Arizona Department of Environmental Quality

Janice K. Brewer, Governor
Henry R. Darwin, Director

Granite Creek Modeling Report

In support of the

Granite Creek *E. coli* TMDL

Verde Watershed
Yavapai County, Arizona

December 2014

Open File Report 14-09

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

Introduction

Based on data collected between 2000 and 2003, the Region 9 Environmental Protection Agency (EPA) placed Granite Creek on the 2006-2008 Water Quality Impaired List for low dissolved oxygen (ADEQ, 2008). *Escherichia coli (E. coli)* has also occasionally exceeded Arizona Surface Water Standards, resulting in official addition to the 303(d) list as a Granite Creek impairment in 2010 for sampling between 2007 and 2009. Miller Creek, a tributary to Granite Creek, was also added to the 303(d) list for *E. coli* impairment in 2010.

The Total Maximum Daily Load (TMDL) development work performed by Arizona Department of Environmental Quality (ADEQ) TMDL staff has included water quality sampling, and tributary flow and precipitation as needed. Sampling has occurred in the watersheds, lakes, and along major tributaries to satisfy source area identification, TMDL modeling and future assessment needs.

Watson Lake, Granite Creek, and its tributaries are located in the upper portion of the Verde River watershed (Figure 1). The Watson Lake watershed is approximately 40 square miles. Upper Granite Creek is considered perennial, although it may not truly conform to that designation. All creeks in the upper watershed appear to be intermittent in flow-regime character, with a higher frequency of flows in the winter/spring (USGS gage in Prescott; Yavapai County Flood Control Alert System). Watson Lake is located approximately mid-way between the headwaters of Granite Creek and Del Rio Springs; these reaches are intermittent to ephemeral but account for the southern and eastern two-thirds of the Little Chino ground water basin (Wirt et. al, 2004).

The intermittent tributaries that drain to Granite Creek within and above the town of Prescott include: Bannon (also known as Banning) Creek, Manzanita Creek, Aspen Creek, Butte Creek, Miller Creek, North Fork of Granite Creek, Government Wash, and Slaughterhouse Gulch (ADEQ, 2011).

This modeling report is a summary and analysis of data collected from 2007 to 2014 for the Granite Creek *E. coli* TMDL project. Stormflow data from 2013 and 2014 were used to update load per square mile and percent reduction figures from an earlier version of this modeling report. The linkage analysis K-S test was performed on data collected between 2007 and 2012.

Previous Modeling

Under a grant to the Prescott Creeks Association, Arizona Nonpoint Source Education for Municipal Officials (AZNEMO) did initial work in the Granite Creek subwatershed using the AGWA (Automated Geospatial Watershed Assessment) GIS interface with the KINEROS (Kinematic Runoff and Erosion) model. ArcGIS-compatible maps with attributes housing KINEROS model outputs were supplied to ADEQ. NEMO employed standard HUC-14 digit subwatersheds within the study area as the basis for further subdivision prior to running the KINEROS model. ADEQ has adopted the set of 24 HUC14 subwatershed divisions above Watson Lake as the basis for Granite Creek analysis (Figure 2). Information from the attributes (consisting mainly of watershed areas and percentages of impervious surfaces) was sparingly employed in the final analysis inasmuch as the AGWA model is targeted to sediment modeling with no relevance for E.

coli analysis in this instance. Generally, sediment yield and E. coli loads correspond with each other directly in Arizona watersheds; however, in this project, they were found to be inversely related. Sediment yields were highest in the forested headwater subwatersheds which were used to establish natural background for *E. coli* loads. As expected, in the more impervious areas within the Prescott city limits, NEMO reported sediment yield declined dramatically, while this project demonstrated that stormflow run-off from city streets and other areas increased *E. coli* loads substantially. Consequently, sediment loading determined from AGWA could not justifiably be used as a proxy for *E. coli* loading. Data on modeled flow rates from the 10 year 24 hour storm were used in the project to confirm the relative rankings of subwatersheds. Attributes regarding each subwatershed's percentage of impervious cover were incorporated into the linkage analysis from this earlier NEMO modeling effort.

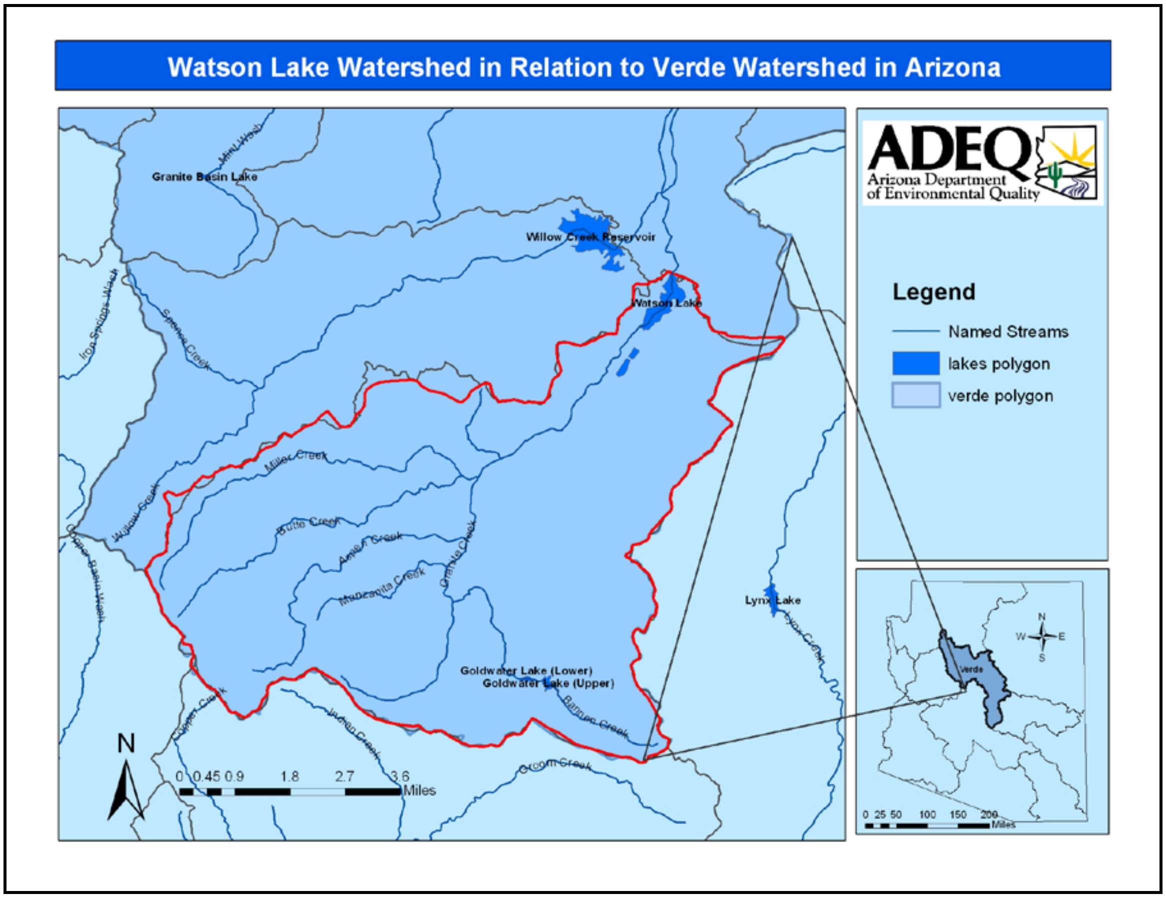

Figure 1. Watson Lake sub-watershed in relation to Verde River Watershed

Data

Discharge and *E. coli* data were collected at Watson Woods at the USGS gauge for Granite Creek near Prescott (USGS gauge 09503000) and Fort Whipple at and near the USGS gauge Granite Creek at Prescott (USGS 09502960), and at several locations within the Prescott city limits. Sampling sites were established to isolate cumulative subwatershed contributions for Miller, Aspen, Manzanita, and Butte Creeks, the North

Fork of Granite Creek, Government Canyon, Slaughterhouse Gulch, and various segments of Granite Creek proper. Additional sampling sites were established in tributary headwaters outside the Prescott metro area for Miller, Granite, and Aspen Creeks (Figure 2). Later sampling sought to fill data gaps for the Acker Park and Slaughterhouse Gulch subwatersheds. Data initially were collected from July 2007 until March 2012, with 190 data points representing both stormflow and baseflow conditions. Three *E. coli* samples were excluded from the dataset for various causes. An additional 68 data points from sampling events in 2013 and 2014 were later incorporated, with the analysis updated in late 2014. Field samples were collected by grab methods and analyzed using the Colilert-18 quantification system. Data is presented in Appendix A – Project Data.

Methods

The methods employed to analyze data for the Granite Creek *E. coli* TMDL project consisted of a two-tier approach. Data were initially analyzed in conjunction with flow duration worksheets for the period of record flow history for the lowest two sampling sites on Granite Creek associated with USGS gauges. These worksheets used baseflow recession coefficients to determine whether a day's flow was to be characterized as stormflow or stable flow (Appendix B - Stormflow Determination / Base Flow Recession Coefficients). Sampling events associated with these flows were categorized into the two classes based on the daily flow's established regime (stormflow, nonstorm flow). Aggregate determinations were made at the two USGS gauges regarding whether water quality standards were attained or not attained on the whole by flow class using target load values derived from the water quality standard. Where the class was found to be currently meeting standards in the aggregate load analysis, no further work was done. All other data were used to calculate loads and derive reductions where warranted. A framework of nested cumulative watersheds to the base of the project area at Watson Woods was employed in determining loads and necessary reductions. Targets were set for the 90th percentile load value (corresponding to a concentration of 235 cfu/100 ml, developed subsequently) for each of the nested subwatersheds.

Representative cumulative flows for each subwatershed were determined through a bootstrap procedure in Systat 12 using associated sampling flows for each sampling site represented in a given subwatershed. The median flow of each dataset was determined using 10,000 iterations, and an upper confidence level of 0.75 for the median was adopted as the representative flow for the set. The representative flow was then multiplied by the target concentration (235 cfu/100 ml as the 90th percentile concentration) and a conversion factor to establish the target for a subwatershed load in G-orgs/day. The existing 90th percentile value from the sample data was then compared against the target and percentage reductions determined where appropriate. Refer to the Target Development section for more information.

Two of the 24 subwatersheds forming the geographic extent of the project's hydrological analysis (Upper Bannon Creek, Watson Lake) are non-contributing areas for the purposes of this project and thus were excluded from further analysis. Upper Bannon Creek lacks any significant hydrologic continuity with the remainder of the watershed due to the presence of Upper and Lower Goldwater Lakes, each with a dam at its lower end. The Watson Lake subwatershed is hydrologically below the Watson Woods subwatershed, the subwatershed of USGS gauge site 09503000 and the lowest subwatershed sampled. The Watson Woods subwatershed marked the lowest area considered in the project scope.

A significant minority of the contributing subwatersheds identified in the project area (four of 22) had either no stormflow data or only one data point associated with a stormflow event (Appendix D). No conclusions could be drawn as to the existing loading of these subwatersheds, as insufficient data existed to determine quantitative benchmarks. However, cumulative loading reflecting these subwatersheds' contributions with numerous samples was still assessed at downstream sampling sites and subsequently analyzed for this report. Consequently, the lack of data from these subwatersheds, while preventing the drawing of conclusions for those particular subwatersheds, does not alter the validity of the analysis on a watershed basis, nor does it hinder or qualify the overall conclusions of this report.

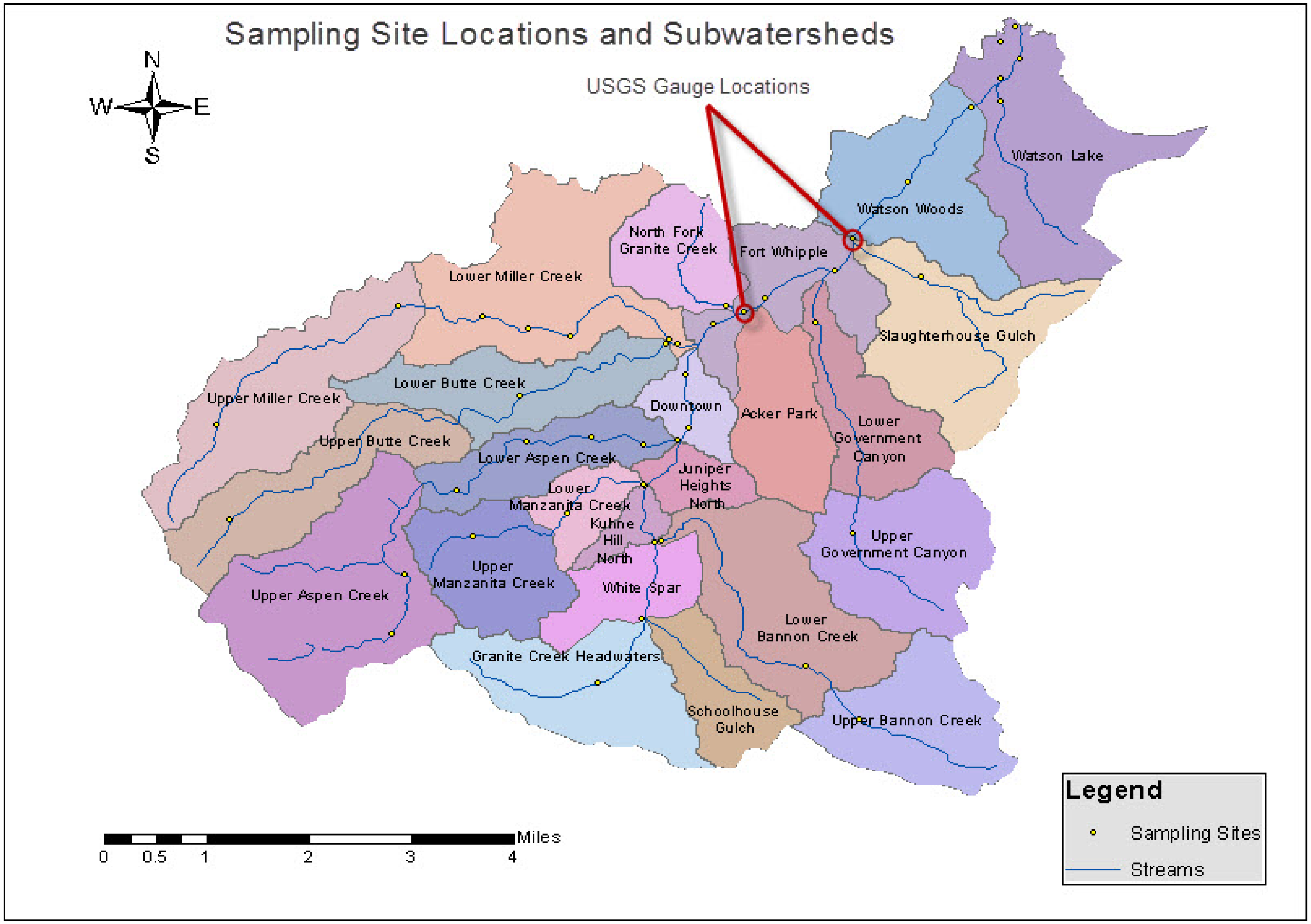

Figure 2. Granite Creek subwatersheds for TMDL analysis

Target Development

Arizona's *E. coli* standard is used as an indicator of bacterial contamination and is designed to protect human health in the case of recreational use of waters with some possibility of small ingestion rates.

Arizona's 2009 water quality standard for *Escherichia coli* reads:

> *The following water quality standards for Escherichia coli (E. coli) are expressed in colony forming units per 100 milliliters (cfu/100 ml) or as a Most Probable Number (MPN):*

E. coli	***FBC***	***PBC***
Geometric mean (minimum of 4 samples in 30 days)	*126*	*126*
Single Sample Maximum	*235*	*575*

Granite Creek is considered a perennial water; hence, it carries the Full Body Contact (FBC) designated use with a single sample maximum (SSM) of 235 cfu/100 ml. This numeric concentration value remains unchanged in the establishment of loading targets for the Granite Creek watershed. However, an implicit margin of safety is built into the analysis by requiring a greater percentage of samples to meet the concentration target than the origins of the *E. coli* standard presume. This is warranted for two reasons: many samples collected in the course of the project exceeded the upper limit of quantification when analyzed (loading is known to be higher than the upper limit of quantification, but the magnitude of the exceedance was not established at the time of sample analysis), and the exceedance rate applied is broadly consistent with how ADEQ evaluates *E. coli* and other parameters for human health and agricultural designated uses in water quality assessments (Appendix C – Derivation of Target Development Framework). Table 1 compiles the critical benchmarks for comparison.

Benchmarks	**Beach study Distribution***	**TMDL Distribution**
Type Distribution	Lognormal	Lognormal
Log (Base 10) Std. Dev.	0.4 log units	0.4 log units
Target Concentration, SSM	235 cfu/100 ml	235 cfu/100ml
Corresponding Percentile of SSM	75th	90th
Geomean of Distribution	126 cfu/100 ml	72 cfu/100 ml
Arithmetic Mean of Distribution	193 cfu/100 ml	110.5 cfu/100 ml

Table 1. Target distribution moments and benchmarks. Beach studies from the 1970s comprised the basis of EPA recommendations to states for the setting of bacterial water quality standards.

Loading data from the Granite Creek basin as a whole was statistically tested for fit with a two-parameter lognormal distribution and found to be generally consistent with the distribution at a p value of 0.05. Three data points of 187 tested comprised outliers at the tails of the distribution. Since the water quality standard presupposes a lognormal distribution for *E. coli* concentrations as outlined in Table 1 and Appendix C, the distribution is taken as a given when determining target loads for the project.

To complete the load target calculation, the 75^{th} upper confidence level (UCL) median flow from the dataset is multiplied by the target concentration and a conversion factor of

0.02445 to yield target bacterial loads in units of Giga-organisms per day (G-orgs/day). The conversion factor of 0.02445 serves to convert the product of *E. coli* densities and flows into daily loads and is derived as follows:

1 cfu/100ml x 1000ml/1L x 28.3L/1 ft^3 x 86,400 sec/1 day x 1 G-org/1x10^9 cfu

The 0.75 UCL median flow value was chosen due to uncertainties in the median value associated with limited sampling events to evaluate at most sites. It also allows for an implicit margin of safety in the target load value that is reasonable when assessed in comparison with other *E. coli* TMDLs.

Baseflow-Stormflow Analysis

Analysis was conducted on the entire dataset for the lowest three sites on the Granite Creek main-stem. These three sites were used as controls to assess the attainment status of each flow class for the entire project watershed. The lowest site of the project area, VRGRA027.35 (located in the Watson Woods subwatershed), was associated with the USGS gauge 09503000 (Granite Creek near Prescott, Ariz.). The other two sites, VRGRA029.64 and VRGRA029.97 (located in the Fort Whipple subwatershed just above the Yavapai Indian Reservation) were associated with USGS Gauge 09502960 (Granite Creek at Prescott, Ariz.). Both USGS gauge locations were analyzed with cumulative loading and discharge data from the project sampling dates by flow class. The 90^{th} percentile values were compared to target values for each class. Results are summarized in Table 2. Target loads presented for each category in Table 2 are the product of the concentration target and the 0.75 UCL category median flow with the conversion factor applied.

Inspection of these results indicates clearly that impairment is due to the influence of stormflow and consequently, the critical conditions necessary to address for the improvement of bacteriological water quality on Granite Creek are stormflow conditions. Subsequent analysis will focus exclusively on stormflow conditions.

90th percentile load
Cumulative Watershed Assessment
Loads in G-orgs/day

	Fort Whipple	Watson Woods
Base/Stable flow		
Number of Samples:	3	7
Existing 90th P-tile Load:	**9.46**	**65.60**
0.75 UCL Category Median Flow:	3.8# cfs	26 cfs
Target Concentration:	235 cfu/100 ml	235 cfu/100 ml
Target Load:	21.70	149.39
Percent Reduction:	**Meets***	**Meets**
Stormflow		
Number of Samples:	11	16
Existing 90th P-tile Load:	**2,070.57**	**4,200.30**
0.75 UCL Category Median Flow:	18.3 cfs	53 cfs
Target Concentration:	235 cfu/100 ml	235 cfu/100 ml
Target Load:	105.15	304.52
Percent Reduction:	**94.9%**	**92.8%**

* - Category and location assessed as provisionally meeting load target. Minimum set size of four necessary for unqualified assessment.
# - Median flow used due to minimal flow samples for establishment of 0.75 UCL flow.

Table 2. Baseflow/Stormflow Cumulative Assessment

Natural Background

Natural background was evaluated for stormflow conditions using nine samples collected in headwater subwatersheds of upper Miller, upper Granite Creek, and upper Aspen Creek. Event concentrations were converted to daily loads using the discharge measured at sampling time. The loads were then ranked, and the 90th percentile load value from the set was selected as the representative stormflow loading for natural background, corresponding with the 90th percentile target evaluation threshold for general stormwater loading. Since there were relatively few data points, the 90th percentile value corresponded to the largest measured load in the set, which was calculated as 18.98 G-orgs/day. This load consisted of a concentration of 50.4 cfu/100 ml and a flow value of 15.4 cfs. It is noted here that the flow of 15.4 cfs associated with this event is of greater magnitude than the cumulative bootstrapped 0.75 UCL median flows for all but three of the subwatersheds characterized (See Appendix D). Consequently, the 90th percentile load calculation for natural background is of greater magnitude than the cumulative load targets for several subwatersheds exhibiting loading excesses. This necessitated employment of the concentration value associated with the event for determining background allocations for several of the subwatersheds. The percentage of the measured concentration of this sampling event relative to the 235 cfu/100 ml target concentration was determined for application to those subwatersheds where application of static loads to determine natural background was disproportionate in size. Most subwatersheds had a natural background allocation set at 21.4% of the total load target based on this concentration-based approach.

This concentration percentage was applied to every subwatershed load target where the application of the 90th percentile static load (18.98 G-orgs/day) resulted in a natural background load relative to the target load of greater than 21.4%. For the lowest two subwatersheds (Fort Whipple, Watson Woods), load targets were of sufficient magnitude to allow for the application of the static load figure without a disproportionate allocation relative to the target granted to natural background. Since natural background loading is not expected to grow, but only attenuate, once water transits into the Prescott city limits, a static load is justified for these two subwatersheds. The percentage relative to the total load allowance will be lower here in percentage terms than the concentration-based approach outlined above. See Appendix D for details.

Linkage Analysis

The linkage analysis is the means by which current water quality conditions are tied to existing physical conditions and processes in the watershed. It provides insight and direction for prioritization of problem areas. Refer to Table 3 for cumulative *E. coli* loading per contributing square mile in the Granite Creek basin. For this project, it is evident upon inspection that stormwater loading from within the Prescott city limits is greatly exacerbating the total *E. coli* loading of Granite Creek and is thus contributing disproportionately to the impairment of the creek. A formal hypothesis was developed and statistically tested: that urbanization and development, with its attendant higher percentage of impervious surfaces, coupled with inadequate stormflow control measures, is the physical cause of the impairment. A simple nominal categorizing of subwatersheds/sites by development status (developed or rural) was applied based on the predominant influence on water quality at each of the sampling sites in the watershed (Refer to Appendix A – Project Data for assignments). Percent impervious area for each subwatershed, listed in Table 3, was a significant attribute, though not the predominant one in the assignment of land use class for each subwatershed; influence at the individual sampling sites overrode subwatershed impervious characteristics in a few cases where characterization differed. Figure 3 exhibits the nonparametric distribution boxplots for stormwater samples by land use class

A Kolmogorov-Smirnov two-sample comparison was run on the medians of each set for data collected between 2007 and 2012. Results indicated with high confidence ($p=0.004$) that the medians were significantly different. After land use categorization, each subwatershed was attributed with the cumulative area upstream in square miles draining to it, including the square mileage of the selected subwatershed itself. Event loads were then normalized by square mile contributions. Stormflow loads by square mile were averaged for each cumulative subwatershed (Table 3). Bolded red load figures in Table 3 are loads and associated locations that require the highest priority in beginning to address stormflow loading problems.

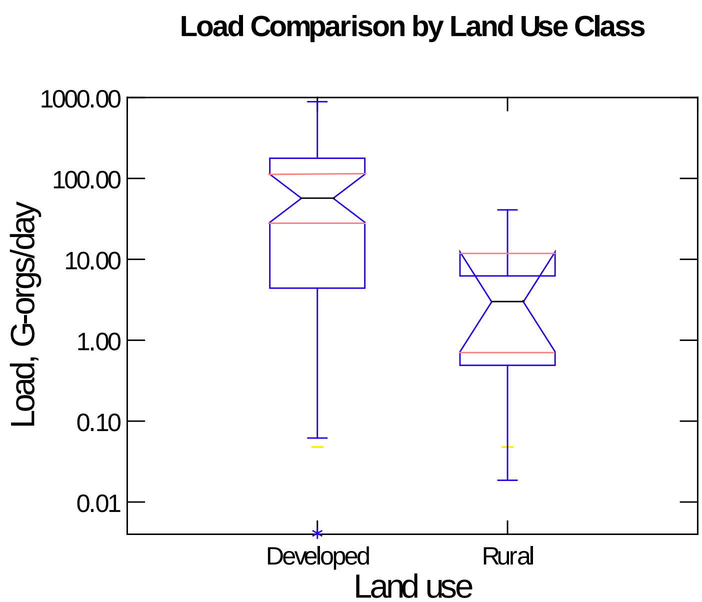

Figure 3. Loading by Land Use Class

Subwatershed Characteristics			Avg. of Load per Square Mile	
Rural/Urban	Subwatershed	Percent Impervious	Nonstorm	Stormflow
Rural	Upper Granite	5	0.01	2.80
	Upper Miller	3	0.06	1.23
	Upper Aspen	4	0.01	0.73
	White Spar	19	0.01	--
	Upper Butte	2	0.0001	--
Developed	Watson Woods	15	1.14	**237.14**
	Slaughterhouse Gulch	21	0.34	**157.79**
	Acker Park	65	--	**141.28**
	Lower Miller	43	0.76	**82.78**
	Fort Whipple	29	0.20	**70.98**
	Lower Manzanita	54	0.59	**59.76**
	North Fork Granite	70	1.17	**55.77**
	Lower Butte	58	0.25	**37.88**
	Upper Manzanita	18	0.33	14.64
	Upper Government*	3	1.65	12.01
	Lower Aspen	68	0.24	11.48
	Lower Government	22	--	11.10
	Lower Bannon*	11	0.07	10.99
	Downtown	83	0.09	10.28
	Kuhne Hill North	42	--	0.91
	White Spar	19	0.0001	0.21

Table 3. Stormflow and non-storm loading per sq. mi., G-orgs/day, Granite Creek basin
* indicates subwatersheds where sampling site characteristics override subwatershed characteristics for land use classification.

These watersheds share the characteristics of having enough data to be reasonably confident of the average loading value with a magnitude of the value that is cause for concern compared to overall developed subwatershed geomean. All highlighted average values in Table 3 exceeded the geomean of subwatershed averages and had sufficient data for confident evaluation. Figure 4 displays a map of the basin graphically depicting the results in Table 3.

Results tabulated by subwatershed pair comparisons are summarized in Table 4. The log difference (Base 10) between the compared subwatersheds gives an indication of the magnitude of the difference in average loads, while the sign of the log difference indicates whether loading is increasing or decreasing relative to its upstream neighbor. Though all project data is reflective of the cumulative loading, the relative decreases or increases in loading from one subwatershed to its upstream neighbor(s) are clearly evident where sufficient data (four or more data points for each subwatershed compared) exist to lend confidence to the conclusion. Subwatershed pairings where each of the pair had four or more data points with the magnitude of the log difference exceeding 0.5 log units are highlighted in red font. Subwatershed pairs exhibiting at least a 0.5 log difference where one of the two compared had fewer than four data points were highlighted in blue font. The highlighted pairs can be employed as diagnostic indicators of particular subwatershed pairings where jumps in *E. coli* densities from upstream to receiving

Watershed	Adjacent Upstream Wshed(s)	Log10 Difference	# Samples	# Samples, US subwshed
Upper Miller	NA	--	4	NA
Upper Granite	NA	--	3	NA
Upper Butte	NA	--	0	NA
Upper Aspen	NA	--	2	NA
White Spar[#]	Upper Granite	--	0	3
Watson Woods	Lower Government	1.33	16	5
	Slaughterhouse Gulch	0.18		4
	Fort Whipple	0.52		11
	Acker Park	0.22		4
Fort Whipple	North Fork Granite	0.10	11	15
	Downtown	0.84		5
	Lower Miller	-0.07		15
Lower Manzanita	Upper Manzanita	0.61	9	3
Lower Miller	Upper Miller	1.83	15	4
Lower Aspen	Upper Aspen	1.20	10	2
Lower Government	Upper Government	-0.03	5	1
Downtown	Kuhne Hill North	1.05	5	1
Kuhne Hill North	White Spar	0.63	1	1
White Spar[#]	Upper Granite	-1.12	1	3
Lower Butte	Upper Butte	*ND*	11	0
Lower Bannon	Upper Bannon	*ND*	6	0
North Fork Granite	NA	--	15	NA
Slaughterhouse Gulch	NA	--	4	NA
Acker Park	NA	--	4	NA
Upper Manzanita	NA	--	3	NA
Upper Government	NA	--	1	NA

- White Spar listed twice. One site reflects rural characteristics; Second site reflects development.

Table 4. Relative loading comparison per square mile by subwatershed
NA - Not Applicable. ND – Not Determined. No samples in one subwatershed for comparison.

subwatersheds point to nonpoint source contributions from within the downstream watershed or from other contributing subwatersheds as problematic areas for improvement prioritization. For the two lowest subwatersheds (Fort Whipple and Watson Woods), this form of diagnostic tracing points back towards the ***non-highlighted*** upstream watersheds grouped with them as primary problem areas – Acker Park, Slaughterhouse Gulch, North Fork Granite Creek, and Lower Miller. Three of these subwatersheds are terminal headwaters and thus cannot be compared in this manner to any other upstream subwatersheds. These subwatersheds are confirmed as problematic by their relatively high rankings in Table 3.

Margin of Safety

No explicit margin of safety was granted. Instead, the margin of safety is implicitly accounted for in the choice of the 90th percentile concentration as the target concentration coupled with the use of the 0.75 UCL for the median flow. The margin of safety was assessed at the Watson Woods and Fort Whipple USGS gauge sites at the base of the project area watershed. Stormflow margins of safety were assessed to be 32.5 percent at Fort Whipple and 36.9 percent at Watson Woods when compared to targets that would result from the application of the water quality standard as written (with geomean determination and an implied 0.75 UCL for the SSM of 235). This somewhat higher MOS than is usually applied is justified in that some of the project stormflow data was reported as greater than 2419.6 cfu/100 ml, the upper limit of an undiluted Colilert sample. Actual loading is known to be higher, but cannot be fully quantified from project data. However, a balance needs to be struck between necessary reductions and the uncertainties associated with sampling events. The interaction between the 0.75 UCL median flow and the 90th P-tile concentration of 235 cfu/100 ml provides that balance and moderates the margin of safety that would apply if simple median flows were employed for load calculations.

Percent Reductions

Appendix D - Targets, Load Allocations, and Percent Reductions summarizes median bootstrapped flows, 0.75 UCL median flows, 90th percentile load targets, load allocations, natural background allocations, and necessary percent reductions for standards attainment for each of the nested subwatersheds in the basin in stormwater conditions. As shown in Table 2, baseflow conditions are meeting TMDL targets in the aggregate and therefore are excluded from further consideration. Subwatersheds represented in Appendix D are exhibited and analyzed using *cumulative* flows and loads, which include all discharge and loading from subwatersheds upstream of the itemized subwatershed. Data resolution was insufficient to statistically break out each subwatershed individually. Headwater subwatersheds can be individually assessed where sufficient data exists to do so.

Subwatersheds of particular concern for high prioritization in implementation measures include Watson Woods and the subwatersheds immediately feeding it, including Acker Park, Slaughterhouse Gulch, Fort Whipple, Lower Miller, North Fork of Granite Creek, Lower Manzanita, and Lower Butte. Major contributing headwater subwatersheds include Acker Park, Slaughterhouse Gulch, and North Fork of Granite Creek. All of these subwatersheds occupy areas of moderate to high density development with a relatively high degree of impervious cover. As headwater subwatersheds, the averages calculated from these were high even without contributing subwatersheds upstream from them.

A map showing Prescott area anthropogenic impact index assignments is displayed in Figure 5. The map exhibits the degree of development present in the Prescott metro area corresponding to the Kolmogorov-Smirnov two-sample comparison addressed in the Linkage Analysis section and roughly correlating to the percent imperviousness measures itemized in Table 3. The figure may be considered a representation of the underlying sources and causes of water quality impairment for Granite Creek and its tributaries. Light, moderate, and heavy development categories in the map received the *Developed* classification in the K-S test, while pristine, federally-managed, and private lands received a *Rural* classification. Some exceptions existed, generally where site characteristics overrode the larger subwatershed's character. Index assignments are nominal only and have no quantifiable source data asssociated with the assignments.

Figure 6 displays a heat map showing cumulative percent reductions by subwatershed. Whereas Figure 4 displays actual existing loading data normalized by contributing watershed area, Figure 6 relates existing loading to target values for attaining water quality standards set forth in the modeling report. These two figures offer slightly different perspectives on the same problem, thus complementing one another in their presentations. Since *E. coli* concentrations and loads can typically range over several orders of magnitude, higher values tend to get compressed at the upper end of the scale for percent reductions: a one order-of-magnitude reduction corresponds to a 90% reduction, while a two order-of-magnitude reduction corresponds to a 99% reduction. Reductions of less than one order-of-magnitude occupy the entire range from 1% to 90%. The scale for percent reductions in Figure 6 was manually determined to discriminate more finely near the top end of the possible range for reductions. Subwatersheds requiring no reductions are shown in dark green. Subwatersheds requiring more than a one order-of-magnitude reduction are shown in red. Data serving as the basis for Figure 6 may be found in Appendix D - Targets, Load Allocations, and Percent Reductions.

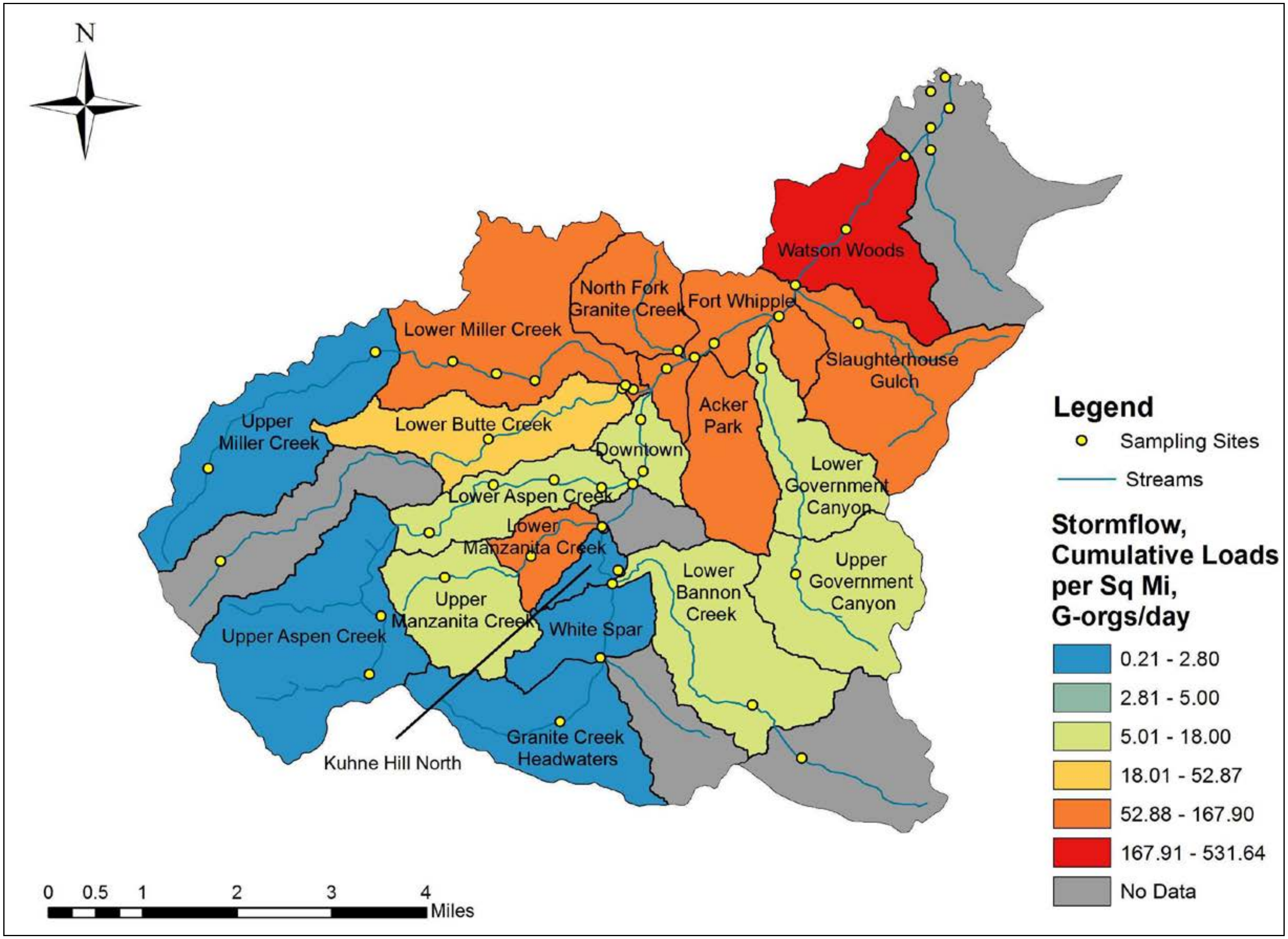

Figure 4. Granite Creek basin cumulative loads per square mile

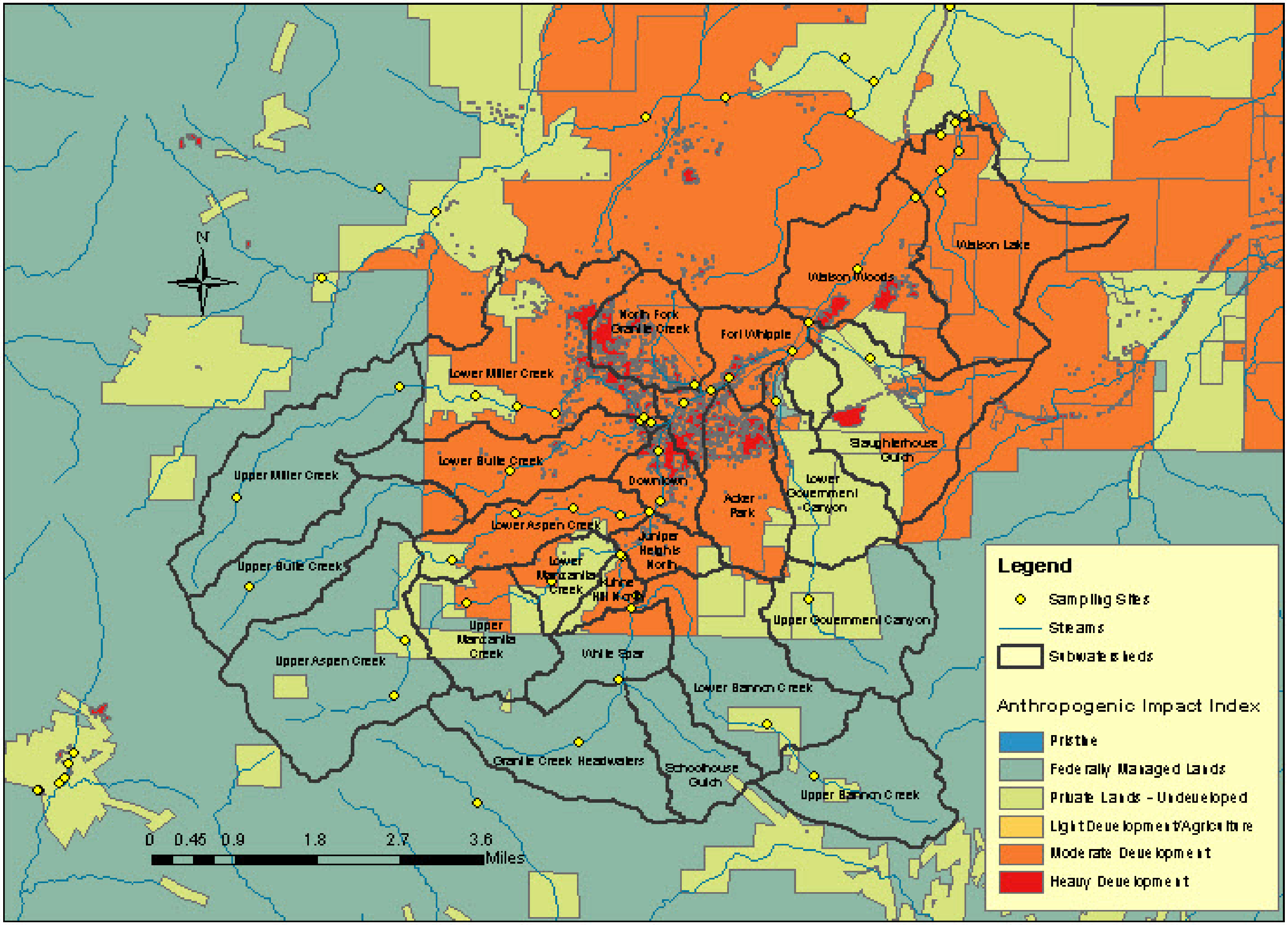

Figure 5. Prescott and Granite Creek basin anthropogenic impact indices
Lands under the administration of Yavapai County may be represented in private land category.

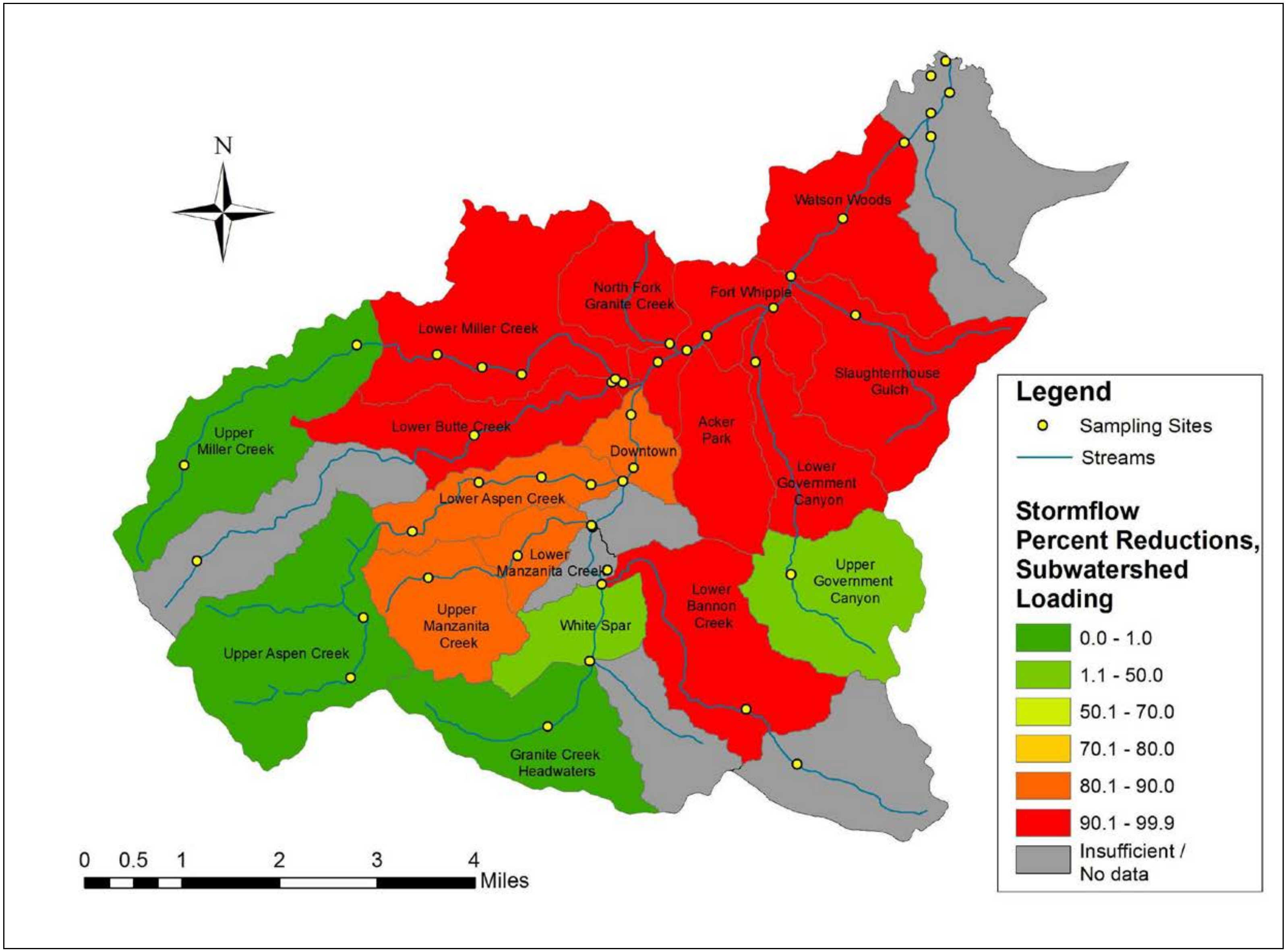

Figure 6. Cumulative percent reductions by subwatershed

References

ADEQ, 2004. The Status of Water Quality in Arizona. Arizona's Integrated 305(b) Assessment and 303(d) Listing Report. August, 2004.

ADEQ, 2008. 2006/2008 Status of Ambient Surface Water Quality in Arizona - Arizona's Integrated 305(b) Assessment and 303(d) Listing Report. November, 2008.

ADEQ. 2009. Arizona Administrative Code, Title 18, Chapter 11. Water Quality Standards.

ADEQ, 2010. Draft 2010 Status of Water Quality in Arizona 305(b) Assessment and 303(d) Listing Report. June, 2012.

ADEQ, 2011. Sample and Analysis Plan: Watson Lake TMDL (Nitrogen, DO, and pH); Granite Creek TMDL (DO); E. coli and Mercury Investigation. July, 2011.

Cleland, Bruce. "TMDL Development from the "Bottom Up"–Part III: Duration Curves and Wet-Weather Assessments" TMDL 2003 Conf. Proc, 2003 - tmdls.com

Environmental Protection Agency, 1986. Ambient Water Quality Criteria for Bacteria – 1986. EPA Publication #EPA440/5-84-002. Washington, D.C.

Environmental Protection Agency, 2006. Water Quality Standards for Coastal Recreation Waters: Using Single Sample Maximum Values in State Water Quality Standards. EPA Publication #EPA823-F-06-013. Washington, D.C.

Environmental Protection Agency, 2007a. "An Approach for Using Load Duration Curves in the Development of TMDLs". EPA 841-B-07-006. August, 2007.

Environmental Protection Agency. 2007b. "Options for Expressing Daily Loads in TMDLs". Draft. June 2007.

Helsel, D.R.. and R.M Hirsch, Statistical Methods in Water Resources: Studies in Environmental Science 49, Elvesier Press, 1992.

Parkhurst, David F. 1998. "Arithmetic Versus Geometric Means for Environmental Concentration Data," Environmental Science and Technology. Volume 32 Issue 3 February 1, 1998.

Ponce, Victor Miguel. 1989. Engineering Hydrology Principles and Practices. Prentice Hall, 1989.

USGS Real-Time Water Data for USGS 09503000 GRANITE CREEK NEAR PRESCOTT, AZ, http://waterdata.usgs.gov/az/nwis/uv?site_no=09503000. Various dates.

USGS Real-Time Water Data for USGS 09502960 GRANITE CREEK AT PRESCOTT, AZ, http://waterdata.usgs.gov/az/nwis/uv?site_no=09502960. Various dates.

Wirt et. al, 2004. Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North- Central Arizona. Open File Report 2004-1411 available at http://www.usgs.pubs/of/2004/1411

Appendix A – Project Data

Rural/Urban	Regime	Date	Site ID	Lab Code	Concen-tration (cfu/100 ml)	Q, cfs (Inst.)	Load, G-orgs/day	Subwshed	Cumula-tive Area (mi²)
Developed	Stormflow	1/7/2008	GRA027.35	>	2,419.60	750	44,369.42	Watson Woods	23.549
Developed	Stormflow	1/28/2008	GRA027.35		1,986.30	350	16,997.76	Watson Woods	23.549
Developed	Stormflow	1/28/2008	GRA029.64		1,553.10	150	5,695.99	Fort Whipple	18.543
Developed	Stormflow	1/27/2008	GRA027.35 dup		547.5	380	5,086.82	Watson Woods	23.549
Developed	Stormflow	7/30/2007	GRA027.35	>	2,419.60	71	4,200.30	Watson Woods	23.549
Developed	Stormflow	1/7/2008	MIL000.32	>	2,419.60	60.33	3569.08	Lower Miller	6.315
Developed	Stormflow	10/5/2010	GRA027.35	>	2419.6	56	3,312.92	Watson Woods	23.549
Developed	Stormflow	12/18/2008	GRA027.35		1299.7	85	2,701.10	Watson Woods	23.549
Developed	Stormflow	1/28/2008	MIL000.32	>	2,419.60	35	2070.57	Lower Miller	6.315
Developed	Stormflow	12/7/2009	GRA027.35	>	2419.6	32	1,893.10	Watson Woods	23.549
Developed	Stormflow	1/7/2008	SHG000.77		1,732.90	32.8	1389.72	Slaughterhouse Gulch	2.614
Developed	Stormflow	10/5/2010	GRA029.97	>	2419.6	23	1360.66	Fort Whipple	18.543
Developed	Stormflow	12/16/2010	GRA029.97		2419.6	15	887.39	Fort Whipple	18.543
Developed	Stormflow	12/7/2009	GRA029.97	>	2419.6	13	769.07	Fort Whipple	18.543
Developed	Stormflow	1/27/2008	MAN000.01		1,299.70	22	699.11	Lower Manzanita	2.334
Developed	Stormflow	3/8/2010	MIL000.32		2419.2	10.5	621.07	Lower Miller	6.315
Developed	Stormflow	3/8/2010	GRA027.35		201.4	110	541.67	Watson Woods	23.549
Developed	Stormflow	7/30/2007	MIL000.32	>	2,419.60	9	532.43	Lower Miller	6.315
Developed	Stormflow	1/7/2008	BTT000.06		631.1	31.5	486.06	Lower Butte	4.028
Developed	Stormflow	7/30/2007	BTT000.06	>	2,419.60	8	473.27	Lower Butte	4.028
Developed	Stormflow	7/30/2007	ASP000.37	>	2419.60	6.00	354.96	Lower Aspen	5.038
Developed	Stormflow	3/22/2012	GRA029.97		767	18.3	343.18	Fort Whipple	18.543
Developed	Stormflow	1/25/2010	GRA027.35		261.3	53	338.61	Watson Woods	23.549
Developed	Stormflow	1/28/2008	GRA031.19		195.6	70	334.77	Downtown	11.147
Developed	Stormflow	1/27/2008	MIL000.32		275.5	40	269.44	Lower Miller	6.315
Developed	Stormflow	12/7/2009	MIL000.32	>	2419.6	4.1	242.55	Lower Miller	6.315
Developed	Stormflow	7/30/2007	MAN000.01	>	2,419.60	4	236.64	Lower Manzanita	2.334
Developed	Stormflow	1/27/2008	MIL001.71		313	25	191.32	Lower Miller	6.315
Developed	Stormflow	1/27/2008	BTT000.06		260.3	30	190.93	Lower Butte	4.028
Developed	Stormflow	7/30/2007	BAN000.06	>	2,419.60	3	177.48	Lower Bannon	2.748
Developed	Stormflow	12/16/2010	MIL000.32	>	2419.6	3	177.48	Lower Miller	6.315
Developed	Stormflow	1/6/2008	GRA027.35		178	39.3	171.04	Watson Woods	23.549
Developed	Stormflow	12/18/2008	GRA031.19		488.4	11.53	137.68	Downtown	11.147
Developed	Stormflow	2/7/2008	GRA027.35		133.4	40	130.47	Watson Woods	23.549
Developed	Stormflow	7/30/2007	NFG000.14	>	2,419.60	2	118.32	North Fork Granite	1.247
Developed	Stormflow	12/16/2010	NFG000.14	>	2419.6	2	118.32	North Fork Granite	1.247
Developed	Stormflow	12/7/2009	BTT000.06		2419.6	1.9	112.40	Lower Butte	4.028
Developed	Stormflow	12/7/2009	BTT000.06 dup	>	2419.6	1.9	112.40	Lower Butte	4.028
Developed	Stormflow	10/5/2010	BTT000.06		2419.6	1.9	112.40	Lower Butte	4.028
Developed	Stormflow	1/27/2008	ASP000.37		222.40	20.00	108.75	Lower Aspen	5.038
Developed	Stormflow	1/7/2008	GOV000.60		866.4	4.99	105.71	Lower Government	3.818
Developed	Stormflow	12/16/2010	BTT000.06		1046.2	4	102.32	Lower Butte	4.028
Developed	Stormflow	1/6/2008	MAN000.01		344	10.41	87.56	Lower Manzanita	2.334
Developed	Stormflow	12/18/2008	MIL000.32		478.6	7.39	86.48	Lower Miller	6.315
Developed	Stormflow	10/5/2010	NGC000.14	>	2419.6	1.3	76.91	North Fork Granite	1.247
Developed	Stormflow	12/16/2010	MAN002.15	>	2419.6	1.2	70.99	Upper Manzanita	1.660
Developed	Stormflow	12/18/2008	MAN000.01		396.8	6.6	64.03	Lower Manzanita	2.334
Developed	Stormflow	10/5/2010	MAN000.01	>	2419.6	1	59.16	Lower Manzanita	2.334
Developed	Stormflow	7/31/2010	GRA029.97	>	2419.6	0.96	56.79	Fort Whipple	18.543
Developed	Stormflow	1/26/2010	MAN000.01		178.2	12	52.28	Lower Manzanita	2.334
Developed	Stormflow	10/5/2010	MIL000.32	>	2419.6	0.88	52.06	Lower Miller	6.315
Developed	Stormflow	1/6/2008	ASP000.37		387.30	5.46	51.70	Lower Aspen	5.038
Developed	Stormflow	12/18/2008	BTT000.06		325.5	5.85	46.56	Lower Butte	4.028
Developed	Stormflow	1/27/2008	GOV003.03		238.2	7	40.77	Upper Government	2.284

Rural/Urban	Regime	Date	Site ID	Lab Code	Concen-tration (cfu/100 ml)	Q, cfs (Inst.)	Load, G-orgs/day	Subwshed	Cumula-tive Area (mi^2)
Developed	Stormflow	12/16/2010	GRA030.48		770.1	2	37.66	Downtown	11.147
Developed	Stormflow	3/8/2010	MAN000.05		124.6	10.5	31.99	Lower Manzanita	2.334
Developed	Stormflow	12/16/2010	GRA030.48		258	5	31.54	Downtown	11.147
Developed	Stormflow	12/16/2010	GRA030.48		579.4	2.2	31.17	Downtown	11.147
Developed	Stormflow	7/31/2010	NGC000.14	>	2419.6	0.5	29.58	North Fork Granite	1.247
Developed	Stormflow	1/28/2008	BTT000.06		47.3	25	28.91	Lower Butte	4.028
Developed	Stormflow	1/27/2008	ASP002.87		139.6	8	27.31	Lower Aspen	5.038
Developed	Stormflow	1/26/2010	MIL002.33		58.1	16	22.73	Lower Miller	6.315
Developed	Stable Flow	1/11/2008	GRA027.35		53.8	17	22.36	Watson Woods	23.549
Developed	Stormflow	12/7/2009	MAN000.01	>	2419.6	0.34	20.11	Lower Manzanita	2.334
Developed	Stormflow	3/8/2010	NFG000.14		193.5	4.2	19.87	North Fork Granite	1.247
Rural	Stormflow	1/27/2008	GRA034.39		50.4	15.4	18.98	Upper Granite	2.288
Developed	Stable Flow	12/12/2007	GRA027.35		46.4	15.12	17.15	Watson Woods	23.549
Developed	Stable Flow	1/11/2008	MIL000.32		344.8	1.6	13.49	Lower Miller	6.315
Developed	Stable Flow	2/7/2008	MIL000.32		68.3	8	13.36	Lower Miller	6.315
Developed	Stable Flow	2/11/2010	GRA027.35		15.5	35	13.26	Watson Woods	23.549
Developed	Stormflow	12/16/2010	BTT001.82		1046.2	0.5	12.79	Lower Butte	4.028
Developed	Stable Flow	2/7/2008	MIL001.71		73.8	6.9	12.45	Lower Miller	6.315
Developed	Stormflow	1/26/2010	ASP001.00		30.5	15	11.19	Lower Aspen	5.038
Developed	Stable Flow	2/14/2009	GRA029.64		50.4	9	11.09	Fort Whipple	18.543
Rural	Stormflow	1/27/2008	MIL003.64		65	6	9.54	Upper Miller	2.922
Developed	Stormflow	1/26/2010	ASP002.11		24.3	14	8.32	Lower Aspen	5.038
Developed	Stormflow	10/5/2010	ASP000.37	>	2419.60	0.14	8.28	Lower Aspen	5.038
Developed	Stable Flow	12/12/2007	MIL000.32		101.4	2.83	7.02	Lower Miller	6.315
Developed	Stormflow	12/18/2008	GRA031.98		238.2	1.19	6.93	Kuhne Hill North	7.595
Developed	Stable Flow	4/13/2011	NFG000.14		231	1.2	6.78	North Fork Granite	1.247
Developed	Stormflow	1/25/2010	NFG000.14		191.8	1.25	5.86	North Fork Granite	1.247
Developed	Stormflow	3/8/2010	ASP000.05		22.80	10.50	5.85	Lower Aspen	5.038
Developed	Stable Flow	2/11/2010	MAN000.05		77.1	3.1	5.84	Lower Manzanita	2.334
Developed	Stable Flow	2/11/2010	MIL000.32		76.6	3.1	5.81	Lower Miller	6.315
Developed	Stable Flow	12/12/2007	BTT000.06		74.4	2.56	4.66	Lower Butte	4.028
Developed	Stormflow	12/15/2009	MAN000.05		856.4	0.21	4.40	Lower Manzanita	2.334
Rural	Stormflow	1/7/2008	MIL003.64		25.6	6.51	4.07	Upper Miller	2.922
Rural	Stormflow	1/27/2008	ASP005.07		54.6	3	4.00	Upper Aspen	3.616
Developed	Stable Flow	2/7/2008	GOV003.03		307.6	0.5	3.76	Upper Government	2.284
Developed	Stormflow	1/26/2010	MIL003.10		9.7	15	3.56	Lower Miller	6.315
Developed	Stable Flow	4/12/2011	ASP000.05		62.70	2.30	3.53	Lower Aspen	5.038
Developed	Stable Flow	1/11/2008	MAN000.01		36.7	3.8	3.41	Lower Manzanita	2.334
Developed	Stormflow	8/2/2010	GRA027.35		172.3	0.72	3.03	Watson Woods	23.549
Developed	Stable Flow	10/20/2010	GRA029.97	>	2419.6	0.05	2.96	Fort Whipple	18.543
Developed	Stable Flow	2/14/2009	ASP000.37		44.30	2.59	2.81	Lower Aspen	5.038
Developed	Stormflow	8/2/2010	GRA029.97		1413.6	0.08	2.77	Fort Whipple	18.543
Developed	Stable Flow	2/7/2008	MAN000.01		14.6	7	2.50	Lower Manzanita	2.334
Developed	Stable Flow	12/12/2007	MAN000.01		38.9	2.62	2.49	Lower Manzanita	2.334
Developed	Stable Flow	12/12/2007	ASP000.37		63.80	1.54	2.40	Lower Aspen	5.038
Developed	Stormflow	10/5/2010	BAN000.06	>	2419.6	0.04	2.37	Lower Bannon	2.748
Developed	Stable Flow	1/11/2008	ASP000.37		25.60	3.65	2.28	Lower Aspen	5.038
Rural	Stormflow	3/8/2010	MIL003.64		43.2	2.1	2.22	Upper Miller	2.922
Developed	Stable Flow	2/14/2009	GRA027.35		7.5	10.16	1.86	Watson Woods	23.549
Developed	Stormflow	3/8/2010	MIL002.33		14.6	4.2	1.50	Lower Miller	6.315
Developed	Stable flow	5/13/2010	GRA027.35		34.1	1.6	1.33	Watson Woods	23.549
Developed	Stable flow	4/16/2010	GRA027.35		12.1	4.4	1.30	Watson Woods	23.549
Rural	Stormflow	3/8/2010	ASP005.07		36.8	1.4	1.26	Upper Aspen	3.616
Developed	Stormflow	1/6/2008	BAN000.06		31	1.44	1.09	Lower Bannon	2.748
Developed	Stable Flow	1/11/2008	BTT000.06		30.1	1.44	1.06	Lower Butte	4.028
Developed	Stormflow	3/8/2010	MAN002.15		20.3	2.1	1.04	Upper Manzanita	1.660

Rural/Urban	Regime	Date	Site ID	Lab Code	Concen-tration (cfu/100 ml)	Q, cfs (Inst.)	Load, G-orgs/day	Subwshed	Cumula-tive Area (mi²)
Developed	Stormflow	12/16/2010	ASP002.70		50.4	0.8	0.99	Lower Aspen	5.038
Developed	Stable Flow	4/13/2011	GRA030.48		9.8	4	0.96	Downtown	11.147
Developed	Stormflow	12/7/2009	GRA032.67		1299.7	0.03	0.95	White Spar	4.494
Developed	Stable Flow	2/11/2010	MAN002.15		60.9	0.62	0.92	Upper Manzanita	1.660
Developed	Stable Flow	2/7/2008	SHG000.77		121.1	0.3	0.89	Slaughterhouse Gulch	2.614
Developed	Stormflow	12/15/2009	ASP000.05		166.40	0.21	0.85	Lower Aspen	5.038
Developed	Stormflow	1/26/2010	MAN002.15		69.7	0.5	0.85	Upper Manzanita	1.660
Developed	Stable Flow	2/7/2008	ASP000.37		15.30	2.10	0.79	Lower Aspen	5.038
Developed	Stable Flow	2/7/2008	BTT000.06		6.3	4.6	0.71	Lower Butte	4.028
Rural	Stable Flow	12/12/2007	MIL003.64		19.7	1.41	0.68	Upper Miller	2.922
Developed	Stable flow	5/13/2010	BAN000.06		62	0.44	0.67	Lower Bannon	2.748
Developed	Stable flow	4/16/2010	GRA029.97		10.9	2.4	0.64	Fort Whipple	18.543
Developed	Stable Flow	2/14/2009	MAN000.01		11	2.27	0.61	Lower Manzanita	2.334
Developed	Stable Flow	10/20/2010	BTT000.06		307.6	0.07	0.53	Lower Butte	4.028
Developed	Stormflow	12/15/2009	BUT000.05		85.7	0.21	0.44	Lower Butte	4.028
Developed	Stable Flow	2/14/2009	BTT000.06		7.5	2.39	0.44	Lower Butte	4.028
Developed	Stable Flow	2/14/2009	MIL000.32		5.2	3.15	0.40	Lower Miller	6.315
Developed	Stormflow	12/15/2009	MIL000.20		75.4	0.21	0.39	Lower Miller	6.315
Developed	Stable Flow	4/13/2011	BTT000.05		7.5	2.1	0.39	Lower Butte	4.028
Developed	Stormflow	8/2/2010	MIL000.38		1732.9	0.008	0.34	Lower Miller	6.315
Rural	Stable Flow	1/11/2008	MIL003.64		10.9	1.2	0.32	Upper Miller	2.922
Developed	Stable Flow	2/11/2010	NFG000.14		9.7	1.24	0.29	North Fork Granite	1.247
Developed	Stormflow	3/8/2010	BAN000.02		5.2	2.1	0.27	Lower Bannon	2.748
Developed	Stable flow	5/13/2010	BTT000.06		42.8	0.24	0.25	Lower Butte	4.028
Developed	Stable flow	5/13/2010	ASP000.37		15.60	0.60	0.23	Lower Aspen	5.038
Developed	Stable flow	5/13/2010	NRG000.56		10.9	0.77	0.21	North Fork Granite	1.247
Developed	Stable Flow	10/20/2010	MAN000.01		275.5	0.03	0.20	Lower Manzanita	2.334
Rural	Stormflow	3/8/2010	GRA034.39		7.4	1.05	0.19	Upper Granite	2.288
Developed	Stormflow	8/2/2010	NFG000.25		2419.2	0.003	0.18	North Fork Granite	1.247
Developed	Stormflow	8/2/2010	NFG000.56		2419.2	0.003	0.18	North Fork Granite	1.247
Developed	Stable Flow	1/11/2008	MAN002.15		33.1	0.2	0.16	Upper Manzanita	1.660
Rural	Stable flow	5/13/2010	GRA033.51		36.4	0.16	0.14	White Spar	4.494
Developed	Stormflow	12/18/2008	GOV000.60		23.3	0.2	0.11	Lower Government	3.818
Developed	Stable Flow	2/11/2010	BAN000.02		7.2	0.62	0.11	Lower Bannon	2.748
Developed	Stable Flow	4/12/2011	MIL002.23		4.1	1	0.10	Lower Miller	6.315
Rural	Stable Flow	4/12/2011	ASP004.57		7.5	0.5	0.09	Upper Aspen	3.616
Developed	Stable flow	5/13/2010	MAN000.01		11	0.32	0.09	Lower Manzanita	2.334
Developed	Stable Flow	2/11/2010	ASP000.05		1.00	3.10	0.08	Lower Aspen	5.038
Rural	Stable Flow	2/11/2010	MIL003.64		4.1	0.62	0.06	Upper Miller	2.922
Developed	Stormflow	12/15/2009	BAN000.06		63.1	0.04	0.06	Lower Bannon	2.748
Developed	Stable flow	4/16/2010	BAN000.02		50.4	0.05	0.06	Lower Bannon	2.748
Developed	Stable Flow	12/12/2007	BAN000.06		14.8	0.17	0.06	Lower Bannon	2.748
Rural	Stable Flow	2/14/2009	GRA033.51		1	2.4	0.06	White Spar	4.494
Rural	Stable Flow	1/11/2008	GRA034.39		2	1.18	0.06	Upper Granite	2.288
Developed	Stable flow	5/13/2010	MIL000.32		8.5	0.23	0.05	Lower Miller	6.315
Developed	Stable flow	4/16/2010	MIL000.32		7.4	0.24	0.04	Lower Miller	6.315
Rural	Stable Flow	2/11/2010	ASP005.07		4.1	0.41	0.04	Upper Aspen	3.616
Rural	Stable Flow	4/12/2011	MIL003.82		3	0.5	0.04	Upper Miller	2.922
Developed	Stable Flow	4/13/2011	MAN000.01		2	0.69	0.03	Lower Manzanita	2.334
Rural	Stable Flow	2/11/2010	GRA034.39		4.1	0.31	0.03	Upper Granite	2.288
Developed	Stable Flow	4/12/2011	ASP001.00		12	0.1	0.03	Lower Aspen	5.038
Rural	Stable Flow	1/11/2008	ASP005.07		3.1	0.37	0.03	Upper Aspen	3.616
Developed	Stable flow	4/20/2010	MAN000.05		6.3	0.18	0.03	Lower Manzanita	2.334
Developed	Stable flow	4/20/2010	MIL002.23		15.8	0.07	0.03	Lower Miller	6.315
Rural	Stormflow	1/26/2010	MIL006.07	<	1	1	0.02	Upper Miller	2.922
Developed	Stable flow	5/13/2010	NFG000.14		1	0.8	0.02	North Fork Granite	1.247

Rural/Urban	Regime	Date	Site ID	Lab Code	Concentration (cfu/100 ml)	Q, cfs (Inst.)	Load, G-orgs/day	Subwshed	Cumulative Area (mi^2)
Developed	Stable flow	5/13/2010	NFG000.14 dup	<	1	0.8	0.02	North Fork Granite	1.247
Rural	Stormflow	1/6/2008	GRA034.39 dup		2	0.38	0.02	Upper Granite	2.288
Developed	Stable flow	5/13/2010	ASP002.87		10.9	0.064	0.02	Lower Aspen	5.038
Developed	Stable Flow	4/12/2011	MAN000.55		3.1	0.2	0.02	Lower Manzanita	2.334
Rural	Stable flow	4/16/2010	ASP005.07		17.5	0.03	0.01	Upper Aspen	3.616
Developed	Stable flow	4/20/2010	BAN000.02		12.2	0.04	0.01	Lower Bannon	2.748
Rural	Stable Flow	4/13/2011	GRA034.39		2	0.2	0.01	Upper Granite	2.288
Rural	Stable Flow	12/12/2007	ASP005.07		2	0.15	0.01	Upper Aspen	3.616
Rural	Stable Flow	12/12/2007	GRA034.39		5.2	0.05	0.01	Upper Granite	2.288
Developed	Stable flow	4/16/2010	BUT000.05	<	1	0.24	0.01	Lower Butte	4.028
Developed	Stormflow	8/2/2010	BAN000.02		83.9	0.002	0.004	Lower Bannon	2.748
Rural	Stable flow	4/16/2010	MIL003.64		3.1	0.05	0.004	Upper Miller	2.922
Developed	Stable flow	5/13/2010	MAN000.55	<	1	0.1	0.002	Lower Manzanita	2.334
Developed	Stable flow	4/20/2010	MIL003.10		1	0.07	0.002	Lower Miller	6.315
Rural	Stable flow	4/20/2010	ASP004.57		3.1	0.02	0.002	Upper Aspen	3.616
Developed	Stable flow	4/20/2010	ASP002.87	<	1	0.04	0.001	Lower Aspen	5.038
Rural	Stable flow	4/16/2010	GRA033.51	<	1	0.03	0.001	White Spar	4.494
Rural	Stable flow	4/20/2010	GRA034.39	<	1	0.02	0.0005	Upper Granite	2.288
Rural	Stable flow	4/16/2010	MIL006.07	<	1	0.02	0.0005	Upper Miller	2.922
Developed	Stable flow	4/20/2010	GRA032.67		1	0.02	0.0005	White Spar	4.494
Rural	Stable flow	4/16/2010	BTT005.70	<	1	0.01	0.0002	Upper Butte	2.102
Developed	Stormflow	8/29/2013	VRACKeast	>	2419.6	0.6	35.50	Acker East	1.535
Developed	Stormflow	8/30/2013	VRACKeast	>	2419.6	1.2	70.99	Acker East	1.535
Developed	Stormflow	11/22/2013	VRACKeast		11,199	2	547.63	Acker East	1.535
Developed	Stormflow	8/13/2014	VRACKeast		1,616	0.1	3.95	Acker East	1.535
Developed	Stormflow	11/22/2013	VRACKwest		1046	2.5	63.94	Acker West	1.535
Developed	Stormflow	8/29/2013	VRACKwest	>	2419.6	0.8	47.33	Acker West	1.535
Developed	Stormflow	8/30/2013	VRACKwest	>	2419.6	1.5	88.74	Acker West	1.535
Developed	Stormflow	8/13/2014	VRACKwest		1,529	0.25	9.35	Acker West	1.535
Developed	Stable flow	7/30/2013	GRA029.97		90.90	0.15	0.33	Fort Whipple	18.543
Developed	Stable flow	8/20/2013	GRA029.97		307.60	0.50	3.76	Fort Whipple	18.543
Developed	Stormflow	8/13/2014	GRA029.97		933	57	1300.28	Fort Whipple - u	18.543
Developed	Stormflow	8/30/2013	GRA029.97		2419.6	35	2070.57	Fort Whipple - u	18.543
Developed	Stormflow	11/22/2013	GRA029.97		4106	24	2409.40	Fort Whipple - u	18.543
Developed	Stormflow	8/29/2013	GRA029.97		1732.9	18	762.65	Fort Whipple - u	18.543
Developed	Stormflow	9/10/2013	GRA029.97		689.6	8	134.89	Fort Whipple - u	18.543
Developed	Stormflow	8/29/2013	VRGOC000.60	>	2419.6	1	59.16	Lower Government	3.818
Developed	Stormflow	11/22/2013	VRGOC000.60		1046	1.2	30.69	Lower Government	3.818
Developed	Stormflow	8/13/2014	VRGOC000.60		886	0.75	16.25	Lower Government	3.818
Developed	Stormflow	8/29/2013	VRGOC000.60	>	2419.6	1	59.16	Lower Government	3.818
Developed	Stormflow	11/22/2013	VRGOC000.60		1046	1.2	30.69	Lower Government	3.818
Developed	Stormflow	8/13/2014	VRGOC000.60		886	0.75	16.25	Lower Government	3.818
Developed	Stormflow	11/22/2013	VRNGC		3076	1	75.21	North Fork Granite	1.247
Developed	Stormflow	8/29/2013	VRNGC000.14		2419.6	3	177.48	North Fork Granite	1.247
Developed	Stormflow	8/30/2013	VRNGC000.14	>	2419.6	4	236.64	North Fork Granite	1.247
Developed	Stormflow	9/10/2013	VRNGC000.14		279.2	0.5	3.41	North Fork Granite	1.247
Developed	Stormflow	11/22/2013	VRNGC000.14		1664	4	162.74	North Fork Granite	1.247
Developed	Stormflow	11/23/2013	VRNGC000.14		259	0.6	3.80	North Fork Granite	1.247
Developed	Stormflow	8/13/2014	VRNGC000.14		598	1	14.62	North Fork Granite	1.247
Developed	Stormflow	8/29/2013	VRSHG	>	2419.6	1.2	70.99	Slaughterhouse Gulch	2.614
Developed	Stormflow	11/22/2013	VRSHG		2851	2.5	174.27	Slaughterhouse Gulch	2.614
Developed	Stormflow	8/13/2014	VRSHG		305	2	14.91	Slaughterhouse Gulch	2.614

Rural/Urban	Regime	Date	Site ID	Lab Code	Concentration (cfu/100 ml)	Q, cfs (Inst.)	Load, G-orgs/day	Subwshed	Cumulative Area (mi^2)
Developed	Stormflow	8/13/2014	VRGOC003.03		480	1.2	14.08	Upper Government	2.288
Rural	Stormflow	9/10/2013	VRMIL003.64		140	0.6	2.05	Upper Miller	2.922
Developed	Stormflow	8/29/2013	GRA027.35	>	2419.6	30	1774.78	Watson Woods	23.549
Developed	Stormflow	8/30/2013	GRA027.35	>	2419.6	45	2662.16	Watson Woods	23.549
Developed	Stormflow	9/10/2013	GRA027.35		402.8	11	108.33	Watson Woods	23.549
Developed	Stormflow	11/22/2013	GRA027.35		3873	40	3787.79	Watson Woods	23.549
Developed	Stormflow	8/13/2014	GRA027.35		1,274	45	1401.72	Watson Woods	23.549

Appendix B - Stormflow Determination / Base Flow Recession Coefficients

Hydrograph Separation Methods and Storm Flow Determinations

Base flow is defined as the portion of a stream's flow attributable to groundwater recharge and interflow (flow between the vadose zone and the surface) and excluding direct precipitation and overland flow. One characteristic of base flow is that it tends to be relatively stable within time limits, and thus presents an ideal flow condition to collect water quality samples reflecting typical values. Hydrologists have traditionally used a graphic technique called base flow separation on hydrographs to partition the various components and magnitudes of discharge for any single storm hydrograph. Briefly, one technique consists of drawing a line from the foot of the rising limb of the hydrograph during a storm to a point on the receding arm of the hydrograph where the curve begins to flatten out (other techniques, as illustrated below, use alternative methods for establishing the demarcation line). The components of flow below the superimposed line are attributable to base flow, while the components of the hydrograph above the drawn line are attributable to precipitation and the effects of precipitation events (Figure 7).

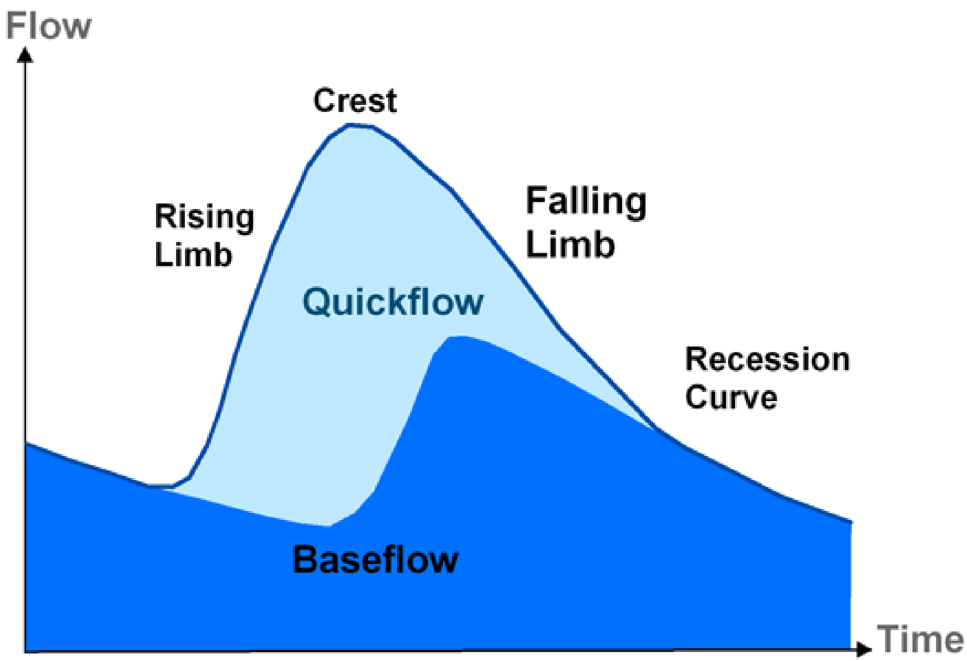

Figure 7. Graphic Base Flow Separation
(Illustration courtesy of Connected Water, 2008)

Some water quality studies use the technique of base flow separation to partition the total flow value into proportions of total flow which can be attributed to base flow and storm flow on any given date. However, ADEQ has noted over years of sample collection that flood flows or hydrograph spikes carry higher concentrations of almost all analytes, particularly *E. coli* and suspended sediment, throughout their durations, which decrease in magnitude as the stream recovers a status of relative stasis. To partition a total load proportionally between a base flow fraction and a storm flow fraction gives a misleading impression of concentrations considered normal or typical for the stream, since the stream's power as exhibited by its increased velocity and volume does not increase in a merely additive fashion, but in exponential fashion. Likewise, concentrations of analytes carried by a stream in a hydrograph spike do not increase merely in an additive manner. For the purpose of TMDL data analysis, it is frequently necessary to identify the periods in the time series of discharges where the hydrograph is actively changing to a degree that indicates the stream is under the influence of a storm event. By doing so and examining data collected outside the storm flow windows, a better and more accurate perspective of the true impairment status of the stream can be gained. The magnitude and duration of the change in flow, while consequential, are secondary in importance to the identification of days in the flow history where the mean discharge of the stream shows a state of instability relative to preceding days' flows.

A method to achieve this identification of stormflow influenced days can be achieved mathematically by a comparison of adjacent time steps' instantaneous or mean flow values. The rate of decline of flow from a hydrograph crest to a condition of relative stability is governed by a natural logarithm exponential decay formula:

$$Q=Q_0e^{-\alpha t}$$

Where Q is flow in cubic feet per second in the current time step
Q_0 is previous time step's flow in cubic feet per second
α is a base flow recession coefficient
And t is the time interval in hours or days.

Solving for alpha, the variable needed to analyze flow recession data, we have

$$\alpha = -\frac{1}{t}\ln(Q/Qo)$$

Where a continuous flow history is available in daily or hourly increments, any given day's flow can be compared to the previous day's flow and the base flow recession (BFR) coefficient (α) can be determined for the preceding time step. In a daily analysis relative to the previous day, *t* defaults to 1 and thus can be disregarded. Negative calculated coefficients represent an increase in flow relative to the previous day, whereas positive recession coefficients represented decreasing flow. Recession coefficients of 0.00 indicate constant flow values from one day to the next. By determining a recession coefficient threshold when considering the entire population of BFRCs, a storm-onset threshold can be set, and flow values for any given day can be considered in the context of preceding days' flows and categorized as storm-related flows or non-storm related flows independently of the magnitude of the flow. This method lends itself well to rapid calculation of large amounts of flow data and case-by case consideration of whether any particular flow value exhibits storm flow or non-storm flow characteristics.

The method is flexible, adaptable and widely applicable to either daily, hourly, or sub-hourly time series flow data, based on durations as minimal as one time step (15 minutes, one hour, or one day) extending to durations of multiple days consistent with analysis requirements. Criteria can be established universally or unique to the analysis of any given site, and adapted in various appropriate ways suitable to the analysis at hand. Criteria applied to characterize a flow time series as storm-flow influenced for this TMDL data analysis are the following:

- Unique base flow recession coefficient thresholds determined by analysis of each gauging station's flow history and drawn from the entire population of calculated BFR coefficients available for analysis.
- Flow event origination threshold calculated as 1.5 times the interquartile range of BFR coefficients for the site added to the 75th percentile value of the BFR coefficient.
- Daily mean flow comparisons.
- Standard 48 hour storm duration used as default analysis. Where necessary, hour by hour analysis was used to determine active stormflow regime.

Conservative assumptions built into this analysis include the following:

- With central tendency of the data set tending towards zero, extending the threshold value from the 75th percentile value by 1.5*IQR ensures a higher event origination threshold, thus ensuring that significant differences in flow comparisons are necessary to change regime characterization for the time step.
- Flow magnitude changes are implicit in the calculation of the BFR coefficient.

.

The BFR coefficient method applied to sites where continuous flow histories exist provides a tool by which episodic site visits and data associated with those visits may be placed in a context of flows near the same date to determine whether storm flow or non-storm flow conditions exist at the sample collection time. As such, the use of this tool as a screening device allows winnowing of the data set for the consideration of exceedance events, load calculations, and load reductions that are fully accordant with the intent of water quality standards where necessary or the basis of the TMDL analysis where called for, and identifies and screens from consideration data that do not meet those criteria.

Appendix C – Derivation of Target Development Framework

The assumptions upon which Arizona's *E. coli* water quality criteria were adopted included a distribution that is lognormal in character with certain defined moments. The prototype bacteria curve with these moments is called the *log-normal criteria curve* (LNCC). All confidence levels serving as SSMs and the geometric mean for various designated uses were derived from and defined by the original LNCC developed as the standard model in EPA bacteria studies (EPA, 1986) (Figure 8, Table 5). The term *single sample maximum* (SSM) is a misnomer as it is applied to Clean Water Act Assessments. The concept was originally conceived as a single number by which beach and swimming area managers could make beach closure decisions on short notice with limited data to evaluate. The number was not intended to be employed as a single "never to exceed" criteria in natural waters assessment. Consequently, there is room for the states to develop and apply their own evaluation criteria with regards to the SSM.

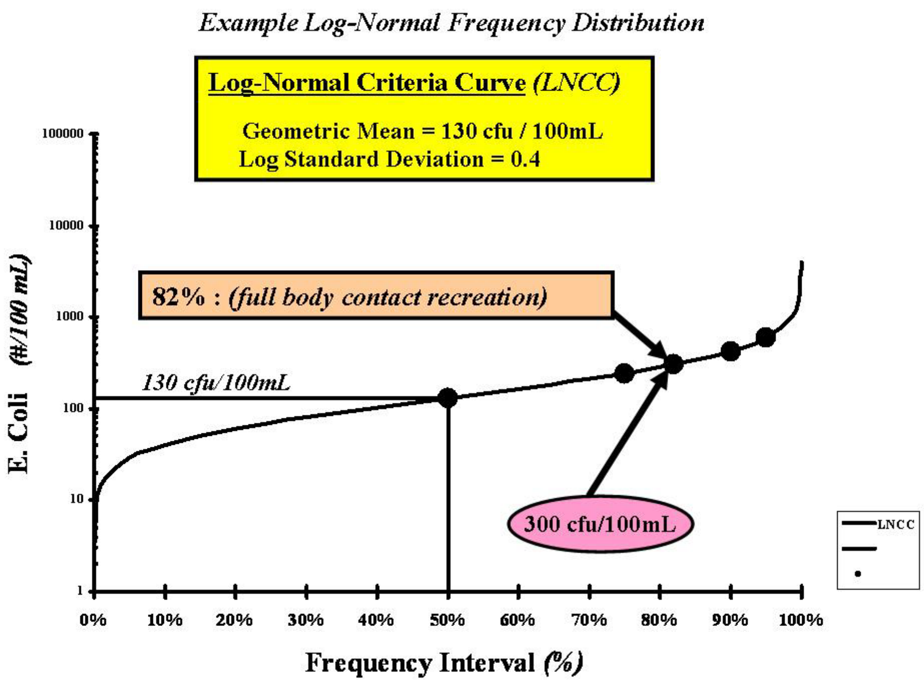

Figure 8. Lognormal criteria curve (LNCC)

The difference in geomeans as compared to the EPA source (following table) is noted. The table constitutes the correct set of values. While the geometric mean is clearly listed as an integral part of Arizona's *E. coli* water quality standard, in practice, Arizona has lacked sufficient data meeting the time period requirement to determine the geometric mean and thus has evaluated reaches for impairments based upon consideration of single sample maximums alone. Arizona's *E. coli* water quality standard was derived from numbers originating in a series of freshwater beach studies undertaken in the 1970s correlating *E. coli* bacterial densities with rates of gastroenteritis (EPA, 1986). The Arizona single sample maximum, drafted directly from EPA recommendations and derived from the freshwater beach studies, originated as a defined point representing a particular confidence level in a cumulative probability distribution with a geometric mean of 126 cfu/100ml (235 cfu/100 ml representing the upper 75th percent confidence level). In practice, however, each incidence of single sample maximum exceedance has been treated as an episode of a violation of an acute criterion. Currently, Arizona's surface water assessment methods stipulate that two or more exceedances of the *E. coli* single sample maximum standard in a three year period is sufficient to deem the waterbody impaired. Assuming quarterly visits to a given site or reach, a typical visitation rate for the ambient monitoring program, an exceedance frequency for the single sample maximum (SSM) of 16.7% or higher denotes impairment. Stormflow conditions are not exempted from consideration under the water quality standard.

In contrast, Arizona's method of determining impairment of waters for other parameters (including all parameters carrying human health and agricultural designated uses) employs binomial distribution-based criteria requiring a minimum 10 percent exceedance frequency with at least 90% confidence. The binomial approach is predicated on determining with statistical confidence the number of successes (episodes of attainment) or failures (exceedances of the water quality standard) in a given number of trials at a given quantiles and confidence levels. As such, it is oriented to determining the frequency of exceedances in a given population and has no direct bearing on the mass-based analysis of total pollutants in the watershed. While the TMDL analysis cannot readily incorporate a binomial-based approach for determining the magnitude of existing loads and quantification of load reductions necessary to attain WQ standards, it can adopt the implied 90th percentile threshold for attainment of such an approach (corresponding with a 10% exceedance rate) to provide a benchmark to determine standards attainment. The 90th percentile value was selected in recognition of the fact that single sample maximums are not intended to be construed as values never to be exceeded (EPA, 2006), but rather represent an implied percentile or confidence level of a frequency distribution. Adopting the 90th percentile value for attainment evaluations adds an implicit margin of safety over the 75th percentile level the single sample maximum value was originally drawn from and obviates the need to include an additional explicit margin of safety.

The parameters of the LNCC include the following:

Geomean: 126 cfu/100 ml
Log standard deviation: 0.4 (Base 10)

From these, EPA has derived the following:
75th percent confidence level: 235 cfu/100 ml
90th percent confidence level: 409 cfu/100 ml
95th percent confidence level: 575 cfu/100 ml
(Table 5)

Additional manipulation of the parameters consistent with the assumptions of the LNCC yields the following:

Log Base 10 of geomean: 2.100
Log Base 10 variance: 0.16
Natural log of geomean: 4.836
Natural log standard deviation: 0.921
Natural log variance: 0.848

The arithmetic mean of the distribution provides a linkage by which to allocate loading by subwatershed in the Granite Creek basin. As a measure of the centroid of the concentrations of the defined distribution, it establishes the center of mass essential to a mass-based analysis in the way that a median representing a demarcation (one-half) of the complete dataset with regard to frequency cannot.

Using the following equation relating the arithmetic and geometric means,

$$m_a = m_g * e^{(0.5*\sigma\,\hat{}\,2)}$$

where m_a is the arithmetic mean
and m_g is the geometric mean
and σ^2 is the log variance,
the corresponding arithmetic mean for the lognormal distribution as defined for the E. coli water quality standard is determined to be 193 cfu/100 ml (rounded to the nearest integer).

The water quality standard presents an SSM of 235 cfu/100 ml which implicitly corresponds with a 75th percentile attainment threshold, or conversely, a 25% exceedance rate. As the standard represents the ultimate benchmark by which to evaluate loading, ensuring that the 90th percentile of the dataset meets 235 cfu/100 ml entails back-solving the following equation for μ_y:

$$\text{Ln(SSM)} = \mu_y + 1.28 * 0.921$$

Where SSM is the 75th percentile upper confidence level of the LNCC (235 cfu/100 ml);
μ_y represents the natural logarithm mean of the distribution;
1.28 is the standard z-score corresponding to a one-sided 90th percentile value;
And 0.921 represents the natural log standard deviation for the LNCC.

The measure of dispersion σ remains the same. The LNCC is essentially translated lower in log-space so that the 90th percentile value corresponds with what was previously the 75th percentile value. The antilog of μ_y calculates to a revised geomean of 72 cfu/100 ml rounded to the nearest integer. The corresponding arithmetic mean to this geomean, using the formula presented previously, is 110.5 cfu/100 ml. The target concentration value, therefore, remains 235 cfu/100 ml, with a greater proportion of the data required to adhere to the SSM to ensure WQ standard attainment. See Table 1 for a compilation of comparative benchmarks. With the averages underlying the distribution in linear space determined in a manner consistent with the assumptions driving the development of the LNCC, the basis for the TMDL analysis is in place with an implicit margin of safety provided.

TABLE 4. CRITERIA FOR INDICATOR FOR BACTERIOLOGICAL DENSITIES

	Acceptable Swimming Associated Gastro-enteritis Rate per 1000 swimmers	Steady State Geometric Mean Indicator Density	Single Sample Maximum Allowable Density: Designated Beach Area (upper 75% C.L.)	Moderate Full Body Contact Recreation upper 82% C.L.)	Lightly Used Full Body Contact Recreation upper 90% C.L.)	Infrequently Used Full Body Contact Recreation (upper 95% C.L.)
Freshwater						
enterococci	8	33 (1)	61	78	107	151
E. coli	8	126 (2)	235	298	409	575
Marine Water						
enterococci	19	35 (3)	104	158	276	501

Notes:

(1) Calculated to nearest whole number using equation:

$$\text{(mean enterococci density)} = \text{antilog}_{10} \frac{\text{illness rate/1000 people} + 6.28}{9.40}$$

(2) Calculated to nearest whole number using equation:

$$\text{(mean } E.\ coli \text{ density)} = \text{antilog}_{10} \frac{\text{illness rate/1000 people} + 11.74}{9.40}$$

(3) Calculated to nearest whole number using equation:

$$\text{(mean enterococci density)} = \text{antilog}_{10} \frac{\text{illness rate/1000 people} - 0.20}{12.17}$$

(4) Single sample limit = antilog$_{10}$ $\left| \text{log}_{10} \text{ indicator geometric mean density/100 ml} + \left\{ \text{Factor determined from areas under the Normal probability curve for the assumed level of probability} \times (\text{log}_{10} \text{ standard deviation}) \right\} \right|$

The appropriate factors for the indicated one sided confidence levels are:

75% C.L. - .675
82% C.L. - .935
90% C.L. - 1.28
95% C.L. - 1.65

(5) Based on the observed log standard deviations. During the EPA studies: 0.4 for freshwater *E. coli* and enterococci; and 0.7 for marine water enterococci. Each jurisdiction should establish its own standard deviation for its conditions which would then vary the single sample limit.

Table 5. EPA's original LNCC criteria, 1986

Appendix D - Targets, Load Allocations, and Percent Reductions

Stormwater Flows, Loads, and Reductions

Subwatershed Name	Flows, Storm, Bootstrap Medians	Flows, Storm, Median 0.75 UCL	Target Load^, 90th P-tile (G-orgs/day)	Existing Load 90th P-tile	Cumulative Percent Reduction	NB Load / Conc	Type	Percentage NB Applied to Target	NB Allocation, G-orgs / day	Load Allocation, G-orgs / day	Cumulative Load Allocation Percent Reduction
Lower Government Canyon	1.08	1.2	6.89	105.71	93.5%	50.4	Concentration	21.4%	1.48	5.42	94.9%
White Spar	0.48	1.2	6.89	11.795	41.5%	50.4	Concentration	21.4%	1.48	5.42	54.1%
Lower Bannon Creek	0.82	1.65	9.48	177.48	94.7%	50.4	Concentration	21.4%	2.03	7.45	95.8%
North Fork Granite Creek	1.36	2	11.49	177.48	93.5%	50.4	Concentration	21.4%	2.46	9.03	94.9%
Upper Manzanita Creek	1.64	2.1	12.07	70.99	83.0%	50.4	Concentration	21.4%	2.58	9.48	86.6%
Upper Aspen Creek	2.20	3	17.24	4.01	**Meets**	NA	NA	*	NA	17.24	**Meets**
Acker Park	2.25	4.5	25.86	611.57	95.8%	50.4	Concentration	21.4%	5.53	20.32	96.7%
Lower Aspen Creek	2.79	5.23	30.05	295.80	89.8%	50.4	Concentration	21.4%	6.43	23.62	92.0%
Upper Miller Creek	3.83	6.51	37.40	9.54	**Meets**	NA	NA	*	NA	37.40	**Meets**
Lower Butte Creek	4.25	7	40.22	473.27	91.5%	50.4	Concentration	21.4%	8.61	31.61	93.3%
Lower Miller Creek	4.76	7	40.22	2,070.57	98.1%	50.4	Concentration	21.4%	8.61	31.61	98.5%
Upper Government Canyon	4.17	7	40.22	40.768	1.3%	50.4	Concentration	21.4%	8.61	31.61	22.5%
Lower Manzanita Creek	4.18	7.25	41.66	342.18	87.8%	50.4	Concentration	21.4%	8.91	32.74	90.4%
Downtown	5.26	11	63.20	576.36	89.0%	50.4	Concentration	21.4%	13.53	49.68	91.4%
Granite Creek Headwaters	4.87	15.4	88.48	18.98	**Meets**	NA	NA	*	NA	88.48	**Meets**
Slaughterhouse Gulch**	9.24	9.62	55.27	1,389.72	96.0%	50.4	Concentration	21.4%	11.83	43.45	96.9%
Fort Whipple	15.48	18.3	105.15	2,070.57	94.9%	18.98	Static Load	18.1%	18.98	86.17	95.8%
Watson Woods	48.07	53	304.52	4,200.30	92.7%	18.98	Static Load	6.2%	18.98	285.54	93.2%
Kuhne Hill North	--	--	--	INSF-1	NA	--	--	--	--	--	--
Upper Butte Creek	--	--	--	No Data	NA	--	--	--	--	--	--
Schoolhouse Gulch	--	--	--	No Data	NA	--	--	--	--	--	--
Juniper Heights North	--	--	--	No Data	NA	--	--	--	--	--	--

* All watershed data constitutes portion of natural background set
INSF-1: indicates insufficient data exists to determine a 90th percentile.
NA - Not applicable
NB - Natural Background
^ - Target load calculated as product of SSM (235 cfu/100 ml), 0.75 UCL median storm flow, and conversion factor.
** 0.75 UCL median flow for Slaughterhouse Gulch extreme outlier value. Average flow value used instead.