MEMO

(External Correspondence)

To: Bruce Albright, BRRWD
Tim James, MPCA

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File: 1915-185

From: Stephanie Johnson, PhD, PE

Subject: Buffalo River Watershed Load Duration Curves

INTRODUCTION

This memorandum summarizes the methods used for and results of creating load duration curves (LDCs) for twenty-two impaired stream segments (delineated by assessment unit identification (AUID) numbers) in the Buffalo River Watershed (BRW). Each of the 22 segments is impaired for aquatic recreation due to elevated *E. coli* levels; some of the reaches are also impaired aquatic life due to high turbidity. Results of the LDCs include computing necessary load reductions within each flow regime of the curve, which will be used to inform the development of total maximum daily loads (TMDLs) for these reaches. This effort was performed under Task 3 of the Buffalo River Watershed Restoration and Protection (WRAP) project.

A list of the 22 AUIDs addressed in this memorandum is included in **Table 1**. Also included is an indication of the impairments that LDCs will be used to address, a list of water quality monitoring stations located within each AUID and the associated SWAT (Soil and Water Assessment Tool) model subbasin which was used to represent flows for creating the curves. The AUIDs, monitoring locations and SWAT subbasins are also shown in **Figure 1**.

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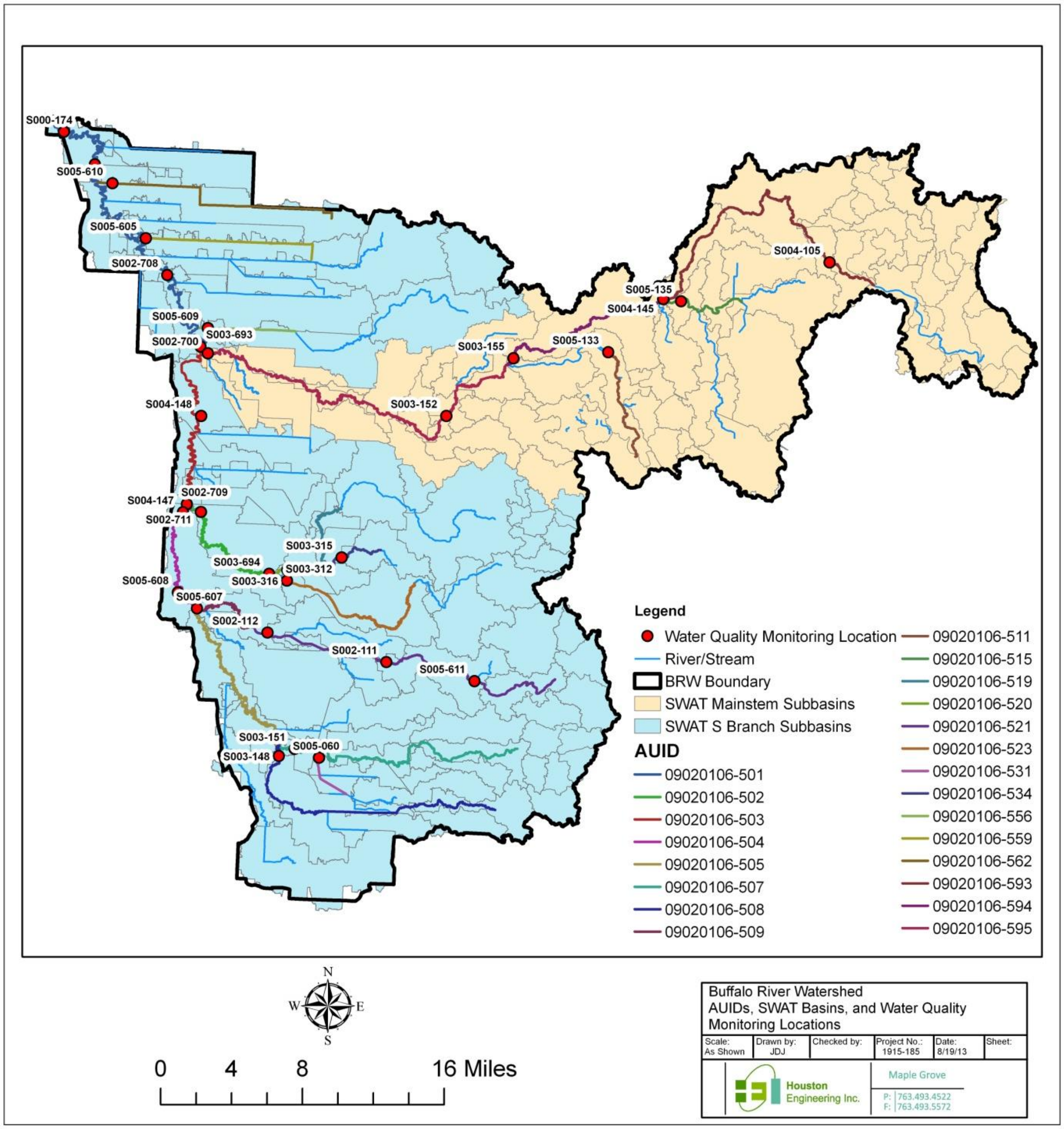


Figure 1. AUIDs, water quality monitoring locations and SWAT model subbasins used for LDCs in the BRW.

Table 1. LDC AUIDs, impairments and data used.

AUID (09020106-XXX)	Impairments	Water Quality Stations	SWAT Subbasin	SWAT Model
501	*E. coli*, Turbidity	S000-174, S002-125, S002-708, S003-693	1	S. Branch
502	*E. coli*, Turbidity	S002-711, S003-694	40	S. Branch
503	*E. coli*, Turbidity	S004-148, S002-709	28	S. Branch
504	*E. coli*, Turbidity	S004-147, S005-608	31	S. Branch
505	*E. coli*, Turbidity	S003-145	32	S. Branch
507	*E. coli*, Turbidity	S003-151	81	S. Branch
508	*E. coli*, Turbidity	S003-148	92	S. Branch
509	*E. coli*, Turbidity	S005-607	61	S. Branch
511	*E. coli*	S005-133	31	Mainstem
515	*E. coli*	S005-135	43	Mainstem
519	*E. coli*	S003-313	42	S. Branch
520	*E. coli*	S003-316	41	S. Branch
521	*E. coli*, Turbidity	S002-112, S002-111,S005-611	62	S. Branch
523	*E. coli*, Turbidity	S003-312	56	S. Branch
531	*E. coli*	S005-060	88	S. Branch
534	*E. coli*	S003-315	55	S. Branch
556	*E. coli*	S005-609	24	S. Branch
559	*E. coli*	S005-605	13	S. Branch
562	*E. coli*	S005-610	7	S. Branch
593	*E. coli*, Turbidity	S004-105	44	Mainstem
594	*E. coli*, Turbidity	S003-155, S004-145	20	Mainstem
595	*E. coli*, Turbidity	S002-700, S003-152	1	Mainstem

METHODOLOGY

LDCs were developed for each of the 22 AUIDs listed in **Table 1**. Each LDC was developed by combining the (simulated) river/stream flow at the downstream end of the AUID with the numeric water quality data available within the segment. Methods detailed in the US Environmental Protection Agency (USEPA) document *An Approach for Using Load Duration Curves in the Development of TMDLs* were used in creating the curves (USEPA, 2007). A summary of this methodology, as applied in the BRW, is provided below; full details on LDC methods can be found in the USEPA guidance (USEPA, 2007).

Data

Observed daily flow data is limited within the BRW; therefore simulated daily mean flows from the BRW SWAT model (HEI, 2013) were used to create the curves. The SWAT model simulates flows from 1995-2009; in order to best capture the flow regimes of each AUID, this entire record was used in development of the LDCs.

The water quality data used in this work was obtained from the Minnesota Pollution Control Agency (MPCA) through their EQuIS (Environmental Quality Information System) database. For the purposes of creating of the curves (which will inform TMDL development), only water quality data from the most recent completed assessment period (2002-2011) was used. While data exists for bacteria and sediment, spanning from 2002-2010, the SWAT model only estimates flows for 1995-2009; therefore the LDCs are based on bacteria and sediment data from the overlapping time period of 2002-2009. **Table 2** summarizes the water quality data used in the bacteria and sediment LDCs for each AUID in the BRW.

Table 2. Water quality data used for each LDC.

AUID (09020106-XXX)	Water Quality Monitoring Locations	*E. coli* Data	Turbidity/TSS Data
501	S000-174, S002-125, S002-708, S003-693	2008-2009	2001, 2003-2009
502	S002-711, S003-694	2009	2005-2007, 2009
503	S004-148, S002-709	2009-2010	2006-2009
504	S004-147, S005-608	2009-2010	2006-2009
505	S003-145	2008-2009	2002-2009
507	S003-151	2008-2009	2002-2009
508	S003-148	2009	2002-2009
509	S005-607	2009-2010	2009
511	S005-133	2008-2009	---
515	S005-135	2008-2010	---
519	S003-313	2009	---
520	S003-316	2008-2010	---
521	S002-112, S002-111,S005-611	2006, 2008-2009	2002-2009
523	S003-312	2008-2009	2003-2009
531	S005-060	2008-2010	---
534	S003-315	2009-2010	---
556	S005-609	2009-2010	---
559	S005-605	2009-2010	---

AUID (09020106-XXX)	Water Quality Monitoring Locations	*E. coli* Data	Turbidity/TSS Data
562	S005-610	2009-2010	---
593	S004-105	2008-2009	2008-2009
594	S003-155, S004-145	2008-2009	2002-2009
595	S002-700, S003-152	2008-2009	2002-2009

--- Not impaired for turbidity/TSS

Bacterial LDCs

To match the time period when the water quality standard is applicable, the bacterial LDCs were created using flow and *E. coli* water quality data from April through October only. Individual loading estimates were calculated by combining the observed *E. coli* concentration and simulated mean daily flow value on each sampling date. The load estimates were separated by month and by station, mainly for purposes of display on the curve. "Allowable" loading curves were created for both the instantaneous (1260 organisms/100mL) and geometric mean, i.e., geomean, (126 organisms/100mL) criteria by multiplying each "allowable" concentration by the simulated mean daily flow values and ranking the flows. A 10% margin of safety (MOS) was applied to each of the "allowable" loading curves.

Sediment (Turbidity) LDCs

Following common practice, sediment LDCs were used as a surrogate to represent and address turbidity impairments in the turbidity-impaired BRW AUIDs. Sediment LDCs were calculated using a combination of total suspended solids (TSS) and turbidity data. When available, TSS was used as the preferred value for calculating sediment loading. However, since turbidity data are more prevalent in the BRW, turbidity was used to estimate TSS values at sites where insufficient TSS data was available. This is consistent with MPCA guidance (MPCA, 2012). TSS and turbidity data was paired for the BRW and a linear regression was applied to test the relationship. The resulting linear regression equation for converting turbidity values (in NTU) in the BRW to TSS (in mg/L) during the 2002-2011 time period is:

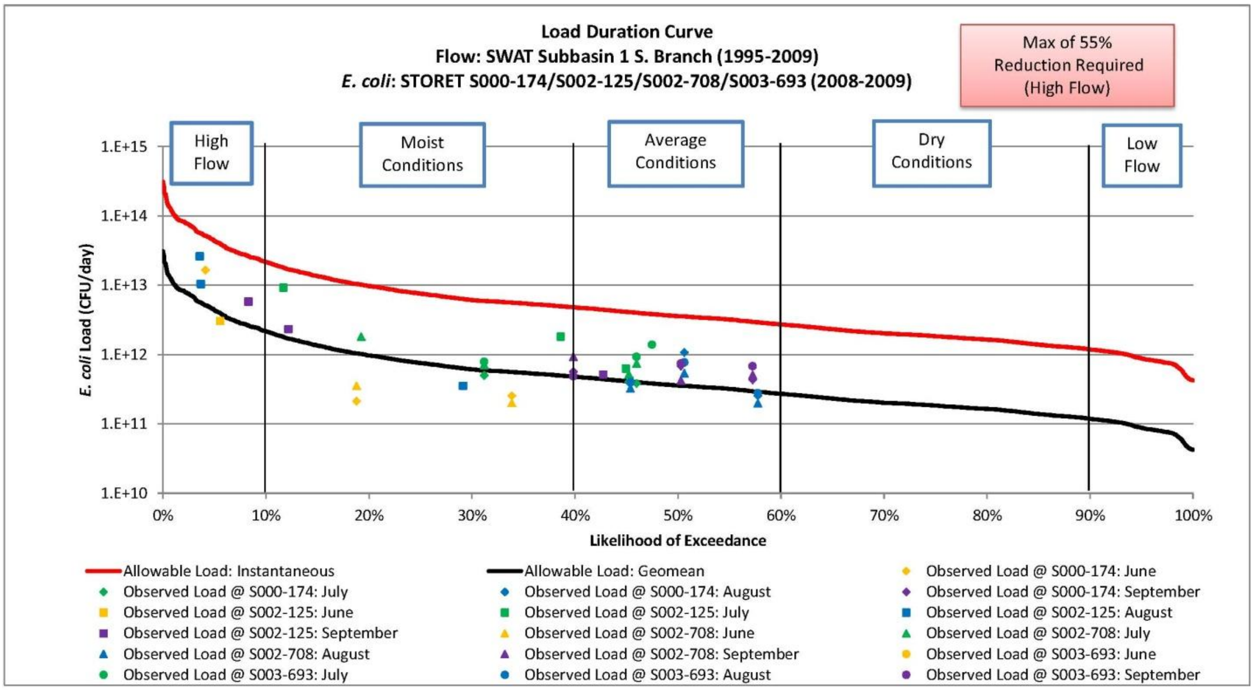
$$TSS = 0.9536 * Turbidity + 8.1967$$

Application of this regression equation to Minnesota's Class 2B stream turbidity water quality standard of 25 NTU (Nephelometric Turbidity Units) yields an "allowable" TSS value of 32 mg/L. As such, it is expected that a stream in the BRW with TSS concentrations of less than or equal to 32 mg/L would meet the turbidity water quality standard. The North Central Hardwood Forest (NCHF) surrogate TSS standard, by comparison, is 100 mg/L (a portion of the BRW lies in the NCHF so this surrogate standard could also be considered applicable). Both of these values were used in creating “allowable” loading curves and computing necessary sediment load reductions. Again, a 10% MOS was applied.

RESULTS

A system’s water quality often varies based on flow regime, with elevated pollutant loadings happening more frequency under one regime or another. Loading dynamics during certain flow conditions can be indicative of the type of pollutant loading causing an exceedance (e.g., point sources contributing more loading under low flow conditions). The LDC approach identifies these flow regimes and presents the observed and “allowable” loading with each, to compute necessary load reductions. To represent different types of flow events, and pollutant loading during these events, five flow regimes were identified in the BRW LDCs based on percent exceedance: High Flow (0%-10%), Moist Conditions (10%-40%), Average Conditions (40%-60%), Dry Conditions (60%-90%), and Low Flow (90%-100%). An example *E. coli* LDC is shown in **Figure 2**. The five flow regimes have been identified in the figure. There was one exception made to the defined flow regimes, for AUID 09020106-562. This stream reach experiences zero flow a considerable amount of the year and, therefore, required the low flow condition to be re-defined; its LDC is included in **Appendix A**.

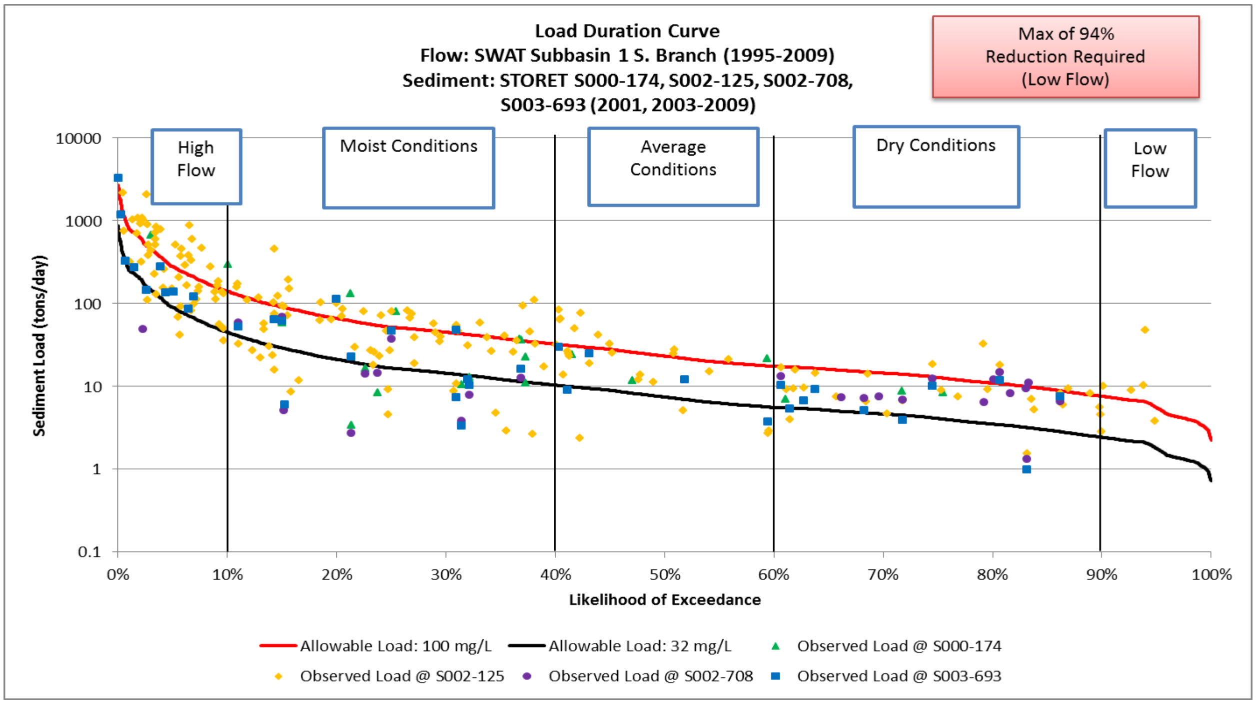
Figure 2. Example bacterial LDC (AUID 09020106-501)



The example bacterial LDC in **Figure 2** was created with flow and water quality data from April through October. The percent likelihood of flow exceedance is shown on the x-axis, while the computed bacterial loading is shown on the y-axis. "Allowable" loadings under each flow condition, based on the instantaneous and geomean standards, are shown with the red and black lines, respectively. Observed loads are also shown, indicated by points on the plot. Observed loads are broken out by station as well as month, allowing for a detailed examination of when and where loading exceedances have occurred. The bacterial LDCs for all of the AUIDs indicating bacterial impairment in **Table 1**a re included in **Appendix A**.

The BRW sediment LDCs were created using similar methods to the bacterial curves, however, the entire annual flow record was used and the empirical loading data was not broken out by month. These modifications are due to the nature by which turbidity impairment are assessed. An example sediment LDC is shown in **Figure 3**.

Figure 3. Example sediment LDC (AUID 09020106-501)



The red line in the sediment LDC represents the "allowable" load based on the NCHF TSS standard of 100 mg/L and the bottom curve represents the "allowable" load based on the BRW turbidity/TSS relationship of 25 NTU to 32 mg/L. The sediment LDCs for all of the AUIDs indicating turbidity impairment in **Table 1** are included in **Appendix B**.

LOAD REDUCTIONS

Bacteria

Total required bacterial load reductions (in organisms/day) and percent load reductions were calculated for each curve, using both the geomean and instantaneous criteria. Methods outlined in the USEPA guidance document (USEPA, 2007) were followed, computing observed and “allowable” loads for each flow regime by combining the median flow in each regime with the applicable water quality criteria and/or representative observed *E. coli* concentration. An example of this process is shown in **Table 3**. The reduction for each criterion (in each flow regime) is determined using the difference between the observed and “allowable” values.

Table 3. Example bacterial load reduction table (AUID 09020106-501)

Flow Regimes	Median Observed Flow (cfs)	Geomean Standard: Observed *E. coli* Geomean (#/100 mL)	Observed *E. coli* Geomean Loading (#/day)	Allowable Load (#/day)	Allowable Load w/ 10% MOS (#/day)	Required Load Reduction (#/day)	% Load Reduction	Instantaneous Standard: *E. coli* Value that 90% are less than (#/100 mL)	Allowable Load (#/day)	Allowable Load w/ 10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction
0-10%	1568	250	$9.6x10^{12}$	$4.8x10^{12}$	$4.4x10^{12}$	$5.2x10^{12}$	**55%**	517	$4.8x10^{13}$	$4.4x10^{13}$	$-2.4x10^{12}$	NR
10-40%	273	98	$6.6x10^{11}$	$8.4x10^{11}$	$7.6x10^{11}$	$-1.0x10^{11}$	NR	411	$8.4x10^{12}$	$7.6x10^{12}$	$-4.8x10^{12}$	NR
40-60%	129	162	$5.1x10^{11}$	$4.0x10^{11}$	$3.6x10^{11}$	$1.6x10^{11}$	**30%**	261	$4.0x10^{12}$	$3.6x10^{12}$	$-2.8x10^{12}$	NR
60-90%	66	---	---	$2.1x10^{11}$	$1.8x10^{11}$	---	---	---	$2.1x10^{12}$	$1.8x10^{12}$	---	---
90-100%	32	---	---	$9.8x10^{10}$	$8.8x10^{10}$	---	---	---	$9.8x10^{11}$	$8.8x10^{11}$	---	---

--- insufficient data

NR – no reduction required

Table 4. Example sediment load reduction table (AUID 09020106-501)

Flow Regime	Observed Data: Median Observed Flow (cfs)	90th % Observed TSS (mg/L)	Average Observed TSS Loading (tons/day)	NCHF TSS Guidance (100 mg/L): Allowable TSS Load (tons/day)	Allowable Load w/ 10% MOS (tons/day)	Required Load Reduction (tons/day)	% Load Reduction	Turbidity/TSS Conversion (32 mg/L): Allowable TSS Load (tons/day)	Allowable Load w/ 10% MOS (tons/day)	Required Load Reduction (tons/day)	% Load Reduction
0-10%	1160	175	547	312.8	281.5	265.9	**49%**	100.1	90.1	457.3	**84%**
10-40%	214	136	78	57.6	51.8	26.5	**34%**	18.4	16.6	61.7	**79%**
40-60%	96	182	47	25.9	23.3	23.9	**51%**	8.3	7.5	39.8	**84%**
60-90%	53	100	14	14.3	12.8	1.4	**10%**	4.6	4.1	10.2	**71%**
90-100%	23	120	8	6.3	5.6	1.9	**25%**	2.0	1.8	5.7	**76%**

Sediment

Similar methods were used to compute the total required sediment load reductions (tons/day) and percent reductions for the NCHF TSS and BRW turbidity/TSS conversion criterion at the median of each of the five flow regimes. An example of this process is shown in **Table 4**. Again, the reduction for each criterion is determined using the difference between the observed and "allowable" loads.

Critical Condition

A summary of the bacterial and sediment load reduction results can be found in **Table 5**. Results are summarized by indicating the maximum required percent load reduction for each curve and the flow regime and water quality criteria under which this maximum reduction occurred (i.e., the critical flow regime and criteria). The critical criterion for each of the bacterial LDCs is consistently the geomean criterion, indicating a chronic bacterial water quality problem in the watershed. The critical condition for turbidity impairments is always under the turbidity/TSS conversion criterion. The critical flow regime for both bacteria and sediment loading is most often under high flow conditions.

Table 5. Maximum required bacterial and sediment load reductions for the BRW.

	Bacterial			Sediment		
AUID (09020106-XXX)	**Max. % Load Reduction**	**Critical Flow Regime**	**Critical Criterion**	**Max. % Load Reduction**	**Critical Flow Regime**	**Critical Criterion**
501	55%	High	Geomean	94%	Low	32 mg/L
502	69%	High / Moist	Geomean	71%	Average	32 mg/L
503	57%	High	Geomean	65%	High	32 mg/L
504	47%	Average	Geomean	44%	Moist	32 mg/L
505	64%	High	Geomean	84%	High	32 mg/L
507	77%	High	Geomean	66%	High	32 mg/L
508	61%	Average	Geomean	46%	Moist	32 mg/L
509	62%	Average	Geomean	59%	Moist	32 mg/L
511	75%	Dry	Geomean	---	---	---
515	71%	Average	Geomean	---	---	---
519	94%	Average	Geomean	---	---	---
520	93%	High	Geomean	---	---	---
521	83%	Dry	Geomean	69%	High	32 mg/L
523	90%	High	Geomean	71%	Moist	32 mg/L
531	90%	High	Geomean	---	---	---
534	79%	High	Geomean	---	---	---
556	67%	High	Geomean	---	---	---
559	72%	Dry	Geomean	---	---	---
562	64%	Dry	Geomean	---	---	---
593	88%	Average	Geomean	41%	High	32 mg/L
594	62%	Average	Geomean	91%	High	32 mg/L
595	57%	Dry	Geomean	93%	High	32 mg/L

--- Not impaired for turbidity

CONCLUSION

Sediment and/or bacteria LDCs were developed for 22 AUIDs in the BRW based on impairment status. The curves were developed following the methods in the USEPA guidance document, *An Approach for Using Load Duration Curves in the Development of TMDLs* (USEPA, 2007). Results of this analysis showed maximum required bacterial load reductions ranging from 47-94%, all based on the geomean *E. coli* criterion, and typically occurring during high flow conditions. Maximum sediment load reductions range from 41-93%, all based on the turbidity/TSS conversion criterion of

32 mg/L, and also most often found during high flow conditions. Results of the LDC analysis will be used to compute TMDLs for these stream segments under future tasks of the BRW WRAP project.

REFERENCES

Houston Engineering, Inc. (HEI). 2013. Buffalo River Watershed SWAT Modeling Final Report. August 13, 2013.

MPCA (Minnesota Pollution Control Agency). 2012. Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List. Minnesota Pollution Control Agency. St. Paul, MN

United States Environmental Protection Agency (USEPA). 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. August 2007.

APPENDIX A. BACTERIAL LOAD DURATION CURVES

Figure A1. AUID 09020106-501 bacterial LDC

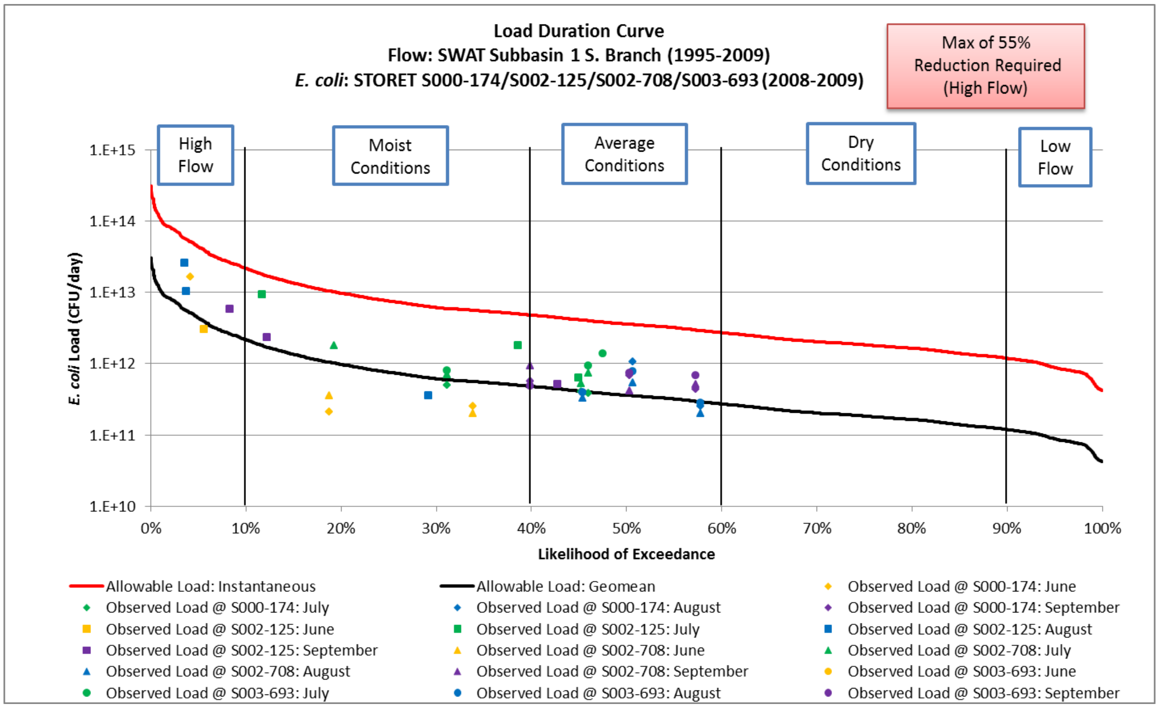


Figure A2. AUID 09020106-502 bacterial LDC

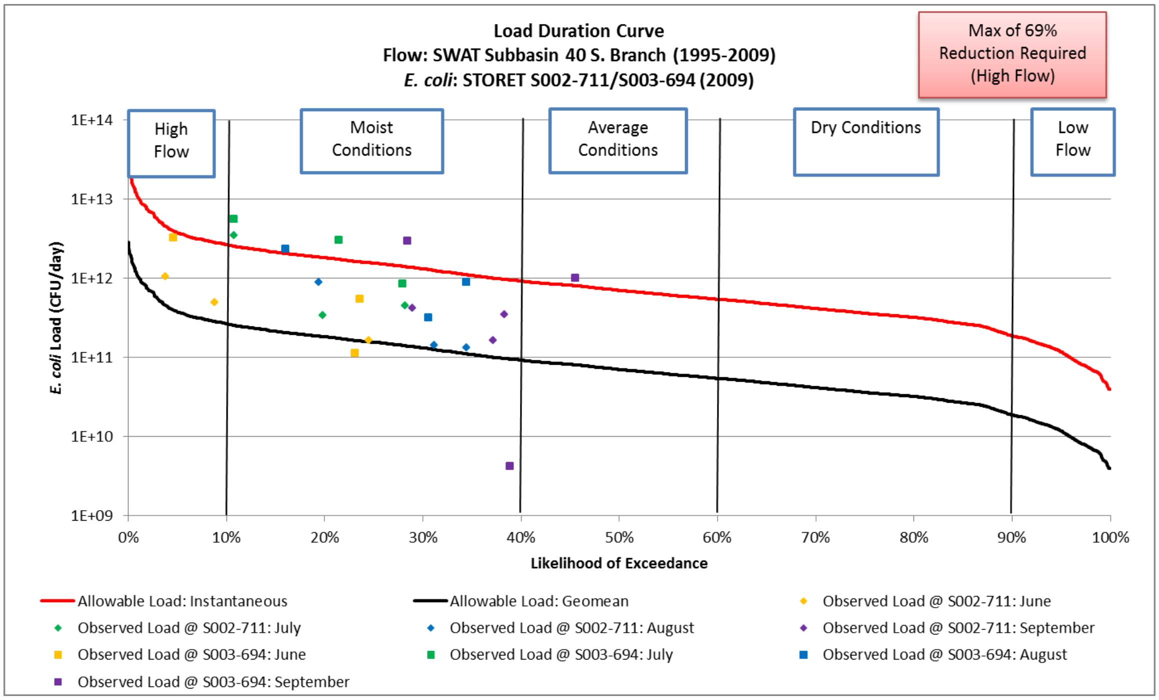


Figure A3. AUID 09020106-503 bacterial LDC

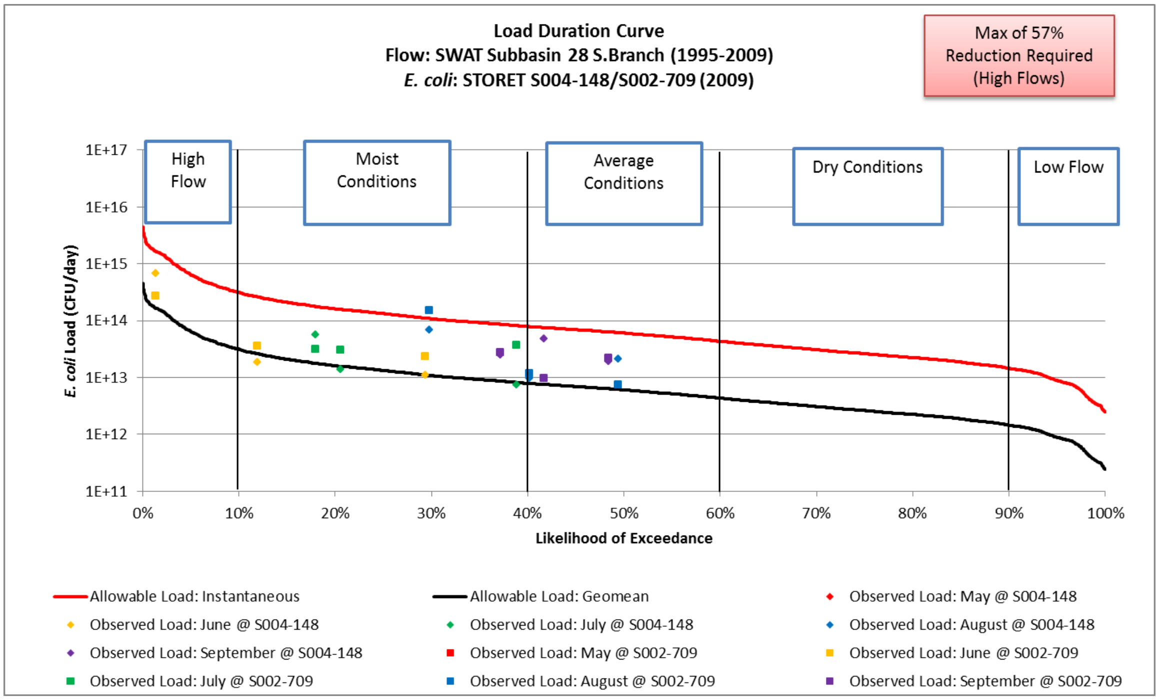


Figure A4. AUID 09020106-504 bacterial LDC

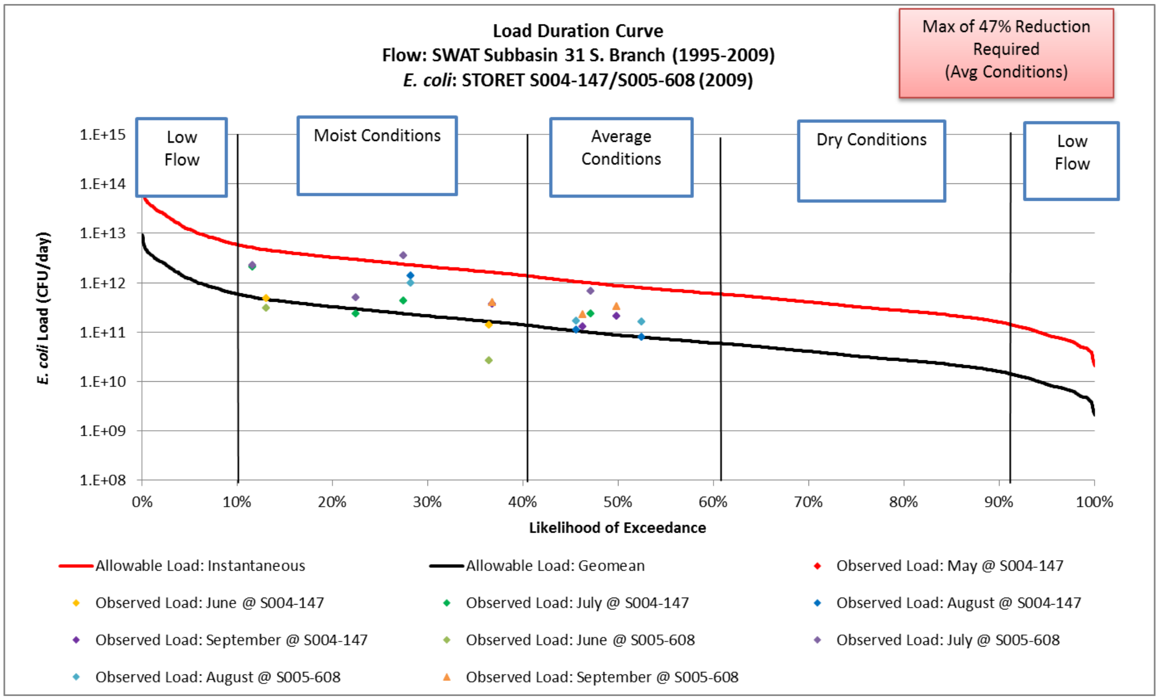


Figure A5. AUID 09020106-505 bacterial LDC

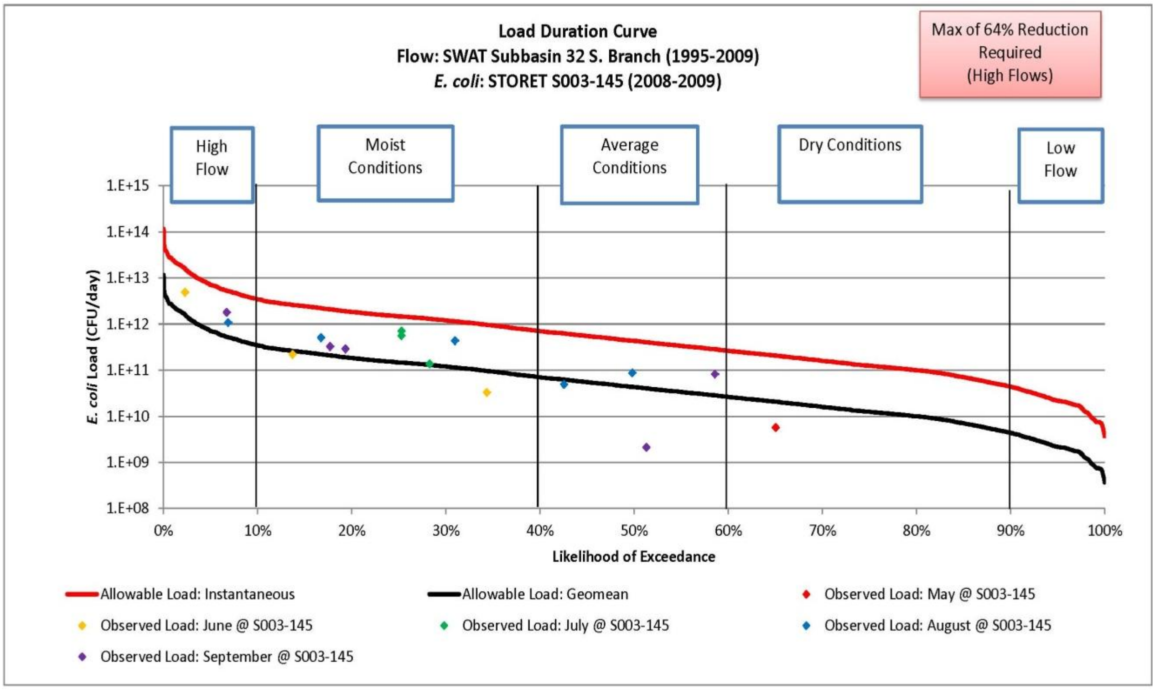


Figure A6. AUID 09020106-507 bacterial LDC

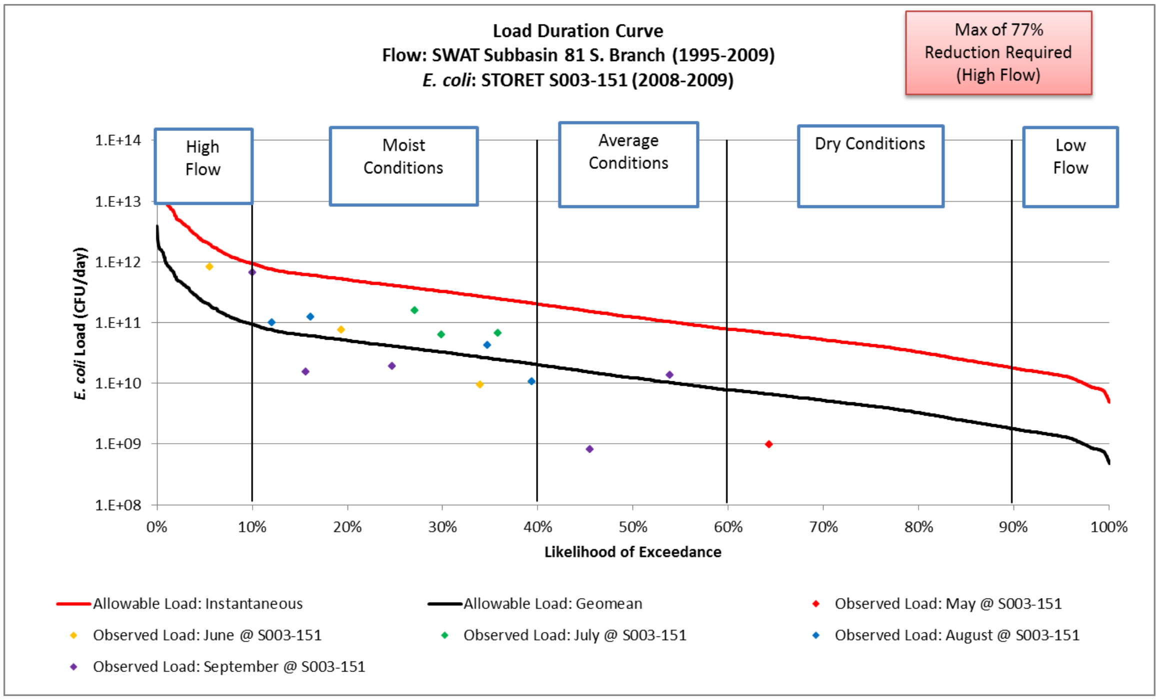


Figure A7. AUID 09020106-508 bacterial LDC

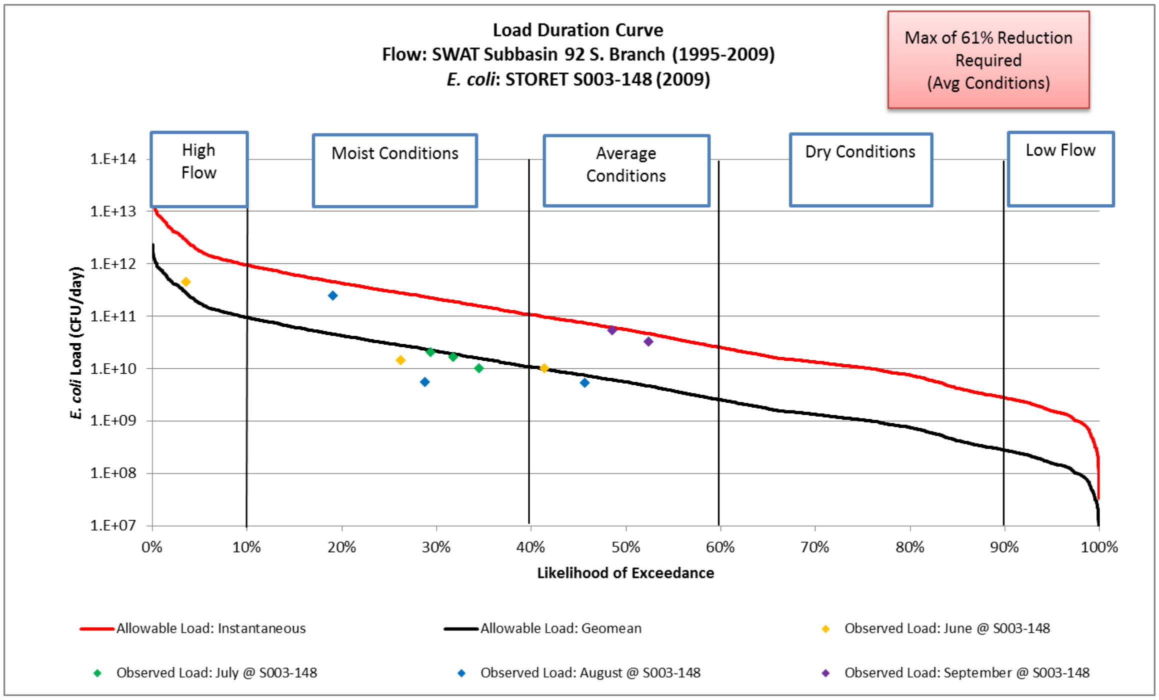


Figure A8. AUID 09020106-509 bacterial LDC

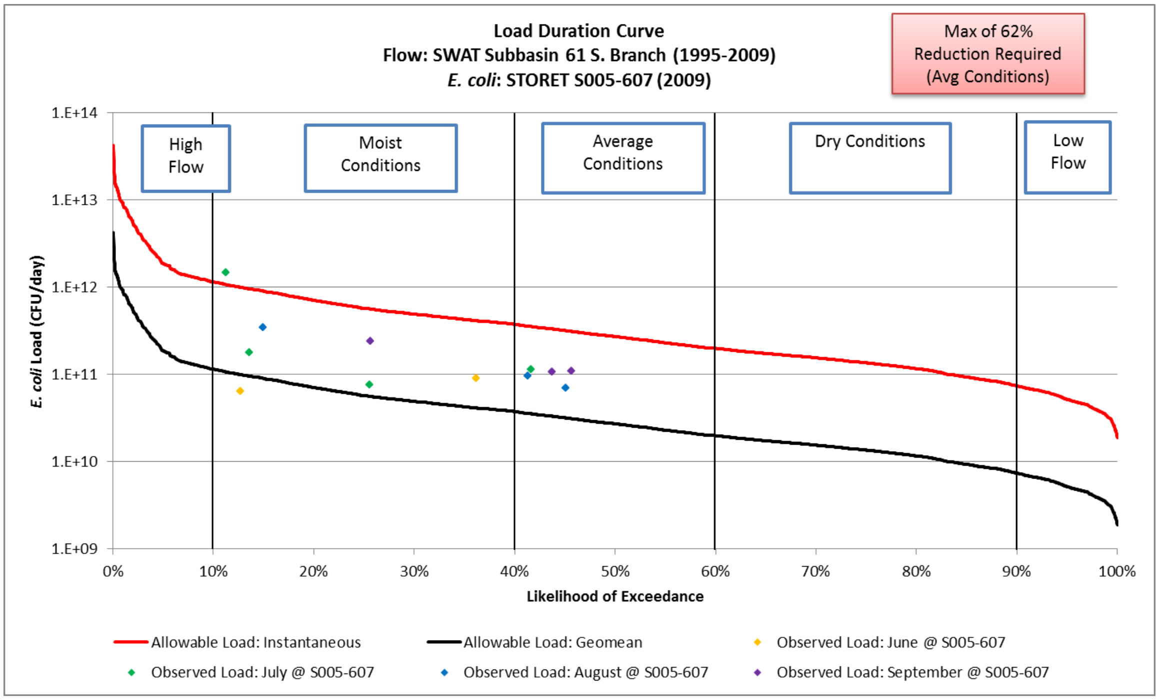


Figure A9. AUID 09020106-511 bacterial LDC

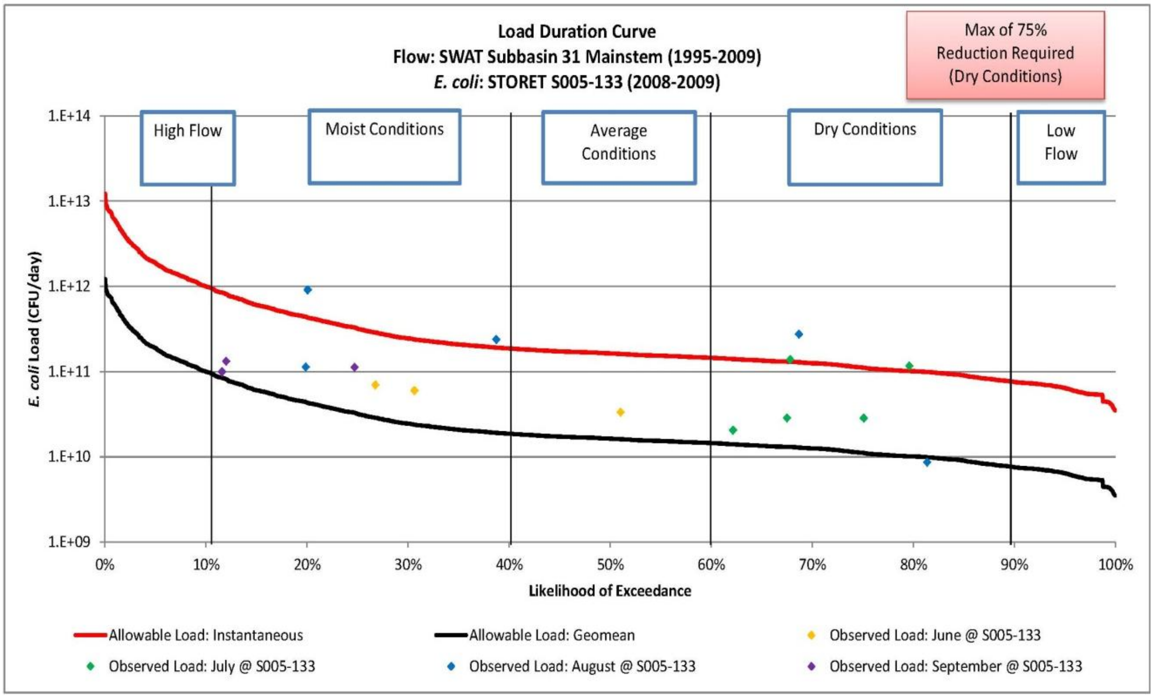


Figure A10. AUID 09020106-515 bacterial LDC

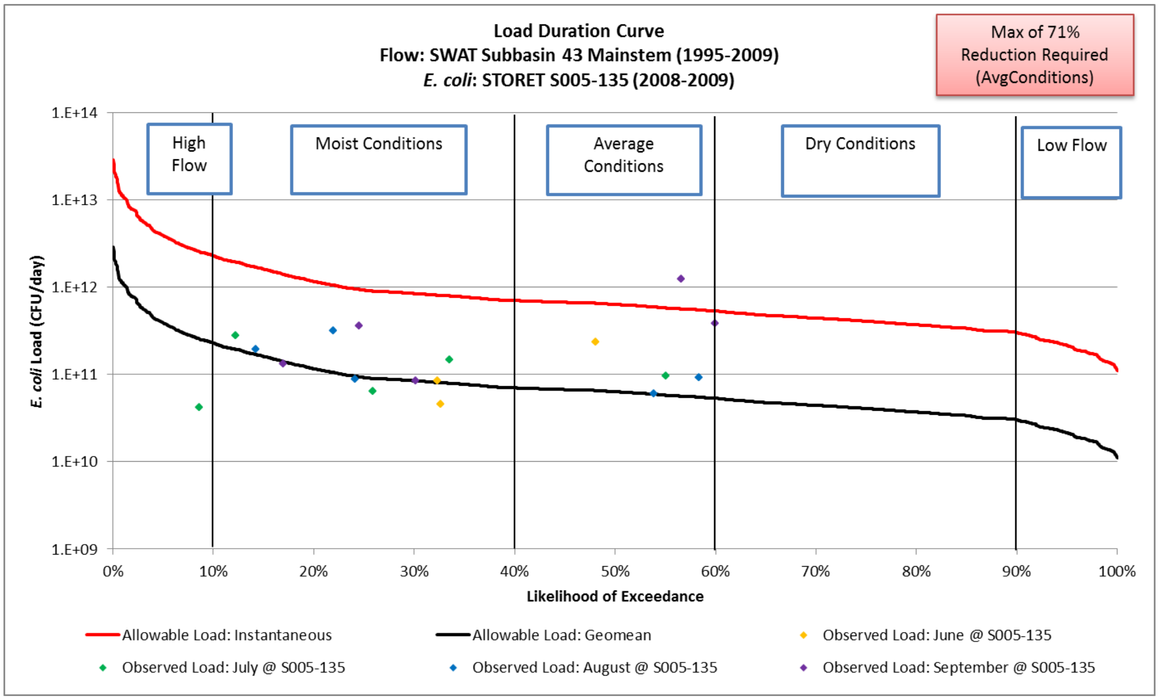


Figure A11. AUID 09020106-519 bacterial LDC

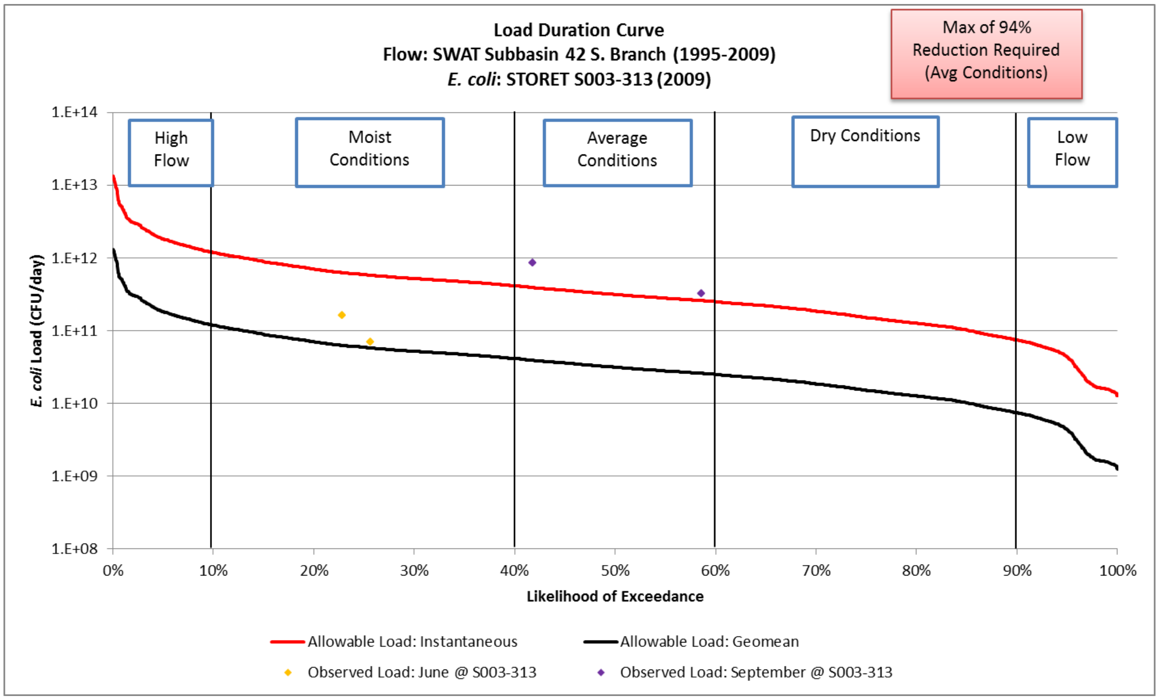


Figure A12. AUID 09020106-520 bacterial LDC

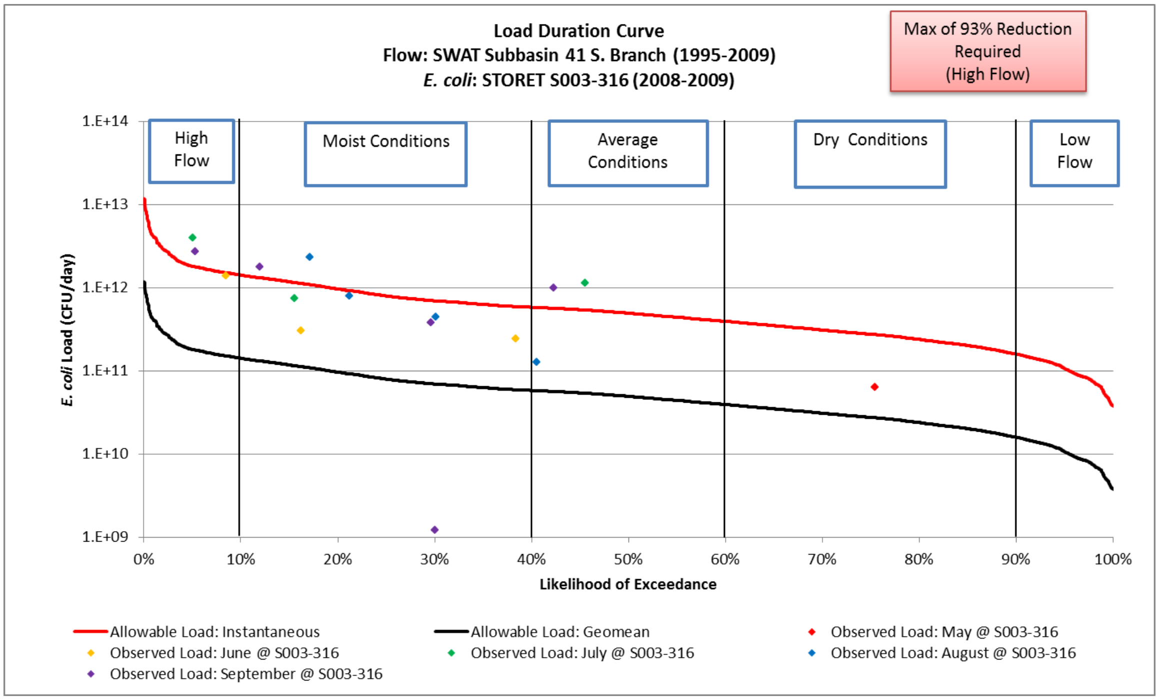


Figure A13. AUID 09020106-521 bacterial LDC

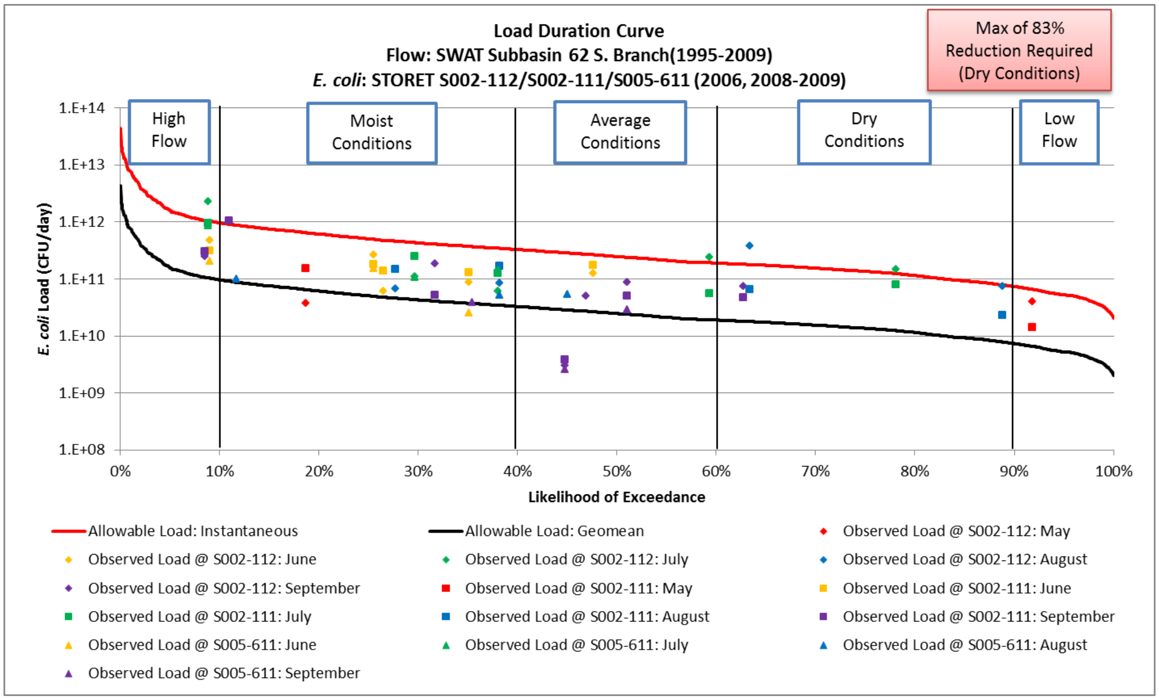


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Figure A14. AUID 09020106-523 bacterial LDC

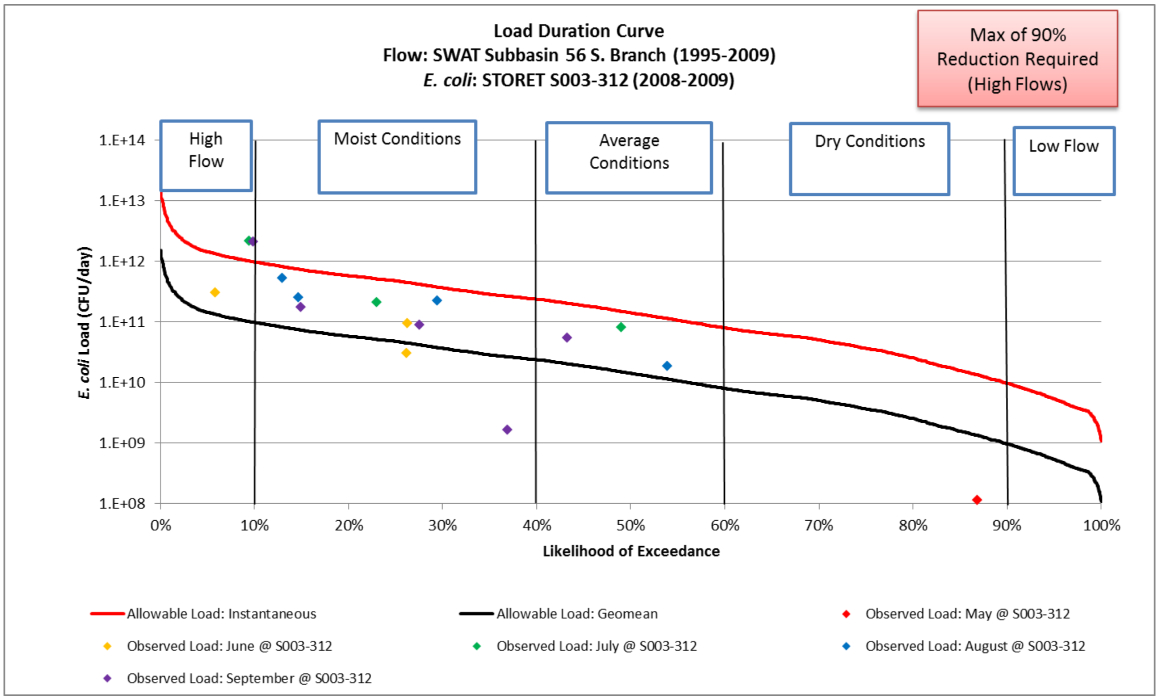


Figure A15. AUID 09020106-531 bacterial LDC

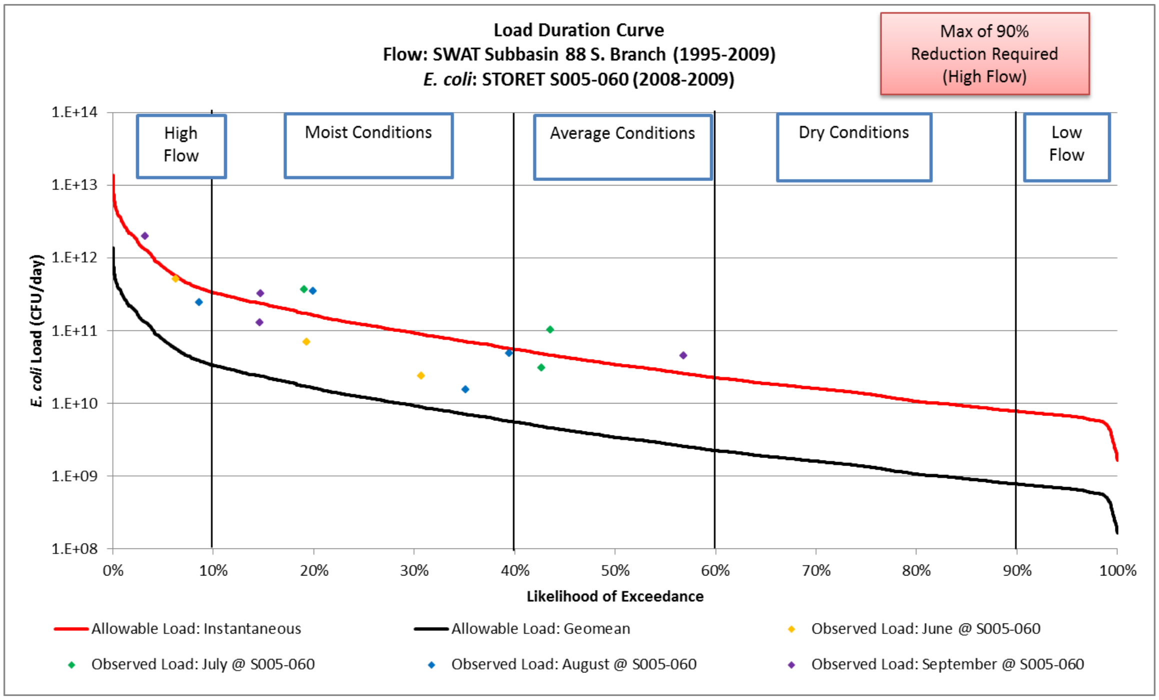


Figure A16. AUID 09020106-534 bacterial LDC

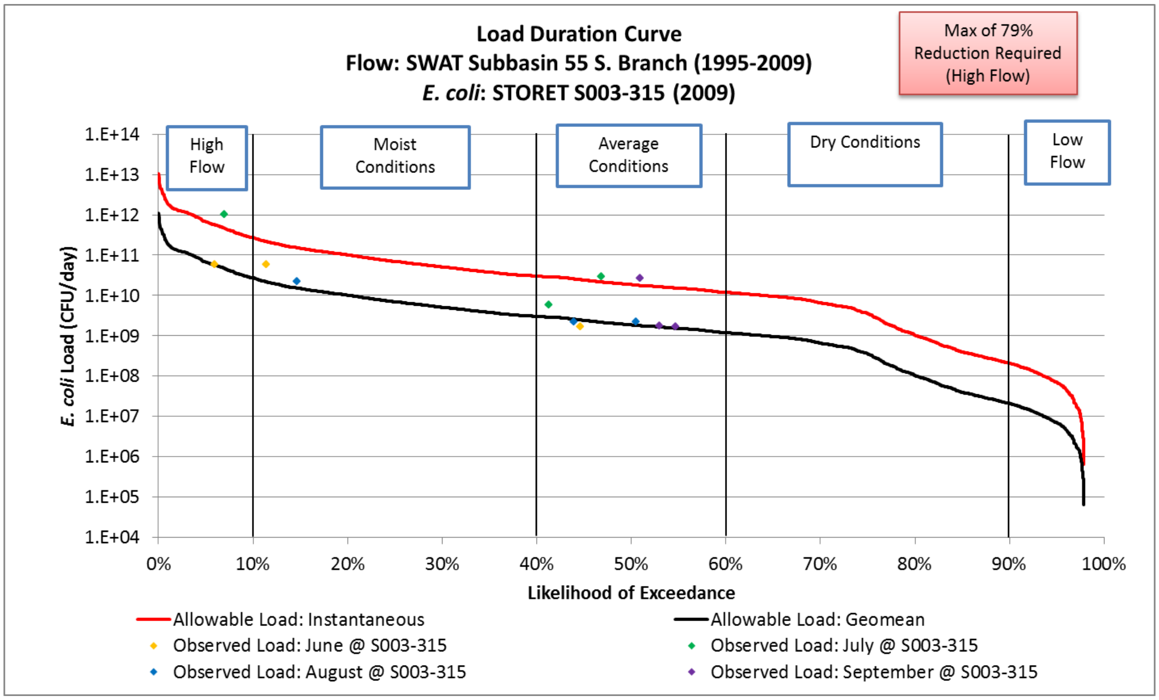


Figure A17. AUID 09020106-556 bacterial LDC

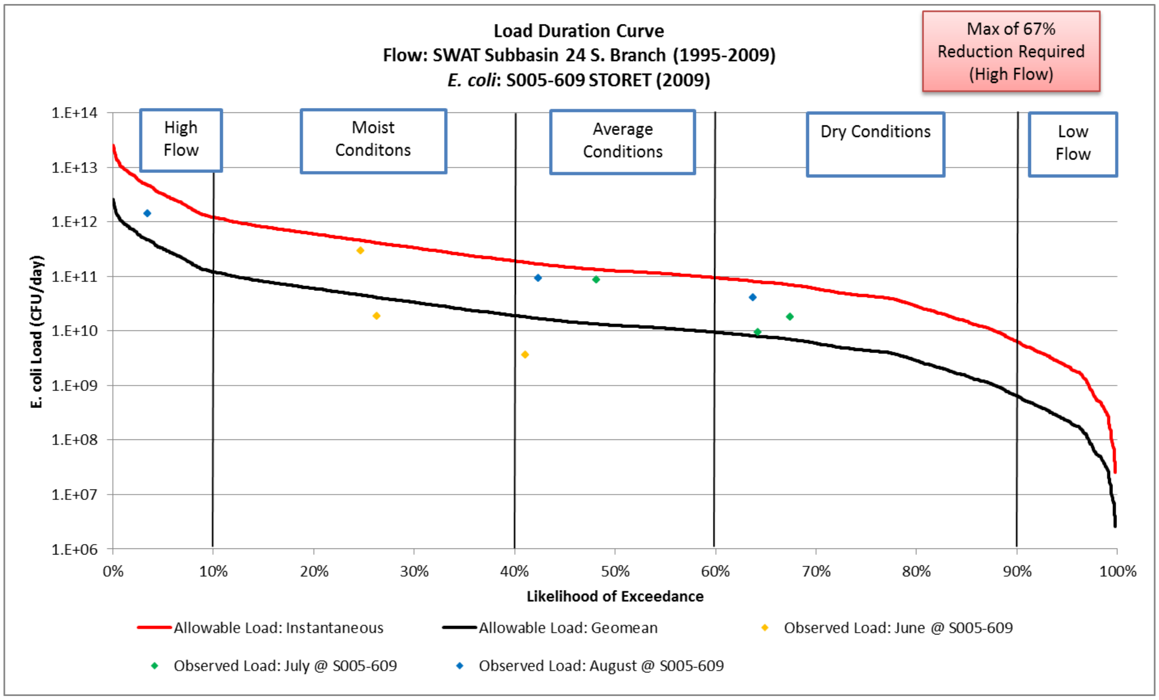


Figure A18. AUID 09020106-559 bacterial LDC

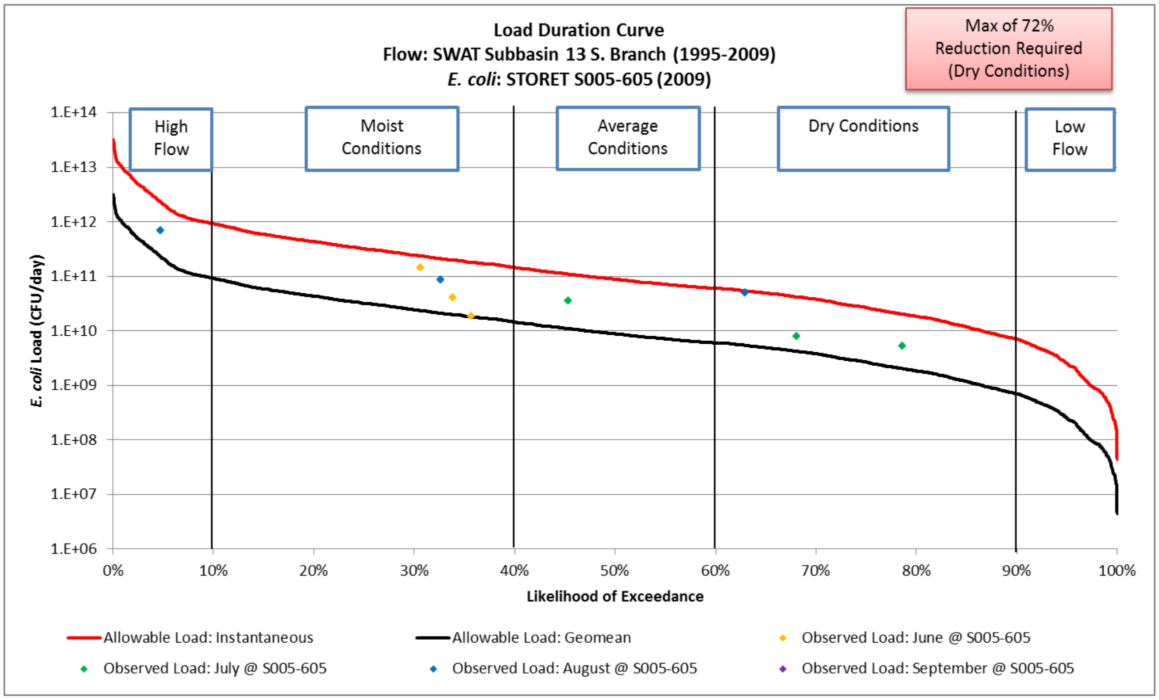


Figure A19. AUID 09020106-562 bacterial LDC

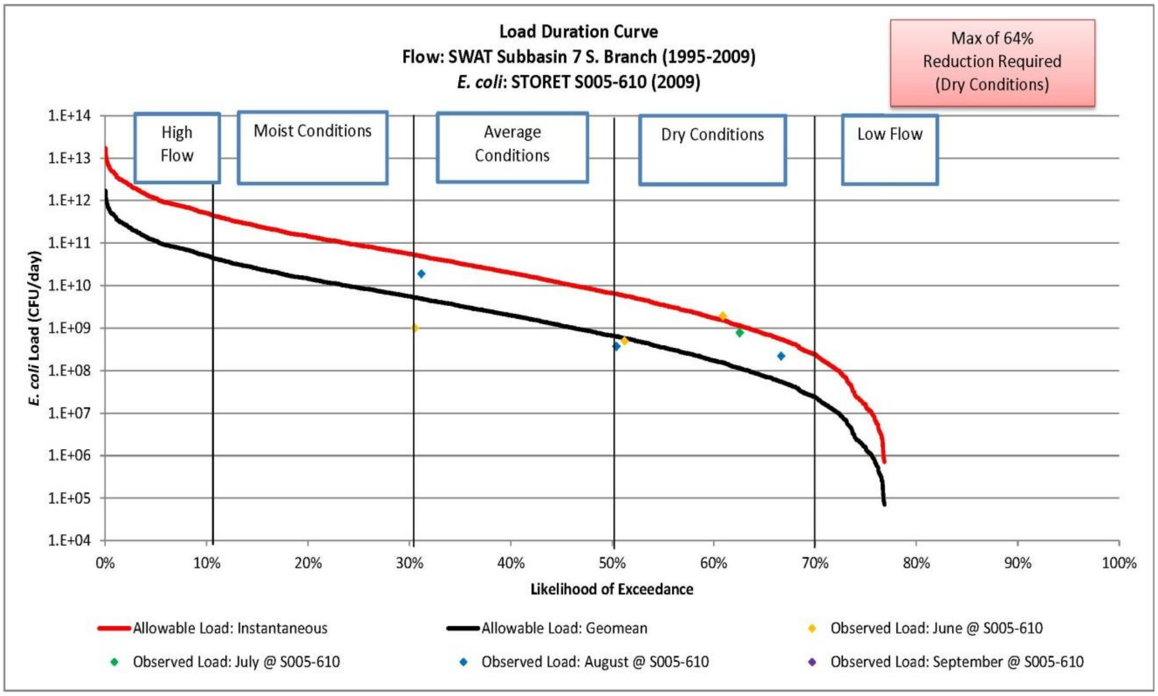


Figure A20. AUID 09020106-593 bacterial LDC

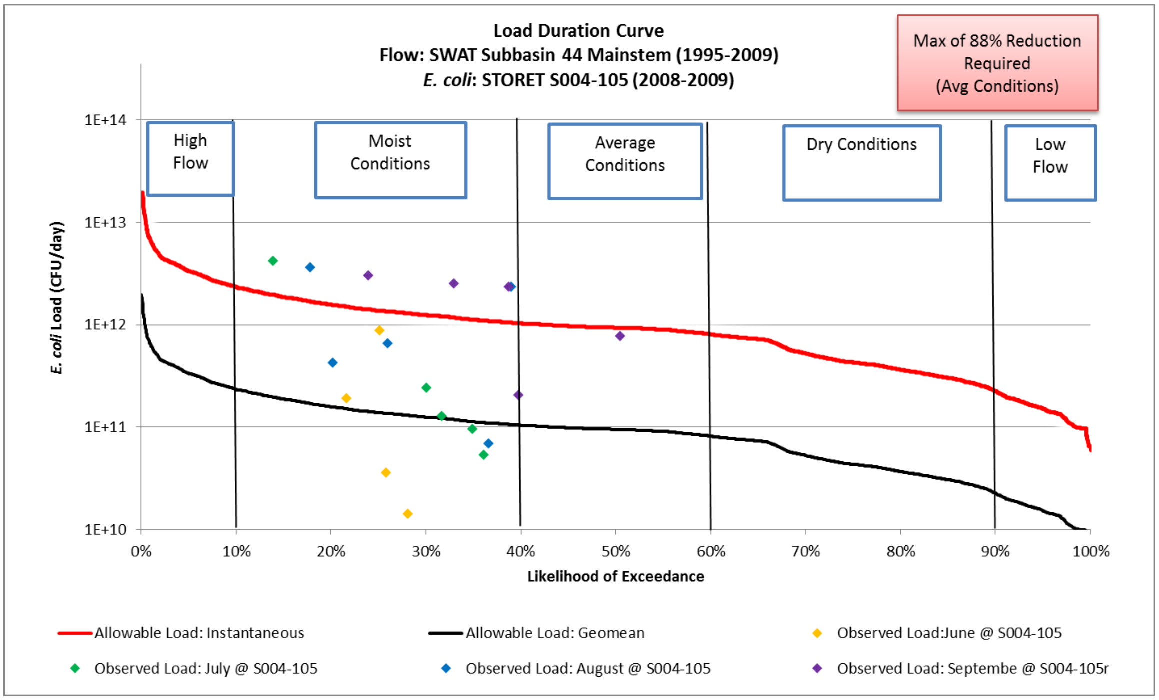


Figure A21. AUID 09020106-594 bacterial LDC

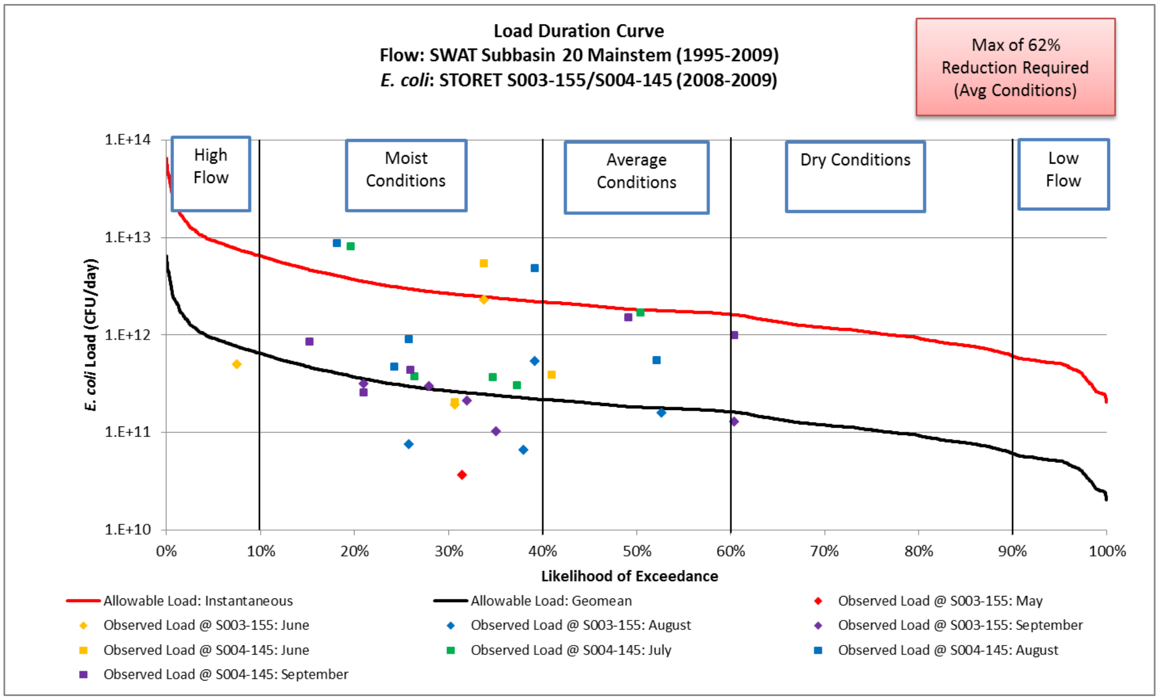
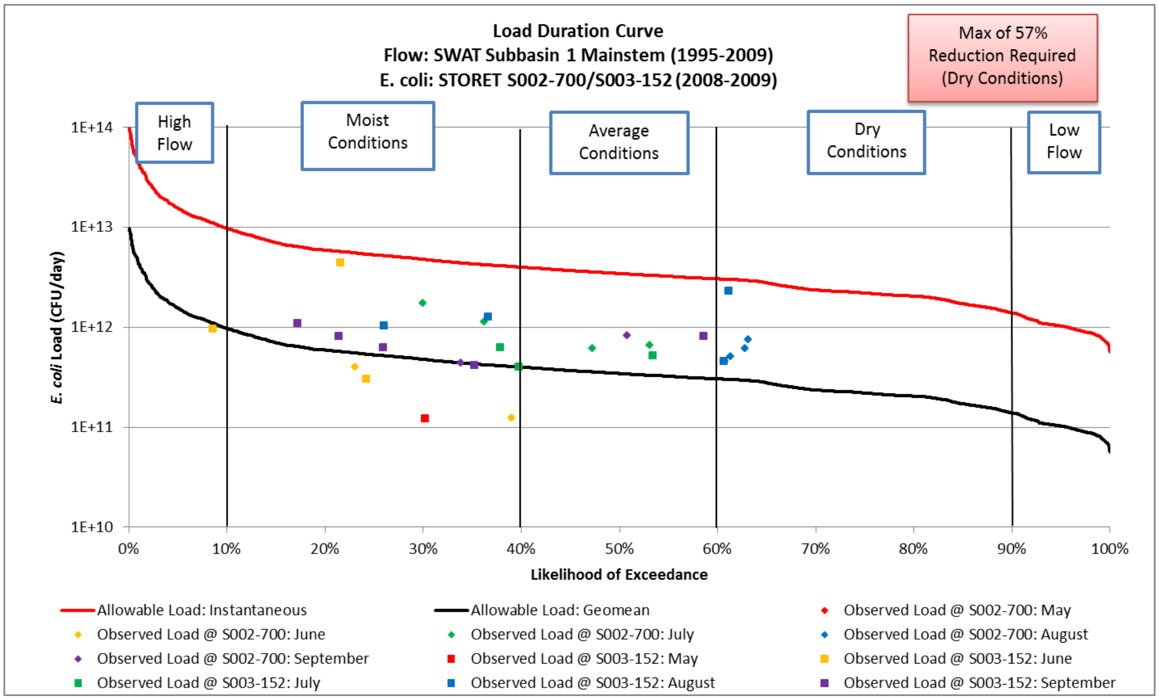


Figure A22. AUID 09020106-595 bacterial LDC



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APPENDIX B. SEDIMENT LOAD DURATION CURVES

Figure B1. AUID 09020106-501 sediment LDC

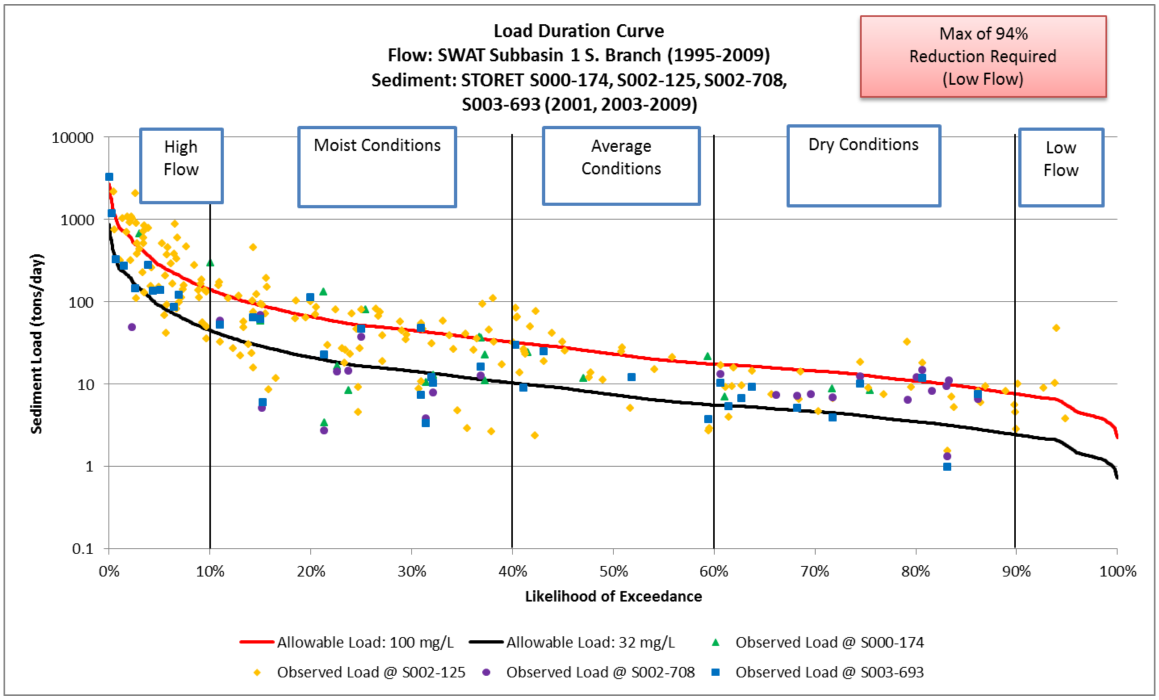

Figure B2. AUID 09020106-502 sediment LDC

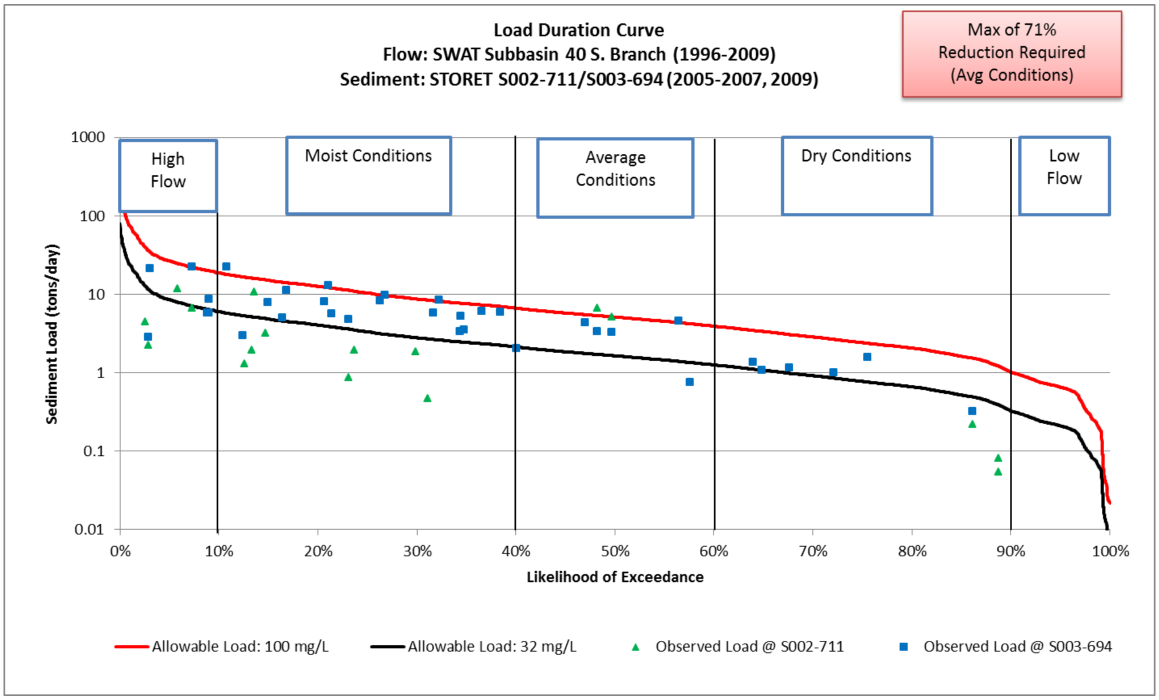

Figure B3. AUID 09020106-503 sediment LDC

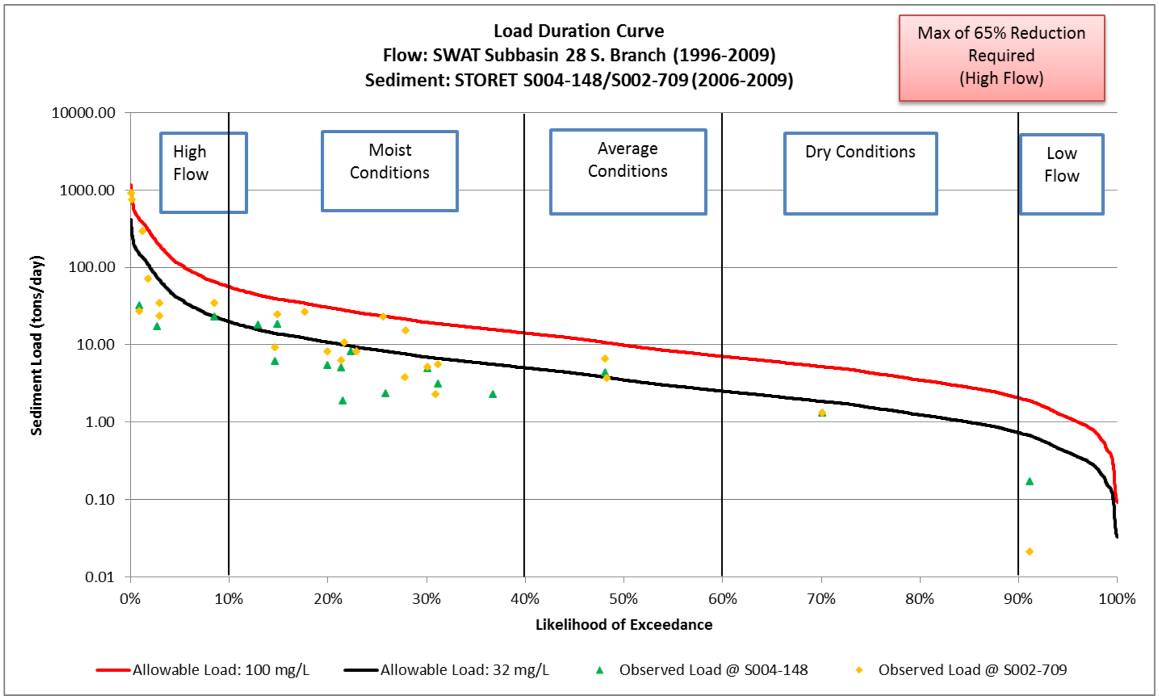

Figure B4. AUID 09020106-504 sediment LDC

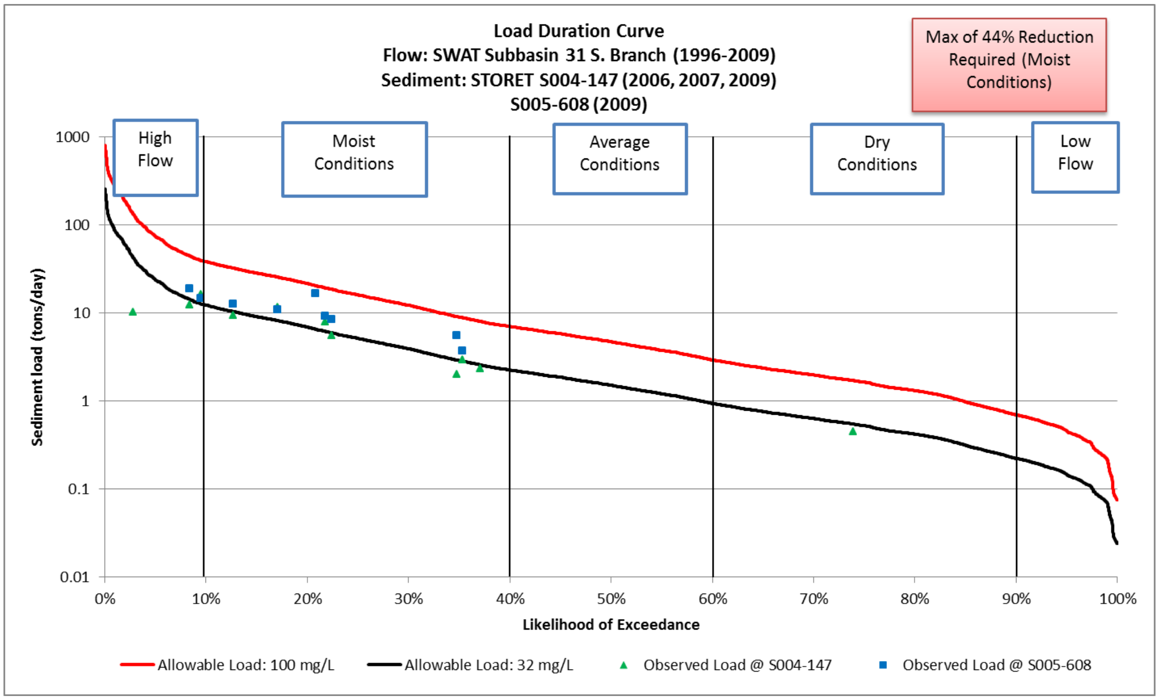

Figure B5. AUID 09020106-505 sediment LDC

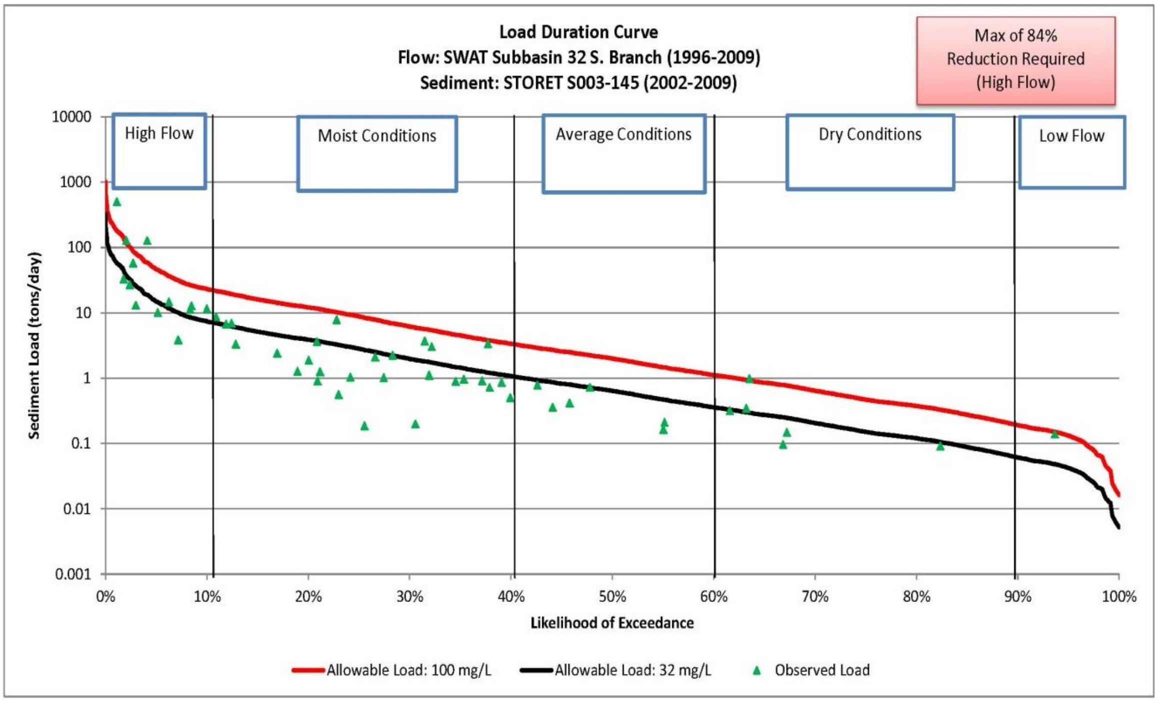

Figure B6. AUID 09020106-507 sediment LDC

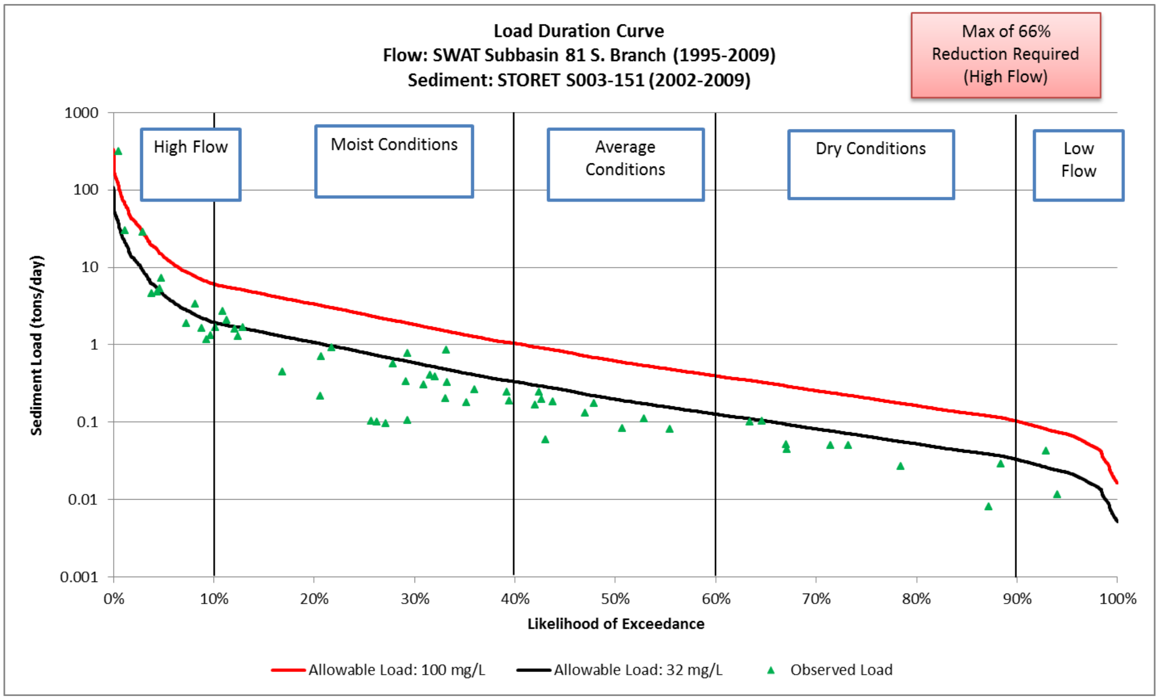

Figure B7. AUID 09020106-508 sediment LDC

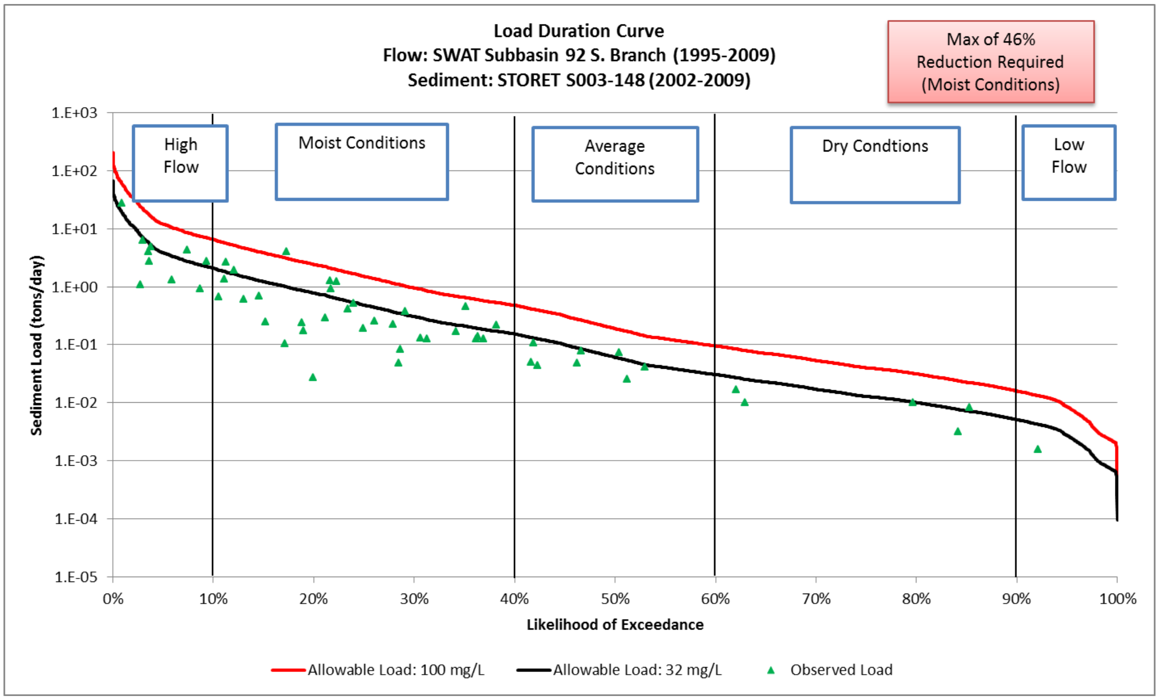

Figure B8. AUID 09020106-509 sediment LDC

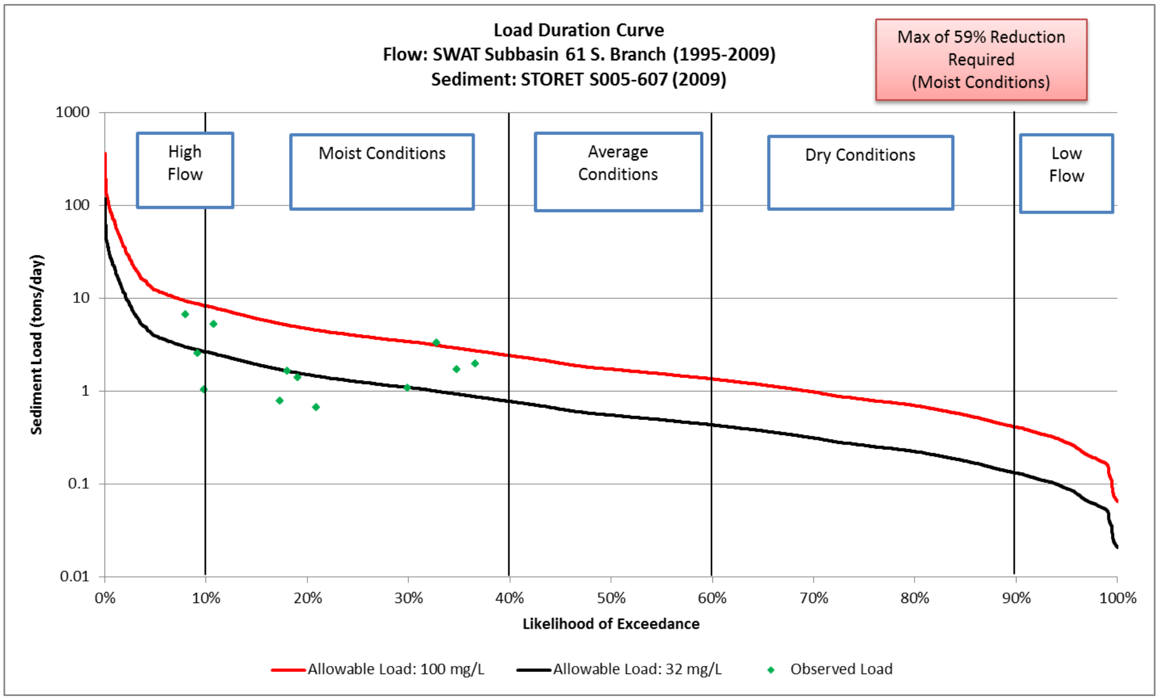

Figure B9. AUID 09020106-521 sediment LDC

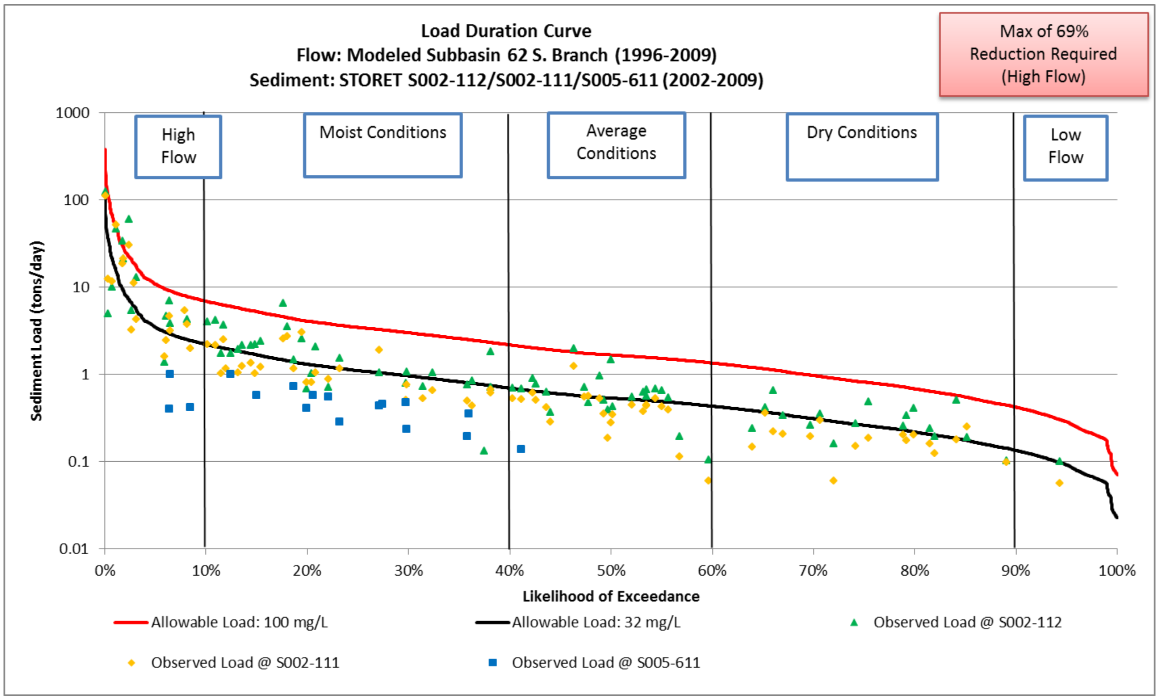

Figure B10. AUID 09020106-523 sediment LDC

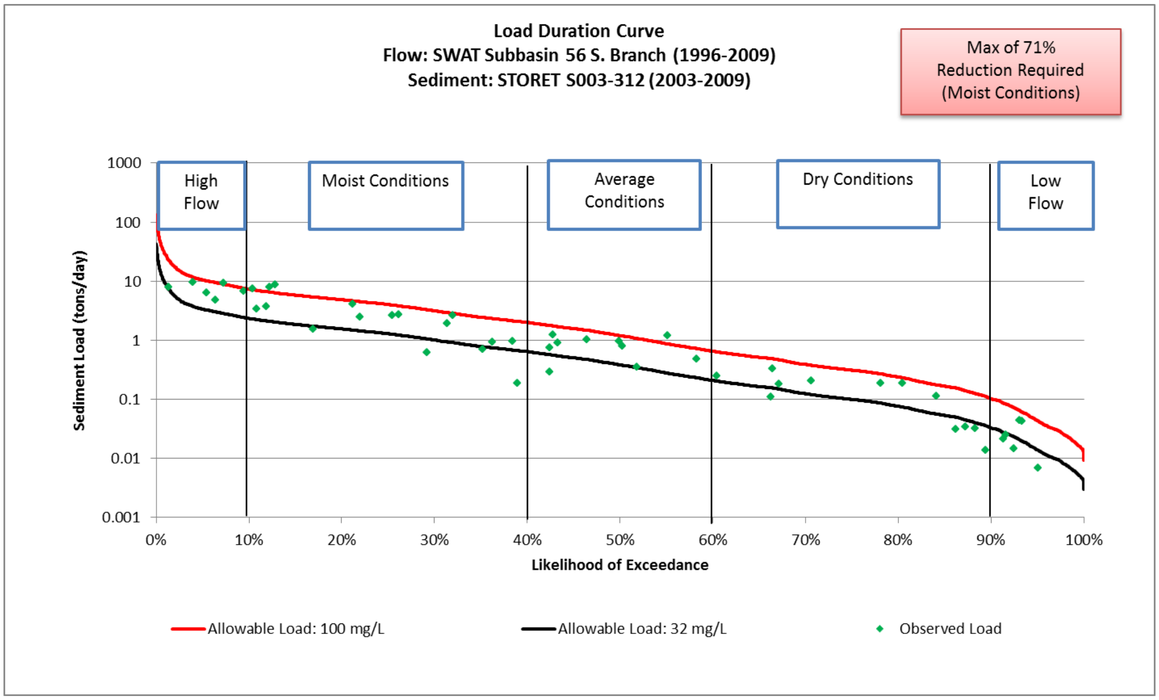

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Figure B11. AUID 09020106-593 sediment LDC

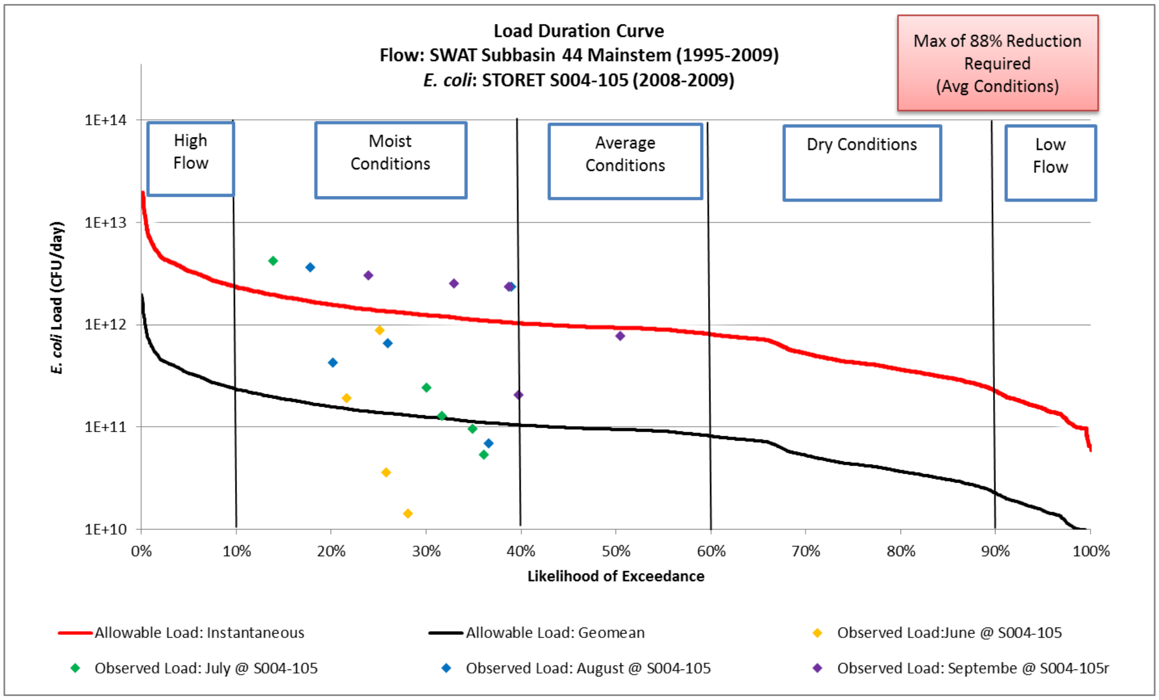

Figure B12. AUID 09020106-594 sediment LDC

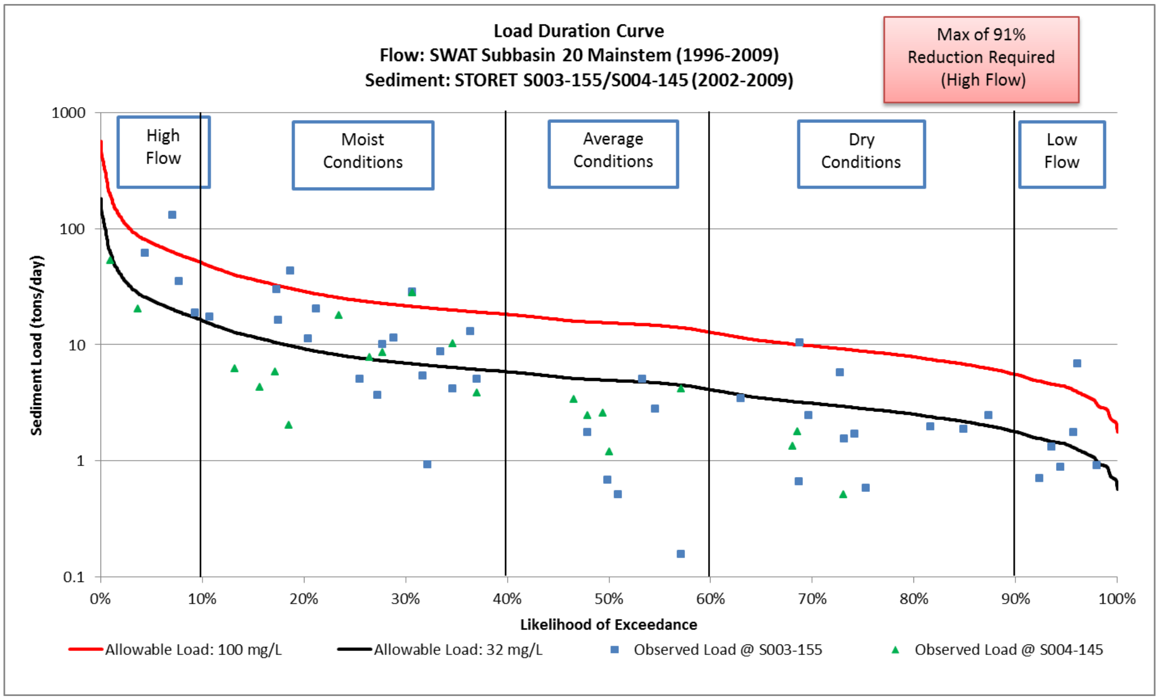

Figure B13. AUID 09020106-595 sediment LDC