HYDROLOGY STUDY FOR FALL RIVER, UPPER BIG THOMPSON RIVER, BLACK CANYON CREEK AND DRY GULCH

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WRIGHT WATER ENGINEERS, INC.
Overview of Presentation

Motivation and purpose of study
Overview of watersheds and published hydrology
Approach to updating hydrology
Progress and schedule
Questions and comments
Motivation and Purpose
Funding Source

- Community Block Development Grant - Disaster Recovery Round 2 Planning Grant

- Administered by the Colorado Department of Local Affairs
Flood Risk

- Four streams studied run through urban areas and affect infrastructure and property along streams.
- Causes of flooding include intense rainfall, which has the potential to occur when soils are saturated, or when snow is melting.
- Other potential hazards include increased runoff from wildfire areas, climate variability, and debris damming/breaching.
- Current peak discharge estimates published in Flood Insurance Study (FIS) date to 1977 (revised in 1985).
Overview of Watersheds
Severe Flood Damage from Mountain Streams
Goals of Study

- Develop peak discharge estimates for 2- (50%), 5- (20%) 10- (10%), 25- (4%), 50- (2%), 100- (1%), 200- (0.5%), and 500-year (0.2%) return period design events for design points in watersheds

- Review, evaluate and incorporate previous studies and observations from September 2013 flood in analysis

- Use multiple methods to assess reasonableness of modeled peak discharges

- Obtain expert peer review on results and recommendations

- Let science and sound engineering guide the way
Governing Principles

1. Use scientifically accepted methods and sound engineering principles

2. Tie hydrology back to reality by comparing with actual rainfall/runoff events
Revised hydrology will be used for:

- New floodplain mapping
- Floodplain Administration
- Planning and mitigation projects
Watersheds and Published Hydrology
Upper Big Thompson

Total Area = \(~87\text{ mi}^2\)

Total Impervious Area = \(~10\text{ mi}^2\)

Maximum Elevation = \(~12,500\text{ feet}\)

Minimum Elevation = \(~7,550\text{ feet}\)
Upper Big Thompson
Upper Big Thompson Watershed
Upper Big Thompson Watershed
Fall River

Total Area = ~40 mi²
Total Impervious Area = ~5 mi²
Maximum Elevation = ~13,500 feet
Minimum Elevation = ~7,550 feet
Fall River
Black Canyon Creek

Total Area = ~10 mi$^2$

Total Impervious Area = ~0.2 mi$^2$

Maximum Elevation = ~12,850 feet

Minimum Elevation = ~7,550 feet
Black Canyon Creek
Dry Gulch

- Total Area = $\sim 6 \text{ mi}^2$
- Total Impervious Area = $\sim 0.2 \text{ mi}^2$
- Maximum Elevation = $\sim 9,000 \text{ feet}$
- Minimum Elevation = $\sim 7,450 \text{ feet}$
Dry Gulch
## Hydrology from FIS

### Based on weighting of gauge records and regression equations

<table>
<thead>
<tr>
<th>Flooding Source and Location</th>
<th>Drainage Area (Square Miles)</th>
<th>10-Percent Annual Chance</th>
<th>2-Percent Annual Chance</th>
<th>1-Percent Annual Chance</th>
<th>0.2-Percent Annual Chance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Thompson River</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At Lake Estes Below Dry Gulch</td>
<td>156</td>
<td>2,250</td>
<td>3,800</td>
<td>4,700</td>
<td>7,200</td>
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<tr>
<td>At Lake Estes</td>
<td>137.5</td>
<td>1,510</td>
<td>1,1990</td>
<td>2,180</td>
<td>2,600</td>
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<tr>
<td>At St. Vrain Avenue</td>
<td>136.9</td>
<td>1,510</td>
<td>1,1990</td>
<td>2,180</td>
<td>2,600</td>
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<tr>
<td>At Confluence with Fall River</td>
<td>87.1</td>
<td>980</td>
<td>1,340</td>
<td>1,460</td>
<td>1,760</td>
</tr>
<tr>
<td>At Crags Drive in Estes Park</td>
<td>87</td>
<td>980</td>
<td>1,340</td>
<td>1,460</td>
<td>1,760</td>
</tr>
</tbody>
</table>

| Black Canyon Creek          |                              |                          |                         |                         |                           |
| At Confluence with Big Thompson River | 10                            | 130                      | 200                     | 230                     | 310                       |
| At Estes Park Corporate Limits | 9.3                          | 120                      | 190                     | 210                     | 290                       |

### Based on regression equations

<table>
<thead>
<tr>
<th>Flooding Source and Location</th>
<th>Drainage Area (Square Miles)</th>
<th>10-Percent Annual Chance</th>
<th>2-Percent Annual Chance</th>
<th>1-Percent Annual Chance</th>
<th>0.2-Percent Annual Chance</th>
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<tr>
<td>Dry Gulch</td>
<td></td>
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<tr>
<td>At Confluence with Big Thompson River</td>
<td>6.25</td>
<td>1,200</td>
<td>2,150</td>
<td>2,600</td>
<td>4,100</td>
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</table>

### Based on regression equations

<table>
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<th>Flooding Source and Location</th>
<th>Drainage Area (Square Miles)</th>
<th>10-Percent Annual Chance</th>
<th>2-Percent Annual Chance</th>
<th>1-Percent Annual Chance</th>
<th>0.2-Percent Annual Chance</th>
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<tbody>
<tr>
<td>Fall River</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At Confluence with Big Thompson River</td>
<td>39.9</td>
<td>450</td>
<td>610</td>
<td>680</td>
<td>830</td>
</tr>
<tr>
<td>At Estes Park Corporate Limits</td>
<td>37.3</td>
<td>450</td>
<td>610</td>
<td>680</td>
<td>830</td>
</tr>
<tr>
<td>At Upstream Detailed Study Limit</td>
<td>37.3</td>
<td>450</td>
<td>610</td>
<td>680</td>
<td>830</td>
</tr>
</tbody>
</table>

Based on weighting of gauge records and regression equations
Other Studies and Relevant Documents

- **Previous Studies**
  - Matrix Design Group, August 2014, *Fish Creek Watershed Hydrology Evaluation Public Infrastructure Project*
  - Farnsworth Group, May 2015, *Final Drainage Report: Dry Gulch Road Rehabilitation*
Other Studies and Relevant Documents

- Relevant Documents
  - Department of Natural Resources and Colorado Water Conservation Board, November 2010, Rules and Regulations for Regulatory Floodplains in Colorado
  - American Society of Engineers, 2009, Curve Number Hydrology
Approach

HEC-geo HMS
USGS Bulletin 17B Flood Frequency Analysis
September 2013 Peak Discharge Frequency Analysis
Unit Peak Discharge Comparisons
Multi-faceted Approach

- **Hydrologic Model (HEC-geo HMS)** – use best available mapping with design storm approach
- **Stream gauge peak flow analysis, evaluation of concurrent peak discharges and saturated/runoff conditions**
- **Comparison of unit peak discharges from 2013 data in context of rainfall experienced**
- **Previous studies**
HEC-HMS

- Hydrologic Modeling System (HMS) developed by United States Army Corps of Engineers Hydrologic Engineering Center (HEC)
- Commonly applied to estimate peak discharges in modeling studies for un-gauged watershed or watersheds with limited periods of gauge records.
- Accepted by FEMA
Watershed Discretization
Data

- Watershed Map
- Digital Elevation Model
- Stream Data
- Soil Survey
- Land Cover
Model Parameterization

- Automated through use of GIS
  - Curve Number
  - Basin Geometric Parameters (slopes, flow accumulation, length to centroid)
  - Flow Path Geometry (lengths, slopes and elevations of conveyance elements)

- Other Parameters
  - Unit Hydrograph
  - Channel Routing
  - Storage Assumptions
  - Crossings
HEC-HMS Model Network
Precipitation Data

- NOAA Atlas 14
  - 1-, 3-, 6-, 12-, and 24-hour depths
- Sub-watersheds assigned to precipitation zones to account for orographic effects
Precipitation Data
6-hr PF estimates with 90% confidence intervals
Latitude: 40.4005°, Longitude: -105.5870°

<table>
<thead>
<tr>
<th>Duration</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>500</th>
<th>1000-yr</th>
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<td>5-min:</td>
<td>0.20</td>
<td>0.23</td>
<td>0.30</td>
<td>0.36</td>
<td>0.48</td>
<td>0.58</td>
<td>0.69</td>
<td>0.83</td>
<td>1.02</td>
<td>1.19</td>
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<td>10-min:</td>
<td>0.30</td>
<td>0.34</td>
<td>0.44</td>
<td>0.53</td>
<td>0.70</td>
<td>0.85</td>
<td>1.02</td>
<td>1.21</td>
<td>1.50</td>
<td>1.74</td>
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<td>15-min:</td>
<td>0.36</td>
<td>0.42</td>
<td>0.53</td>
<td>0.65</td>
<td>0.85</td>
<td>1.03</td>
<td>1.24</td>
<td>1.48</td>
<td>1.83</td>
<td>2.12</td>
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<td>30-min:</td>
<td>0.46</td>
<td>0.53</td>
<td>0.67</td>
<td>0.82</td>
<td>1.07</td>
<td>1.30</td>
<td>1.57</td>
<td>1.87</td>
<td>2.32</td>
<td>2.70</td>
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<tr>
<td>60-min:</td>
<td>0.58</td>
<td>0.65</td>
<td>0.81</td>
<td>0.98</td>
<td>1.30</td>
<td>1.59</td>
<td>1.93</td>
<td>2.33</td>
<td>2.92</td>
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<td>2-hr:</td>
<td>0.69</td>
<td>0.76</td>
<td>0.94</td>
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<td>1.52</td>
<td>1.88</td>
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<td>4.15</td>
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<td>3-hr:</td>
<td>0.79</td>
<td>0.85</td>
<td>1.04</td>
<td>1.26</td>
<td>1.68</td>
<td>2.08</td>
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<td>3.11</td>
<td>3.96</td>
<td>4.69</td>
</tr>
<tr>
<td>6-hr:</td>
<td>0.98</td>
<td>1.05</td>
<td>1.26</td>
<td>1.52</td>
<td>2.01</td>
<td>2.49</td>
<td>3.05</td>
<td>3.72</td>
<td>4.74</td>
<td>5.61</td>
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<tr>
<td>12-hr:</td>
<td>1.22</td>
<td>1.32</td>
<td>1.58</td>
<td>1.89</td>
<td>2.46</td>
<td>3.00</td>
<td>3.64</td>
<td>4.39</td>
<td>5.52</td>
<td>6.50</td>
</tr>
<tr>
<td>24-hr:</td>
<td>1.48</td>
<td>1.63</td>
<td>1.99</td>
<td>2.37</td>
<td>3.04</td>
<td>3.67</td>
<td>4.38</td>
<td>5.21</td>
<td>6.45</td>
<td>7.50</td>
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</tbody>
</table>
Precipitation Input – Design Storms

- SCS Type II Distributions
- 24-hour, 12-hour, 6-hour, 3-hour
Depth Area Reduction Factors

Figure 5-13. Depth reduction factor (DRF) curves for infrequent storm events
Technical Details – Loss Method

Curves on this sheet are for the case $I_a = 0.2S$, so that

$$Q = \frac{(P-0.2S)^2}{P + 0.8S}$$

Sensitivity

- Homogeneity of sub-basin land use
- Ranges of published CN values based on soil type
- Antecedent Moisture Condition
Technical Details – Loss Method
Technical Details – Unit Hydrograph

- **Snyder unit hydrograph figure and equations**
  \[ t_l = C_t(L_{ca} L)^{0.3} \]  
  (9.24)

  where  
  - \( t_l \) = the lag time (hr) between the center of mass of the rainfall excess for a specified type of storm and the peak rate of flow
  - \( L_{ca} \) = the distance along the main stream (mi) from the base to a point nearest the center of gravity of the basin
  - \( L \) = length of the main stream channel (mi) from the base outlet to the upstream end of the stream and including the additional distance to the watershed divide
  - \( C_t \) = a coefficient representing variations of types and locations of streams

- **Snyder UH used for Fish Creek study**

- **Cp and Ct factors are calibration parameters**
Technical Details – Unit Hydrograph

**Snyder unit hydrograph figure and equations**

\[ t_{IR} = t_l + 0.25(t_R - t_r) \]  \hspace{1cm} (9.27)

where \( t_{IR} \) = the adjusted lag time (hr)
\( t_l \) = the original lag time (hr)
\( t_R \) = the desired unit-hydrograph duration (hr)
\( t_r \) = the original unit-hydrograph duration = \( t_l/5.5 \) (hr)

\[ Q_P = \frac{640 \, C_P \, A}{t_{IR}} \]  \hspace{1cm} (9.28)

where \( Q_P \) = the peak discharge (cfs)
\( C_P \) = the coefficient accounting for flood wave and storage conditions; it is a function of lag time, duration of runoff-producing rain, effective area contributing to peak flow, and drainage area
\( A \) = the watershed size (mi\(^2\))
\( t_{IR} \) = the lag time (hr)
Technical Details - Routing

- Kinematic wave equations and illustration

\[ Q = \alpha A^m \]

\[ \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \]

\[ \frac{\partial A}{\partial t} + \alpha m A^{(m-1)} \frac{\partial A}{\partial x} = q \]

This equation is a kinematic-wave approximation of the equations of motion. HEC-HMS represents the overland flow element as a wide rectangular channel of unit width; \( \alpha=1.486S^{1/2}/N \) and \( m=5/3 \). \( N \) is not Manning’s \( n \), but rather an overland flow roughness factor (Table 6-1).

- Sensitivity
  - Initial roughness parameters selected based on typical channel characteristics
  - Slope/velocity considerations
Technical Details - Routing

Table 8-2. Kinematic wave routing model information requirements

<table>
<thead>
<tr>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Shape of the cross section: Is it trapezoidal, rectangular, or circular?</td>
</tr>
<tr>
<td>Principle dimension: bottom width of the channel, diameter of the conduit.</td>
</tr>
<tr>
<td>Side slope of trapezoidal shape.</td>
</tr>
<tr>
<td>Length of the reach.</td>
</tr>
<tr>
<td>Slope of the energy grade line.</td>
</tr>
<tr>
<td>Manning $n$, roughness coefficient for channel flow.</td>
</tr>
</tbody>
</table>
Technical Details – Hydrograph

Superposition
Stream Gauge Analysis

- Bulletin 17B
- Stream Gauges Used in Analysis
  - USGS 06733000 – Big Thompson at Estes Park
    - 52 years
  - USGS 402114105350101 – Big Thompson below Moraine Park
    - 17 years
  - USGS 06732500 – Fall River at Estes Park
    - 26 years
Snowmelt Influence

- Snow melt versus rain influenced
- Big Thompson at Estes Park
  - May = 5
  - June = 45
  - July = 2
- Big Thompson below Moraine Park
  - May = 4
  - June = 11
  - July = 1
  - September = 1
- Fall River at Estes Park
  - May = 1
  - June = 15
Flood Frequency Plots

Bulletin 17B Plot for Fall River
Return Period

Flow (cfs)

Probability

- Computed Curve
- Expected Probability Curve
- 95 Percent Confidence Limit
- Observed Events (Weibull plotting positions)
- 5 Percent Confidence Limit
- High Outlier
Other Data

- Dr. Robert Jarrett (retired USGS) 2013 peak flow estimates
- NRCS 2013 peak flow estimates
- Fish Creek hydrology report
- Other reports from 2013 flood
- Regional regression equations
Progress and Schedule
## Progress and Projections

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<th>UBT</th>
<th>BCC</th>
<th>DG</th>
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<tbody>
<tr>
<td>Data/mapping gathering</td>
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<td>✓</td>
<td>✓</td>
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<td>Sept 2013 High Water Marks and Precipitation</td>
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<td>Design Points</td>
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<td>Sub-basin and Stream Delineations</td>
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<td>Late May</td>
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<td>Final Model</td>
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<td>Early June</td>
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<tr>
<td>Report</td>
<td>July</td>
<td>July</td>
<td>July</td>
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</table>
Next Planned Meetings

- June 14th Board Meeting (tentative)
- June 15th Public Meeting (tentative)

- Town of Estes Park Flood Mitigation: [www.estes.org/floodmitigation](http://www.estes.org/floodmitigation)
Questions, Comments and Discussion

Primary Contact for further questions/comments:

Tina Kurtz
Environmental Planner
Town of Estes Park, Community Development Dept.
(970) 577-3732
tkurtz@estes.org