French Broad, Nolichucky, and Pigeon River Basin Hydrologic Model Inflow Development

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Geographic Scope of Model
Upper French Broad Schematic (2/2)
Pigeon Schematic
Unimpairment

• Unimpaired (or “naturalized”) inflows necessary for testing impacts of alternative operating policies and demand levels

• Impairments include water withdrawals/discharges and reservoir regulation (including net evaporation)

• Goal: Force inflows to match monthly unimpaired gage flows, meaning measurement error is embedded in impairments and not gage flows
  – USGS gage data is treated as ground truth
### Gages Used – Nolichucky and Pigeon

<table>
<thead>
<tr>
<th>USGS Number</th>
<th>Description</th>
<th>Period of Record</th>
<th>Drainage Area (mi²)</th>
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<td>Mud Creek at Naples, NC</td>
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<td>North Fork Swannanoa River near Walkertown, NC</td>
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<td>Beetree Creek near Swannanoa, NC</td>
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<td>N Fork Swannanoa R nr Black Mountain, NC</td>
<td>2/1926 – 4/1958</td>
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</table>
Nolichucky Basin - Gage Timeline

Reference gages outside of basin used for inflow development are not shown
Reference gages outside of basin used for inflow development are not shown
Upper French Broad Basin - Gage Timeline

Reference gages outside of basin used for inflow development are not shown.
Nolichucky Basin – Gage Map

Legend

- Reservoirs
- USGS Gages

Flow Direction

- Level of impairment determined by gage flow relative to upstream impairments.
- If gage flow is:
  - Less than 10x u/s impairments → Little/None
  - 10-25x u/s impairments → Moderate
  - Greater than 25x u/s impairments → Significant

Gage has significant impairment
Gage has moderate impairment
Gage has little or no impairment

(2007 avg flow, LT avg flow)

- Nolichucky at Poplar (n/a, 986 cfs)
- Cane River near Sioux (n/a, 247 cfs)
- South Toe at Newdale (n/a, 175 cfs)
- North Toe at Altapass (n/a, 188 cfs)
- Cane River Dam
- Beaver Creek Dam
- South Toe near Celo (70 cfs, 142 cfs)
Pigeon Basin – Gage Map

Legend
- Reservoirs
- USGS Gages

Flow Direction

• Level of impairment determined by gage flow relative to upstream impairments.
• If gage flow is:
  - Less than 10x u/s impairments → Little/None
  - 10-25x u/s impairments → Moderate
  - Greater than 25x u/s impairments → Significant

Pigeon Below Power Plant (554 cfs, 1001 cfs)

Cataloochee near Cataloochee (59 cfs, 110 cfs)

Jonathan Creek (n/a, 129 cfs)

Waynesville Reservoir

Pigeon near Hepco (387 cfs, 663 cfs)

Lake Junaluska

Pigeon near Canton (169 cfs, 319 cfs)

WF Pigeon at Bethel (86 cfs, 155 cfs)

EF Pigeon (78 cfs, 140 cfs)

WF Pigeon near Waynesville (n/a, 164 cfs)

Legend
- Reservoirs
- USGS Gages

Flow Direction

• Level of impairment determined by gage flow relative to upstream impairments.
• If gage flow is:
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Pigeon Basin – Gage Map

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WF Pigeon at Bethel (86 cfs, 155 cfs)

EF Pigeon (78 cfs, 140 cfs)

WF Pigeon near Waynesville (n/a, 164 cfs)
Upper French Broad Basin – Gage Map

Legend
- Reservoirs
- USGS Gages
- Hydropower
- Flow Direction

- Level of impairment determined by gage flow relative to upstream impairments.
- If gage flow is:
  - Less than 10x u/s impairments → Little/None
  - 10-25x u/s impairments → Moderate
  - Greater than 25x u/s impairments → Significant

- French Broad at Asheville (1205 cfs, 2013 cfs)
- French Broad near Fletcher (1003 cfs, 1550 cfs)
- French Broad at Blantyre (635 cfs, 982 cfs)
- French Broad at Marshall (79 cfs, 151 cfs)
- French Broad at Hot Springs (n/a, 2656 cfs)
- French Broad at Rosman (146 cfs, 165 cfs)
- Marshall Hydropower Plant
- Bee Tree Reservoir
- North Fork Reservoir

Gage flow relative to upstream impairments:
- Gage has significant impairment
- Gage has moderate impairment
- Gage has little or no impairment

(2007 avg flow, LT avg flow)
# Reservoir Summary

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Year Constructed</th>
<th>Drainage Area (mi²)</th>
<th>Usable Storage (MG)</th>
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<td>1964</td>
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<td>Mars Hill</td>
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<td>Marshall</td>
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<tr>
<td>Hendersonville</td>
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</table>

Year Constructed Source: “Dams_June_2008” GIS files  
Drainage Area and Usable Storage Source: “Dams_June_2008” GIS files and “03 LWSP Data.xlsx”
Reservoir Storage
Inflow Development Methodology

• Reservoirs
  – Use unimpaired stream gages immediately upstream
  – Back-calculate from reservoir outflows and change in storage, adjust for upstream impairments, if data is available
  – Use drainage-area adjustment of nearby unimpaired gage

• Other nodes (e.g., stream gaging sites, withdrawal/discharge sites on rivers, environmental flow points of interest, etc.)
  – Adjust inflows for upstream impairments
Inflow Development Methodology (cont’d)

• 1. Unimpair major basin gages (mainstem and tributary) by adding back historic upstream impairments
• 2. Compute flows and gains on a monthly basis
• 3. Extend flow and gains with incomplete records using monthly and annual correlations with other gages using USGS software Fillin
• 4. Scale filled-in flows and gains to ensure total inflow to downstream points matches actual unimpaired gage flows.
• 5. Disaggregate monthly filled in flows to daily using local unimpaired gage to preserve natural variation
  – Impairment data is often only available on a monthly average, and can cause noise on a daily basis
  – Goal: to build daily flows whose variation is representative of history while preserving monthly gage flows as ground truth
Inflows for Asheville’s Reservoirs

• Inflows for Bee Tree and North Fork reservoirs had previously been developed for an OASIS model and are used for this model

• North Fork inflows
  – From 1926 to 1953, used flows from the gage immediately downstream of the existing reservoir site, adjusted for Asheville withdrawals upstream to get “unimpaired” flows and further adjusted for the slightly smaller drainage area at the reservoir
  – From 1954 to 1997, used Fillin to estimate flows based on flows at other locations
  – From 1998 to 2003, used “back-calculated” inflows from the City’s reservoir records adding change in storage, withdrawal, net evap to downstream flow
• Evaporation from adjusted Bee Tree pan evaporation study, precipitation from North Fork and adjusted Asheville and Black Mountain records

• Bee Tree inflows
  – Bee Tree creek gage, adjusted for drainage area
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<tr>
<th>Date</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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Spreadsheet Showing Gage Unimpairment

Unimpaired French Broad River at Marshall, NC

Discharge cfs
Nolichucky Withdrawals and Discharges (2013-17)
Impairments in Nolichucky Basin (1930-2017)
Pigeon Withdrawals and Discharges (2013-17)
Impairments in Pigeon Basin (1930-2017)
Upper French Broad Withdrawals and Discharges (2013-17)

Average WD = 180.9 mgd, Average Ret = 164.8 mgd
Average non-steam plant WD = 38.5 mgd, Average non-steam plant Ret = 23.0 mgd
Impairments in Upper French Broad Basin (1930-2017)

Average WD = 7.7 mgd, Average Ret = Average non-steam plant WD = 5.8 mgd
Flow Comparison: French Broad River at Asheville, daily

Unimpaired Gage = daily gage flow adjusted for impairments upstream
Naturalized Inflow = monthly cumulative inflow disaggregated to daily to preserve natural variation
Flow Comparison: French Broad River at Asheville, monthly

**Unimpaired Gage** = daily gage flow adjusted for impairments upstream

**Naturalized Inflow** = monthly cumulative inflow disaggregated to daily to preserve natural variation
Flow Comparison: Pigeon River at Hepco, daily

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Flow Comparison: Pigeon River at Hepco, monthly

Unimpaired Gage = daily gage flow adjusted for impairments upstream
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Flow Comparison: Nolichucky River at Poplar, daily

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Flow Comparison: Nolichucky River at Poplar, monthly

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Basin Withdrawals

- Burnsville WTP
- Red Hill Quartz Processing Plant (Red Hill Facility)
- Crystal Operation (Crystal Facility)
- Canton - Penland Street WTP
- Maggie Valley WTP - Campbell Creek
- Weaverville - Lawrence T. Sprinkle Jr. WTF
- Asheville Steam Electric Power Plant - Lake Julian
- Shadow Creek Trout Farm
- Asheville - Mills River Regional WTP
- Hendersonville WTP - Bradley Creek
- Bobby N. Setzer State Fish Hatchery - Davidson River
- North Buncombe Quarry - Pond 3

- The Quartz Corp USA (K-T Feldspar) - Pine Mountain
- Schoolhouse Quartz Facility
- Spruce Pine WTP - Beaver Creek
- Waynesville WTP
- Maggie Valley WTP - Jonathan Creek
- Woodfin Sanitary WSD - Sugar Camp Fork WTP
- Columbus Creek Trout Farm
- Davidson River Village
- Asheville - William DeBruhl WTP
- Hendersonville WTP - NF Mills River
- Bobby N. Setzer State Fish Hatchery - Grogan Creek
- Quartz Operation (Quartz/Feldspar Facility)
- The Feldspar Corporation
- Spruce Pine WTP - North Toe
- Blue Ridge Paper Products Inc - Canton Mill
- Brevard - Cathey's Creek WTP
- Asheville Steam Electric Power Plant - French Broad
- Gladys Fork Trout Hatchery
- Asheville - North Fork WTP
- Hendersonville WTP - Mills River
- Mars Hill WTP
- North Buncombe Quarry - Pond #1
Basin Returns as Fraction of Monthly Demand

Graph showing the basin returns as a fraction of monthly demand for various locations, including Bobby N. Setzer State Fish Hatchery, Agfa Corporation, Brevard WWTP, Asheville - William DeBruhl WTP, Hendersonville WWTP, Mars Hill - Marshall WWTP, Shadow Creek Trout Farm, and others, from January to December.
Other Basin WW Returns

- Clement Pappas Plant
- MSD of Buncombe County - French Broad River WRF
- Town of Rosman - Rosman WWTP
- Bakersville WWTP
- Transylvania Utilities Inc - Connestee Falls WWTP #1
- GE Lighting Solutions, LLC
- Silver Line Plastics Corporation
- Newland WWTP
Basin Data Needs

• Nolichucky
  – Beaver Creek Reservoir SAE and Historic Reservoir Data

• Pigeon
  – SAE and Historic Reservoir Data:
    • Waterville Lake
      – Already have daily minimum levels 2003-2018
        » (Lake Waterville Daily Minimum Levels 2003-2018.xlsx)
    • Lake Junaluska
Basin Data Needs (cont’d)

• Upper French Broad
  – SAE and Historic Reservoir Data:
    • Lake Julian
    • Bradley Creek Reservoir
    • Hendersonville Reservoir
    • Marshall (Redmon Dam)
Next Step – Model Simulation

- Basecase and alternative scenarios to be developed
- For each scenario, test a given set of facilities, operating policies, and demands over the historic inflow record
- Basecase
  - Use recent demand levels and patterns
  - Incorporate drought plans on file with DWR
- Alternatives
  - Adjust facilities, operating policies, and demands
- Documentation
- Training