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

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Advancing the Management of Water Resources

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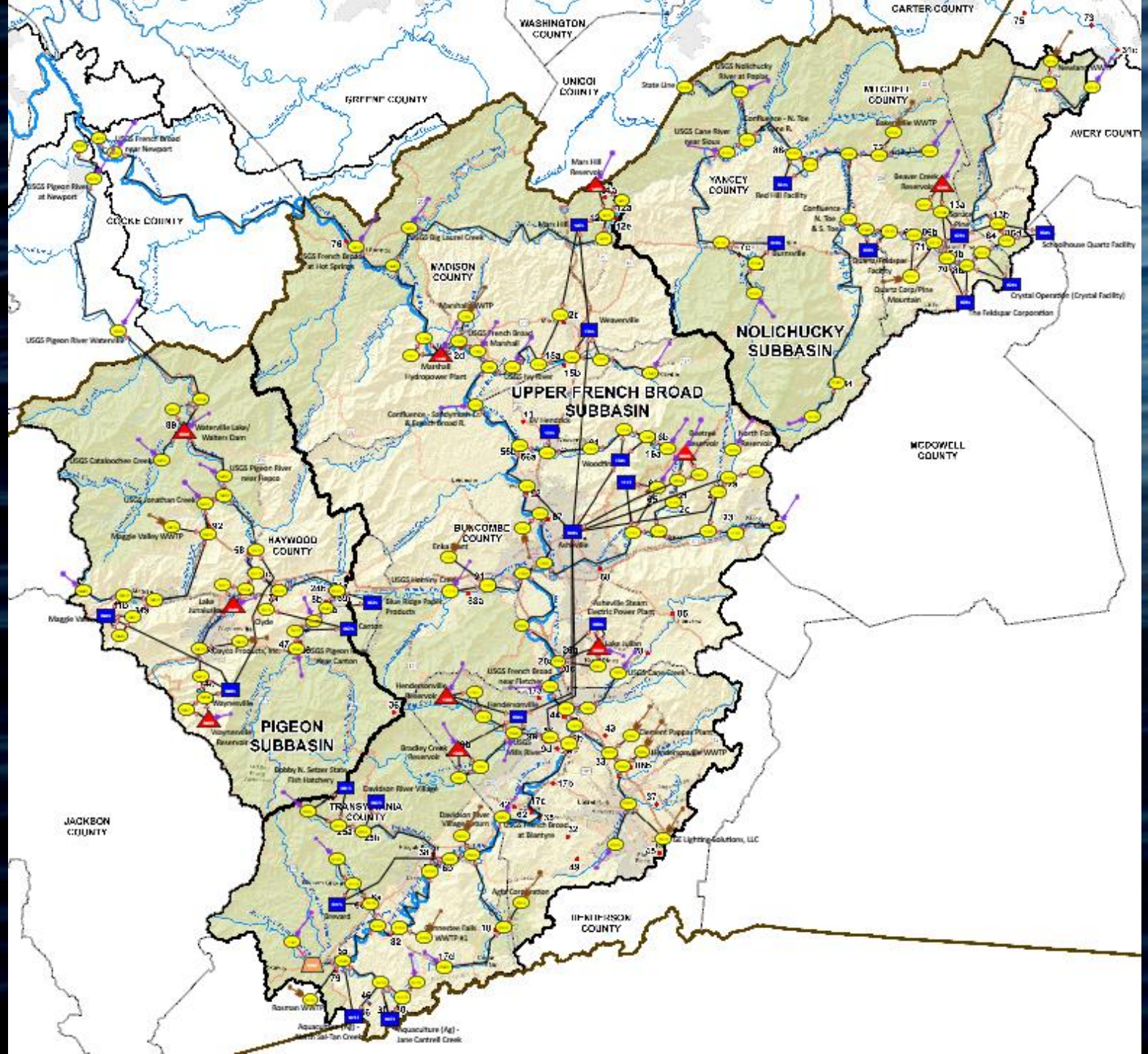
Geographic Scope of Model



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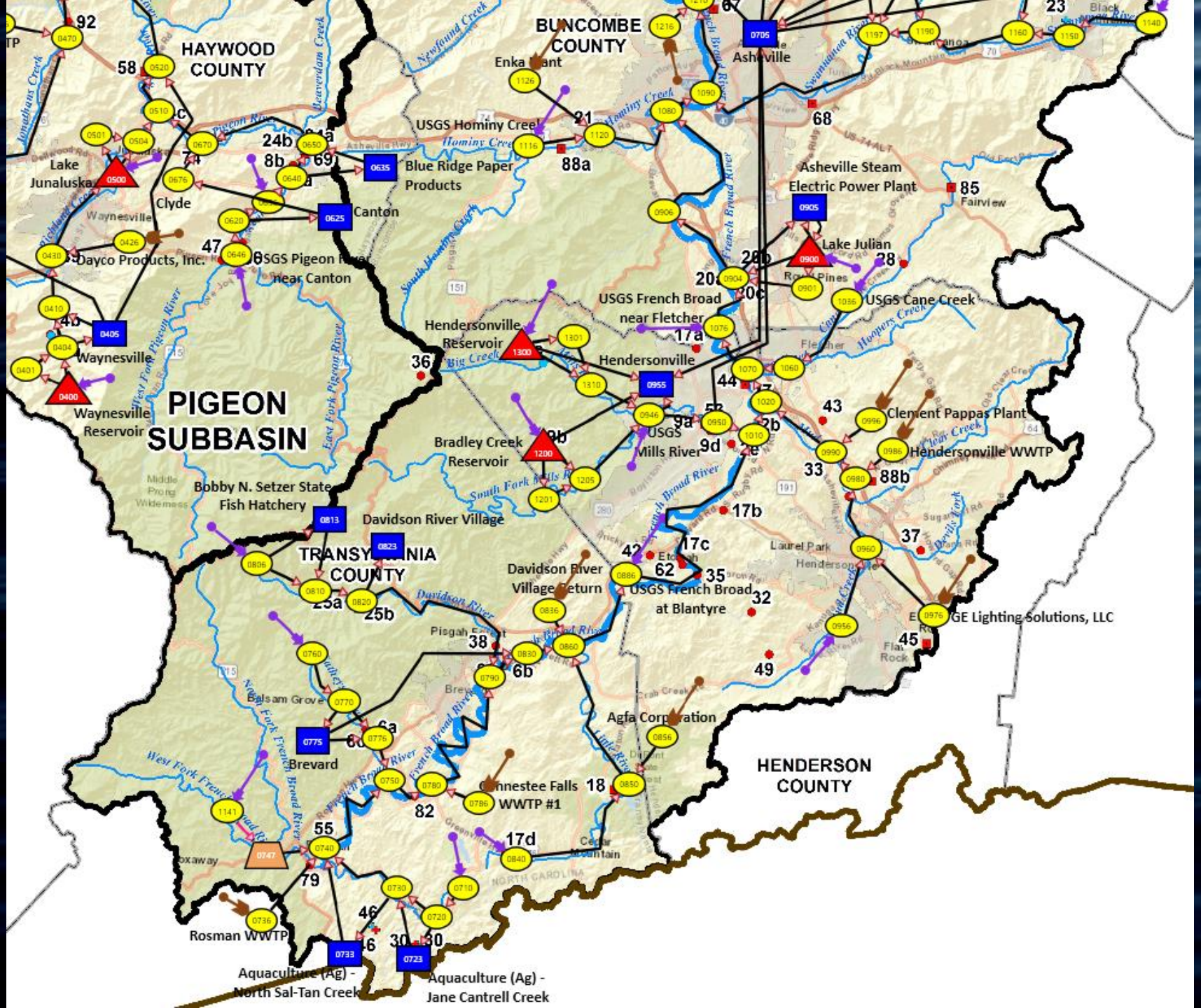

Upper French Broad Schematic (1/2)

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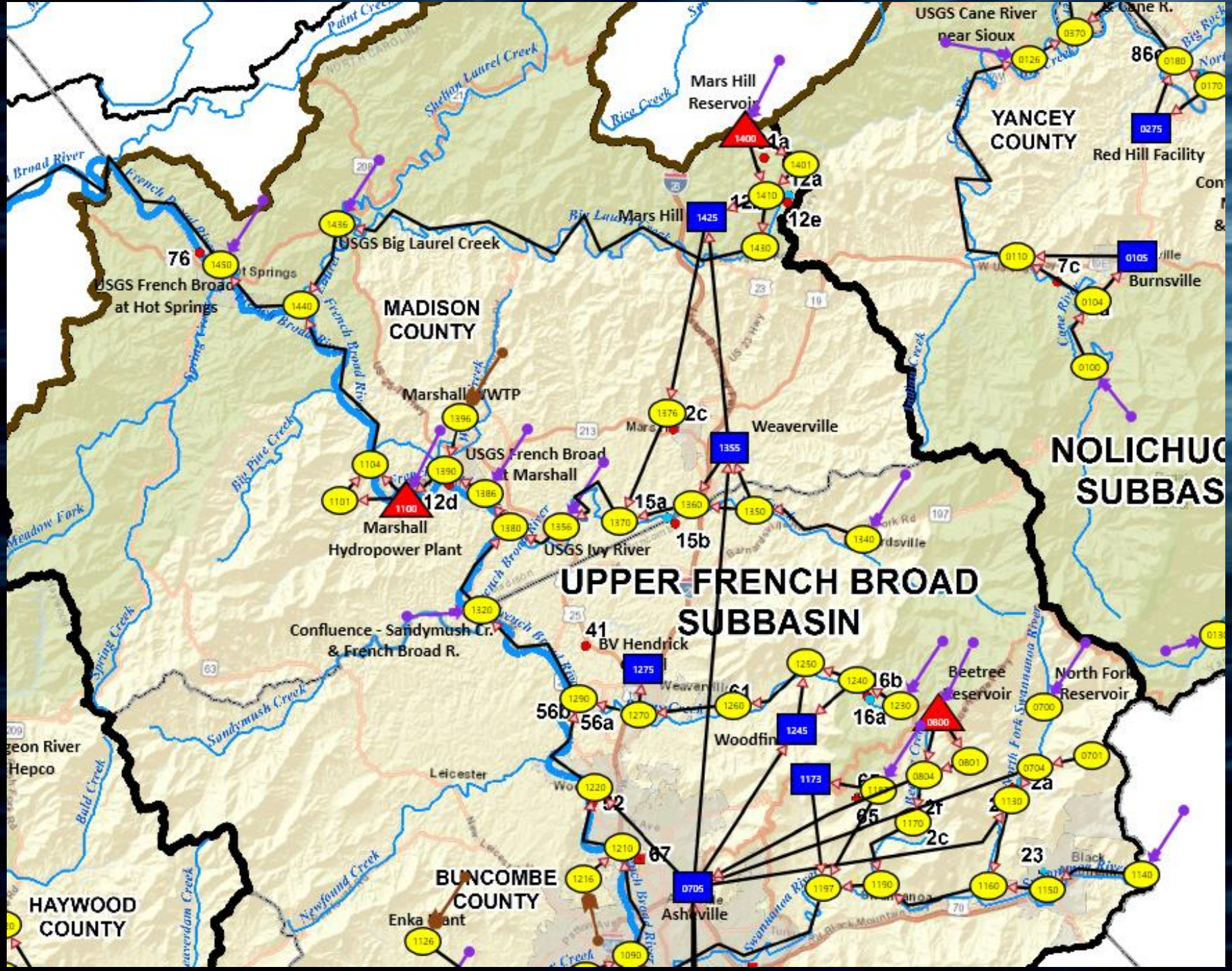
Upper French Broad Schematic (2/2)



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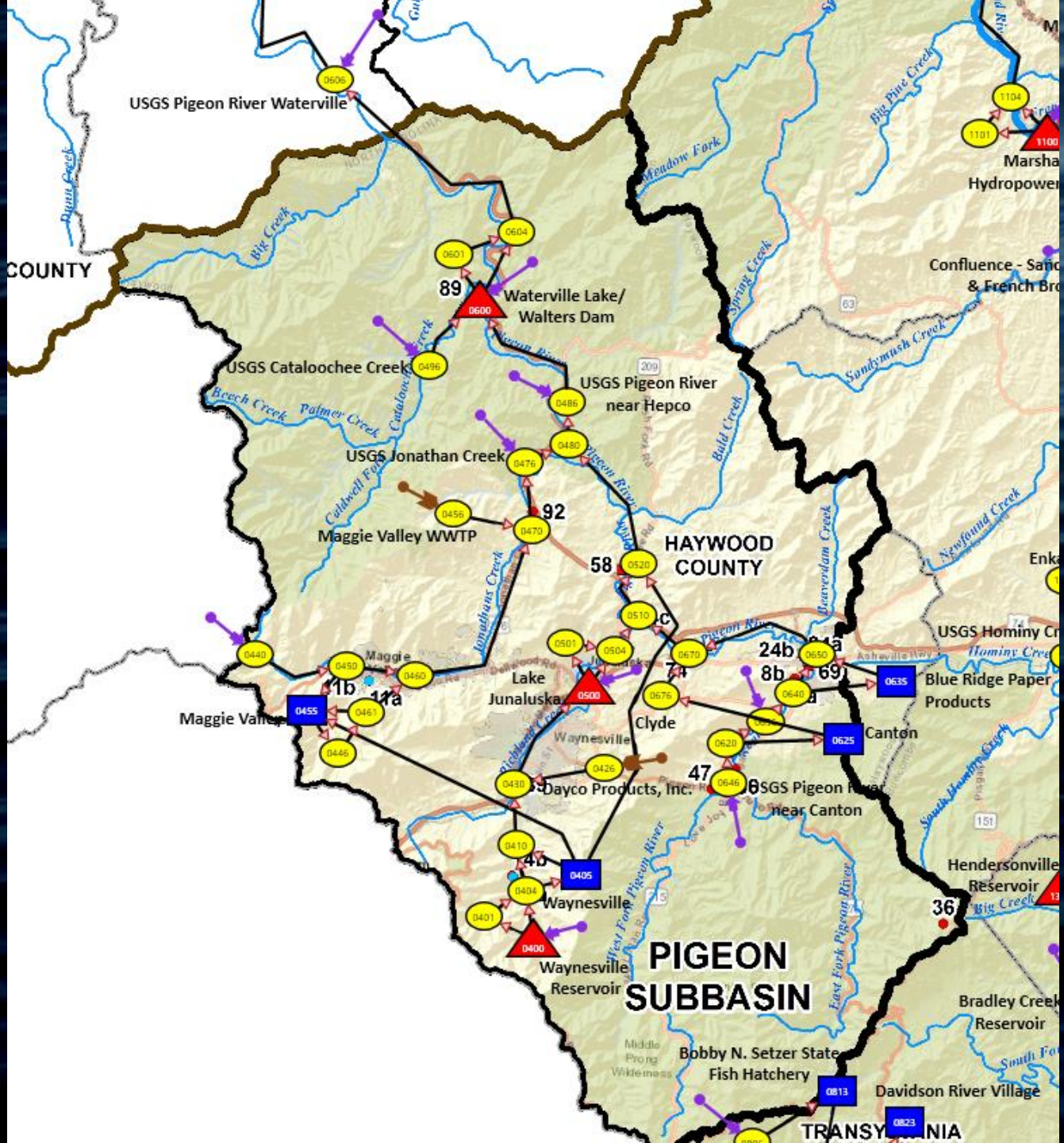
Pigeon Schematic



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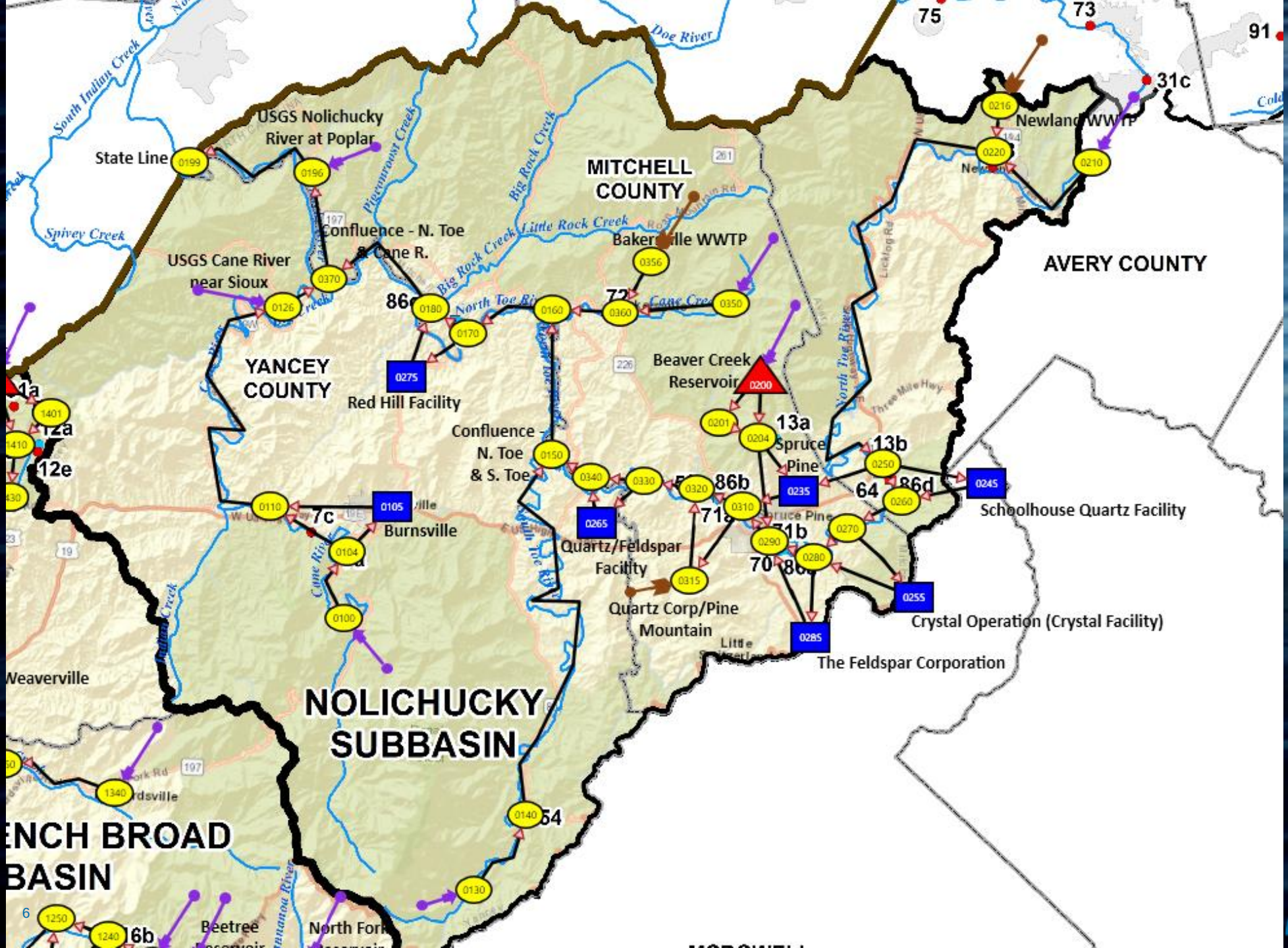
Nolichucky Schematic



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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

Nolichucky

Pigeon

USGS Number	Description	Period of Record	Drainage Area (mi²)
03464000	Cane River Near Sioux, NC	4/1934 – 10/1971	157.0
03463300	South Toe River Near Celo, NC	8/1957 – Present	43.3
03463500	South Toe River at Newdale, NC	4/1934 – 9/1952	60.8
03464500	Nolichucky River at Poplar, NC	1/1930 – 9/1955	608.0
03462000	North Toe River at Altapass, NC	10/1938 – 12/1957	104.0
03459000	Jonathan Creek near Cove Creek, NC	4/1930 – 10/1972	65.3
03459500	Pigeon River near Hepco, NC	1/1930 – Present	350.0
03460000	Cataloochee Creek near Cataloochee, NC	4/1934 – 9/1952; 10/1962 - Present	49.2
03460795	Pigeon R Bl Power Plant nr Waterville, NC	2/1997 – Present	538.0
03457000	Pigeon River at Canton, NC	1/1930 – 11/1984	133.0
03456991	Pigeon River near Canton, NC	1/1930 – 9/1931; 10/1932 - Present	130.0
03457500	Allen Creek near Hazelwood, NC	8/1949 – 10/1972	14.4
03461500	Pigeon River at Newport, TN	6/1945 – 2/1982; 3/1996 – Present	666.0
03456100	West Fork Pigeon River at Bethel, NC	1/1981 - Present	58.4
03456000	W Fk Pigeon R Bl Lake Logan nr Waynesville, NC	3/1954 – 12/1980	55.3
03456500	East Fork Pigeon River near Canton, NC	3/1954 - Present	51.5

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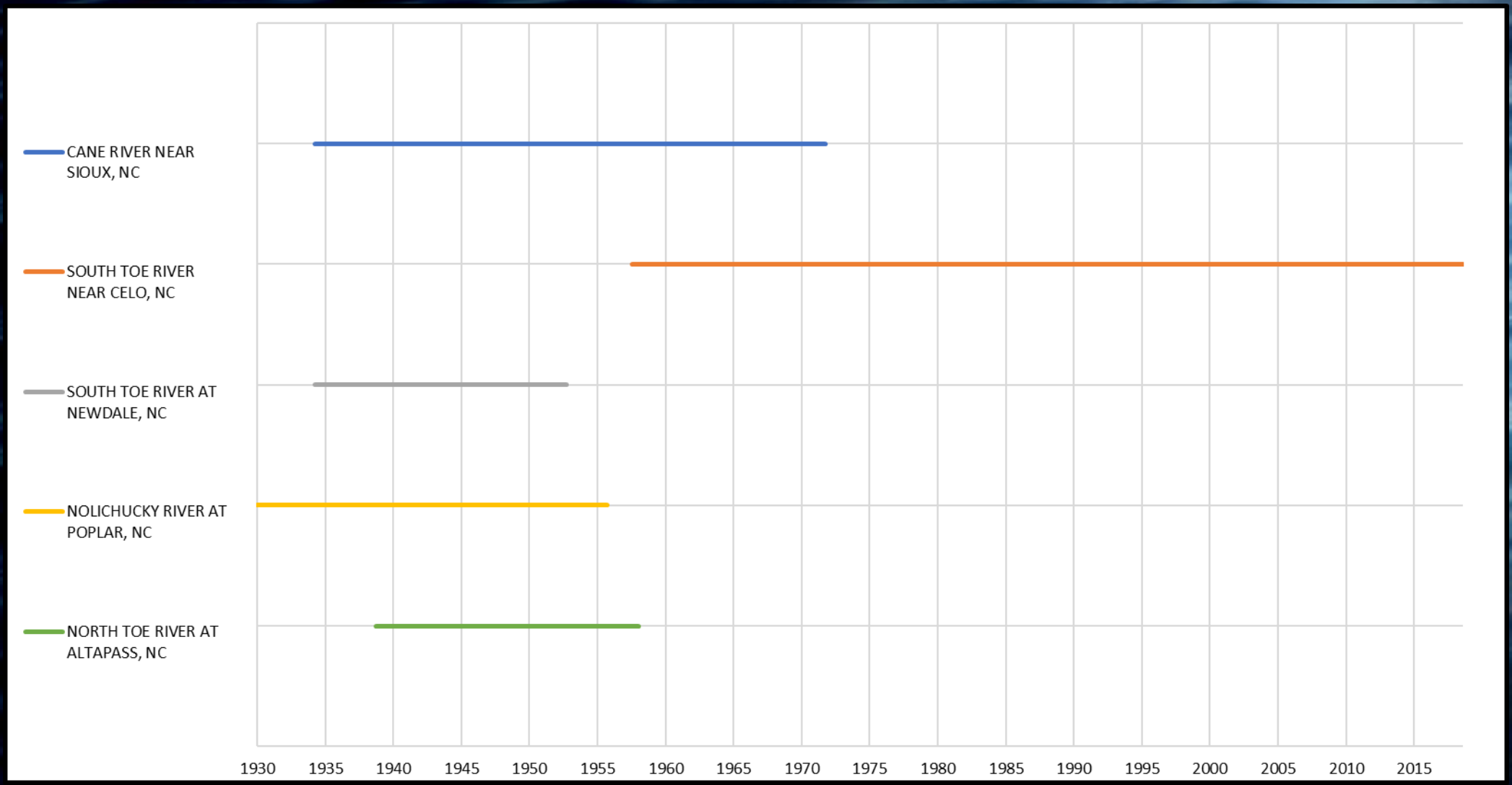
Gages Used – Upper French Broad

USGS Number	Description	Period of Record	Drainage Area (mi^2)
03447500	Cane Creek at Fletcher, NC	10/1942 – 9/1958	63.1
03447687	French Broad River near Fletcher, NC	7/2001 – Present	640.0
03448500	Hominy Creek at Candler, NC	10/1942 – 10/1977	79.8
03453000	Ivy River near Marshall, NC	4/1934 – 10/1973; 7/1994 – Present	158.0
03453500	French Broad River at Marshall, NC	10/1942 - Present	1332.0
03454000	Big Laurel Creek near Stackhouse, NC	4/1934 – 10/1971	126.0
03455000	French Broad River near Newport, TN	1/1930 - Present	1858.0
03439500	French Broad at Calvert, NC	1/1930 – 9/1955	103.0
03439000	French Broad River at Rosman, NC	10/1935 - Present	67.9
03440000	Catheys Creek near Brevard, NC	10/1944 – 9/2004	11.7
03441000	Davidson River near Brevard, NC	1/1930 - Present	40.4
03441500	Little River near Penrose, NC	10/1942 – 9/1955	41.4
03443000	French Broad River at Blantyre, NC	1/1930 - Present	296.0
03454500	French Broad River at Hot Springs, NC	4/1934 – 9/1949; 8/2011 - Present	1567.0
03451500	French Broad River at Asheville, NC	1/1930 - Present	945.0
03451000	Swannanoa River at Biltmore, NC	6/1934 - Present	130.0
03448000	French Broad River at Bent Creek, NC	6/1934 – 12/1986	676.0
03446000	Mills River near Mills River, NC	4/1934 - Present	66.7
03447000	Mud Creek at Naples, NC	10/1938 – 9/1955	109.0
03446500	Clear Creek near Hendersonville, NC	7/1945 – 9/1955	42.2
03452000	Sandymush Creek near Alexander, NC	10/1942 – 9/1955	79.5
0344894205	North Fork Swannanoa River near Walkertown, NC	10/2004 – Present	14.5
03450000	Beetree Creek near Swannanoa, NC	10/2004 - Present	5.46
03449000	N Fork Swannanoa R nr Black Mountain, NC	2/1926 – 4/1958	23.8

Nolichucky Basin - Gage Timeline



Reference gages outside of basin used for inflow development are not shown

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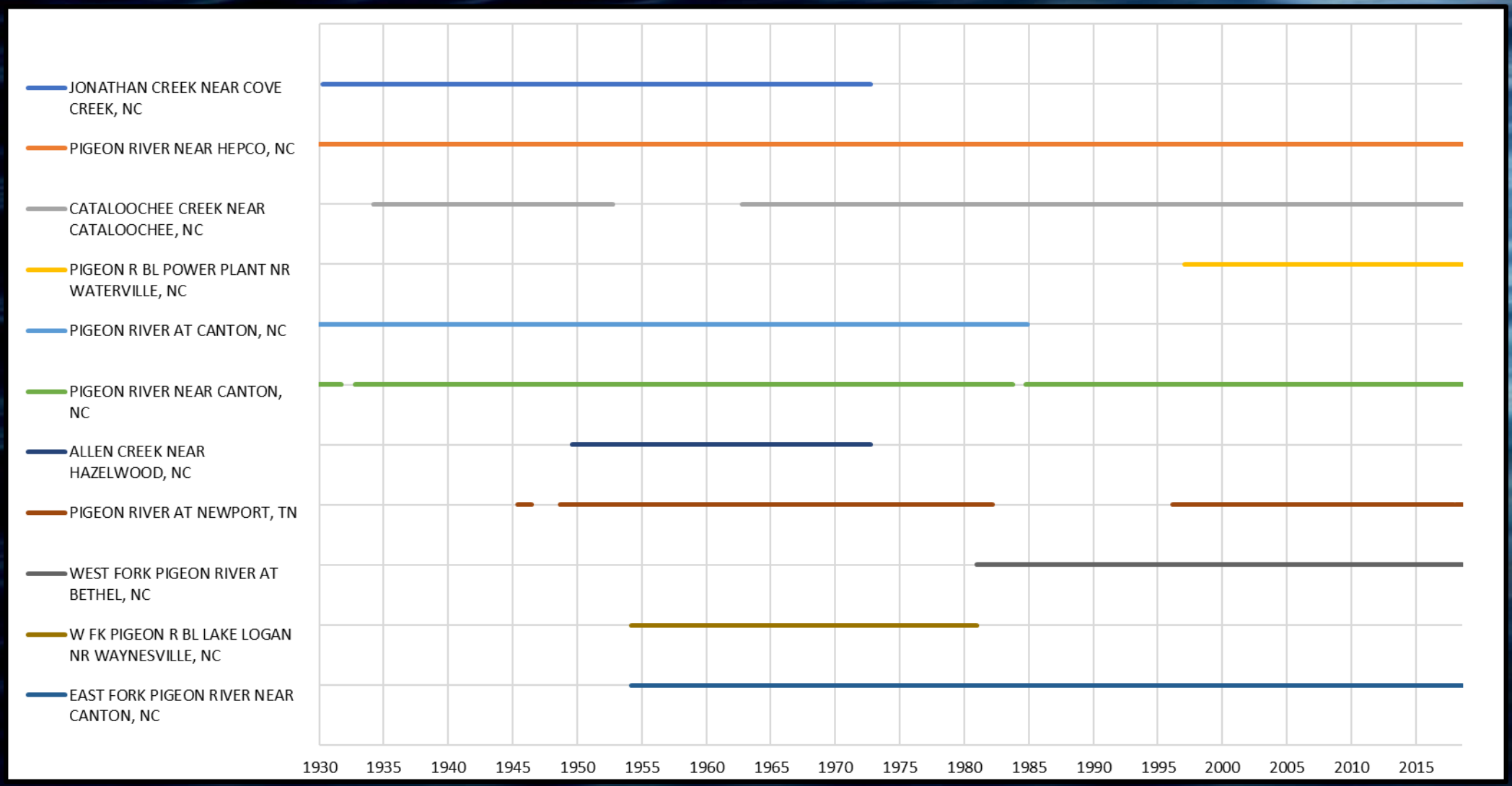
Pigeon Basin - Gage Timeline



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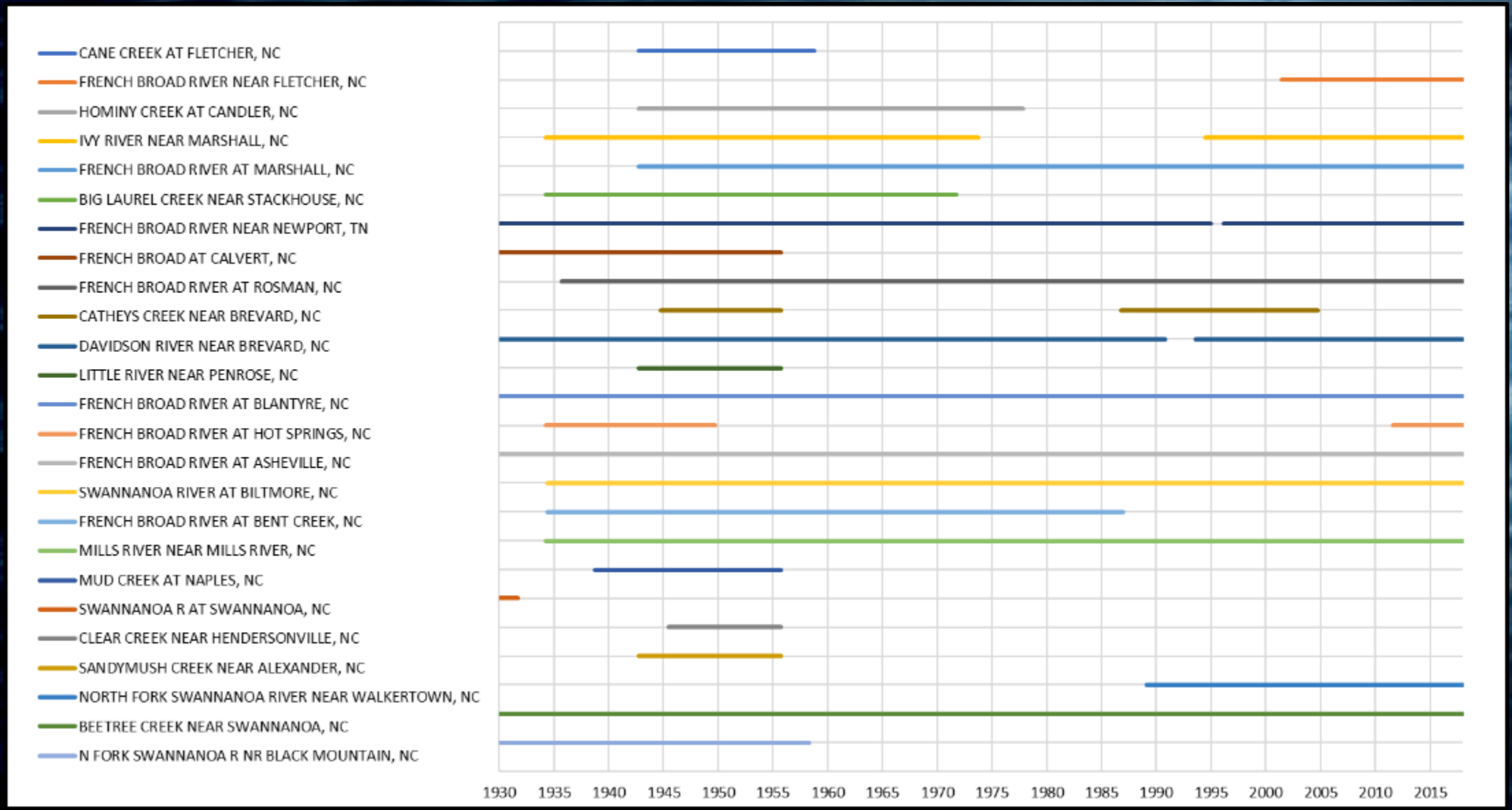
Upper French Broad Basin - Gage Timeline



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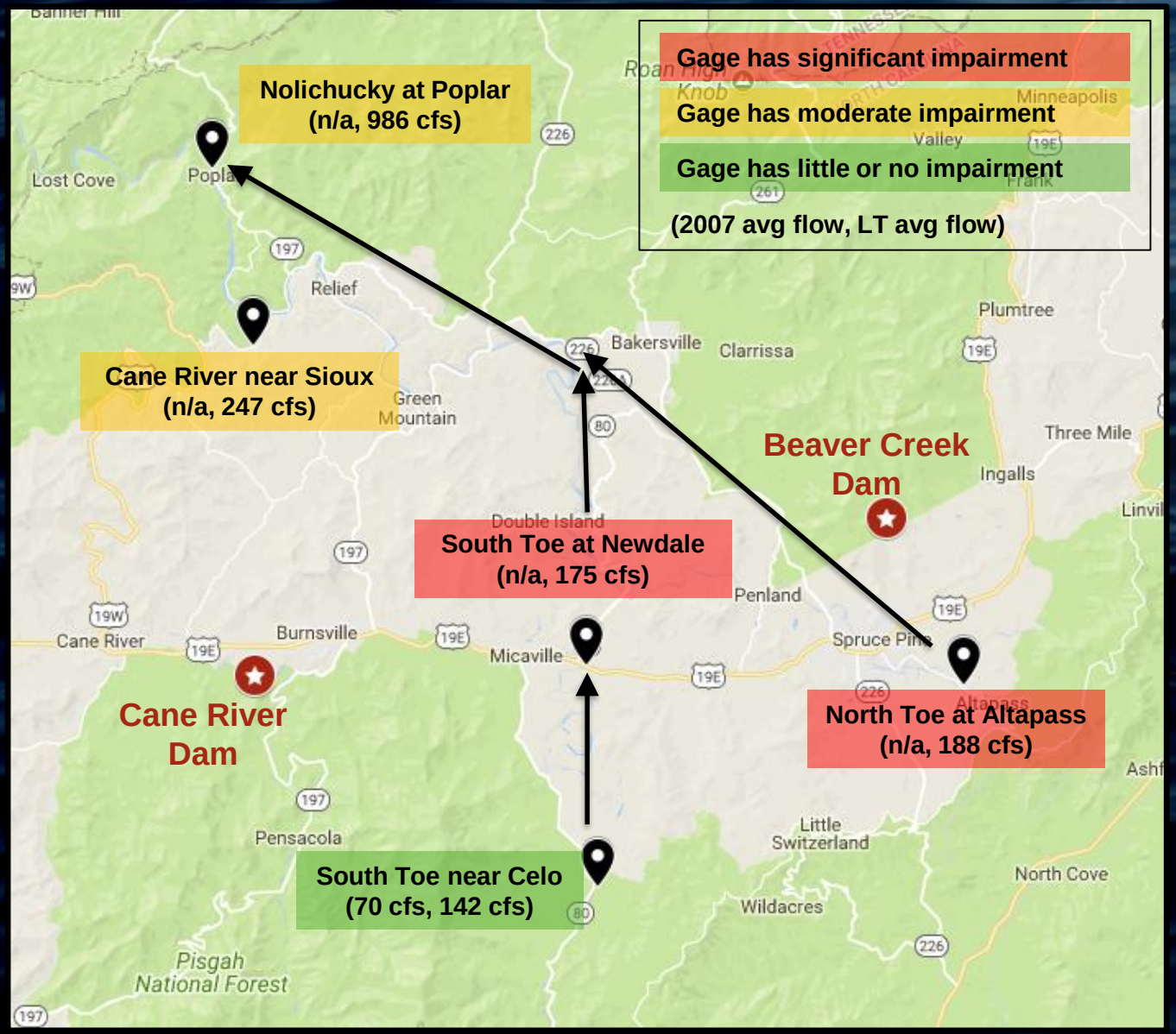
Nolichucky Basin – Gage Map



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

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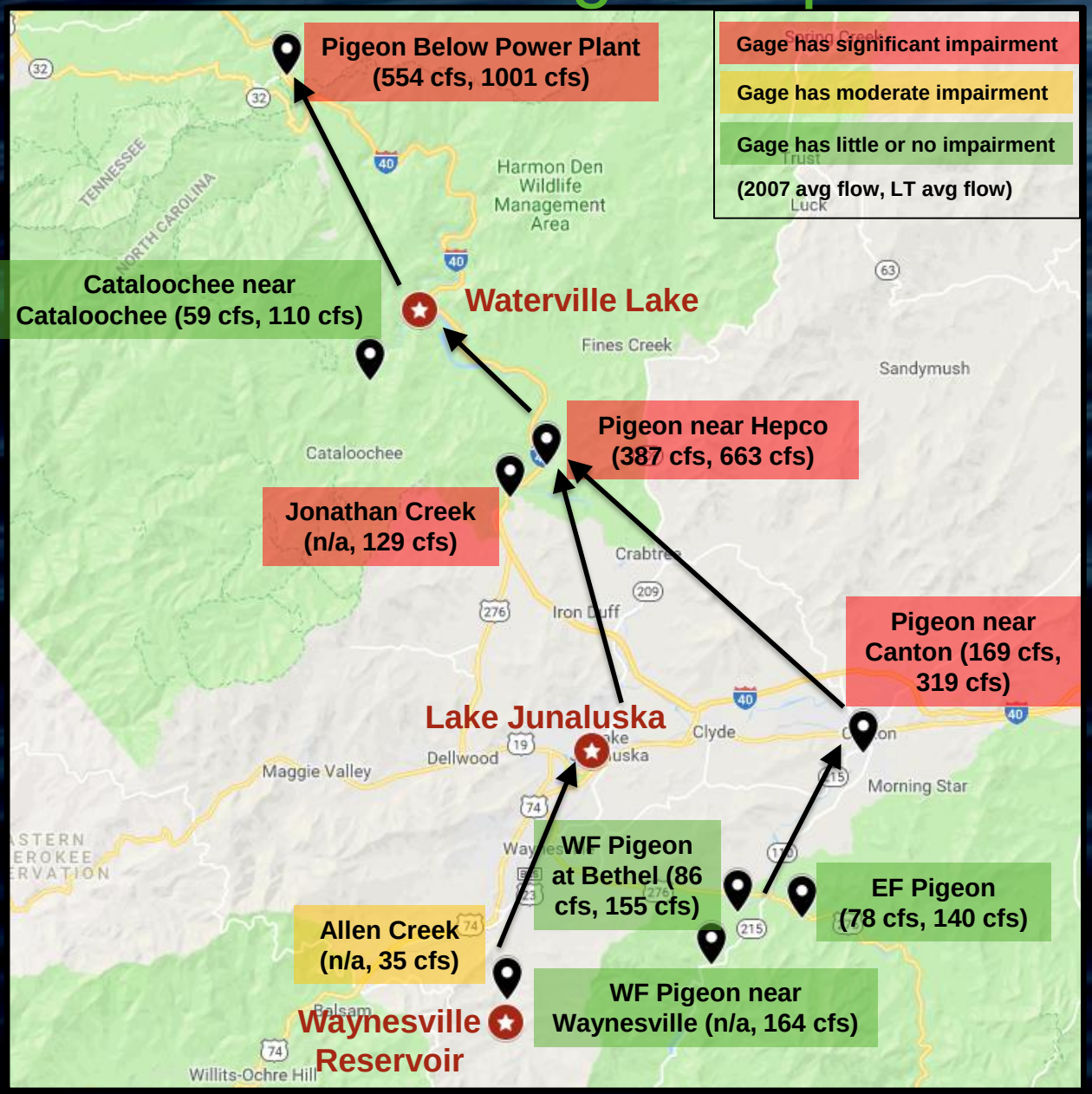
Pigeon Basin – Gage Map



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HYDROLOGICS

Upper French Broad Basin – Gage Map

Legend

- Reservoirs
- USGS Gages
- Hydropower
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Reservoir Summary

	Year Constructed	Drainage Area (mi^2)	Usable Storage (MG)
Beaver Creek		1.75	11
Junaluska	1913	63.6	
Waterville	1929	455.0	6,700
Waynesville	1982	12.9	450
Julian	1964	4.78	2,935
Beetree	1927	7.62	466
North Fork	1954	21.9	4,086
Mars Hill		0.836	10
Marshall	1911		
Bradley Creek		10.3	3
Hendersonville		13.8	4

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

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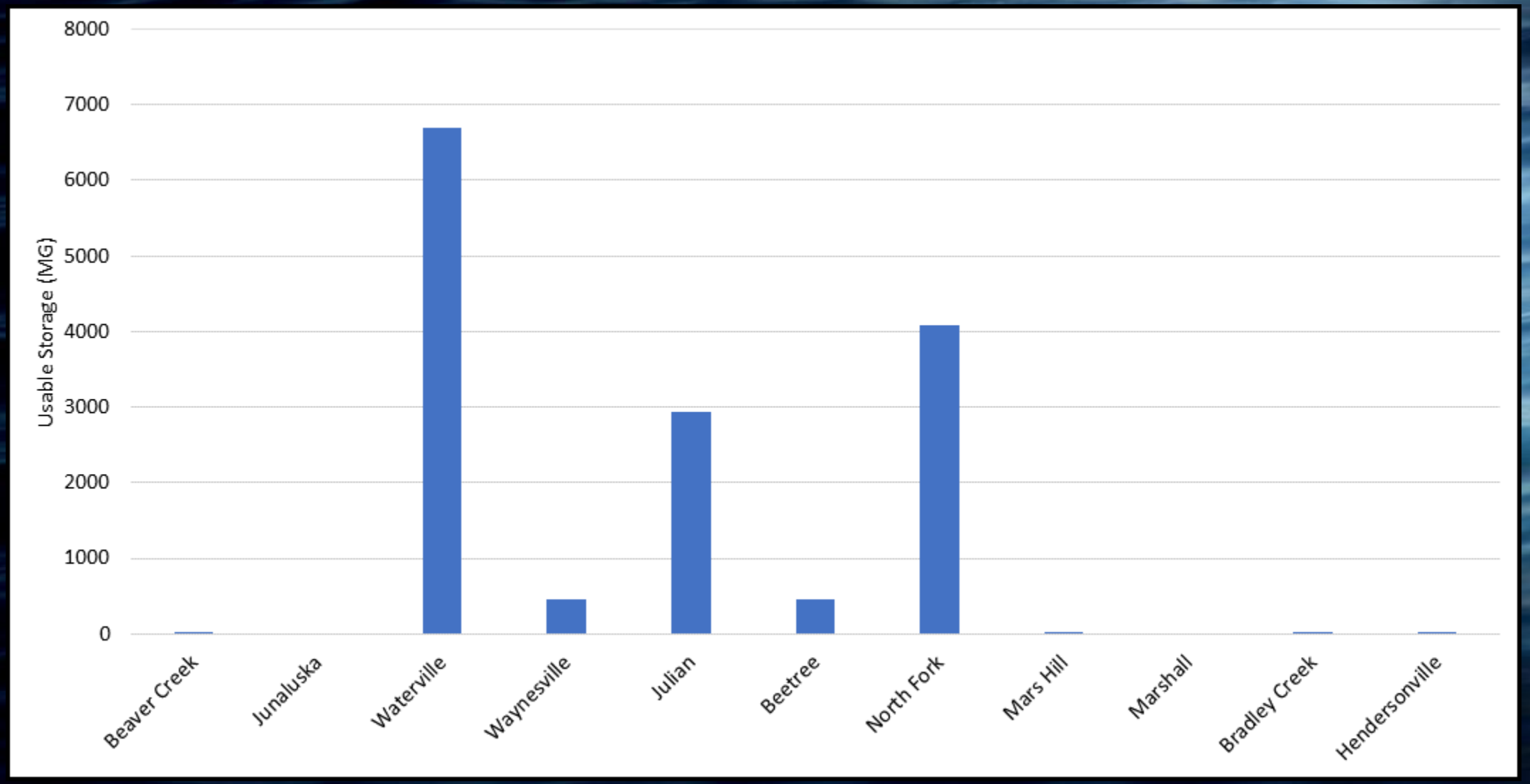
Reservoir Storage



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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
  - Used Fillin to extend record 1975-1979, 1981-1985

Spreadsheet Showing Gage Unimpairment

	A	B	C	D	E	F	G	H	I	J	K	N
1			*node 1386*									
2												
3		Sugar Camp Fork WTP	Irrigation u/s FB at Marshall gage	Silver Line Plastics Co	French Broad River WRF	Sugar Camp Fork WTP	North Buncombe Quarry Pond #1	North Buncombe Quarry Pump #3	Impairments u/s Marshall	Total u/s Impairments, this reach	#03453500 French Broad River at Marshall, NC	Unimpaired French Broad River at Marshall, NC
4		Withdrawal	Withdrawal	Return	Return	Return	Return	Return			Discharge	Discharge
5												
6	Date	mgd	mgd	mgd	mgd	mgd	mgd	mgd	mgd	mgd	cfs	cfs
32110	11/23/2017	1.00	0.10	0.13	26.60	0.02	0.04	0.00	-25.70	-4.72	1650.00	1642.70
32111	11/24/2017	1.00	0.10	0.13	26.60	0.02	0.04	0.00	-25.70	-4.72	1600.00	1592.70
32112	11/25/2017	1.00	0.10	0.13	26.60	0.02	0.04	0.00	-25.70	-4.72	1580.00	1572.70
32113	11/26/2017	1.00	0.10	0.13	26.60	0.02	0.04	0.00	-25.70	-4.72	1540.00	1532.70
32114	11/27/2017	1.00	0.10	0.13	26.60	0.02	0.04	0.00	-25.70	-4.72	1500.00	1492.70
32115	11/28/2017	1.00	0.10	0.13	26.60	0.02	0.04	0.00	-25.70	-4.72	1460.00	1452.70
32116	11/29/2017	1.00	0.10	0.13	26.60	0.02	0.04	0.00	-25.70	-4.72	1440.00	1432.70
32117	11/30/2017	1.00	0.10	0.13	26.60	0.02	0.04	0.00	-25.70	-4.72	1430.00	1422.70
32118	12/1/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1430.00	1394.82
32119	12/2/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1420.00	1384.82
32120	12/3/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1390.00	1354.82
32121	12/4/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1360.00	1324.82
32122	12/5/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1380.00	1344.82
32123	12/6/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1730.00	1694.82
32124	12/7/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1580.00	1544.82
32125	12/8/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1470.00	1434.82
32126	12/9/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1620.00	1584.82
32127	12/10/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1650.00	1614.82
32128	12/11/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1500.00	1464.82
32129	12/12/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1510.00	1474.82
32130	12/13/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1570.00	1534.82
32131	12/14/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1510.00	1474.82
32132	12/15/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1470.00	1434.82
32133	12/16/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1430.00	1394.82
32134	12/17/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1380.00	1344.82
32135	12/18/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1390.00	1354.82
32136	12/19/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	1410.00	1374.82
32137	12/20/2017	1.02	0.10	0.13	19.23	0.02	0.04	0.00	-18.31	-22.74	2590.00	2554.82

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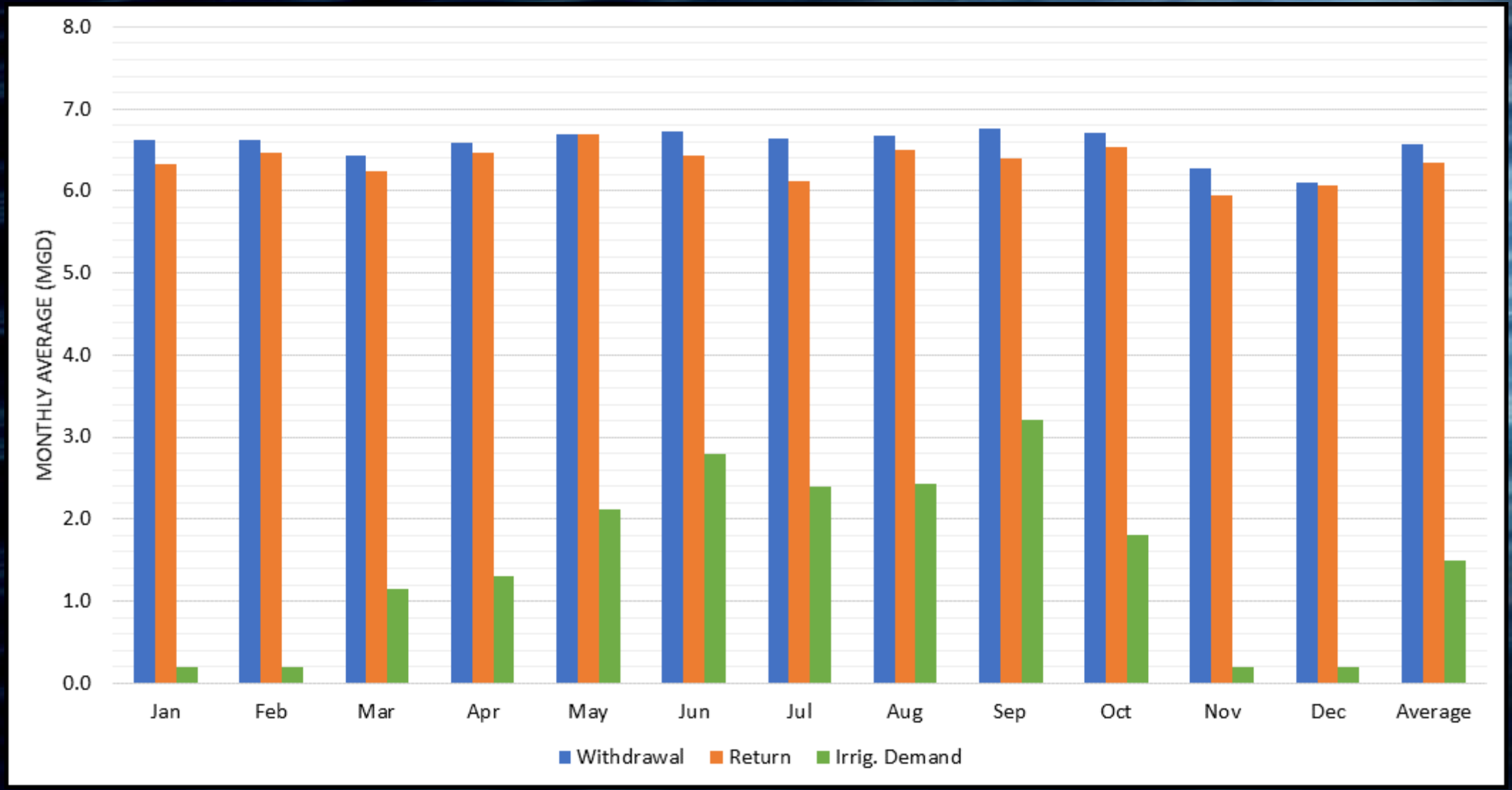
Nolichucky Withdrawals and Discharges (2013-17)



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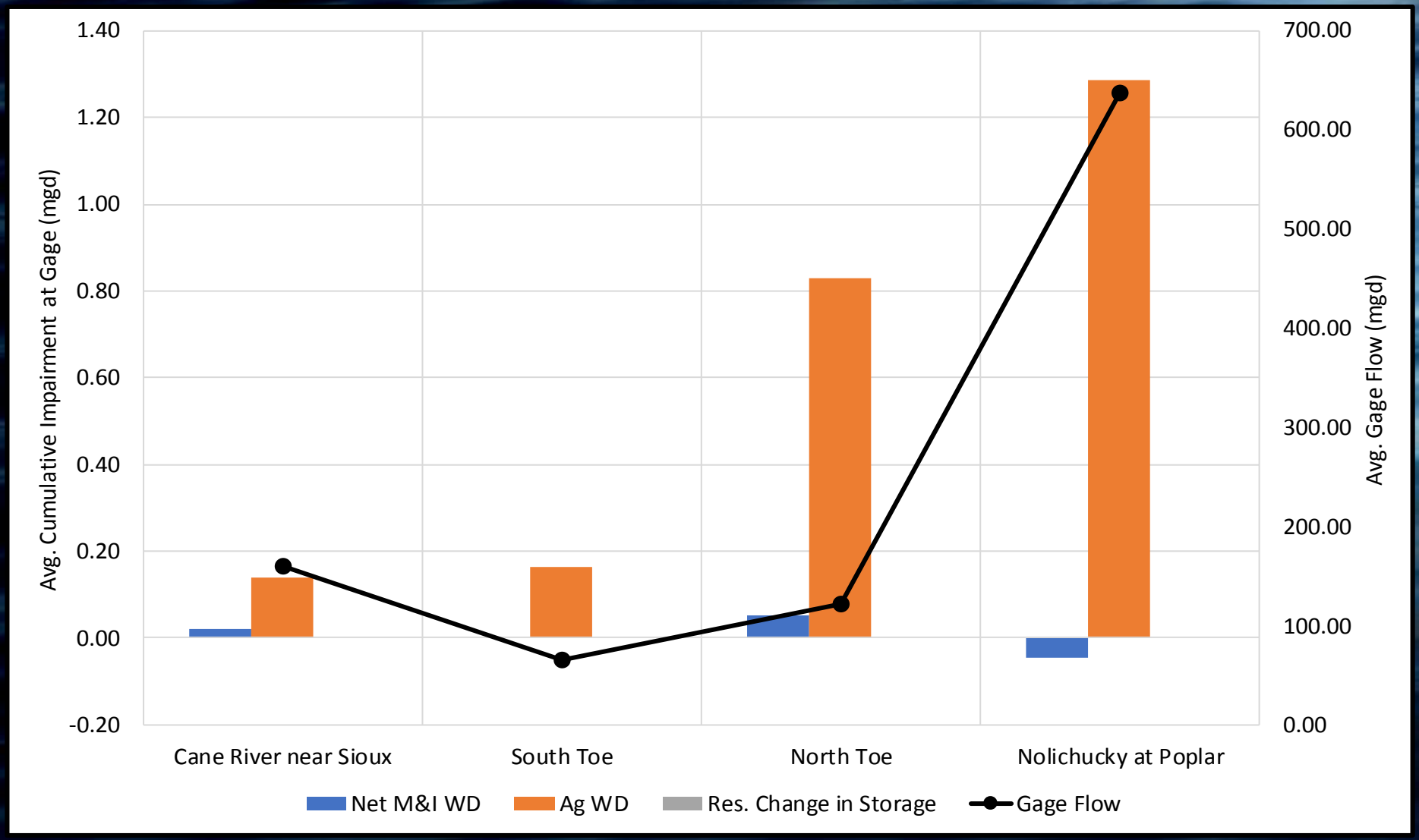
Impairments in Nolichucky Basin (1930-2017)



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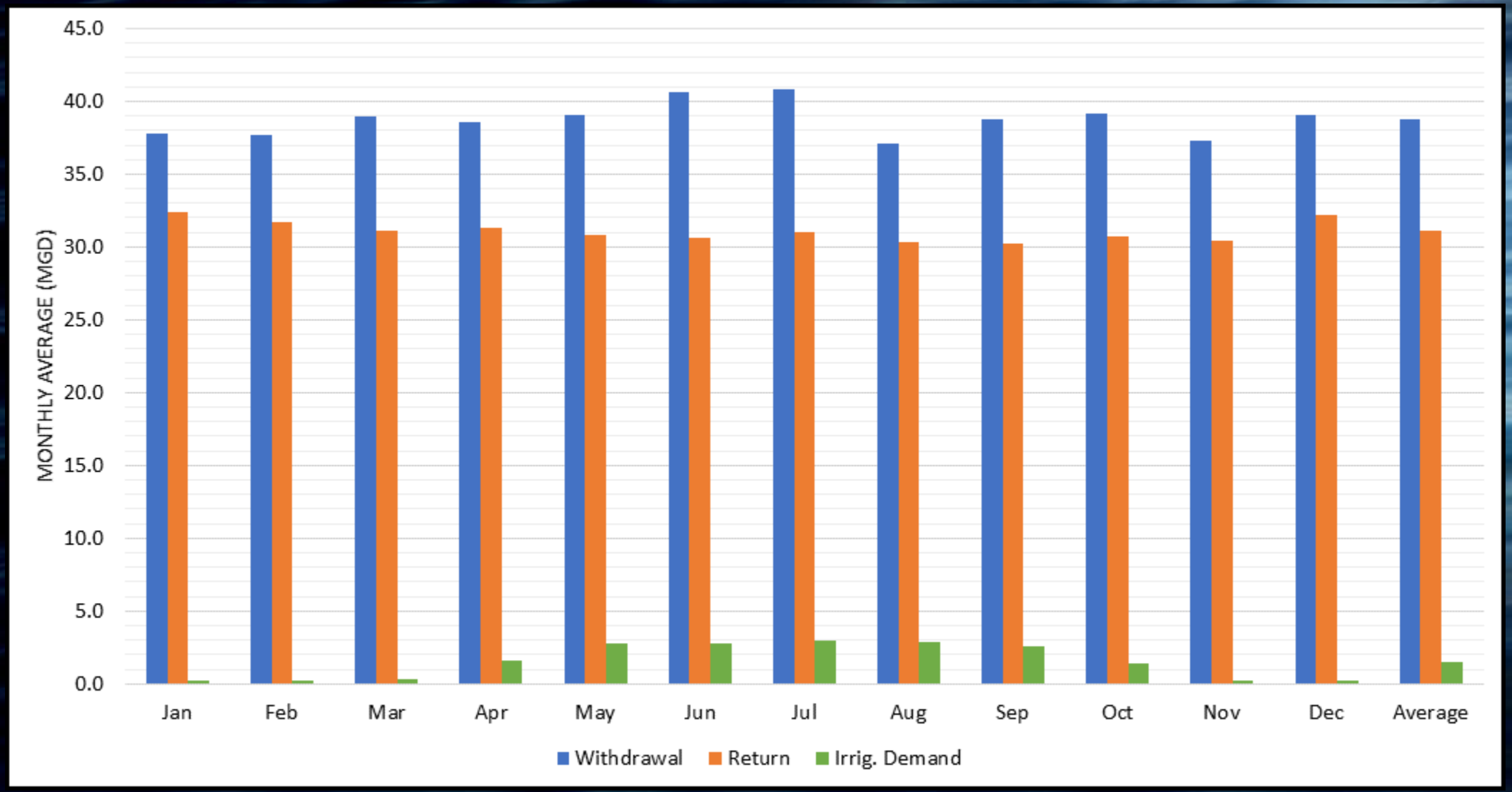
Pigeon Withdrawals and Discharges (2013-17)



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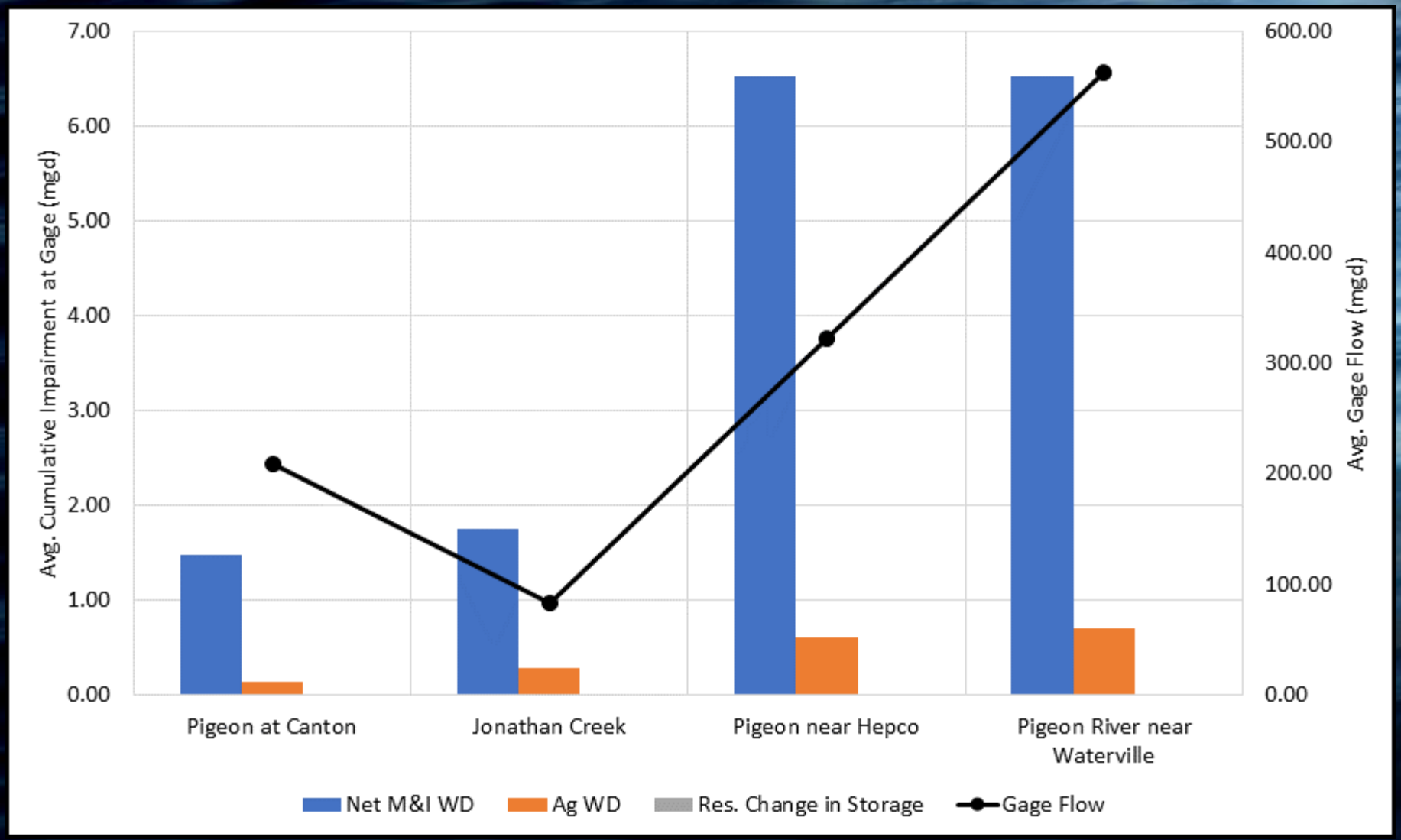
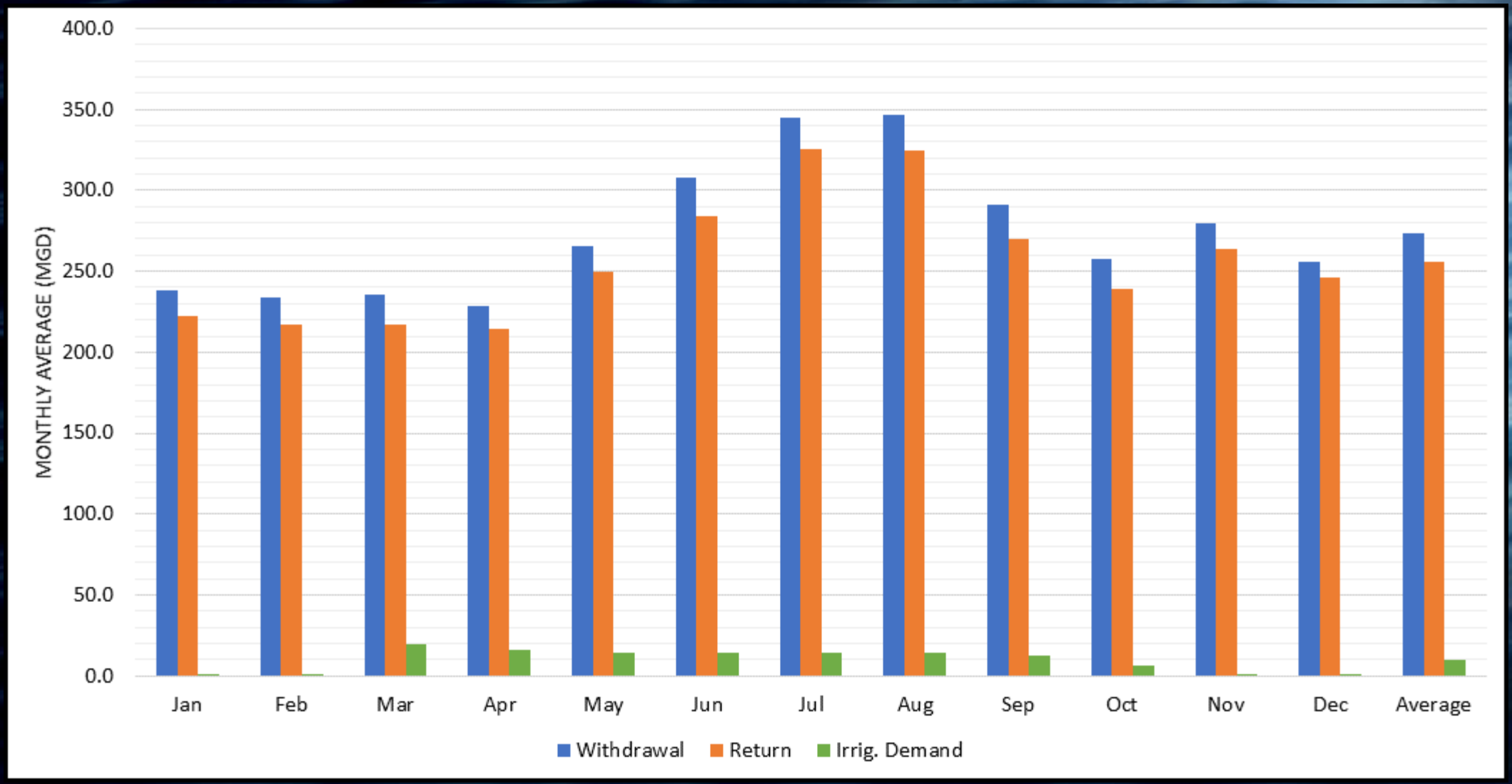
Impairments in Pigeon Basin (1930-2017)



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

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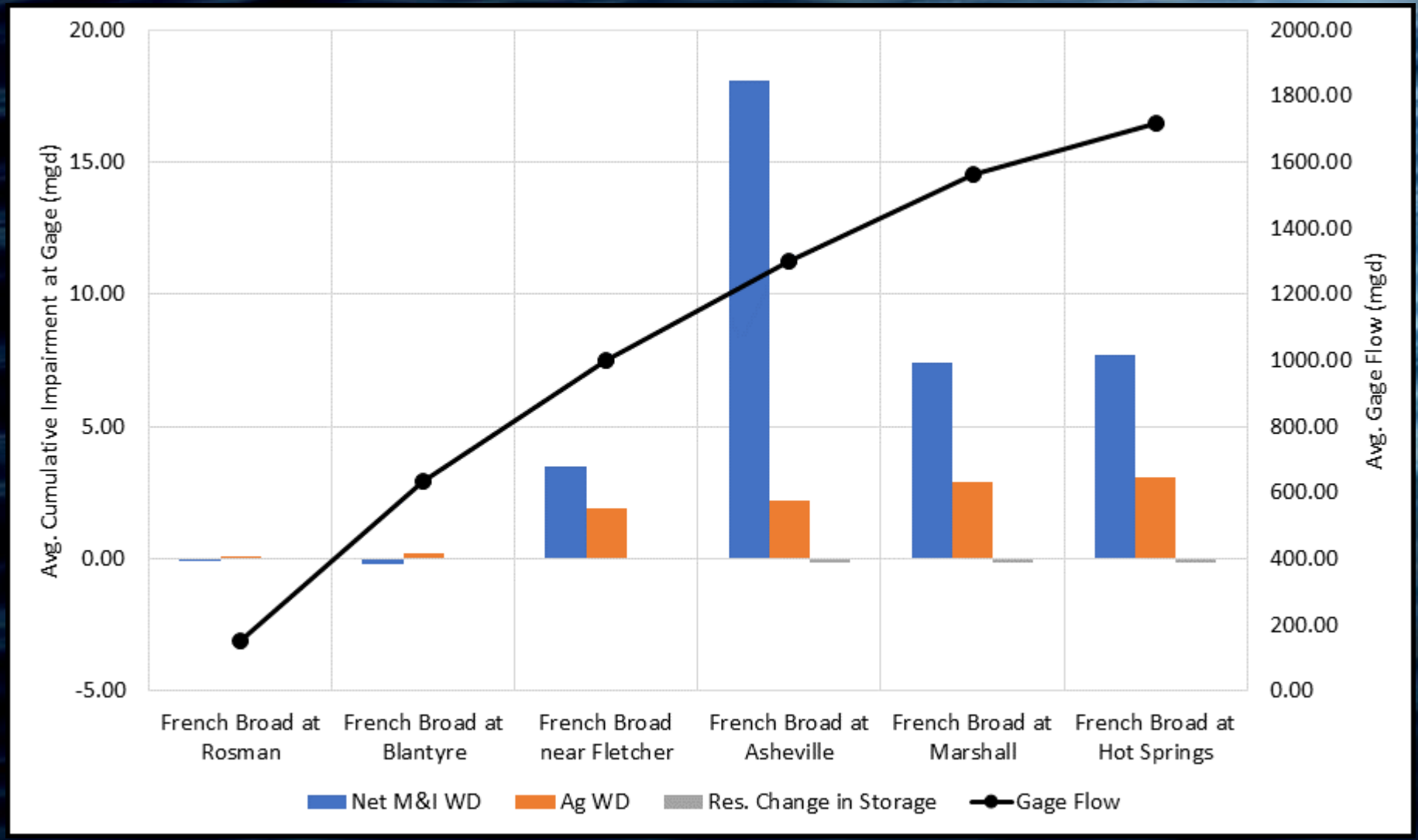
Impairments in Upper French Broad Basin (1930-2017)



Average WD = 7.7 mgd, Average Ret =
Average non-steam plant WD = 5.8 mgd

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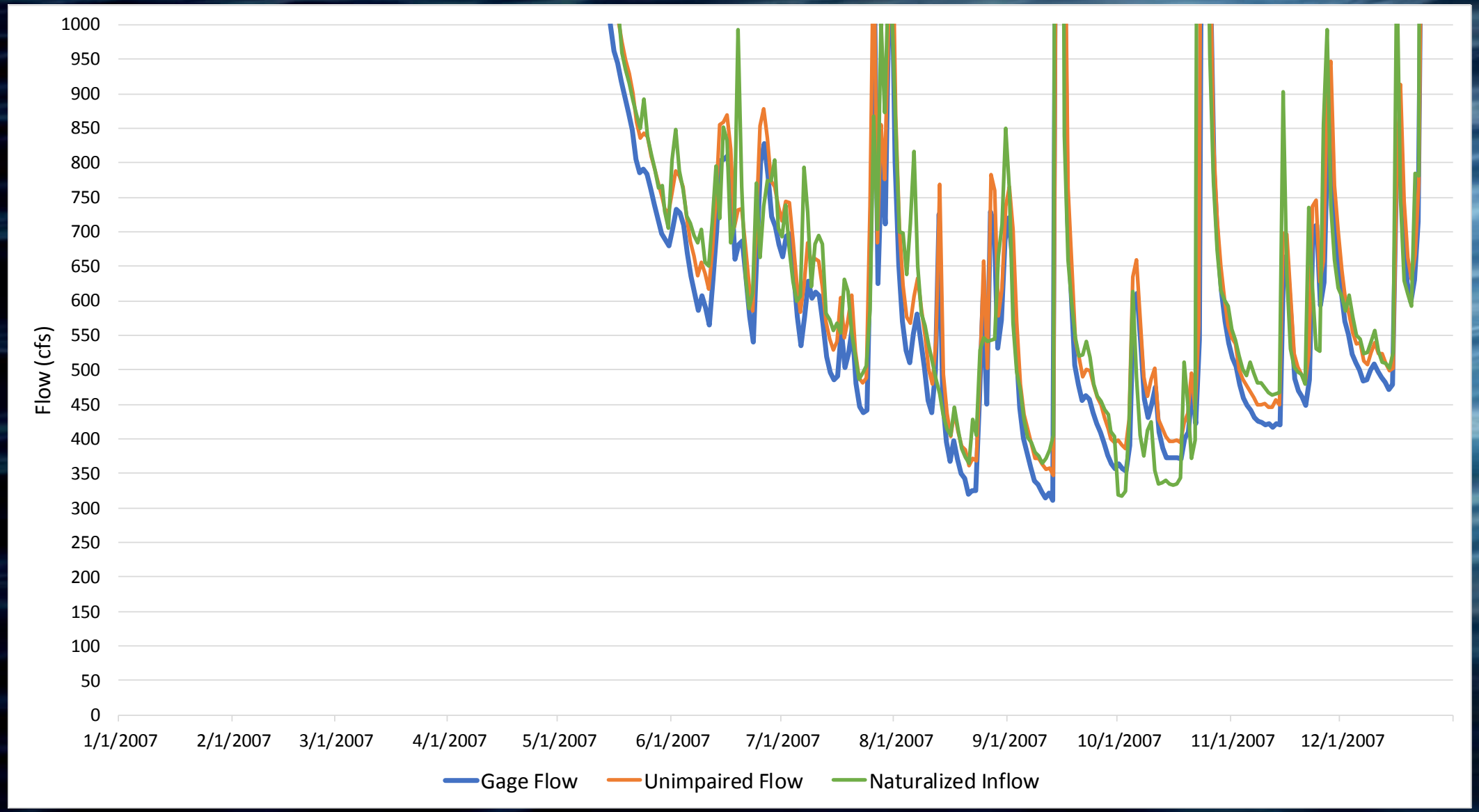
Flow Comparison: French Broad River at Asheville, daily



Unimpaired Gage = daily gage flow adjusted for impairments upstream
Naturalized Inflow = monthly cumulative inflow disaggregated to daily to preserve natural variation

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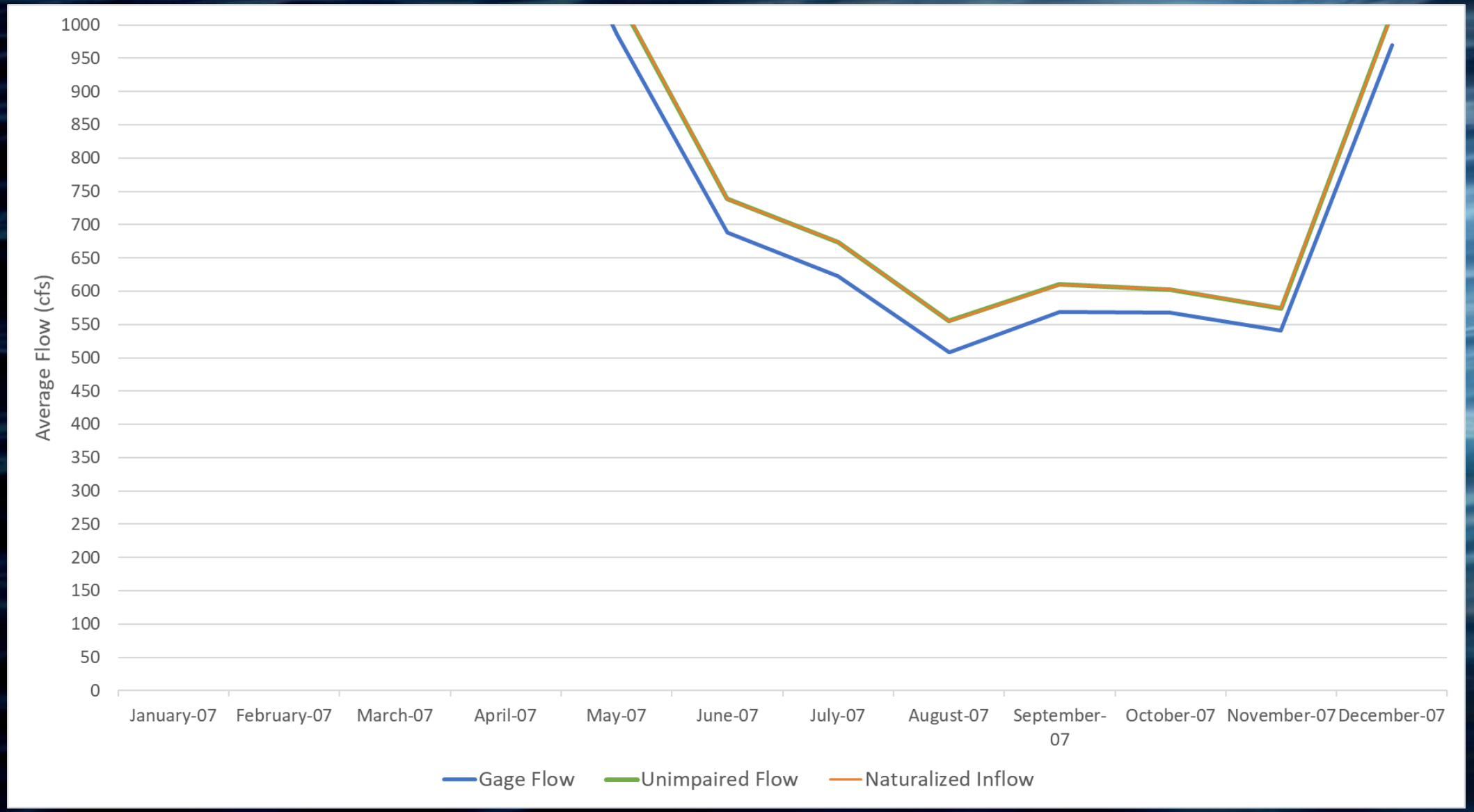
Flow Comparison: French Broad River at Asheville, monthly



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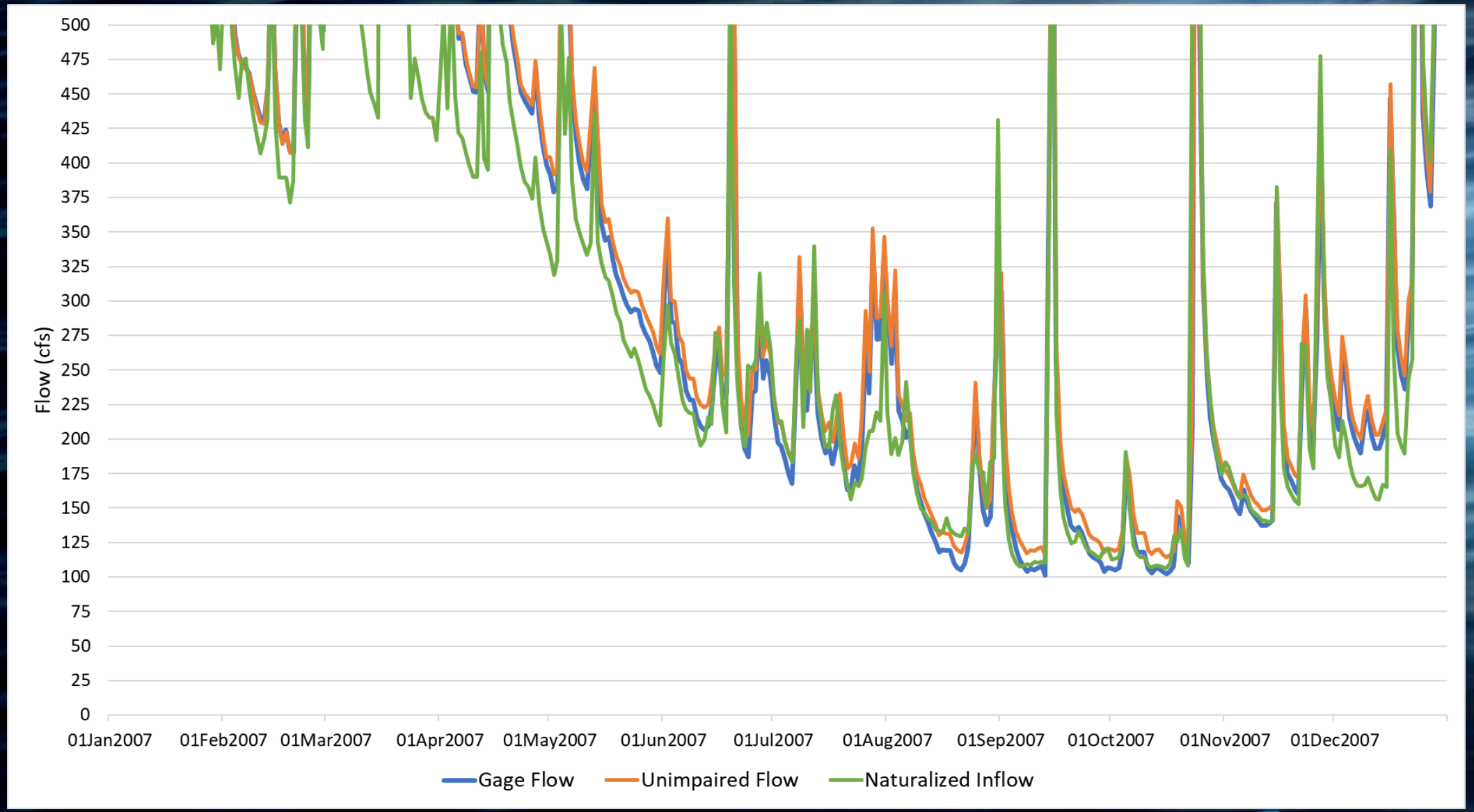
Flow Comparison: Pigeon River at Hepco, daily



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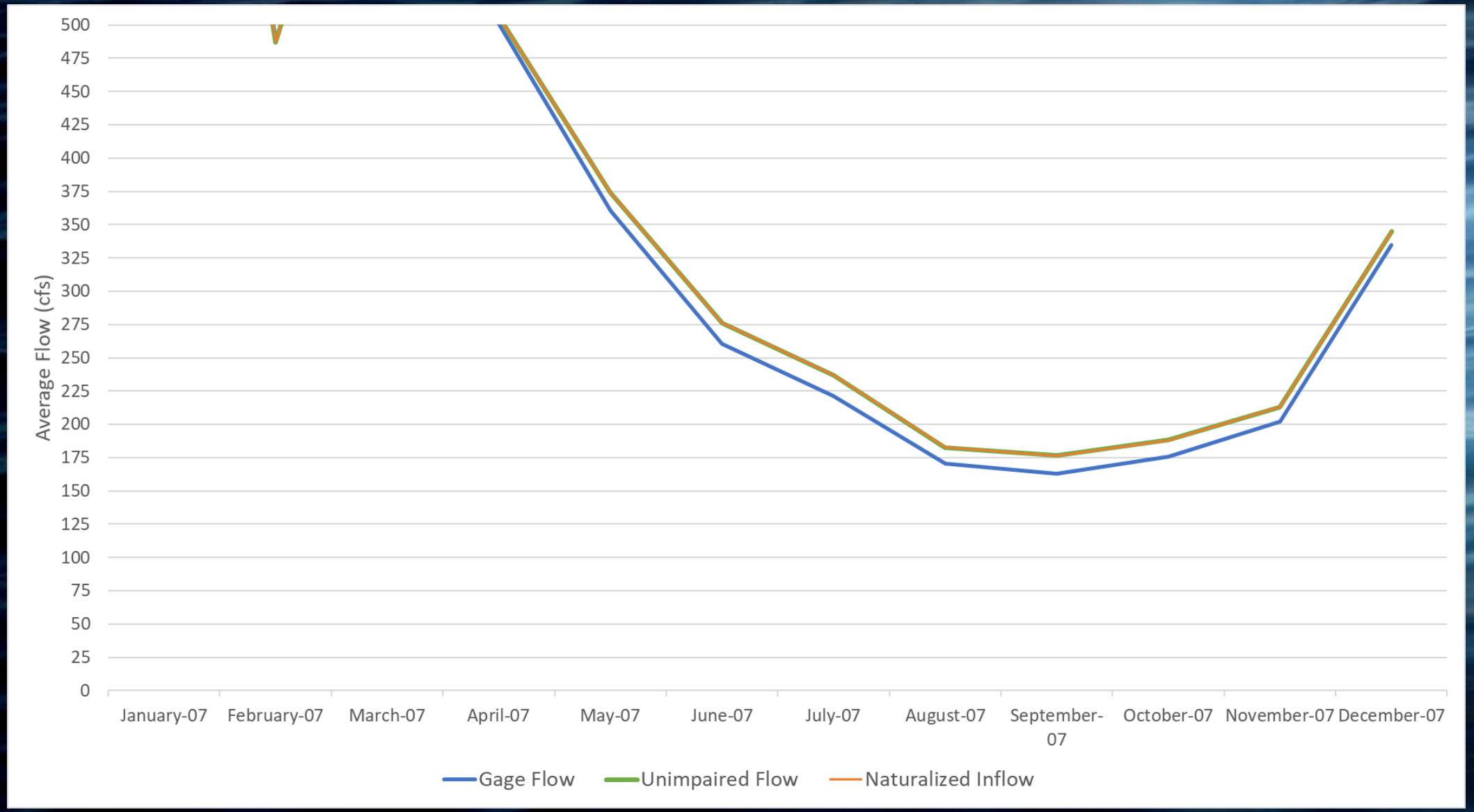

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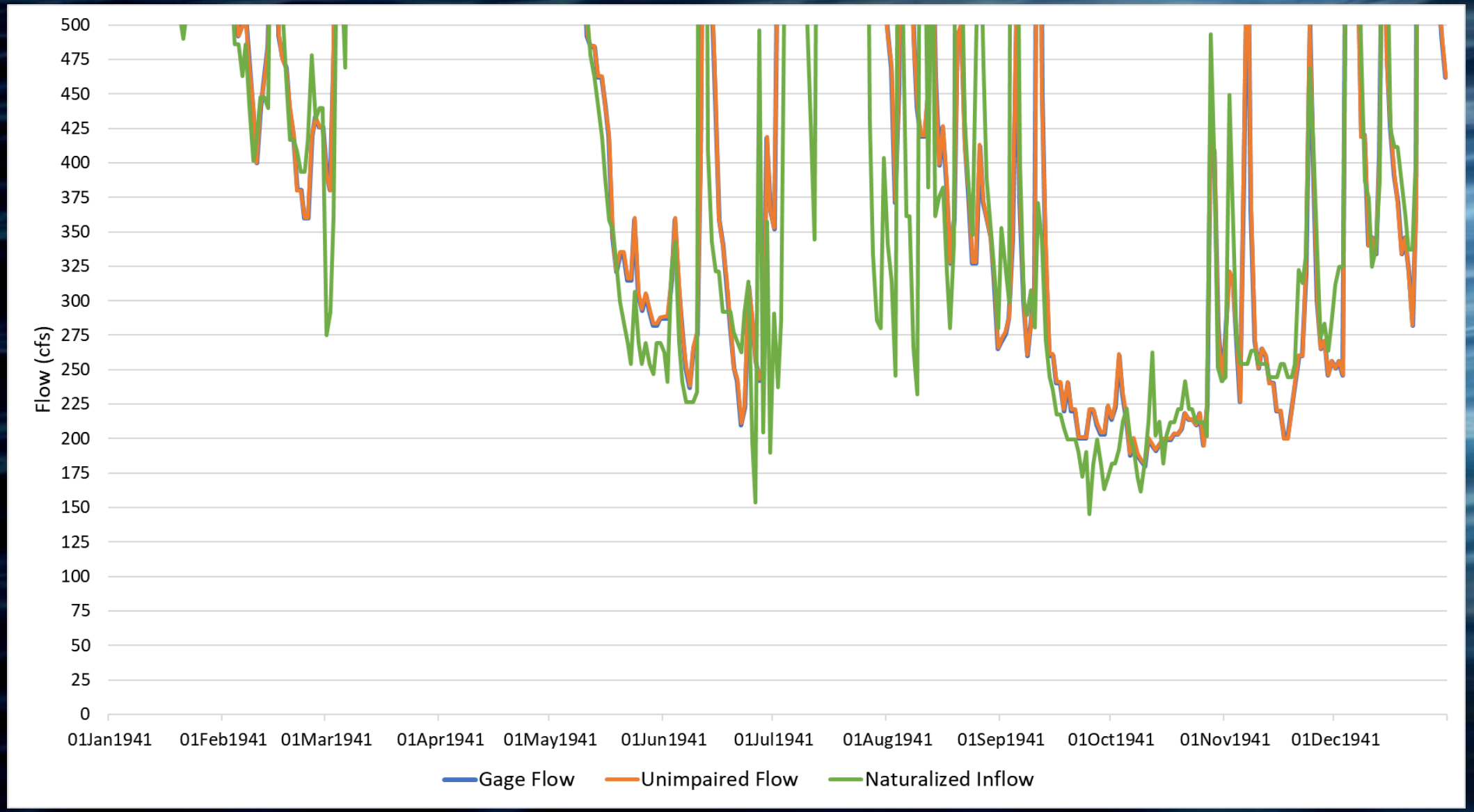
Flow Comparison: Nolichucky River at Poplar, daily



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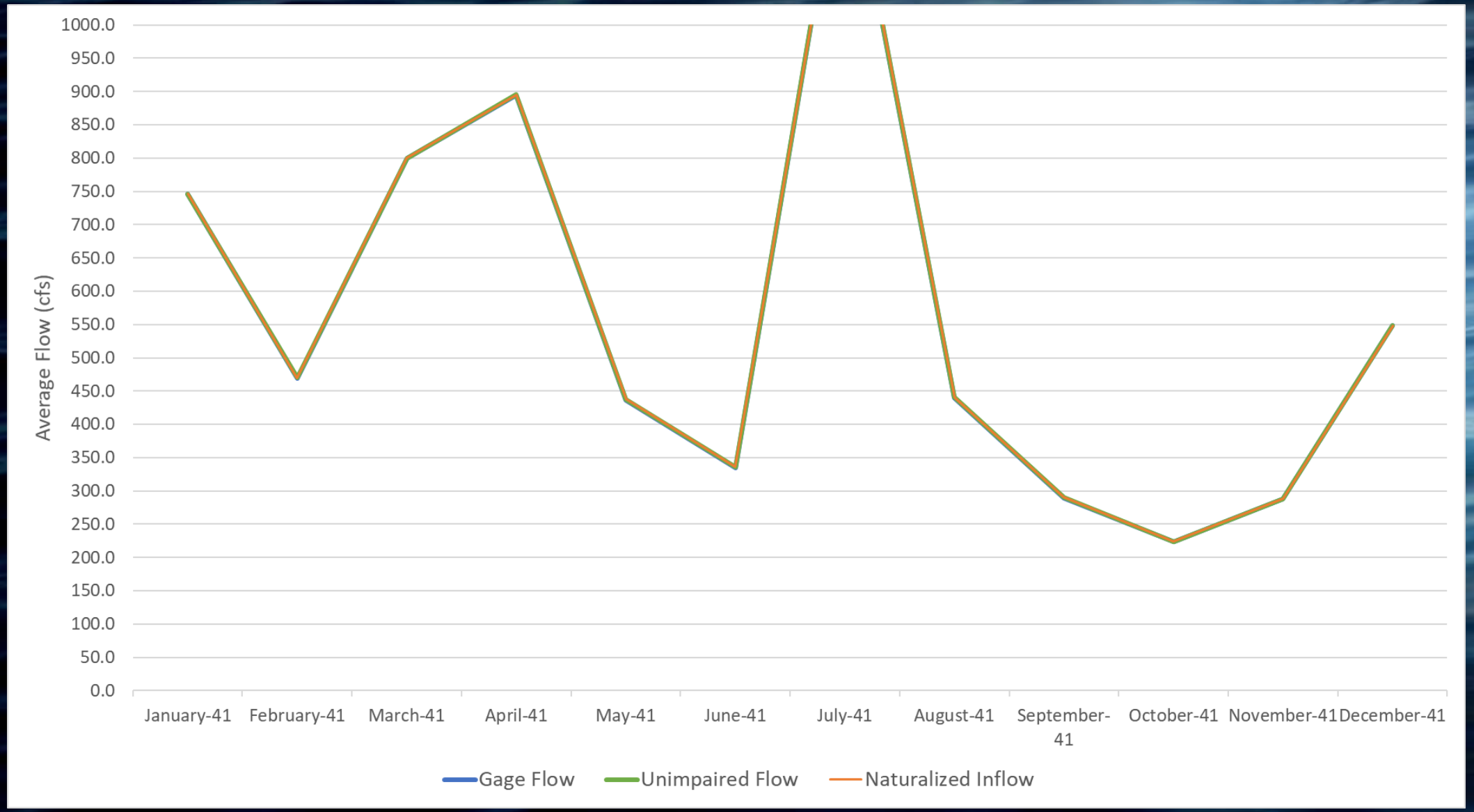

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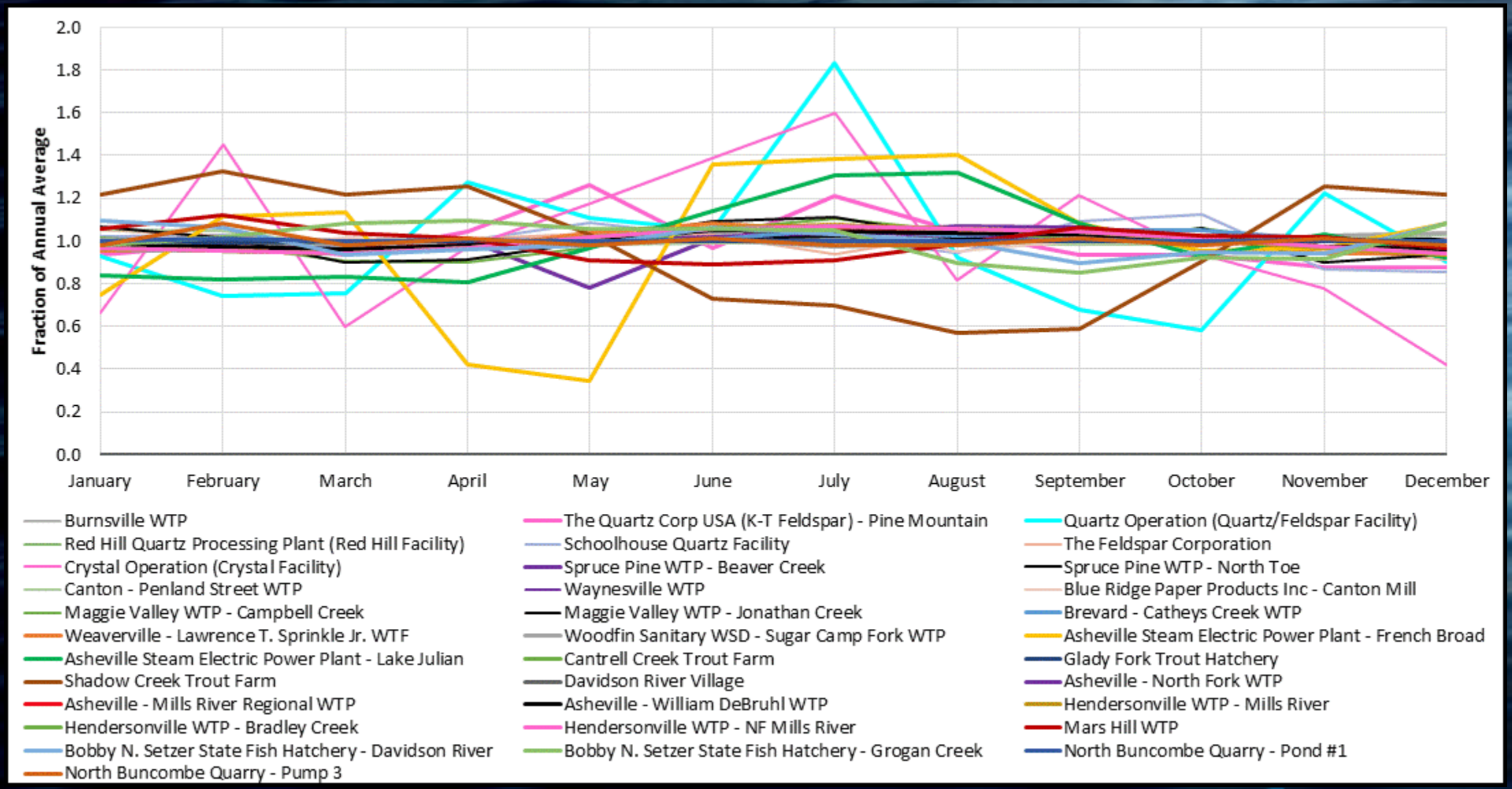
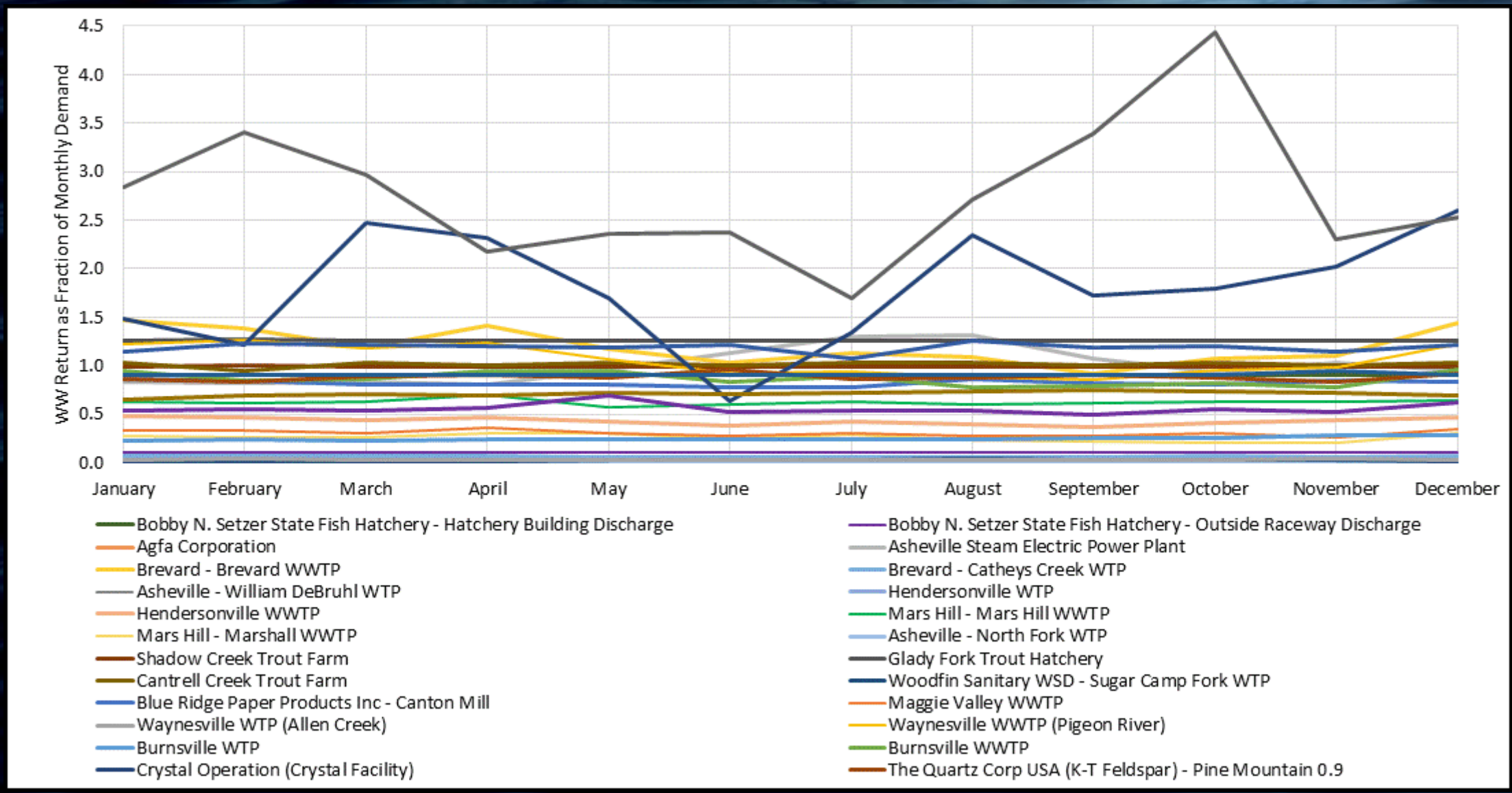
Basin Withdrawals

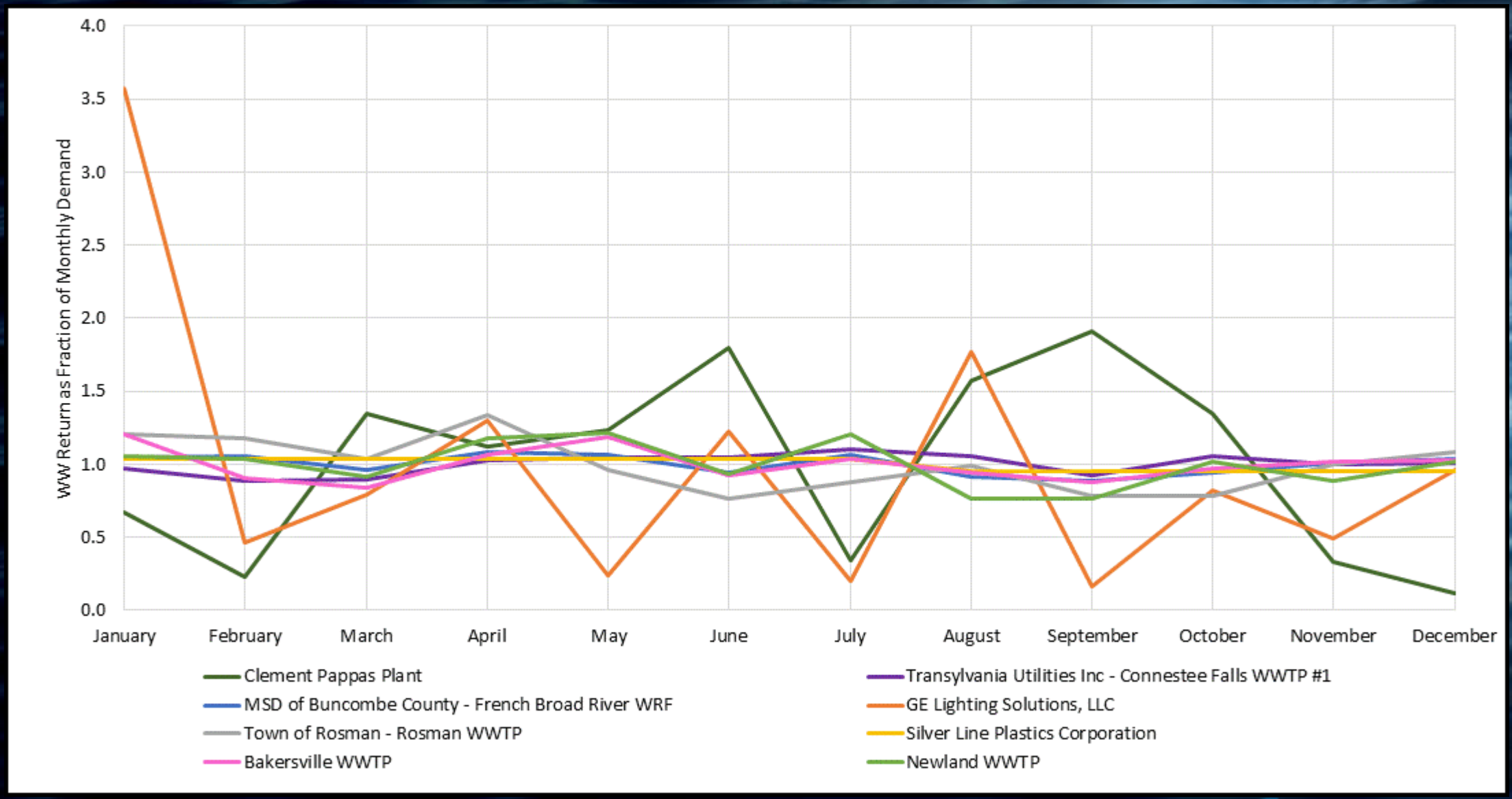


Basin Returns as Fraction of Monthly Demand



HYDROLOGICS

Other Basin WW Returns



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