Analysis to Support Criteria Period Selection

September 9, 2009

Approach

► Flow-based

- Review Malcolm-Pirnie flow analysis (from 7/16/09 memo)
- Perform flow analysis to support critical period selection
  - Consider 9 major tributaries
  - Evaluate different combinations of monthly flows
  - Apply allocation multiplier to consider relative impacts
  - Consider correlation between flow and DO exceedances

► Water quality-based

► Regional and national approaches

Malcolm-Pirnie Flow Analysis - Approach

- ► Evaluated selection of 1996-1998 as 3-year critical condition
- ► Calculated 3-year running averages of seasonal flow and determined corresponding flow percentiles
  - 1967-2009
  - January through May
  - Susquehanna and Potomac

Malcolm-Pirnie Flow Analysis - Results

- Highest average Jan-May inflow was 1996-1998
- Critical period of 1996-1998 is too extreme
  - contains 93rd and 98th percentile flow years
  - represents a 40-year return period
  - represents the 100th percentile
- Recommend:
  - 10-year return period
  - 1993-1995 or 1994-1996

Replication of Malcolm-Pirnie Flow Analysis

- Repeated the analysis using flow data presented in the report and raw data
  - 3-year averages based on flows in the report did not exactly match what is presented
    - Does not affect the percentile calculations
  - Using USGS data resulted in similar discrepancies in 3-year running averages
- Yielded same conclusions

Analysis to Support Critical Period Selection

- Flow data analyzed for 1978 through 2009 (Patuxent flow gage limited time period…did not begin until 1977)
- Average flows calculated for 9 tributaries for each year
- Evaluated combinations of different monthly flow durations from September through July (e.g., average flows for Jan-May, Dec-March, etc.)
- Calculated running 3-year averages using only flows from the months within the potential critical period under evaluation

Time Periods			
Gage ID	**Description**	**Start**	**End**
1668000	RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	9/19/1907	8/25/2009
1646502	POTOMAC RIVER (ADJUSTED) NEAR WASH, DC	3/1/1930	7/31/2009
2037500	JAMES RIVER NEAR RICHMOND, VA	10/1/1934	8/25/2009
1674500	MATTAPONI RIVER NEAR BEULAHVILLE, VA	9/19/1941	8/25/2009
1673000	PAMUNKEY RIVER NEAR HANOVER, VA	10/1/1941	8/25/2009
1491000	CHOPTANK RIVER NEAR GREENSBORO, MD	1/1/1948	8/25/2009
1578310	SUSQUEHANNA RIVER AT CONOWINGO, MD	10/1/1967	8/25/2009
2041650	APPOMATTOX RIVER AT MATOACA, VA	10/1/1969	8/25/2009
1594440	PATUXENT RIVER NEAR BOWIE, MD	6/27/1977	8/25/2009

Calculations

- ► Probability of each 3-year flow average was determined using the Weibull Plotting Position computed as:

$$\frac{1}{T_r} = p = \frac{m}{(n+1)}$$

where: p is the probability, m is the rank, and n is the count of the dataset

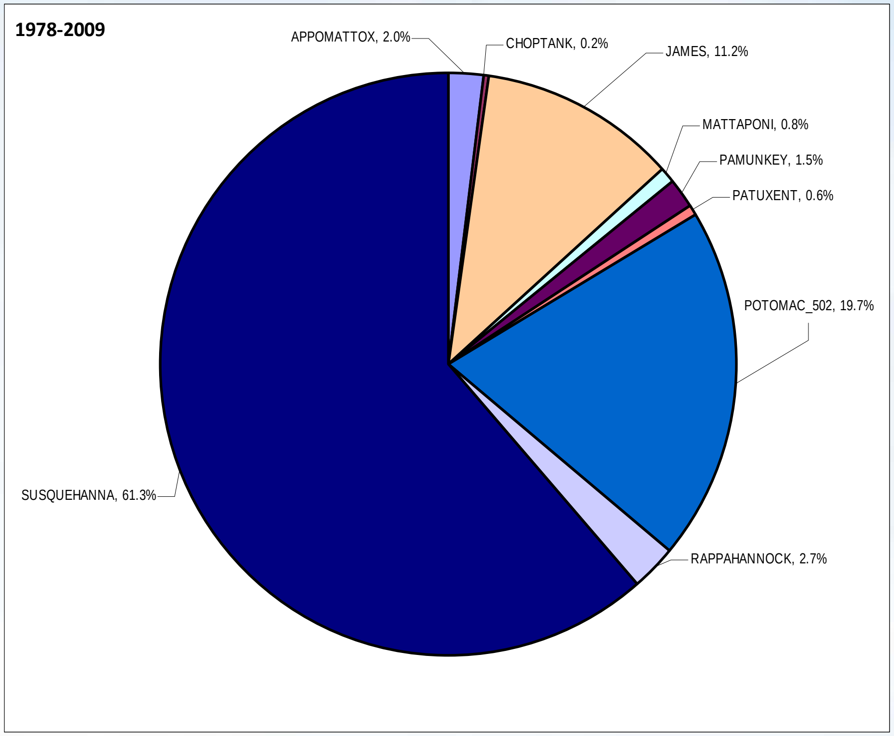
- ► Return period is inverse of probability
- ► Different approach than Malcolm-Pirnie Study, which used percentile ranks
- ► Regression performed on 3-year flow average to determine correlation with the DO percent exceedances

Use of Tributary Multipliers

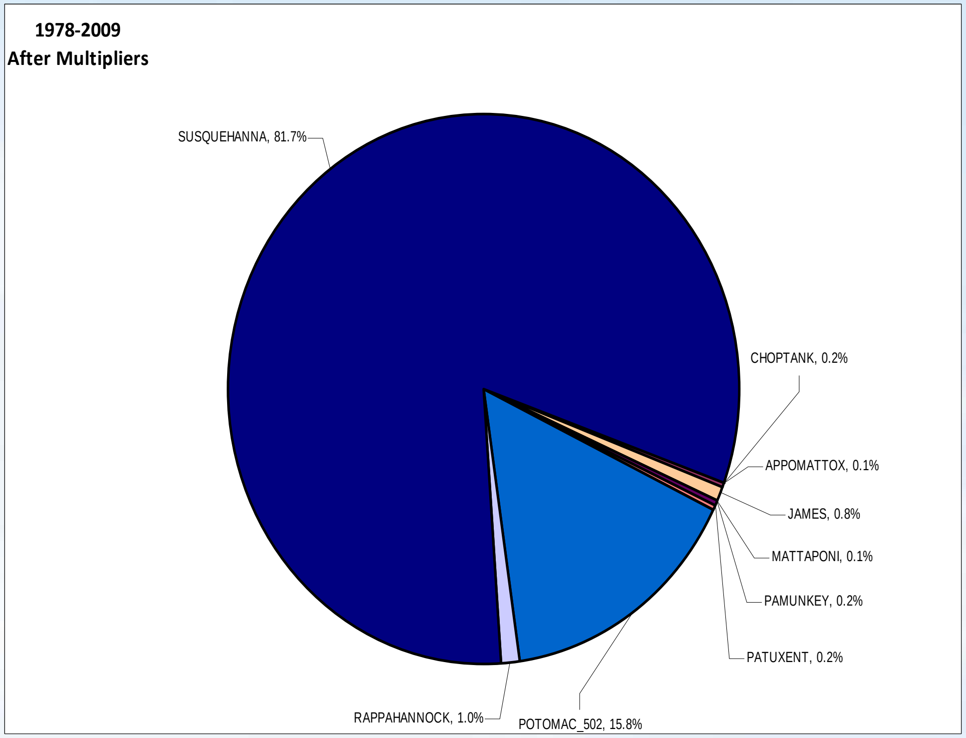
- Flows from different tributaries don’t equally impact conditions in the Bay
- Used CBPO allocation multipliers
- Translated to a 0.0 - 1.0 scale
- Flow analysis repeated using multipliers

Basin	Multiplier	Adjusted Ratio
Appomattox	0.533111028	0.017
Choptank	6.929861533	0.217
James	0.533111028	0.017
Mattaponi	0.798423188	0.025
Pamunkey	0.798423188	0.025
Patuxent	3.093385849	0.097
Potomac	6.188243619	0.193
Rappahannock	2.809613056	0.088
Susquehanna	10.3187158	0.322
		1.000

Tributary Flow Contributions with and without Multiplier Ratios



Flow Contributions



Flow Contributions with Multiplier Ratio

Return Periods by Monthly Duration:

Without Multiplier

% DO Exceedences --->		25.87%	25.92%	24.26%	27.84%	26.05%	31.11%	27.24%
Interval	R2	1992-1994	1993-1995	1994-1996	1996-1998	1997-1999	2003-2005	2004-2006
		Return Period						
SEP-JUNE	0.54	4.43	6.20	3.44	15.50	2.58	31.00	7.75
NOV-JUNE	0.53	6.20	7.75	5.17	31.00	2.07	15.50	4.43
SEP-JULY	0.53	4.43	5.17	3.44	15.50	2.58	31.00	10.33
NOV-JULY	0.52	6.20	7.75	4.43	15.50	2.07	31.00	5.17
DEC-JUNE	0.52	7.75	6.20	4.43	31.00	2.38	15.50	3.88
SEP-MAY	0.51	4.43	6.20	3.88	15.50	3.10	31.00	7.75
DEC-JULY	0.51	6.20	7.75	4.43	31.00	2.21	15.50	3.88
OCT-JUNE	0.50	5.17	6.20	4.43	15.50	2.38	31.00	7.75
OCT-JULY	0.49	5.17	6.20	4.43	15.50	2.21	31.00	7.75
NOV-MAY	0.48	6.20	7.75	5.17	31.00	3.10	15.50	4.43
SEP-APR	0.48	4.43	5.17	3.44	15.50	3.10	31.00	10.33
OCT-MAY	0.46	5.17	7.75	4.43	31.00	2.82	10.33	6.20
DEC-MAY	0.46	10.33	7.75	5.17	31.00	2.82	6.20	3.88
JAN-JUNE	0.44	10.33	6.20	4.43	31.00	2.58	5.17	2.21
JAN-JULY	0.44	6.20	5.17	4.43	31.00	2.21	7.75	2.82
NOV-APR	0.44	7.75	10.33	4.43	31.00	3.10	15.50	5.17
OCT-APR	0.42	5.17	7.75	3.44	31.00	3.10	15.50	6.20
SEP-MAR	0.42	2.82	3.44	3.88	15.50	4.43	31.00	10.33
DEC-APR	0.40	10.33	15.50	5.17	31.00	3.10	6.20	4.43
NOV-MAR	0.39	3.10	3.44	6.20	31.00	4.43	15.50	7.75
JAN-MAY	0.37	10.33	7.75	6.20	31.00	3.10	4.43	2.21
OCT-MAR	0.36	2.82	3.44	4.43	31.00	3.88	10.33	7.75
DEC-MAR	0.36	3.44	5.17	7.75	31.00	4.43	10.33	6.20
JAN-APR	0.32	31.00	15.50	6.20	10.33	3.44	3.88	2.38
JAN-MAR	0.26	5.17	6.20	10.33	31.00	7.75	3.88	2.58

Note: Only 3-yr periods with >6 yr return periods are shown; >6 yr return periods are highlighted

Return Periods by Monthly Duration:

With Multiplier

% DO Exceedences --->		25.87%	25.92%	24.26%	27.84%	26.05%	31.11%	27.24%
Interval	R2	1992-1994	1993-1995	1994-1996	1996-1998	1997-1999	2003-2005	2004-2006
		Return Period						
SEP-JUNE	0.53	4.43	5.17	3.44	7.75	2.21	31.00	15.50
NOV-JUNE	0.53	5.17	6.20	4.43	15.50	1.94	31.00	7.75
DEC-JUNE	0.52	6.20	7.75	3.88	15.50	1.94	31.00	4.43
SEP-JULY	0.52	3.88	5.17	3.44	10.33	2.07	31.00	15.50
NOV-JULY	0.52	5.17	6.20	4.43	15.50	1.94	31.00	10.33
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SEP-APR	0.46	4.43	5.17	3.44	6.20	2.82	31.00	15.50
JAN-JULY	0.46	10.33	5.17	4.43	31.00	1.55	15.50	3.88
JAN-JUNE	0.46	10.33	6.20	4.43	31.00	1.82	5.17	2.82
DEC-MAY	0.45	7.75	10.33	5.17	31.00	2.21	6.20	4.43
OCT-MAY	0.44	5.17	6.20	3.88	15.50	2.21	10.33	7.75
NOV-APR	0.42	7.75	10.33	3.88	15.50	2.58	31.00	6.20
SEP-MAR	0.41	2.07	3.10	3.88	10.33	4.43	15.50	31.00
OCT-APR	0.41	5.17	6.20	3.44	10.33	2.58	31.00	7.75
DEC-APR	0.40	15.50	31.00	4.43	10.33	2.58	7.75	5.17
NOV-MAR	0.38	2.58	3.10	5.17	31.00	3.44	15.50	10.33
JAN-MAY	0.37	15.50	7.75	6.20	31.00	2.38	5.17	2.82
DEC-MAR	0.37	2.58	3.44	6.20	31.00	3.88	15.50	10.33
OCT-MAR	0.35	2.38	3.10	4.43	31.00	3.44	10.33	15.50
JAN-APR	0.32	31.00	15.50	6.20	10.33	2.58	5.17	3.44
JAN-MAR	0.28	2.58	3.88	10.33	31.00	7.75	6.20	2.82

Note: Only 3-yr periods with >6 yr return periods are shown; >6 yr return periods are highlighted

Monthly Span

- Monthly span should be extended beyond that in the Malcolm-Pirnie Study (Jan-May)
- Jan-May had one of the lower correlations with DO exceedances
- 3-year average flows with the highest correlation to DO exceedances generally include longer monthly spans (i.e., from early fall of the previous year through summer)
- 3-year average flow spanning Sep-Jun had highest correlation to DO exceedances

Preliminary Interim Findings

- 2003-2005 and 1996-1998 generally represent highest return periods
  - 2003-2005
    - highest for longer monthly span (when flow is more closely correlated with DO exceedances)
  - 1996-1998
    - highest for shorter monthly span (as in Malcolm-Pirnie study)
    - closer to 10 year return period for months when flow more closely correlates with DO exceedances
- 1992-1994 and 1993-1995
  - generally lower than 10 year return periods
  - higher return periods (10 year or more) when flow is not strongly correlated with DO exceedances

Next Steps for Completion of Flow-based Critical Period Analysis

- Determine return periods using USGS methodology
  - Log Pearson III Method of flood frequency analysis
    - Bulletin 17B: Guidelines for Determining Flood Flow Frequency
- Compare Log Pearson III results to Weibull Plotting Position results
- Other analytical methods, e.g. Gringorten and Cunnane, may also be considered
- Bring updated results to the September 14 or September 21 WQGIT conference call for final decision on the critical period

Water Quality-based Critical Period Assessment

- Flow
  - Reasonable surrogate for climate
  - Does not capture all wind, rain, temperature, and other factors
- Water quality
  - Incorporates climate
  - Considers anthropogenic factors
    - Point source loads
    - BMPs
    - Land use

Water Quality-based Critical Period

Period	DO below (	Probability	Return Period
2003-2005	31.11%	0.05	21.0
1996-1998	27.84%	0.10	10.5
2004-2006	27.24%	0.14	7.0
1998-2000	26.57%	0.19	5.3
1997-1999	26.05%	0.24	4.2
2002-2004	25.97%	0.29	3.5
2001-2003	25.93%	0.33	3.0
1993-1995	25.92%	0.38	2.6
1992-1994	25.87%	0.43	2.3
1986-1988	25.60%	0.48	2.1
1987-1989	25.23%	0.52	1.9
1991-1993	24.97%	0.57	1.8
1994-1996	24.26%	0.62	1.6
1985-1987	23.07%	0.67	1.5
1988-1990	22.83%	0.71	1.4
1995-1997	22.58%	0.76	1.3
1989-1991	22.36%	0.81	1.2
1999-2001	22.32%	0.86	1.2
2000-2002	21.60%	0.90	1.1
1990-1992	21.11%	0.95	1.1

- Water quality return period has 1996-1998 as the 10 year recurrence interval
- Anthropogenic effects are included, but lessened by the observation that 1996-1998 is near the middle of the assessed period
- Another line of evidence

Regional Practices - Critical Period

- How do States determine the hydrology critical period?
  - All States: Dependent upon pollutant, WQS, TMDL endpoint as well as amount of flow data available
  - All States: Typically use representative data with a range of flows including high, low, and average
  - MD: Time-variable models use worst condition in calibration period; steady state models for nutrients use 7Q10
  - DE: 7Q10 used for free flowing streams; tidal streams use calibration period with critical condition of monthly average or seasonal average
  - VA: Critical period selected based on dry, average and wet years
  - PA: Starting to use growing season average for nutrients
  - WV: Watershed TMDLs use representative precipitation induced flow data over a 6-year period with high, low, and average conditions

Regional Practices – Baseline Year

- ► Under allocation scenarios, what land uses do States employ?
  - All states typically use the most recent land use data from 2002 or 2007 depending upon state information
  - WV has employed more recent land use modification information for certain transient land uses (i.e., mining)
  - NY has used historical land use data for certain pollutants (i.e., PCBs)

Regional Practices – Baseline Year

- What point source flows do States use?
  - Different approaches for different sources
  - Measured data for calibration and baseline (PA, MD, DE)
  - Design flow/concentrations for allocations (PA, MD, DE, VA, WV)
  - Precipitation induced sources get allocations based on modeled flow (WV, VA)
  - Industrial Wastewater get allocations based on production based maximum flow and permit concentrations (MD, VA, PA)
  - NY starts with measured data (may go to level of technology). Design flow is used as a backstop

What Others Have Done

- **TMDL Analysis to Achieve Water Quality Standards for DO in Long Island Sound (NYSDEC 2000)**
  - Annual surveys from 1986-1998 and a review of historical data indicated that the 1988-1989 modeling time frame was the most severe period of hypoxia on record.
  - As a result, model simulations of reduced nitrogen inputs were used to predict water quality conditions that would result during the same physical conditions that exist during the 1988-89 period.
  - Use of 1988-89 worst case scenario considered as an implicit MOS

- **TMDL for Nitrogen in the Peconic Estuary Program Study Area, Including Waterbodies Currently Impaired Due to Low DO (Peconic Estuary Program 2007)**
  - EFDC model was calibrated using an eight-year period from October 1, 1988 to September 30, 1996.
    - Included all seasons of the year as well as extreme wet and dry years
  - Monitoring data indicated that the October 2000 to September 2002 time frame was the most severe period of hypoxia on record from 1988-2002.
  - October 1, 2000 to September 30, 2002 was selected as the critical period for the TMDL model runs.

Feedback/Direction Requested

- Reminder: WQ Team previously decided on the representative hydrologic period of 1991-2000
- Recommend decision criteria for selecting the critical period:
  - Select the critical period within the hydrologic period 1991-2000 (representative of long-term hydrology, within model calibration period, ease of model operations)
  - Three-year period (match criteria assessment period)
  - Representation of around a 10-year return period (consistent with TMDLs in Bay watershed states, supports implicit margin of safety)
- Feedback Requested: 1) overall methodology as described, 2) planned next steps and 3) recommended decision criteria