stage

Improved Floodplain Connectivity

Addition of Wood

Fish passage

Natural Hydraulic Conditions
Clear Creek
Goals

1) Remove armored rip rap

2) Improve floodplain connectivity

3) Convert single stage to three-stage

4) Establish riparian vegetation

5) Enhance in-channel bedform features (i.e. spawning area development and depth cover)
Overview
High-Intensity

Before
Single-stage
Confinement = 1.2
F-stream type
High-Intensity

After

Three-stage

Confinement=2.0

Bc -Stream Type
High-Intensity Before
### High-Intensity

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Quantity</th>
<th>Units</th>
<th>Total</th>
<th>% of Total Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat Boulder</td>
<td>153</td>
<td>Each</td>
<td>234</td>
<td>65%</td>
</tr>
<tr>
<td>Boulder Structure</td>
<td>8</td>
<td>Each</td>
<td>9</td>
<td>89%</td>
</tr>
<tr>
<td>Boulder Toe</td>
<td>2,458</td>
<td>LF</td>
<td>2,708</td>
<td>91%</td>
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<tr>
<td>Pool Development</td>
<td>10</td>
<td>SF</td>
<td>14</td>
<td>71%</td>
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<tr>
<td>Point-Bar Development</td>
<td>5,420</td>
<td>SF</td>
<td>5,420</td>
<td>100%</td>
</tr>
<tr>
<td>Riparian Bench</td>
<td>18,775</td>
<td>SF</td>
<td>18,775</td>
<td>100%</td>
</tr>
</tbody>
</table>
High-Intensity Treatment: Trout Density (#/mile)

Brown Trout Density (#/mile)

Year

High-Intensity Treatment: Trout Density (#/mile)

160% increase
High-Intensity Treatment: Trout Biomass (lbs/ acres)

Year

Brown Trout Biomass (lbs/acre)

CONSTRUCTION

High-Intensity Treatment: Trout Density (#/mile)

160% increase

High-Intensity Treatment: Trout Biomass (lbs/ acres)

408% increase
Low-Intensity

Before
Single-stage
Confinement=1.2
F-stream type
After

Single-stage Confinement=1.2

F-stream type

Low-Intensity
## Low-Intensity

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Quantity</th>
<th>Units</th>
<th>Total</th>
<th>% of Total Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat Boulder</td>
<td>81</td>
<td>Each</td>
<td>234</td>
<td>35%</td>
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<tr>
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<td>Each</td>
<td>9</td>
<td>11%</td>
</tr>
<tr>
<td>Boulder Toe</td>
<td>250</td>
<td>LF</td>
<td>2,708</td>
<td>9%</td>
</tr>
<tr>
<td>Pool Development</td>
<td>4</td>
<td>Each</td>
<td>14</td>
<td>29%</td>
</tr>
<tr>
<td>Point-Bar Development</td>
<td>0</td>
<td>SF</td>
<td>5,420</td>
<td>0%</td>
</tr>
<tr>
<td>Riparian Bench</td>
<td>0</td>
<td>SF</td>
<td>18,775</td>
<td>0%</td>
</tr>
</tbody>
</table>
Low-Intensity Treatment: Trout Density (#/mile)

Brown Trout Density (#/mile)

- 2012: Low-Intensity Treatment
- 2013: Low-Intensity Treatment
- 2014: Low-Intensity Treatment
- Spring 2015: Low-Intensity Treatment
- 2015: Construction
- 2016: Construction
- 2017: Construction
- 2018: Construction
Low-Intensity Treatment: Trout Density (#/mile)

77% increase
Low-Intensity Treatment: Trout Biomass (lbs/acre)

Brown Trout Biomass (lbs/acre) vs Year

- 2012: 40 lbs/acre
- 2013: 30 lbs/acre
- 2014: 50 lbs/acre
- Spring 2015: 80 lbs/acre
- 2015: 60 lbs/acre
- 2016: 50 lbs/acre
- 2017: 90 lbs/acre
- 2018: 70 lbs/acre
Low-Intensity Treatment: Trout Density (#/mile)

77% increase

Low-Intensity Treatment: Trout Biomass (lbs/ acres)

59% increase
Kleinschmidt Creek - full channel restoration
Conversion of a C5 to an E4 stream type

<table>
<thead>
<tr>
<th>Channel form</th>
<th>Before (C5)</th>
<th>After (E4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel length - (km)</td>
<td>1.97</td>
<td>2.73</td>
</tr>
<tr>
<td>Sinuosity</td>
<td>1.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Stream slope - (m/m)</td>
<td>0.0058</td>
<td>0.0040</td>
</tr>
<tr>
<td>Valley slope - (m/m)</td>
<td>0.0064</td>
<td>0.0064</td>
</tr>
<tr>
<td>Bankfull discharge - $Q_{bkf}$ (m$^3$/s)</td>
<td>0.71</td>
<td>0.71</td>
</tr>
<tr>
<td>Bankfull width - $W_{bkf}$ (m)</td>
<td>20.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Bankfull depth - $d_{bkf}$ (m)</td>
<td>0.13</td>
<td>0.35</td>
</tr>
<tr>
<td>Bankfull W/D ratio</td>
<td>150</td>
<td>8.8</td>
</tr>
<tr>
<td>Bankfull cross-sectional area - $A_{bkf}$ (m$^2$)</td>
<td>2.6</td>
<td>1.1</td>
</tr>
</tbody>
</table>

**Hydraulic function**

| Bankfull mean velocity - $\bar{u}_{bkf}$ (m/s) | 0.27 | 0.67 |
| Bankfull shear stress - $T$ (newtons/m$^2$)   | 7.4  | 13.7 |
| Particle entrainment size (mm)                | 11   | 21   |

Pierce et al., 2015, TAFS, 144, 184–195
Trout response to channel restoration in Kleinschmidt Creek, 1998–2012

Pierce et al., 2015, TAFS, 144, 184–195
Before/After Control/Treatment Study

Monitoring Results: Buckley Ranch

BACI study

C. Wood

B. Rock

A. Unimproved
Control-Utreated
Boulder-Treated Vs Control-Untreated
**Boulder-Treated Vs Control-Untreated**

**Monitoring Period:**
1990-2018: 28 YEARS!

**Pre- vs Post:**
- Boulder-Treated: 56% increase compared with pre-project baseline.

- Control-untreated: 53% decline over the same time period.

**Boulder vs Control:**
- Brown trout biomass in the boulder-treated reach averaged 32% higher over the control-untreated reach.
Toewood-Treated
Toewood-Treated Vs Control-Untreated

Brown trout biomass (lbs/acre)

Year

2010
2011
2012
2013
2014
2015
2016
2018

Toewood-Treated
Control-Untreated
Toewood-Treated vs Control: Untreated

Monitoring Period:
2010-2018: 8 YEARS

Toewood-Treated vs Control:
• Brown trout biomass in the boulder-treated reach averaged 34% higher over the control-untreated reach
Toewood-Treated Vs Boulder-Treated

Brown trout biomass (lbs/acre)

Year

2010 2011 2012 2013 2014 2015 2016 2018
Toewood-Treated Vs Boulder-Treated

Monitoring Period:
2010-2018: 8 YEARS

Toewood-Treated vs Boulder-Treated:
• Brown trout biomass in the Toewood-Treated reach averaged 7% higher over the Boulder-Treated
Toewood-Treated Vs Reference

Brown trout biomass (lbs/acre)

Year

2010 2011 2012 2013 2015 2016 2018

Reference
Toewood-Treated
Toewood-Treated Vs Reference

Monitoring Period:
2010-2018: 8 YEARS

• Brown trout biomass in the Reference reach averaged 107% higher over the Toewood-Treated
Summary

 Restoration of natural stream forms (NCD) may restore natural habitats that provide the functions necessary for improving fish populations over time.
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- Departure from natural conditions may have negative consequences to fish populations that may not recover without physical intervention.
**Summary**

- Restoration of natural stream forms (NCD) may restore natural habitats that provide the functions necessary for improving fish populations over time.

- Departure from natural conditions may have negative consequences to fish populations that may not recover without physical intervention.

- Assess limiting factors that may occur outside of geomorphology (channel forms) including departures from natural hydrologic regimes, hydraulics, physicochemical properties, and barriers.
Summary

Not all treatment alternatives are equal. Some treatments will accomplish a “bigger bang for the buck”
Summary

Not all treatment alternatives are equal. Some treatments will accomplish a “bigger bang for the buck”

Carefully consider selection of reference reaches for biological monitoring. Use an average of multiple reference sites if possible