Total Maximum Daily Loads (TMDLs) Analysis for the Watersheds of Army Creek, Red Lion Creek, and Dragon Run Creek, Delaware

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Executive Summary

Section 303(d) of the Clean Water Act requires States to identify water quality impaired waterways and to develop Total Maximum Daily Loads (TMDLs) for the pollutants that impair those waterways. The Delaware Department of Natural Resources and Environmental Control (DNREC) has identified that the water quality of Army Creek (segments DE020-001, DE020-002, DE020-003), Red Lion Creek (segments DE270-001-01 and DE270-001-02), and Dragon Run Creek (segments DE130-001 and DE130-002) was impaired because of elevated bacteria and nutrient levels and low dissolved oxygen concentrations. These segments were placed on the State's 1996 (1), 1998 (2), 2002 (3), 2004 (4), and draft 2006 (5) 303(d) lists and were targeted for development of TMDLs.

The Army Creek, Red Lion Creek, and Dragon Run Creek watersheds are situated in the upper portion of the Delaware Bay and Estuary Drainage Basin on the eastern edge of Delaware in New Castle County, north of the Chesapeake and Delaware Canal. The Army Creek Watershed lies furthest to the north with the Christina River Watershed bounding the northern edge. The Red Lion Creek Watershed lies to the south of the Army Creek Watershed and to the north of the Dragon Run Creek Watershed. The Dragon Run Creek Watershed lies furthest to the south with the C & D Canal Watershed bounding the southern edge. Each stream flows to the east and discharges into the Delaware River. The three watersheds are similar in size. The Army Creek Watershed is 26.0 km^2, the Red Lion Creek Watershed is 28.4 km^2, and the Dragon Run Creek Watershed is 26.9 km^2.

There are several point source facilities within the Army Creek, Red Lion Creek, and Dragon Run Creek watersheds, however, all treated wastewater is discharged into the Delaware River and not into these three tributaries.

Therefore, all pollutants are coming from nonpoint sources. Since New Castle County in its entirety has been issued a Municipal Separate Storm Sewer System (MS4) permit (NPDES Permit # DE 0051071), the nonpoint source TMDL loads will be assigned a wasteload allocation.

The "Total Maximum Daily Loads (TMDLs) Analysis for the Watersheds of Army Creek, Red Lion Creek, and Dragon Run Creek, Delaware," documents the technical basis and development of the Army Creek, Red Lion Creek, and Dragon Run Creek TMDLs. The development of the Army Creek, Red Lion Creek, and Dragon Run Creek nutrient TMDLs was based on the assessment of Army Creek, Red Lion Creek, and Dragon Run Creek water quality and water flow under two different environmental conditions – annual average condition and summer critical condition. The annual average condition considers medians of water quality and average water flow in the period of 2002-2005. The critical condition considers summer (June – September) water quality and 7Q10 water flow of the 2002-2005 period. The U.S. EPA's Enhanced Stream Water Quality Model (Qual2K) was used as the framework for the water quality assessments. Water quality and discharge data collected during the 2002-2005 period was used to calibrate the models and data collected during the summer from the same period was used to simulate the critical conditions.

The State of Delaware has an instantaneous minimum dissolved oxygen standard of 4.0 mg/l and daily average dissolved oxygen standard of 5.5 mg/l. Additionally, the State has nutrient targets of 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus. Load reduction scenarios under annual average conditions and summer critical conditions were evaluated using calibrated models. The results showed that 40% reductions of total nitrogen and total phosphorus are required in Army Creek, Red Lion Creek, and Dragon Run Creek.

This analysis has determined TMDLs that will require the following nutrient reductions from the 2002-2005 baseline period. Under average conditions in Army Creek, total nitrogen should be reduced from the baseline level of 18.4 kg/day (40.5 lb/day) to the level of 11.0 kg/day (24.3 lb/day), and total phosphorous should be reduced from the baseline of 1.54 kg/day (3.40 lb/day) to the level of 0.93 kg/day (2.04 lb/day).

Under average conditions in Red Lion Creek, total nitrogen should be reduced from the baseline level of 91.7 kg/day (202 lb/day) to the level of 55.0 kg/day (121 lb/day), and total phosphorous should be reduced from the baseline of 2.80 kg/day (6.17 lb/day) to the level of 1.68 kg/day (3.70 lb/day).

Under average conditions in Dragon Run Creek, total nitrogen should be reduced from the baseline of 60.3 kg/day (133 lb/day) to the level of 36.2 kg/day (79.7 lb/day), and total phosphorous should be reduced from the baseline of 3.21 kg/day (7.08 lb/day) to the level of 1.93 kg/day (4.25 lb/day).

Bacteria impairments were not included in the Qual2K modeling but were evaluated using the cumulative distribution approach to determine the reductions required within the watersheds to achieve water quality standards (100 colony forming units (CFU) enterococci/100 mL as a geometric mean).

In the Army Creek Watershed, the overall bacteria loading shall be reduced by 37% from the 1997 - 2005 baseline levels.

In the Red Lion Creek Watershed, the overall bacteria load shall be reduced by 38% from the 1997 - 2005 baseline levels.

In the Dragon Run Creek Watershed, the overall bacteria loading shall be reduced by 15% from the 1997 - 2005 baseline levels.

Draft proposed TMDLs for the Army Creek, Red Lion Creek, and Dragon Run Creek watersheds were reviewed during a public workshop held on May 16, 2006. All comments received at the workshop and during the May 1st through 31st comment period were considered by DNREC. This report has been updated to address comments regarding a more detailed discussion of sources of pollution (Section 1.5), the process of selecting a Qual2K simulation date (Section 3), the handling of stormwater outfall loads (Section 4), and conservative assumptions supporting the implicit margin of safety (Section 6.6). In addition, since the workshop, further nutrient modeling analyses have been conducted in the Army Creek Watershed to address the unnamed tributary to Army Creek, which was recently listed as impaired for bacteria, nutrients, and dissolved oxygen in the draft 2006 303d list (5). Changes to the Army Creek Qual2K Model can be found in Section 2.2 and the modeling results are presented in Section 3.1. Also since the workshop, a minor modification was made in the bacteria analyses, resulting in slight changes to the bacteria percent reductions for the Army Creek, Red Lion Creek, and Dragon Run Creek watersheds. The bacteria analyses are presented in Section 5 of the report.

1.0 Introduction
1.1 Background

Section 303(d) of the Clean Water Act (CWA) as amended by the Water Quality Act of 1987, requires States to identify water quality limited waters to develop Total Maximum Daily Loads (TMDLs) for pollutants of concern. The Delaware Department of Natural Resources and Environmental Control has identified the waters of Army Creek (segments DE020-001, DE020-002, DE020-003), Red Lion Creek (segments DE270-001-01 and DE270-001-02), and Dragon Run Creek (segments DE130-001 and DE130-002) as water quality limited waters. These segments were placed on the State's 1996 (1), 1998 (2), 2002 (3), 2004 (4) , and draft 2006 (5) 303(d) lists, and targeted for TMDL development. The red line showing the impaired segments listed on the 303(d) lists is presented in Figures 1-1 through 1-3. Table 1-1 is an excerpt from the State of Delaware's draft 2006 303(d) List for the Army Creek, Red Lion Creek, and Dragon Run Creek watersheds.

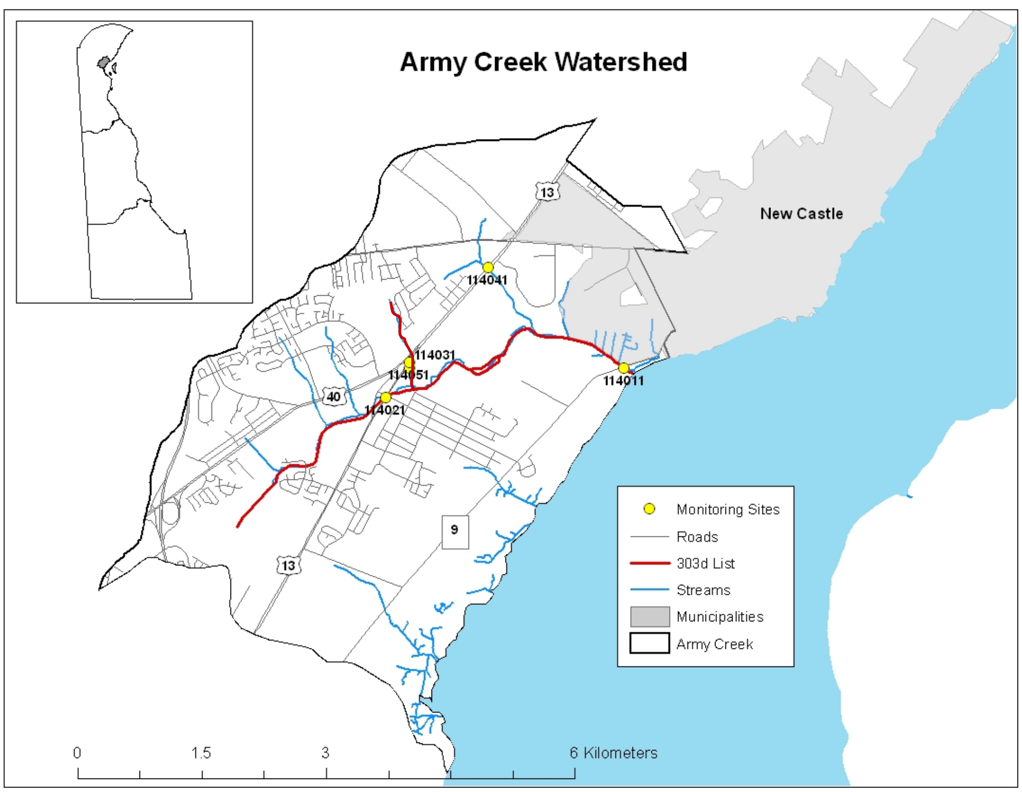


Figure 1- 1 Army Creek Watershed Map

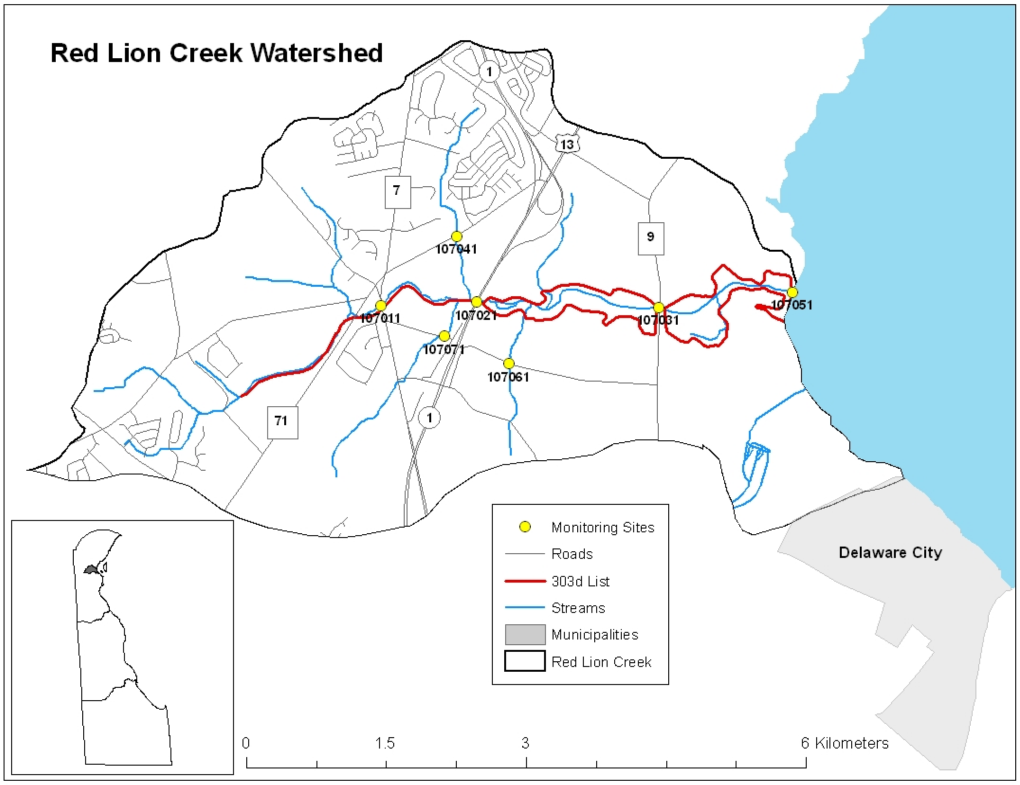


Figure 1- 2 Red Lion Creek Watershed Map

Figure 1- 3 Dragon Run Creek Watershed Map

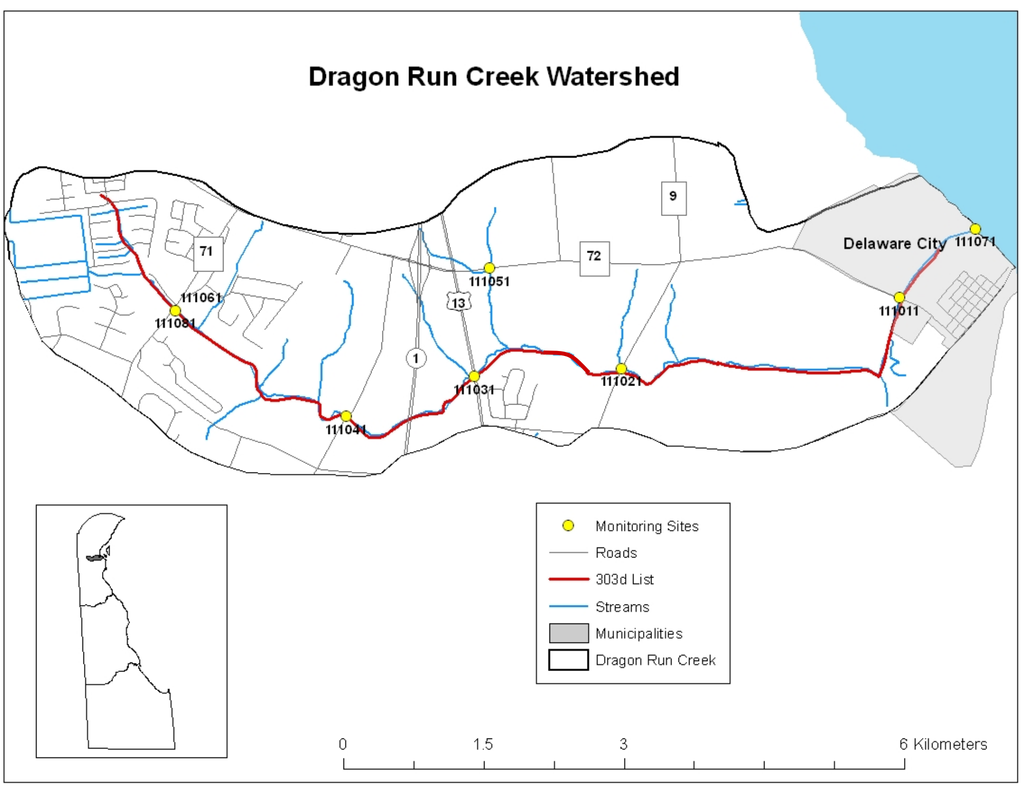


Table 1- 1 Excerpt from the State of Delaware's Draft 2006 303(d) List for the Army Creek, Red Lion Creek, and Dragon Run Creek Watersheds

WATERBODY ID	WATERSHED NAME	SEGMENT	DESCRIPTION	SIZE AFFECTED	POLLUTANT(S) AND/OR STRESSOR(S)	PROBABLE SOURCE(S)	TARGET DATE FOR TMDL
DE020-001	Army Creek	Lower	Route 13 to mouth at Delaware River	9.2 km	Bacteria, nutrients, and DO	NPS	2006
DE020-002	Army Creek	Upper	Headwaters to Route 13	1.8 km	Bacteria, nutrients, and DO	NPS	2006
DE020-003	Army Creek	Unnamed tributary	Headwaters to confluence with mainstem	1.3 km	Bacteria, nutrients, and DO	NPS	2006
DE270-001-01	Red Lion Creek	Lower	Route 13 to mouth at Delaware River	2.4 km	Bacteria, nutrients, and DO	NPS	2006
DE270-001-02	Red Lion Creek	Upper	Headwaters to Route 13	5.1 km	Bacteria, and nutrients	NPS	2006
DE130-001	Dragon Run Creek	Lower	Water supply pond to mouth at Delaware River	5.1 km	Bacteria, nutrients, and DO	NPS	2006
DE130-002	Dragon Run Creek	Upper	Headwaters to water supply pond	12.1 km	Bacteria, nutrients, and DO	NPS	2006

1.1.1 Army Creek Watershed

Army Creek Watershed drains approximately 26.0 km^2 in east central New Castle County. The Christina River Watershed lies to the north and the Red Lion Creek Watershed is to the south. Army Creek flows to the east towards the Delaware River. The stream is free flowing, however, a tidegate is located at the mouth, which only allows discharge from Army Creek to Delaware River during low tides, such that there is no tidal influence in the creek.

Concerns in the watershed include low dissolved oxygen, nutrient over-enrichment, and high levels of bacteria. The entire watershed resides in a Municipal Separate Storm Sewer System (MS4) permitted region (NPDES Permit # DE 0051071 issued to New Castle County). Additionally, one point source, a National Pollutant Discharge Elimination System (NPDES) facility, has been identified in the watershed, however, due to the facility's outfall locations, all pollutants are from nonpoint sources (see Table 1-7 for more details on this facility).

The land use within the watershed is dominated by urban areas. The detailed land use information for this watershed is based on 2002 Delaware Office of State Planning Coordination land cover data (6). Figure 1-4 shows the geographic distribution of different land uses in the Army Creek Watershed. The land use activity in the watershed consists of 15.2 km^2 of residential, commercial and industrial area (58% of the watershed), 3.5 km^2 of agriculture (13% of the watershed), 2.5 km^2 of forest (10% of the watershed), 2.4 km^2 of wetland (9% of the watershed), 1.8 km^2 of barren or transitional lands (7% of the watershed), 0.5 km^2 of rangeland (2% of the watershed) and 0.2 km^2 of water (1% of the watershed). The summary of relative distribution of land use coverage is presented in the pie chart in Figure 1-5. The city of New Castle, the only incorporated town, is situated in the northern portion of the watershed.

The soils in the upper two-thirds of the watershed are classified as the Matapeake-Sassafras association, which has been described by the Natural Resource Conservation Service as, "well drained, medium textured and moderately course textured soils with subsoils that are moderately fine or medium textured." The soils in the lower one-third of the watershed are classified as tidal marsh. The soils are nearly level to the east grading to rolling with some steep slopes in the headwaters (7).

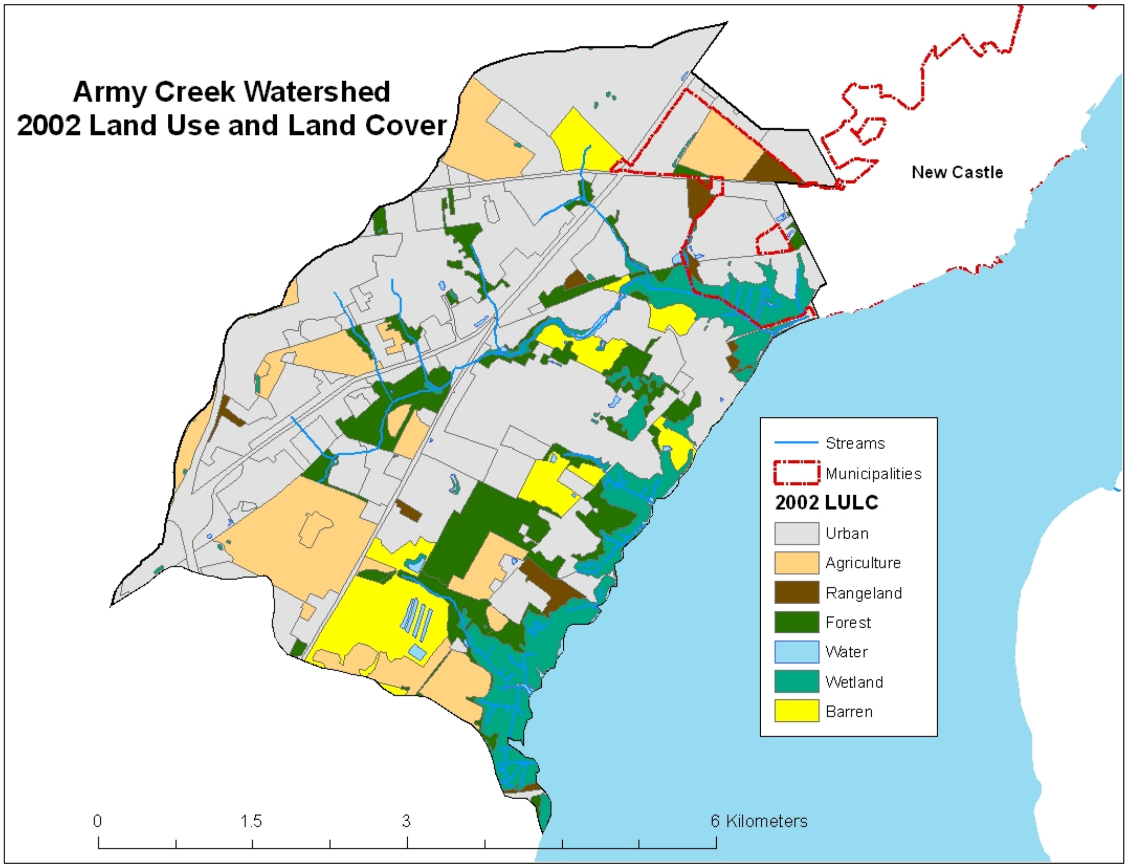
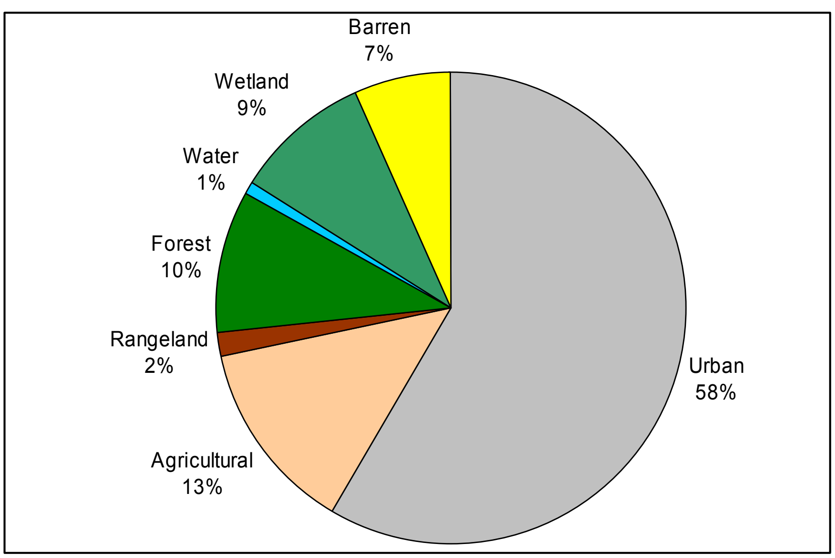


Figure 1- 4 Army Creek Watershed 2002 Land Use and Land Cover

Figure 1- 5 Land Use Percentages in Army Creek Watershed



1.1.2 Red Lion Creek Watershed

Red Lion Creek Watershed drains approximately 28.4 km^2 in east central New Castle County. The Army Creek Watershed lies to the north and the Dragon Run Creek Watershed is to the south. Red Lion Creek flows to the east towards the Delaware River. The stream is free flowing, however, a tidegate is located at the mouth, which only allows discharge from Red Lion Creek to Delaware River during low tides, such that there is no tidal influence in the creek.

Concerns in the watershed include low dissolved oxygen, nutrient over-enrichment, and high levels of bacteria. The entire watershed resides in an MS4 permitted region (NPDES Permit # DE 0051071 issued to New Castle County). Additionally, several point sources, NPDES facilities, have been identified in the watershed, however, due to the outfall locations, all pollutants are from nonpoint sources (see Table 1-7 for more details on these facilities).

The land use within the watershed is dominated by urban areas. The detailed land use information for this watershed is based on 2002 Delaware Office of State Planning Coordination land cover data (6). Figure 1-6 shows the geographic distribution of different land uses in the Red Lion Creek Watershed. The land use activity in the watershed consists of 11.9 km^2 of residential, commercial and industrial area (43% of the watershed), 6.1 km^2 of agriculture (21% of the watershed), 3.8 km^2 of forest (13% of the watershed), 3.0 km^2 of wetland (10% of the watershed), 1.5 km^2 of barren or transitional lands (5% of the watershed), 1.5 km^2 of rangeland (5% of the watershed) and 0.7 km^2 of water (3% of the watershed). The summary of relative distribution of land use coverage is presented in the pie chart in Figure 1-7. There are no incorporated towns in the watershed.

The soils grade from tidal marsh to the Matapeake-Sassafras association, which has been described by the Natural Resource Conservation Service as, “well drained, medium textured and moderately course textured soils with subsoils that are moderately fine or medium textured.” The slopes are moderate with some steep slopes along banks in the uppermost headwaters (7).

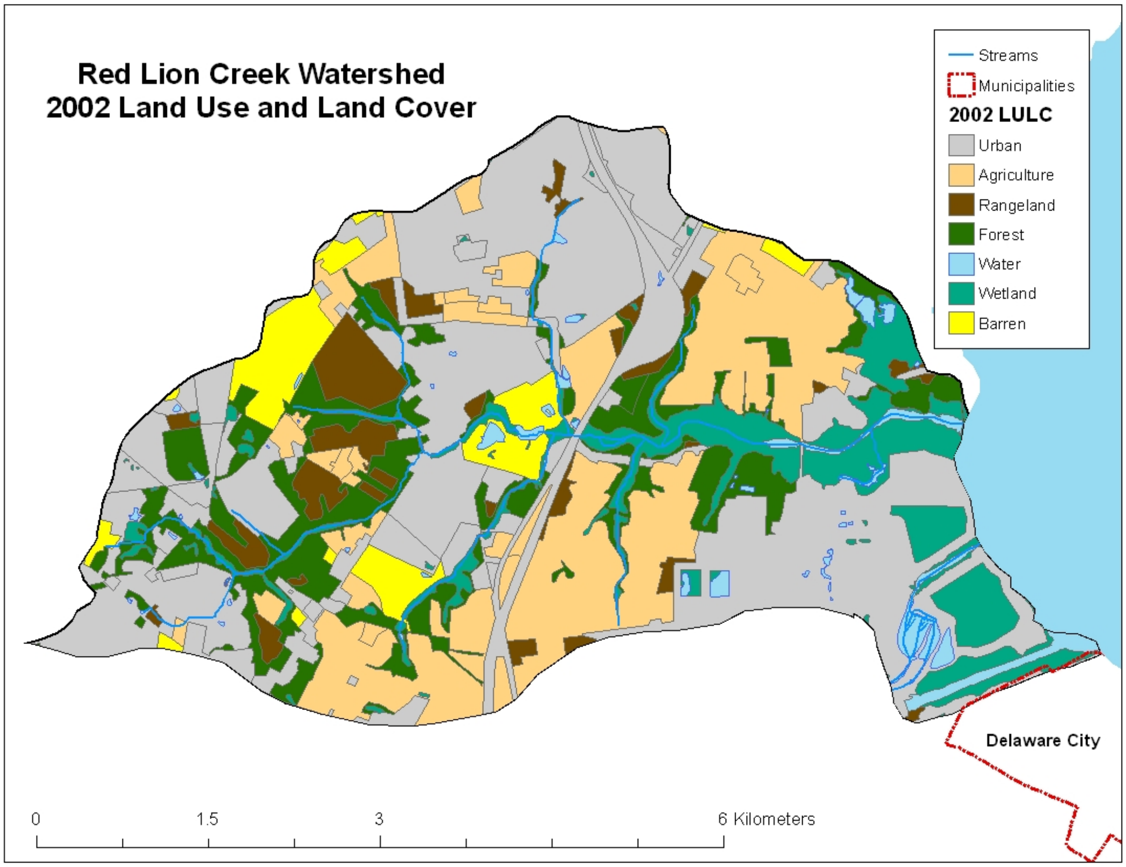
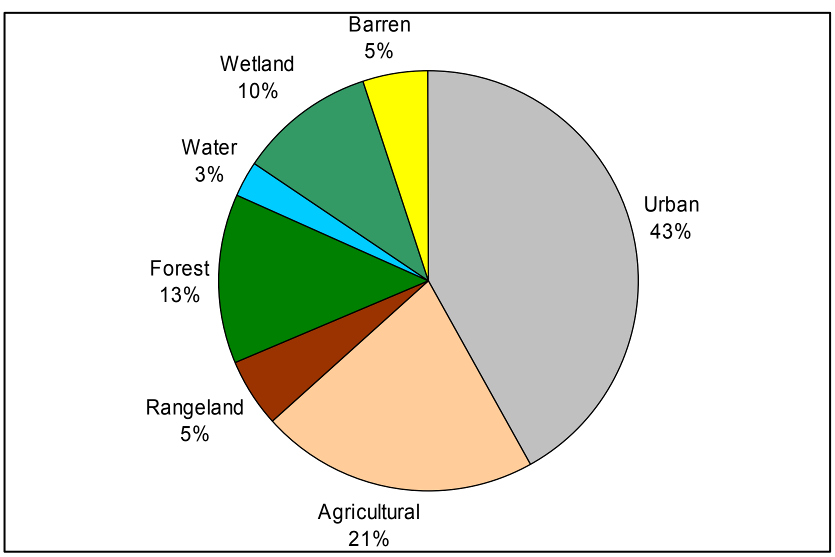


Figure 1- 6 Red Lion Creek Watershed 2002 Land Use and Land Cover

Figure 1- 7 Land Use Percentages in Red Lion Creek Watershed



1.1.3 Dragon Run Creek Watershed

Dragon Run Creek Watershed drains approximately 26.9 km^2 in east central New Castle County. The Red Lion Creek Watershed lies to the north and the C&D Canal Watershed is to the south. Dragon Run Creek flows to the east towards the Delaware River. The stream is free flowing, however, a tidegate is located at the mouth, which only allows discharge from Dragon Run Creek to Delaware River during low tides, such that there is no tidal influence in the creek.

Concerns in the watershed include low dissolved oxygen, nutrient over-enrichment, and high levels of bacteria. The entire watershed resides in an MS4 permitted region (NPDES Permit # DE 0051071 issued to New Castle County). Additionally, several point sources, NPDES facilities, have been identified in the watershed, however, due to the outfall locations, all pollutants are from nonpoint sources (see Table 1-7 for more details on these facilities).

The land use within the watershed is dominated by urban areas. The detailed land use information for this watershed is based on 2002 Delaware Office of State Planning Coordination land cover data (6). Figure 1-8 shows the geographic distribution of different land uses in the Dragon Run Creek Watershed. The land use activity in the watershed consists of 11.4 km^2 of residential, commercial and industrial area (43% of the watershed), 8.2 km^2 of agriculture (30% of the watershed), 3.3 km^2 of forest (12% of the watershed), 2.6 km^2 of wetland (10% of the watershed), 0.4 km^2 of barren or transitional lands (2% of the watershed), 0.5 km^2 of rangeland (2% of the watershed) and 0.4 km^2 of water (1% of the watershed). The summary of relative distribution of land use coverage is presented in the pie chart in Figure 1-9. Delaware City, the only incorporated town in the watershed is situated in the eastern portion of the watershed.

The soils include the Matapeake-Sassafras association, which has been described by the Natural Resource Conservation Service as, "well drained, medium textured and moderately course textured soils with subsoils that are moderately fine or medium textured" with tidal marsh along the creek and coast line. The soils are level to gently sloping with some steep slopes in the upper half of the watershed along the creek (7).

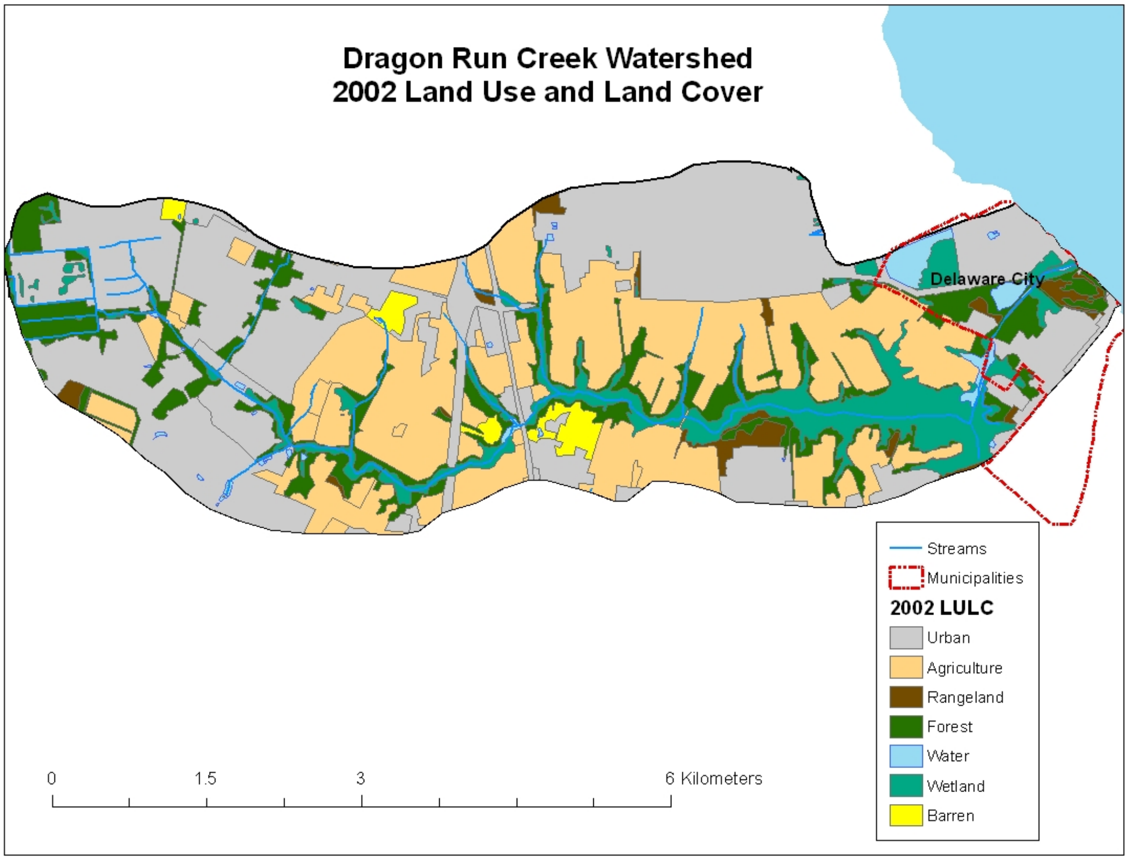
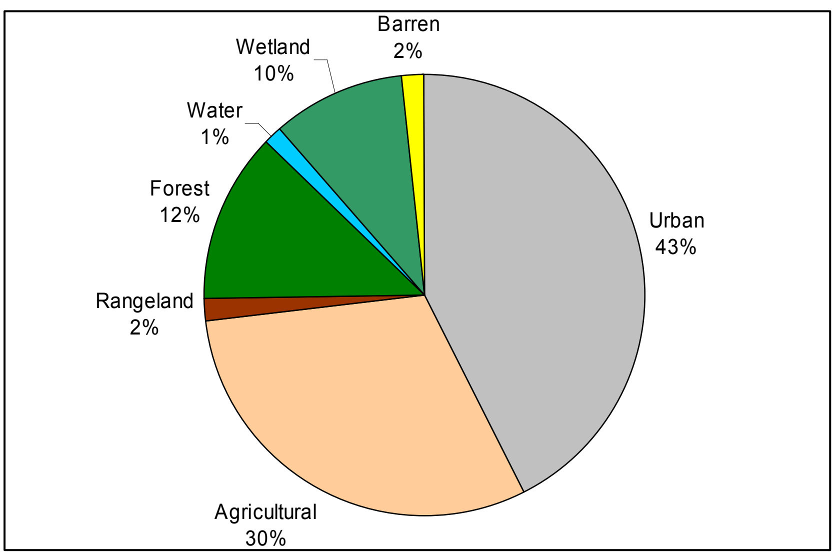


Figure 1- 8 Dragon Run Creek Watershed 2002 Land Use and Land Cover

Figure 1- 9 Land Use Percentages in Dragon Run Creek Watershed



1.2 Designated Uses

The purpose of establishing TMDLs is to reduce the pollutants to levels that result in meeting applicable water quality standards and support designated uses of the streams. Table 1-2 is an excerpt from Section 3 of the State of Delaware Surface Water Quality Standards, as amended, July 11, 2004 (8), which specifies the designated uses for the waters of Army Creek, Red Lion Creek, and Dragon Run Creek.

Table 1- 2 Excerpt from the State of Delaware's Surface Water Quality Standards, as amended, July 11, 2004 (8) Listing the Designated Uses for the Army Creek, Red Lion Creek, and Dragon Run Creek Watersheds

	Primary Contact Recreation	Secondary Contact Recreation	Fish, Aquatic Life, and Wildlife	Industrial Water Supply	Agricultural Water Supply	Public Water Supply Source
Army Creek	X	X	X		(a)	
Red Lion Creek	X	X	X	X	(a)	(a), (b)
Dragon Run Creek	X	X	X	X	(a)	(a)

(a) Designated use for freshwater segments only.
(b) Goal use not currently attained.

1.3 Applicable Water Quality Standards and Nutrient Guidelines

To protect the designated uses, the following section of the State of Delaware Surface Water Quality Standards, amended July 11, 2004 (8), provides specific narrative and numeric criteria concerning the waters of Army Creek, Red Lion Creek, and Dragon Run Creek:

Section 4 Criteria to Protect Designated Uses

Based on the above section, the following is a brief summary of pertinent water quality standards that are applicable to the waters of Army Creek, Red Lion Creek, and Dragon Run Creek:

a. Dissolved Oxygen (Section 4.5.2.1):
   - Daily average shall not be less than 5.5 mg/l
   - Instantaneous minimum shall not be less than 4.0 mg/l

b. Bacteria (enterococcus) (Section 4.6):
   - 30 day geometric mean shall not exceed 100 CFU/100 mL

c. Nutrients (Section 4.6.2):
   - It shall be the policy of this Department to minimize nutrient input to surface waters from point and human induced non-point sources.
   - The types of, and need for, nutrient controls shall be established on a site-specific basis.

In the absence of national numeric nutrient criteria, DNREC has used target thresholds of 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus as indicators of excessive nutrient levels in the streams. The above target levels have been used as the guideline for the 305(b) assessment reports and the 303(d) listing of impaired waters, and are generally accepted by the scientific community to be an indication of over-enriched waters.

1.4 Stream Water Quality Conditions and Water Quality Impairment

The lower segment of Army Creek was listed on the State of Delaware's 303(d) list for nutrient and dissolved oxygen impairments in 1996. The upper segment was added to the list for the same impairments in 1998, while the unnamed tributary was listed for nutrient and dissolved oxygen in 2006. The entire mainstem of Army Creek was listed for bacteria in 2002, while the unnamed tributary was listed in 2006. Additional water quality monitoring data collected between 2002 and 2005 at several stations within the watershed indicate that median concentrations of dissolved oxygen are above the 5.5 mg/l daily average standard, however, there are numerous excursions below this value and the 4.0 mg/l instantaneous minimum dissolved oxygen standard. Similarly, median total nitrogen and total phosphorus concentrations are below the target values of 3.0 mg/l and 0.2 mg/l, respectively, however, on several occasions, concentrations exceeded these values.

The entire length of Red Lion Creek was listed on the State of Delaware's 303(d) list for nutrient impairments in 1996, as was the lower segment for dissolved oxygen impairments, and the upper segment for bacteria impairments. The lower segment was also later listed for bacteria impairments in 2002. Additional water quality monitoring data collected between 2002 and 2005 at several

stations within the watershed indicate that median concentrations of dissolved oxygen are above the 5.5 mg/l daily average standard, however, there are a few excursions below this value and the 4.0 mg/l instantaneous minimum dissolved oxygen standard. Similarly, median total nitrogen and total phosphorus concentrations in the mainstem of Red Lion Creek are below the target values of 3.0 mg/l and 0.2 mg/l, respectively, however, on numerous occasions, nitrogen concentrations exceeded these values in the tributaries.

The upper segment of Dragon Run Creek was listed on the State of Delaware's 303(d) list for nutrient, dissolved oxygen, and bacteria impairments in 1996. The lower segment was added to the list for nutrient and dissolved oxygen impairments in 1998, while the bacteria impairments in the lower segment were added in 2002. Additional water quality monitoring data collected between 2002 and 2005 at several stations within the watershed indicate that median concentrations of dissolved oxygen are above the 5.5 mg/l daily average standard in the upper reaches of the creek, but are below the same value in the lower reaches. Additionally, there are numerous excursions below the 4.0 mg/l instantaneous minimum dissolved oxygen standard at most monitoring stations. Median total nitrogen and total phosphorus concentrations are below the target values of 3.0 mg/l and 0.2 mg/l, respectively, however, concentrations exceeded these values on a few occasions.

Considering the above water quality impairments, a watershed-wide TMDL is required for each watershed to ensure that all applicable water quality standards are achieved.

To support the model development for the Army Creek, Red Lion Creek, and Dragon Run Creek watersheds, the Department has conducted extensive water quality monitoring (Table 1-3 and Figures 1-1 through 1-3). Monitoring stations, usually at stream road crossings, are listed in Table 1-3 according to the watersheds in which they reside. Each station has been given a STORET identification number, which is a cataloging number for EPA's STORage and RETrieval repository. Several of the sites are part of the State's General Assessment Monitoring Network (GAMN), with samples collected at least quarterly over a long term to support the development of Watershed Assessment (305(b)) Reports. Those same stations have had continuous monitoring for stretches of several days at a time, where physical parameters like temperature, pH, and dissolved oxygen are measured using electric probes. The majority of the sites within the watersheds were sampled for TMDL development between May 2002 and August 2005. At each station, grab samples were analyzed for a suite of 24 water quality parameters (9). Monitoring data collected during 2002-2005 are presented in Figures 1-10 through 1-15.

Table 1- 3 Army Creek, Red Lion Creek, and Dragon Run Creek Water Quality Monitoring Stations

Monitoring Location	STORET No.	TMDL (active during 2002-2005)	GAMN (long term)	Continuous Monitoring
Army Creek Watershed				
1. Army Creek at Route 9	114011	√	√	√
2. Army Creek at Route 13	114021	√	√	√
3. Unnamed tributary to Army Creek at Route 13, near Route 40 split	114031			
4. Unnamed tributary to Army Creek at Route 13, south of Hares Corner	114041	√		
5. Unnamed tributary to Army Creek at Route 13, near Route 40 split	114051	√		
Red Lion Creek Watershed				
1. Red Lion Creek at Bear Corbit Road (Route 7)	107011	√	√	√
2. Red Lion Creek at Route 13	107021			
3. Red Lion Creek at Route 9	107031	√	√	√
4. Unnamed tributary to Red Lion Creek at Red Lion Road (Route 71)	107041	√		
5. Red Lion Creek near mouth at sluice gate	107051			
6. Unnamed tributary to Red Lion Creek at Governor Lea Road (Road 405)	107061	√		
7. Doll Run, tributary to Red Lion Creek, at Governor Lea Road (Road 405)	107071	√		
Dragon Run Creek Watershed				
1. Dragon Run Creek at 5^{th} Street (Route 9)	111011	√	√	√
2. Dragon Run Creek at Clarks Corner Road (Road 378)	111021	√		
3. Dragon Run Creek at Route 13	111031	√	√	√
4. Dragon Run Creek at McCoy Road (Road 407)	111041	√		
5. Unnamed tributary to Dragon Run Creek at Wrangle Hill Road (Route 72)	111051			
6. Dragon Run Creek at Red Lion Road (Route 71)	111061			
7. Dragon Run Creek near mouth at sluice gate	111071			
8. Dragon Run Creek at Red Lion Road (Route 71)	111081	√		

1.4.1 Army Creek Watershed

Table 1-4 presents the median concentrations of monitoring data collected during the 2002-2005 period. The monitoring data showed that occasional dissolved oxygen violations occurred at all four monitoring sites, with concentrations below 5.5 mg/l occurring most often during summer months (Figure 1-10). Similarly, occasional violations of the State of Delaware's total nitrogen and total phosphorus target threshold values of 3.0 mg/l and 0.2 mg/l, respectively, occurred in Army Creek. Total nitrogen concentrations ranged between 0.33 mg/l and 3.99 mg/l. Phosphorus concentrations ranged between 0.02 mg/l and 0.55 mg/l.

Based on the monitoring data, Delaware's draft 2006 305(b) Report (5) showed that elevated nutrient levels and low DO concentrations impaired Army Creek and its designated uses were not fully supported for aquatic life and primary contact recreation.

Table 1- 4 Median Water Quality Conditions at Four Monitoring Locations in Army Creek Watershed during 2002-2005

Monitoring	Water Temp	Field DO	BOD5	Chlor-a	Org-N	NH3-N	NO2-N	NO3-N	TN	Org-P	Dis-P	TP
Station	C	mg/l	mg/l	ug/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
114011	17.99	6.26	2.40	4.23	0.84	0.16	0.04	0.32	1.51	0.11	0.02	0.14
114021	16.00	7.66	2.40	2.00	0.69	0.09	0.08	0.69	1.76	0.11	0.04	0.13
114041	18.05	7.14	2.40	2.15	0.92	0.11	0.08	0.68	1.74	0.10	0.03	0.13
114051	15.91	7.47	2.40	4.30	0.63	0.07	0.08	0.76	1.61	0.04	0.01	0.06

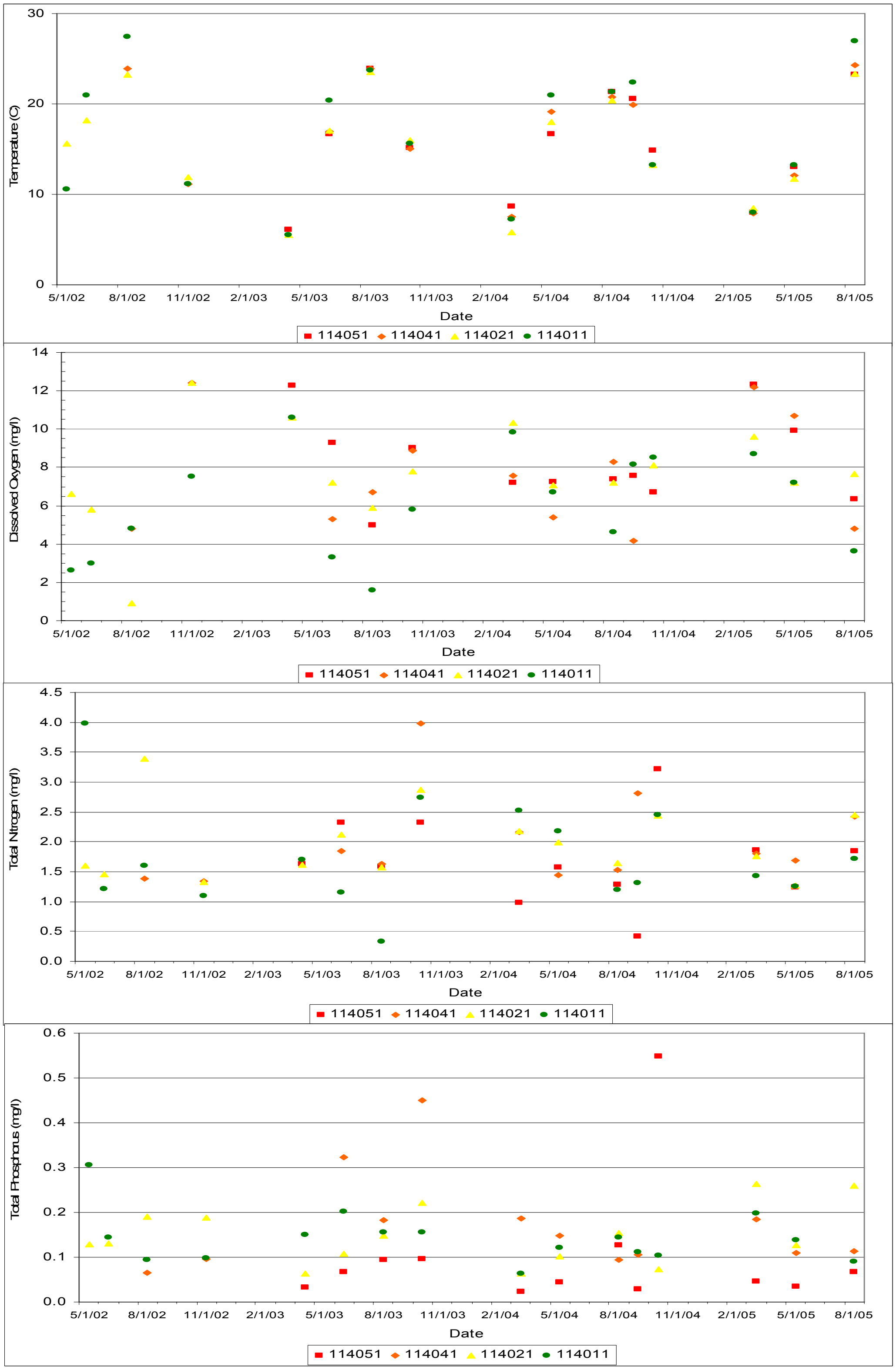


Figure 1- 10 Observed Temperature, DO, TN, and TP at Four Monitoring Locations in Army Creek Watershed

The State of Delaware water quality standard for enterococcus is a geometric mean of 100 CFU/100 mL. Enterococci are present in fecal material and are used as an indicator organism with which a correlation to illness rates has been established. The level of risk associated with primary contact recreation in waters with an enterococcus concentration of 100 CFU/100 mL has been deemed appropriate and is the basis for the current State of Delaware water quality standards for bacteria. Figure 1-11 illustrates the bacteria concentrations in the Army Creek Watershed; it is clearly much greater than the bacteria standard.

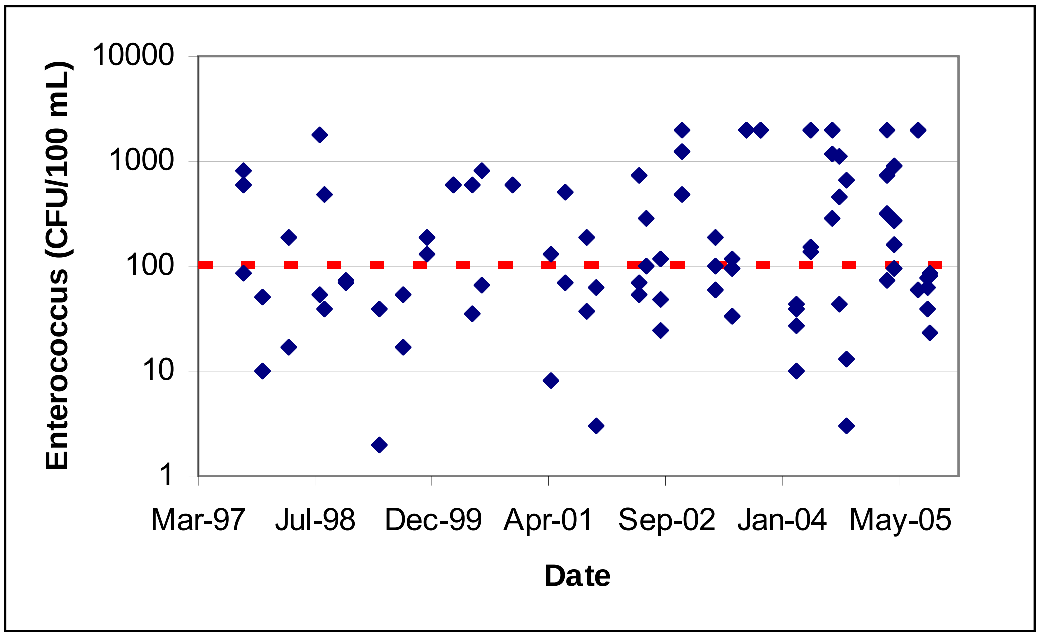


Figure 1- 11 Enterococcus Concentrations in Army Creek Watershed

1.4.2 Red Lion Creek Watershed

Table 1-5 presents the median concentrations of monitoring data collected during the 2002-2005 period. The monitoring data showed that occasional dissolved oxygen violations occurred at all but two of the monitoring sites, with concentrations below 5.5 mg/l during summer months (Figure 1-12). Nitrogen levels frequently exceeded the State of Delaware's total nitrogen target threshold value of 3.0 mg/l, with ranges between 0.48 mg/l and 5.22 mg/l. Phosphorus levels ranging between 0.00 mg/l and 0.18 mg/l were relatively low and never exceeded the 0.2 mg/l target for total phosphorus at any station.

Based on the monitoring data, Delaware's draft 2006 305(b) Report (5) showed that elevated nutrient levels and low DO concentrations impaired Red Lion Creek and its designated uses were not fully supported for aquatic life or primary contact recreation.

Table 1- 5 Median Water Quality Conditions at Five Monitoring Locations in Red Lion Creek Watershed during 2002-2005

Monitoring	Water Temp	Field DO	BOD5	Chlor-a	Org-N	NH3-N	NO2-N	NO3-N	TN	Org-P	Dis-P	TP
Station	C	mg/l	mg/l	ug/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
107011	15.89	8.45	2.40	2.67	0.49	0.08	0.06	0.51	1.17	0.05	0.01	0.06
107031	19.54	6.34	2.40	4.85	0.87	0.13	0.07	0.60	1.66	0.10	0.01	0.10
107041	17.18	7.08	2.40	9.30	0.63	0.14	0.14	1.25	2.21	0.06	0.01	0.07
107061	13.96	9.19	2.40	1.00	0.56	0.04	0.37	3.35	4.34	0.04	0.01	0.04
107071	15.88	8.59	2.40	2.00	0.53	0.07	0.26	2.34	3.30	0.04	0.01	0.05

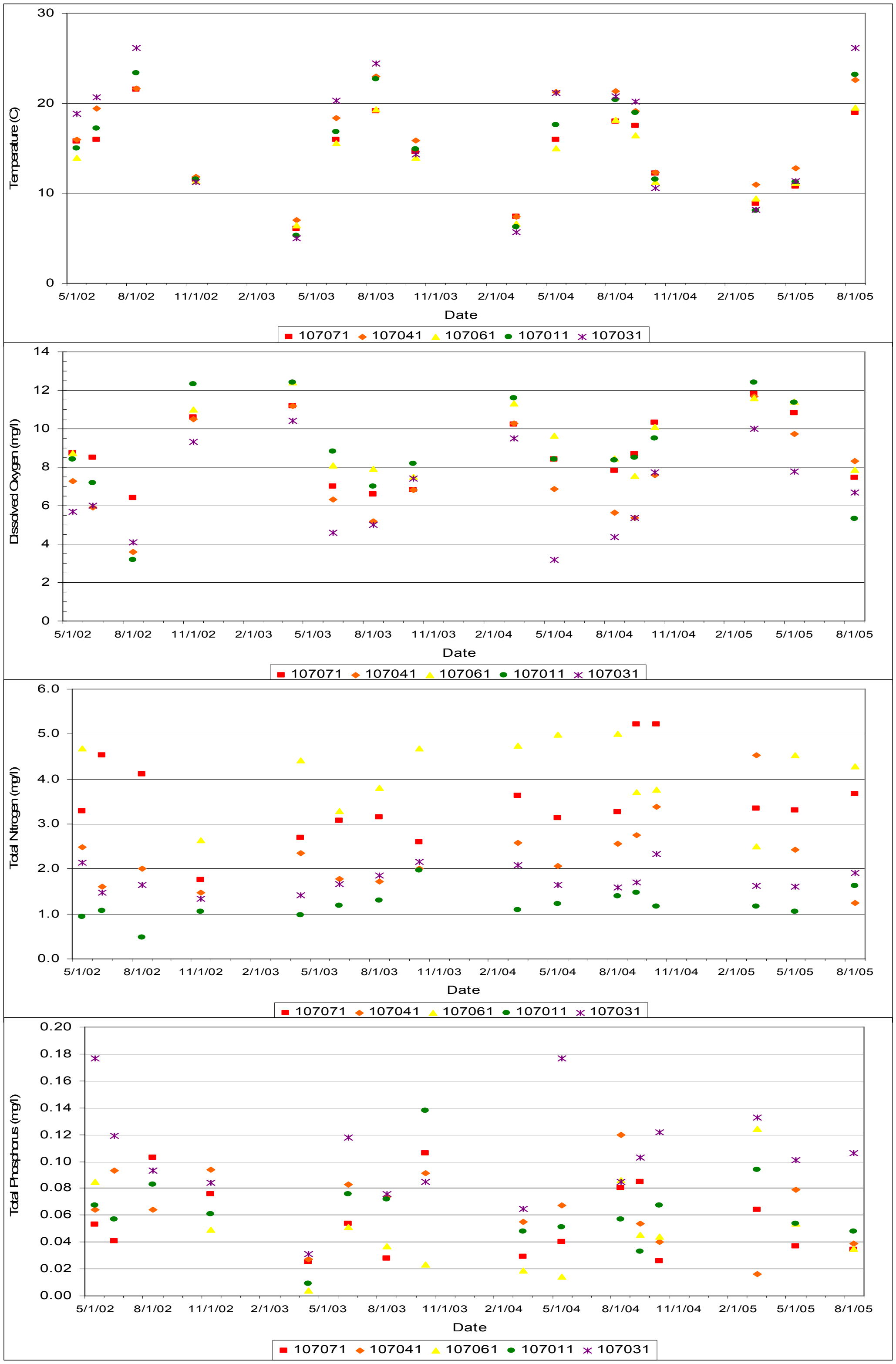


Figure 1- 12 Observed Temperature, DO, TN, and TP at Five Monitoring Locations in Red Lion Creek Watershed

Figure 1-13 illustrates the bacteria concentrations in the Red Lion Creek Watershed; it is clearly much greater than the bacteria standard.

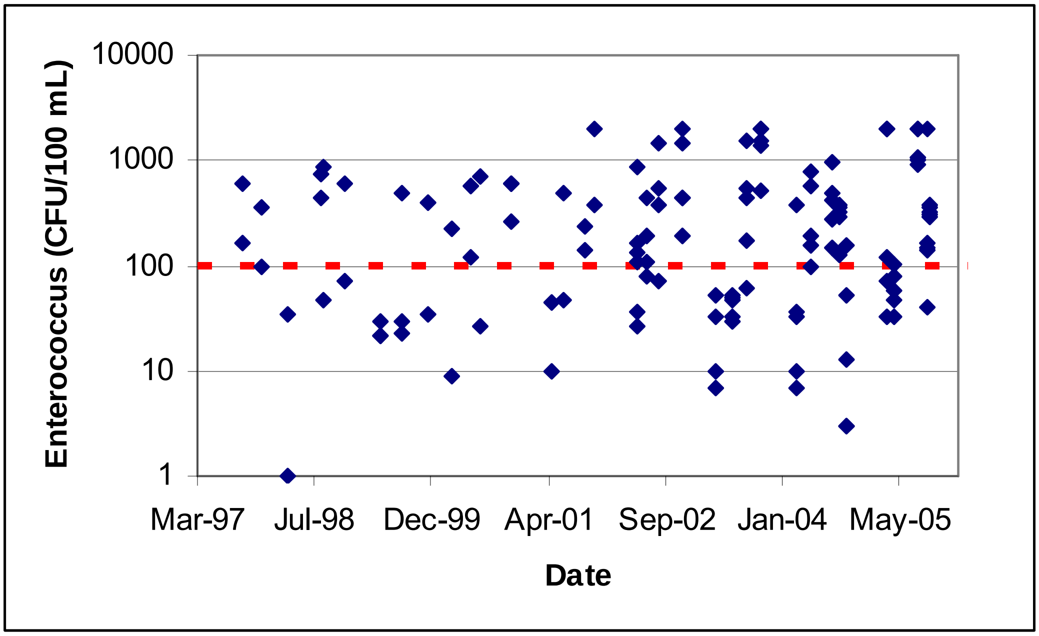


Figure 1- 13 Enterococcus Concentrations in Red Lion Creek Watershed

1.4.3 Dragon Run Creek Watershed

Table 1-6 presents the median concentrations of monitoring data collected during the 2002-2005 period. The monitoring data showed that dissolved oxygen concentrations fell below the 5.5 mg/l daily average standard and the 4.0 mg/l instantaneous minimum standard at all stations but one (Figure 1-13). Total nitrogen concentrations were less than the 3.0 mg/l target at all stations but one, with ranges between 0.34 and 3.88 mg/l. Similarly, total phosphorus concentrations were less than the 0.2 mg/l target at all stations but one with ranges between 0.01 and 0.29 mg/l.

Based on the monitoring data, Delaware's draft 2006 305(b) Reports (5) showed that elevated nutrient levels and low DO concentrations impaired Dragon Run Creek and its designated uses were only partially supported for aquatic life and primary contact recreation.

Table 1- 6 Median Water Quality Conditions at Five Monitoring Locations in Dragon Run Creek Watershed during 2002-2005

Monitoring	Water Temp	Field DO	BOD5	Chlor-a	Org-N	NH3-N	NO2-N	NO3-N	TN	Org-P	Dis-P	TP
Station	C	mg/l	mg/l	ug/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
111011	19.33	5.30	2.40	4.00	0.86	0.05	0.00	0.04	1.05	0.07	0.02	0.11
111021	16.69	4.65	2.40	3.00	0.63	0.08	0.09	0.82	1.29	0.06	0.01	0.06
111031	17.45	4.62	2.40	2.80	0.62	0.06	0.13	1.14	1.95	0.05	0.01	0.06
111041	17.81	7.33	2.40	3.37	0.52	0.10	0.08	0.72	1.38	0.06	0.01	0.08
111081	16.14	9.20	2.40	2.00	0.53	0.07	0.10	0.90	1.78	0.05	0.01	0.06

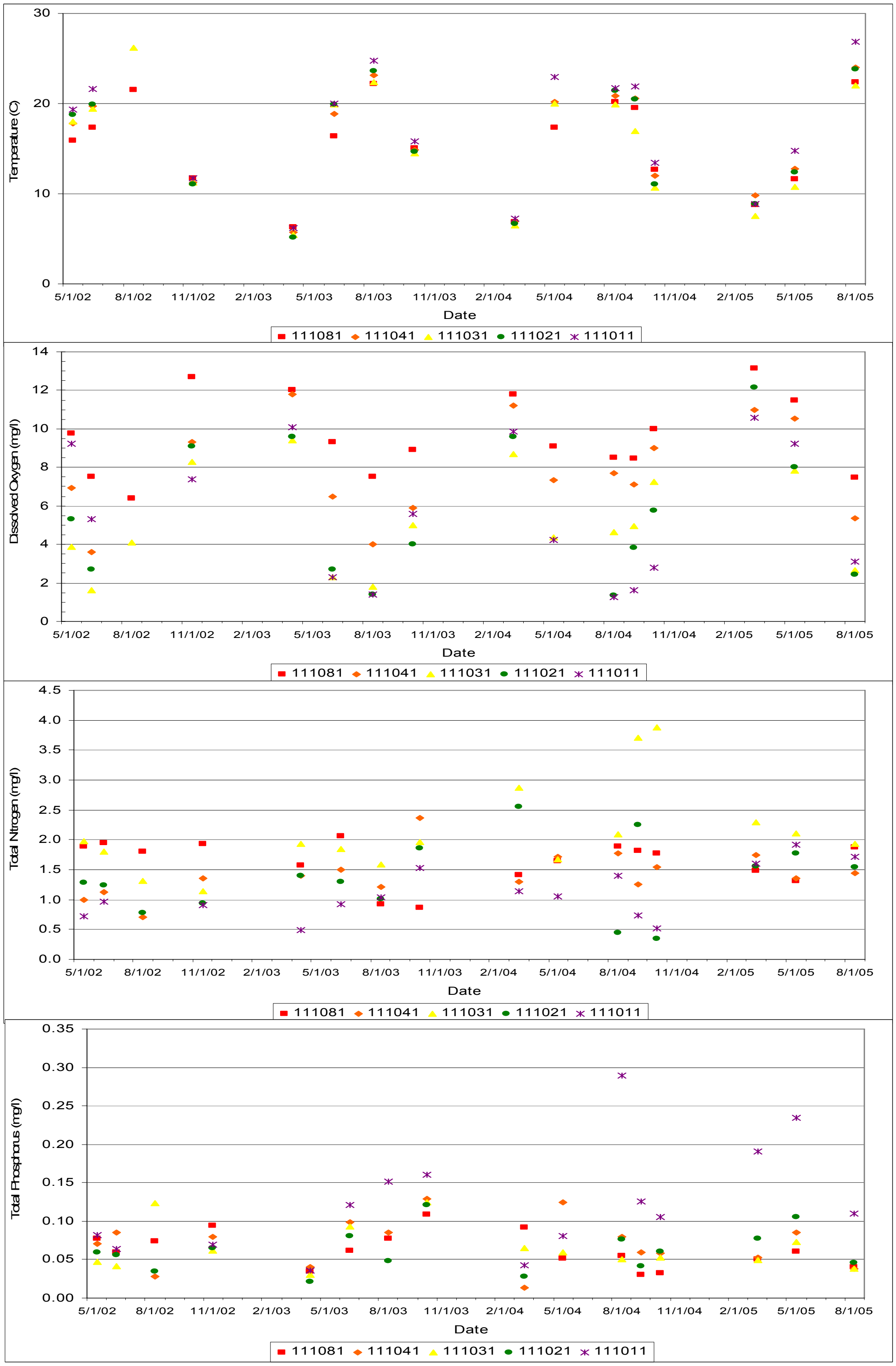


Figure 1- 14 Observed Temperature, DO, TN, and TP at Five Monitoring Locations in Dragon Run Creek Watershed

Figure 1-15 illustrates the bacteria concentrations in the Dragon Run Creek Watershed; it is clearly much greater than the bacteria standard.

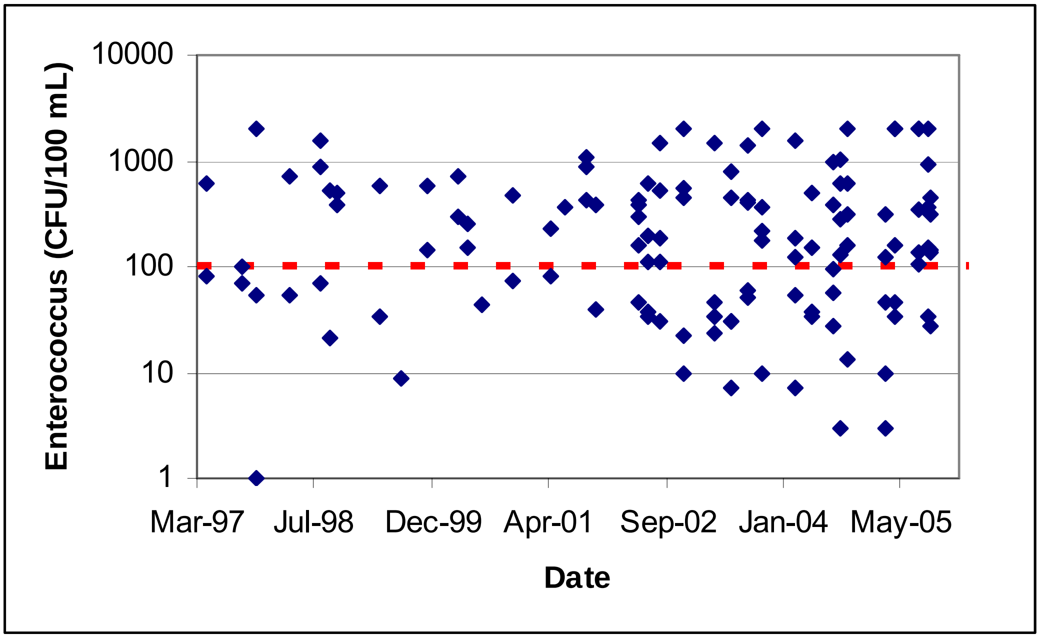


Figure 1- 15 Enterococcus Concentrations in Dragon Run Creek Watershed

1.5 Sources of Pollution

Several nutrient and bacteria sources were identified throughout the data assessment and modeling efforts. Sources can be divided into two categories – point sources and nonpoint sources.

1.5.1 Point Sources

Point source discharges often include municipal and industrial wastewater treatment plants that are subject to the National Pollution Discharge Elimination System (NPDES) permits. Ten NPDES facilities located within the Army Creek, Red Lion Creek, and Dragon Run Creek Watersheds were in operation for all or part of the water quality monitoring period (2002-2005) (Table 1-7). However, as it can be seen from Table 1-7, all treated sanitary sewerage and any industrial wastewater, such as treated process water or non-contact cooling water, are discharged to Delaware River. In the past, the Chloromone Corporation discharged process water along with stormwater to Red Lion Creek. However, the permittee began hauling their wastewater to a pumping station outside of the watershed prior to 1998. The facility's permit was later voided in 2003. Therefore, the only discharges to the tributaries during the monitoring and modeling period were from stormwater outfalls. Since discharges from stormwater outfalls are expected to only occur during storm events and high flow conditions, they are considered as a source during the nutrient-DO annual average scenarios and the bacteria wet condition analyses. TMDLs are established to protect water quality during the most critical periods. For nutrients, this is often during low flow conditions, while for bacteria, critical conditions often occur during high flow periods.

1.5.2 Nonpoint Sources

Nonpoint source pollutants are generally defined as those pollutants that are a result of common, widespread activities, such as urban or agricultural runoff. Several nonpoint sources exist in these impaired watersheds, such as agricultural practices, septic systems, and other urban influences.

Urban and suburban areas in watersheds are potential sources of bacteria and nutrients to streams. The 2002 land use and land cover data (6) show that these three watersheds are primarily urban (Army Creek Watershed: 58%, Red Lion Creek Watershed: 43%, Dragon Run Creek Watershed: 43%). Some sources associated with urban areas include lawn fertilizers, domestic pet wastes, industrial wastes, runoff from construction sites, and failing sewage systems. Contaminants may build up on surfaces and washoff to streams, especially from impervious surfaces, when rain events occur. All three watersheds reside in a Municipal Separate Storm Sewer System (MS4) permitted region (NPDES Permit # DE 0051071 issued to New Castle County) and storm discharges could

contribute nonpoint source pollutants through surface water discharges.

Septic systems are another potential source of contamination because nutrients and bacteria from the systems can reach the surface water through groundwaters. It is important to maintain septic systems to prevent leakage and ensure proper waste treatment. An ArcView GIS analysis was done to determine the number of septic systems existing in each watershed. There are about 450 septic systems in the Army Creek Watershed, approximately 1,400 in the Red Lion Creek Watershed, and roughly 1,050 in the Dragon Run Creek Watershed. These have the potential to contaminate local water resources if not properly maintained.

Agricultural areas also can be a significant source of pollutants in terms of runoff and/or direct contributions of contaminants to streams. The 2002 land use and land cover data (6) for these watersheds show that agricultural uses are the next most abundant behind urban land uses (Army Creek Watershed: 13%, Red Lion Creek Watershed: 21%, Dragon Run Creek Watershed: 30%). There are no animal feeding operations in these watersheds, and due to the location of these watersheds with respect to other watersheds with more intensive animal production, there is likely no manure fertilizer utilized. Therefore, potential agricultural pollutants in these watersheds may come from fertilizer, pesticide, and insecticide applications to croplands.

Contribution of discharges from MS4 and septic systems, as well as any other potential nonpoint nutrient and bacteria sources are considered in the water quality models through calibration to actual site specific surface water quality data. Thus, the loads from the above nonpoint sources are generally considered in the TMDL analyses.

Table 1- 7 NPDES Facilities located in the Army Creek, Red Lion Creek, and Dragon Run Creek Watersheds

NPDES Permit #	Facility Name	Status	# of Outfalls	Discharge Description	Receiving Water
DE 0000256	Valero Energy Corp.	Active	9	Process water and stormwater	Delaware River
			1	Stormwater	Red Lion Creek
			3	Stormwater	Dragon Run Creek
DE 0000485	Printpack, Inc.	Active	5	Cooling water and stormwater	Delaware River
DE 0000612	Formosa Plastics Corp.	Active	1	Process water and stormwater	Delaware River
			1	Stormwater	Red Lion Creek
			1	Stormwater	Dragon Run Creek
DE 0000647	Kaneka DE Corp.	Voided	1	Process water and stormwater	Delaware River
DE 0020001	Metachem	Voided	3	Process water and stormwater	Delaware River
DE 0021555	NCC Dep.of Public Works (DE City STP)	Active	1	Treated sanitary sewerage	Delaware River
DE 0050601	Valero Energy Corp. (DE City Power Plant)	Active	11	Process water and stormwater	Delaware River
DE 0050636	Chloramone Corporation	Voided	1	Process water and stormwater	Red Lion Creek
DE 0050911	Occidental Chemical Corporation	Active	2	Process water	Delaware River
			4	Stormwater	Red Lion Creek
DE 0051039	VPI Mirrex Corporation	Active	3	Process water and stormwater	Delaware River
			2	Stormwater	Dragon Run Creek

1.6 Objective and Scope of the TMDL Analysis for the Army Creek, Red Lion Creek, and Dragon Run Creek Watersheds

The objective of the TMDL analysis for the Army Creek, Red Lion Creek, and Dragon Run Creek watersheds is to estimate the maximum amount of nutrients and bacteria that Army Creek, Red Lion Creek, and Dragon Run Creek can receive without violating water quality standards. Under such loads, the water quality standards of dissolved oxygen and bacteria will be met at all segments and targets of total nitrogen and total phosphorus will be reached at acceptable levels.

To reach the objective, DNREC:

- Nutrient and dissolved oxygen modeling
  - Established water quality models for Army Creek, Red Lion Creek, and Dragon Run Creek using U.S. EPA's Qual2K as a framework,
  - Calibrated Army Creek, Red Lion Creek, and Dragon Run Creek Qual2K models to the average conditions of water quality and stream flow during the 2002-2005 period,
  - Estimated baseline nutrient loadings under the average conditions during the 2002-2005 period
  - Applied and evaluated summer loading conditions using the calibrated models,
  - Calculated nutrient loadings under the TMDL scenarios
- Bacteria modeling
  - Estimated bacteria reductions to the 1997-2005 baseline period under wet versus dry conditions using the cumulative distribution approach

Chapter 2 of this report provides a brief review of the Army Creek Qual2K Model, the Red Lion Creek Qual2K Model, and the Dragon Run Creek Qual2K Model. The results of the calibration runs and the summer loading scenario runs are presented in Chapter 3. An estimation of the Army Creek, Red Lion Creek, and Dragon Run Creek nutrient TMDLs and nutrient load allocations are discussed in Chapter 4. Chapter 5 gives a discussion of the bacteria load estimation and the bacteria reductions calculated under different conditions (wet versus dry). Finally, Chapter 6 discusses the regulatory requirements for TMDLs.

2.0 Army Creek, Red Lion Creek, and Dragon Run Creek Watershed Water Quality Models

2.1 The Stream Water Quality Model (Qual2K)

The Stream Water Quality Model (Qual2K) was chosen as the framework for water quality modeling of Army Creek, Red Lion Creek, and Dragon Run Creek. Qual2K is supported by the U.S. EPA and has been widely used for studying the impact of conventional pollutants on free flowing streams. Qual2K FORTRAN version 2.03, which was provided by Dr. Steve Chapra via the EPA Region 3 office, was used in this study (10).

Army Creek, Red Lion Creek, and Dragon Run Creek are small streams. The annual mean flow of Army Creek is 0.10 cubic meters per second (cms). The width and depth of this stream ranges between 1.0 to 6.0 meters and 0.16 to 0.36 meters, respectively. The annual mean flow of Red Lion Creek is 0.36 cms. The width and depth of this stream ranges between 1.0 to 25.0 meters and 0.25 to 0.34 meters, respectively. The annual mean flow of Dragon Run Creek is 0.25 cms. The width and depth of this stream ranges between 1.0 to 6.0 meters and 0.34 to 0.72 meters, respectively. Water quality concerns for each of the systems include elevated nutrient and bacteria levels and low dissolved oxygen concentrations. The bacteria analysis is discussed in Chapter 5.

The Qual2K model is suitable for simulating the hydrological and water quality conditions of a free flowing stream. It is a simple one-dimensional model, but consists of the basic stream transport and mixing processes. The kinetic processes employed in Qual2K address nutrient cycles, algal growth, and dissolved oxygen dynamics. Compared to other available models, Qual2K is the best suited for the conditions of Army Creek, Red Lion Creek, and Dragon Run Creek. Therefore, Qual2K was selected as the tool to develop the water quality models for the Army Creek, Red Lion Creek, and Dragon Run Creek watersheds and used to conduct the nutrient TMDL analyses.

The model runs under the Microsoft Excel environment as designed by the program authors (10). Data inputs in the Army Creek Qual2K Model, the Red Lion Creek Qual2K Model, and the Dragon Run Creek Qual2K Model are summarized below.

2.2 Input Data for the Army Creek Qual2K Model

The Army Creek Qual2K Model is set up as a one dimensional, steady state model. It simulates average in-stream water quality conditions including dissolved oxygen, BOD, algae as chlorophyll-*a*, as well as various forms of nitrogen and phosphorous. Water temperature and diurnal changes of algae are also simulated. The major input data groups for the Army Creek Qual2K Model are summarized below.

2.2.1 Model Segmentation

The Army Creek Qual2K Model consists of five model reaches starting from its headwater to the sluice gate situated at the confluence with the Delaware River. The model covers approximately 6 km of stream length. Figure 2-1 displays the reaches on the watershed map. Due to the structure of Qual2K, each reach is further divided into a number of computational elements. A length of 1.0 km was assigned to all computational elements within the Army Creek Qual2K Model. A summary of reach lengths and the number of computational elements per reach is presented in Table 2-1.

Table 2- 1 Army Creek Qual2K Model Reaches

Reach Number	Description	Reach Length (km)	Number of Computational Elements
1	Upper reach from headwaters to below Llangollen Blvd. at confluence with unnamed tributary to Army Creek; two unnamed tributaries	1.6	10
2	Unnamed tributary to Army Creek	1.0	10
3	Middle reach below confluence with unnamed tributary	1.4	10
4	Middle reach above Route 9; one unnamed tributary	1.0	10
5	Lower reach starting above Route 9 to sluice gate at confluence with Delaware River; one unnamed tributary	1.0	10
Total Army Creek		6.0	50

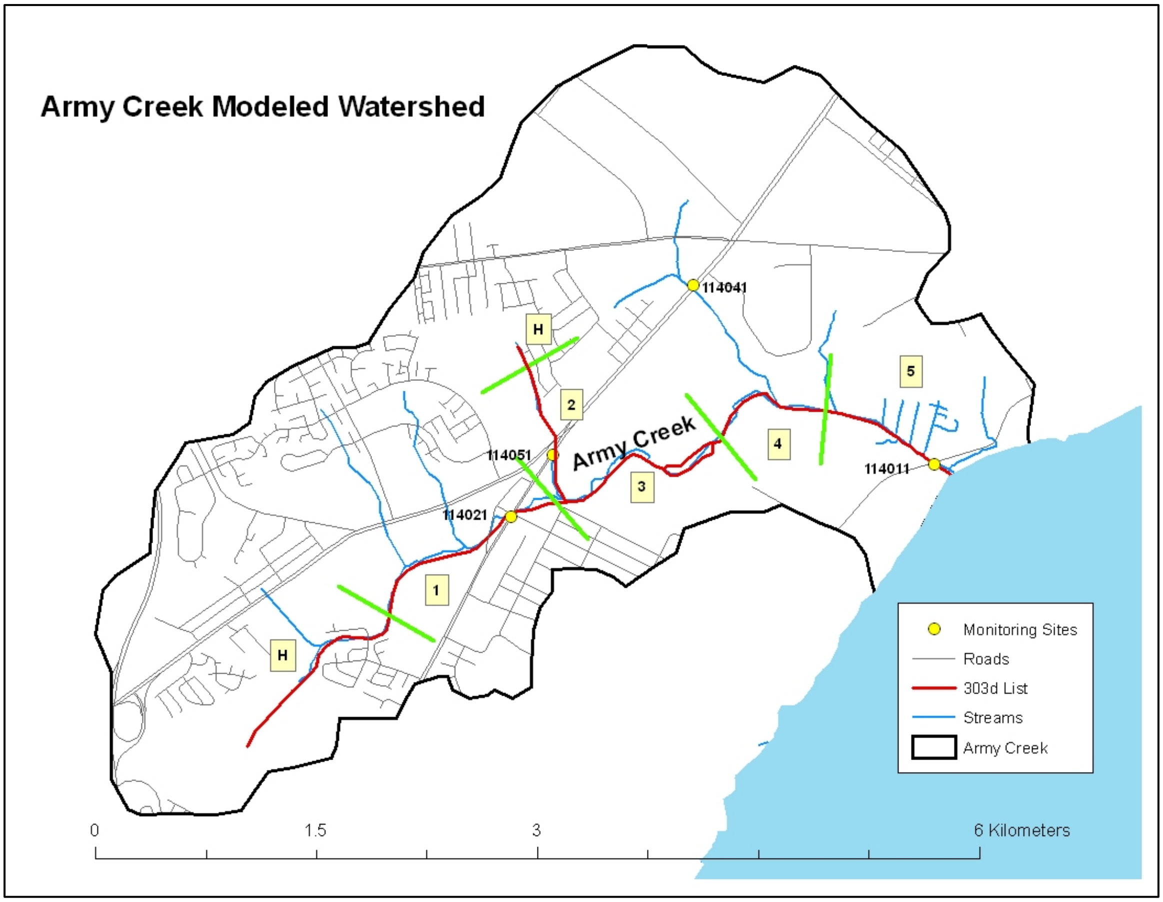


Figure 2- 1 Reaches of Army Creek Qual2K Model

2.2.2 Flow Balance

There are no active USGS gauging stations in the Army Creek, Red Lion Creek, or Dragon Run Creek watersheds. A gauge (USGS 01482200) (11), which was in operation from July 19, 1978 through September 30, 1981, was situated midway on Army Creek between the headwaters and outlet to the Delaware River. However, since no gauge was in place on Army Creek during the water quality monitoring period (2002-2005), discharge data for that period must be estimated.

The gauge data from the Christina River station at Cooches Bridge (USGS 01478000) (11) was considered reasonable for estimating flow for Army Creek since it has similar geology, topography, land use, and it is located in the adjacent Christina River Watershed. The drainage area to the Cooches Bridge station is 53.09 km^2 and the average discharge between October 2000 and September 2005 was 0.94 cms. The estimated runoff rate at Cooches Bridge for this period is approximately 0.018 $m^3/km^2/sec$. This is somewhat greater than the runoff rate estimated using the older Army Creek gauge data (0.006

$m^3/km^2/sec$), due to the different analysis periods, smaller drainage area (6.27 km^2), and smaller average flow rate (0.036 cms). Since no other discharge record was available from a watershed with more similar characteristics for the period of time water quality monitoring data was collected in Army Creek, the Cooches Bridge data was considered acceptable (Figure 2-2).

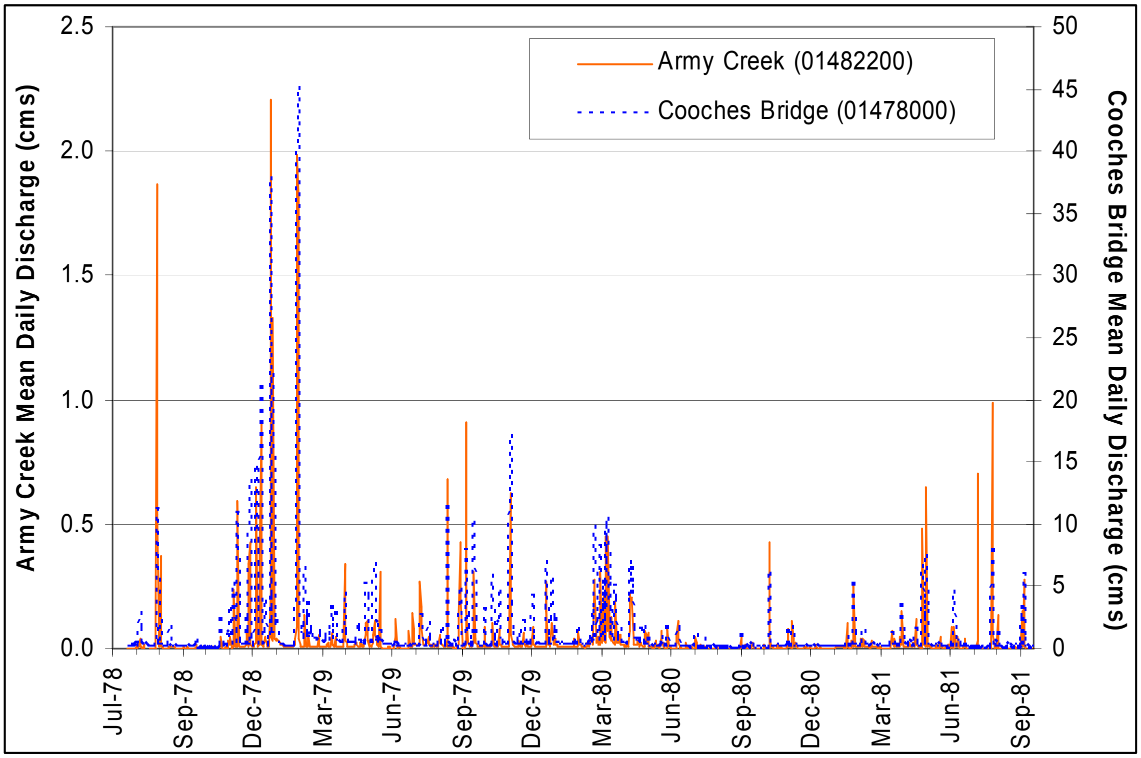


Figure 2- 2 Mean Daily Discharge at the Army Creek and Cooches Bridge Gauging Stations

Army Creek and Cooches Bridge discharge data from 1978 to 1981 were correlated with an R2 of 0.7438, ensuring that the Cooches Bridge data could adequately estimate the Army Creek discharge record for the more recent monitoring period. The Cooches Bridge discharge record for October 2000 through September 2005 was averaged and the regression equation was used to estimate the annual average discharge at the location of the old Army Creek gauge.

Both annual average flow and 7Q10 flow (a low flow of 7-day duration with a recurrence interval of 10 years) conditions will be considered for development of the Army Creek, Red Lion Creek, and Dragon Run Creek watershed models and analysis of their TMDLs. The annual average flow is used for model calibration while the 7Q10 flow is used in model scenario runs to simulate the critical condition possibly occurring in summer low flow and warm weather situations.

Annual average flow was the result of averaging the Cooches Bridge daily mean flows over the period of October 2000 through September 2005 and using the regression equation to calculate the annual average flow at the old Army Creek gauge. The Cooches Bridge 7Q10 flow was determined using version 2.1 of DFLOW, a program used to calculate design stream flows. The regression equation for the Cooches Bridge and Army Creek flow relationship was not suitable for estimating the 7Q10 flow at the old Army Creek gauging station however, due to an apparent zero flow result. Flowing water, even at a minimal rate, is required for the Qual2K model to function. Therefore, the 7Q10 of Army Creek was estimated using the Cooches Bridge 7Q10 and a ratio of the gauged drainage areas.

Table 2-4 lists the Army Creek sub-watershed drainage areas as well as the estimated annual average and 7Q10 flows, which were computed using a ratio of flow to drainage area.

Table 2- 2 Army Creek Qual2K Model Discharge Data

Description of Drainage Area	Drainage Area	Annual Average		Critical Condition	
	km^2	ft^3/s	m^3/s	ft^3/s	m^3/s
Headwater of mainstem (R1)	3.72	0.81	0.0230	0.10	0.0029
Tributary 1, Reach 1	0.99	0.22	0.0061	0.03	0.0008
Tributary 2, Reach 1	0.63	0.14	0.0039	0.02	0.0005
Reach 1 diffuse inflow	1.21	0.26	0.0075	0.03	0.0009
Headwater of tributary (R2)	0.98	0.22	0.0061	0.03	0.0008
Reach 2 diffuse inflow	0.88	0.19	0.0055	0.02	0.0007
Reach 3 diffuse inflow	1.15	0.25	0.0071	0.03	0.0009
Tributary 3, Reach 4	3.33	0.73	0.0206	0.09	0.0026
Reach 4 diffuse inflow	0.53	0.12	0.0033	0.01	0.0004
Tributary 4, Reach 5	1.85	0.40	0.0114	0.05	0.0014
Reach 5 diffuse inflow	1.65	0.36	0.0102	0.05	0.0013
Army Creek Total	16.92	3.70	0.1047	0.46	0.0130

2.2.3 Hydraulic Characteristics

The Army Creek Qual2K Model uses the Manning equation to describe stream hydraulic characteristics, where it is assumed that each element has a trapezoidal channel shape, with side slopes of zero, according to the equation below,

$$Q = (S_o^{1/2}/n)*(A_c^{5/3}/P^{2/3})$$

where Q is flow (cms), S_o is bottom slope (m/m), n is the Manning roughness coefficient, A_c is the cross-sectional area (m^2), and P is the wetted perimeter (m). Channel slope was estimated using a GIS shapefile of elevation, which is based on USGS topographic maps. The Manning roughness values typically range from 0.015 for smooth man-made cannels to 0.15 for rough natural channels (10). The roughness coefficient (n) was adjusted to 0.12 for the entire stretch of Army Creek to calibrate the model. Estimates of channel bottom width and depth were made based on a visit to Army Creek in September 2005. The Manning Equation factors input into the Army Creek Model for the headwater and model reaches are displayed in Table 2-3.

Table 2- 3 Army Creek Qual2K Model Manning Equation Parameters

	Channel Slope	Manning n	Bottom Width (m)	
			Annual Average	Critical Condition
Headwater of mainstem (R1)	0.0050	0.12	1.0	1.0
Reach 1	0.0025	0.12	1.5	1.0
Headwater of tributary (R2)	0.0050	0.12	0.8	0.6
Reach 2	0.0050	0.12	1.0	0.7
Reach 3	0.0006	0.12	3.5	1.5
Reach 4	0.0003	0.12	5.0	2.0
Reach 5	0.0002	0.12	6.0	2.5

2.2.4 System Parameters

The physical, chemical, and biological processes simulated by Qual2K are represented by a set of equations that contain many system parameters. Some are global constants, some are spatial variables, and some are temperature dependent. Detailed descriptions of these parameters and associated processes are available in the Qual2K user's manual (10). The various rates used in the Army Creek Qual2K Model are listed in Tables 2-4 through 2-6.

Table 2- 4 Army Creek Qual2K Model Climatic Rate Input Parameters

Parameter	Value		Unit
	Annual Average	Critical Condition	
Air Temperature	16	25	Degrees C
Dew Point Temperature	10	20	Degrees C
Wind Speed	2-4	2-4	m/s
Cloud Cover	50	50	%
Shade	15-75	15-75	%

Table 2- 5 Army Creek Qual2K Model Water Column Rates

Parameter	Value	Unit	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	0.1	m/d	v_i
Oxygen:			
Reaeration model	Tsivoglou-Neal, 1.0-1.7	/d	
Temperature correction	1.024		q_a
Reaeration wind effect	None		
O_2 for C oxidation	2.67	gO_2/gC	r_{oc}
O_2 for NH_4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhibition CBOD oxidation model	Exponential		
Oxygen inhibition CBOD oxidation parameter	0.60	L/mgO_2	K_{socf}
Oxygen inhibition nitrification model	Exponential		
Oxygen inhibition nitrification parameter	0.60	L/mgO_2	K_{sona}
Oxygen enhancement denitrification model	Exponential		
Oxygen enhancement denitrification parameter	0.60	L/mgO_2	K_{sodn}
Oxygen inhibition phytoplankton respiration model	Exponential		
Oxygen inhibition phytoplankton respiration parameter	0.60	L/mgO_2	K_{sop}
Oxygen enhancement bottom algae respiration model	Exponential		
Oxygen enhancement bottom algae respiration parameter	0.60	L/mgO_2	K_{sob}
Bottom sediment oxygen demand coverage	100	%	
Prescribed sediment oxygen demand	0.0-0.4	$gO_2/m^2/d$	
Slow CBOD:			

Hydrolysis rate	1	/d	k_{hc}
Temperature correction	1.05		q_{hc}
Oxidation rate	0	/d	k_{dcs}
Temperature correction	1.05		q_{dcs}
Fast CBOD:			
Oxidation rate	0.2	/d	k_{dc}
Temperature correction	1.05		q_{dc}
Organic Nitrogen:			
Hydrolysis rate	0.4	/d	k_{hn}
Temperature correction	1.05		q_{hn}
Settling velocity	0.01-0.05	m/d	v_{on}
Ammonium:			
Nitrification rate	4	/d	k_{na}
Temperature correction	1.05		q_{na}
Prescribed NH_4 flux	200	mgN/m^2/d	
Nitrate:			
Denitrification rate	0	/d	k_{dn}
Temperature correction	1.05		q_{dn}
Sediment denitrification transfer coefficient	0	m/d	v_{di}
Temperature correction	1.05		q_{di}
Organic Phosphorus:			
Hydrolysis rate	1	/d	k_{hp}
Temperature correction	1.05		q_{hp}
Settling velocity	0.01-0.05	m/d	v_{op}
Inorganic Phosphorus:			
Settling velocity	0	m/d	v_{ip}
Inorganic P sorption coefficient	0	L/mgD	K_{dpi}
Sediment P oxygen attenuation half saturation constant	0.05	mgO$_2$/l	k_{spi}
Prescribed inorganic P flux	25	mgP/m^2/d	
Phytoplankton:			
Maximum growth rate	2	/d	k_{gp}
Temperature correction	1.066		q_{gp}
Respiration rate	0.275	/d	k_{rp}
Temperature correction	1.05		q_{rp}
Death rate	0	/d	k_{dp}
Temperature correction	1.05		q_{dp}
N half saturation constant	155	ugN/l	k_{sNp}
P half saturation constant	26	ugP/l	k_{sPp}
Inorganic C half saturation constant	1.30E-05	moles/l	k_{sCp}
Light model	Half saturation		
Light constant	57.6	Langley's/d	K_{Lp}

Ammonia preference	25	ugN/l	k_{hnxp}
Settling velocity	0.1	m/d	v_a
Bottom Algae:			
Growth model	First-order		
Maximum growth rate	2	mgA/m^2/d or /d	C_{gb}
Temperature correction	1.066		q_{gb}
First-order model carrying capacity	100	mgA/m^2	$a_{b,max}$
Respiration rate	0.275	/d	k_{rb}
Temperature correction	1.05		q_{rb}
Excretion rate	0	/d	k_{eb}
Temperature correction	1.05		q_{db}
Death rate	0	/d	k_{db}
Temperature correction	1.05		q_{db}
External N half saturation constant	300	ugN/l	k_{sNb}
External P half saturation constant	50	ugP/l	k_{sPb}
Inorganic C half saturation constant	1.30E-05	moles/l	k_{sCb}
Light model	Half saturation		
Light constant	50	Langley’s/d	K_{Lb}
Ammonia preference	25	ugN/l	k_{hnxb}
Subsistence quota for N	7.2	mgN/mgA	q_{0N}
Subsistence quota for P	1	mgP/mgA	q_{0P}
Maximum uptake rate for N	720	mgN/mgA/d	r_{mN}
Maximum uptake rate for P	100	mgP/mgA/d	r_{mP}
Internal N half saturation constant	9	mgN/mgA	K_{qN}
Internal P half saturation constant	1.3	mgP/mgA	K_{qP}
Bottom algae coverage	50	%	
Detritus (POM):			
Dissolution rate	0.2	/d	k_{dt}
Temperature correction	1.05		q_{dt}
Fraction of dissolution to fast CBOD	0.00		F_f
Settling velocity	0.1	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temperature correction	1.07		q_{dx}
Settling velocity	1	m/d	v_x
Light efficiency factor	0.00		a_{path}
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

Table 2- 6 Army Creek Qual2K Model Light and Heat Rates

Parameter	Value	Unit	Symbol
Photosynthetically Available Radiation	0.47		
Background light extinction	0.2	*/m*	k_{eb}
Linear chlorophyll light extinction	0.0088	*1/m-(ugA/l)*	a_p
Nonlinear chlorophyll light extinction	0.054	*1/m-(ugA/l)2/3*	a_{pn}
Inorganic suspended solids light extinction	0.052	*1/m-(mgD/l)*	a_i
Detritus light extinction	0.174	*1/m-(mgD/l)*	a_o
Solar shortwave radiation model			
Atmospheric attenuation model for solar	Bras		
Bras solar parameter (used if Bras solar model is selected)			
Atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	2		n_{fac}
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)			
Atmospheric transmission coefficient (0.70-0.91, default 0.8)	0.8		a_{tc}
Downwelling atmospheric longwave IR radiation			
Atmospheric longwave emissivity model	Brunt		
Evaporation and air convection/conduction			
Wind speed function for evaporation and air convection/conduction	Adams 1		
Sediment heat parameters			
Sediment thermal thickness	10	*cm*	H_s
Sediment thermal diffusivity	0.005	cm^2/s	a_s
Sediment density	1.6	g/cm^3	r_s
Water density	1	g/cm^3	r_w
Sediment heat capacity	0.4	$cal/(g\ ^oC)$	C_{ps}
Water heat capacity	1	$cal/(g\ ^oC)$	C_{pw}
Sediment diagenesis model			
Compute SOD and nutrient fluxes	Yes		

2.2.5 Boundary Conditions

Qual2K uses different data groups to define model boundary conditions. It uses the headwater data group to define the most upstream boundary conditions of a model domain. Downstream boundary condition can be defined by the user, or computed internally. The point source data group defines the condition of point source discharge from facilities or small tributaries that input to the simulated stream segments.

The headwater and tributary conditions of the Army Creek Qual2K Model were defined by monitoring data collected at stations 114041 and 114051. Data from both stations, which are located on unnamed tributaries to Army Creek, were combined together. Median concentrations from the 2002 -2005 period were used with average flows to calibrate the model for average conditions. To calibrate the model for critical conditions, median concentrations of the summer months (June – September) were used with the 7Q10 flow. Table 2-7 lists the annual average and critical condition model input values. The option of internally calculating the downstream boundary conditions was selected for the Army Creek Qual2K Model.

Table 2- 7 Army Creek Qual2K Model Headwater/Tributary Source Input Values

Parameter	Value		Unit
	Annual Average	Critical Condition	
Temperature	16.65	21.35	Degrees C
Conductivity	255.50	215.00	umhos
Inorganic Solids	4.35	4.50	mgD/l
Dissolved Oxygen	7.47	6.36	mgO_2/l
CBODslow	1.45	1.34	mgO_2/l
CBODfast	2.89	2.68	mgO_2/l
Organic Nitrogen	757.00	776.00	ugN/l
NH4-Nitrogen	87.50	81.00	ugN/l
NO3-Nitrogen	687.60	845.10	ugN/l
Organic Phosphorus	115.00	115.00	ugP/l
Inorganic Phosphorus (SRP)	45.00	45.00	ugP/l
Phytoplankton	2.88	2.66	ugA/l
Detritus (POM)	10.15	10.50	mgD/l
Pathogen	NA	NA	cfu/100 mL
Alkalinity	42.05	42.20	$mgCaCO_3/l$
pH	7.28	7.30	s.u.

2.2.6 Diffuse Sources

The diffuse source data group defines the condition of uniformly distributed flow over the entire length of the reach. The uniformly distributed flow could be groundwater inflow and/or distributed surface runoff that can be assumed constant over time. Water quality parameter concentrations for diffuse source waters were estimated by beginning with the same values used for the headwater/tributary sources (described above). These values were then adjusted, if necessary, to account for groundwater inputs. Diffuse source input values for annual average and critical conditions are presented in Table 2-8.

Table 2- 8 Army Creek Qual2K Model Diffuse Source Input Values

Parameter	Value		Unit
	Annual Average	Critical Condition	
Temperature	16.64	21.35	Degrees C
Conductivity	255.00	255.00	umhos
Inorganic Solids	6.30	6.30	mgD/l
Dissolved Oxygen	5.31-5.92	5.31-5.92	mgO_2/l
CBODslow	1.60	1.60	mgO_2/l
CBODfast	3.20	3.20	mgO_2/l
Organic Nitrogen	2,000.00	2,000.00	ugN/l
NH4-Nitrogen	250.00	250.00	ugN/l
NO3-Nitrogen	1,000.00	1,000.00	ugN/l
Organic Phosphorus	150.00	150.00	ugP/l
Inorganic Phosphorus (SRP)	50.00	50.00	ugP/l
Phytoplankton	4.20	4.20	ugA/l
Detritus (POM)	15.00	15.00	mgD/l
Pathogen	NA	NA	cfu/100 mL
Alkalinity	50.00	50.00	$mgCaCO_3/l$
pH	7.35	7.35	s.u.

2.3 Red Lion Creek Qual2K Model Input Data

The major input data groups for the Red Lion Creek Qual2K Model are summarized below.

2.3.1 Model Segmentation

The Red Lion Creek Qual2K Model consists of seven model reaches starting from its headwater to the sluice gate situated at the confluence with the Delaware River. The model covers approximately 7 km of stream length. Figure 2-3 displays the reaches on the watershed map. Each reach is further divided into computational elements with a length of 1.0 km. A summary of reach lengths and the number of computational elements per reach is presented in Table 2-9.

Table 2- 9 Red Lion Creek Qual2K Model Reaches

Reach Number	Description	Reach Length (km)	Number of Computational Elements
1	Upper reach from headwaters to above Red Lion Road	1.0	10
2	Middle reach above Bear Corbit Road; one unnamed tributary	1.0	10
3	Middle reach above Route 1/Route 13; Doll Run Tributary	1.0	10
4	Middle reach below Route 1/Route 13; two unnamed tributaries	1.0	10
5	Middle reach above Route 9; two unnamed tributaries	1.0	10
6	Middle reach below Route 9	1.0	10
7	Lower reach below Route 9 to sluice gate at confluence with Delaware River	1.0	10
Total Red Lion Creek		7.0	70

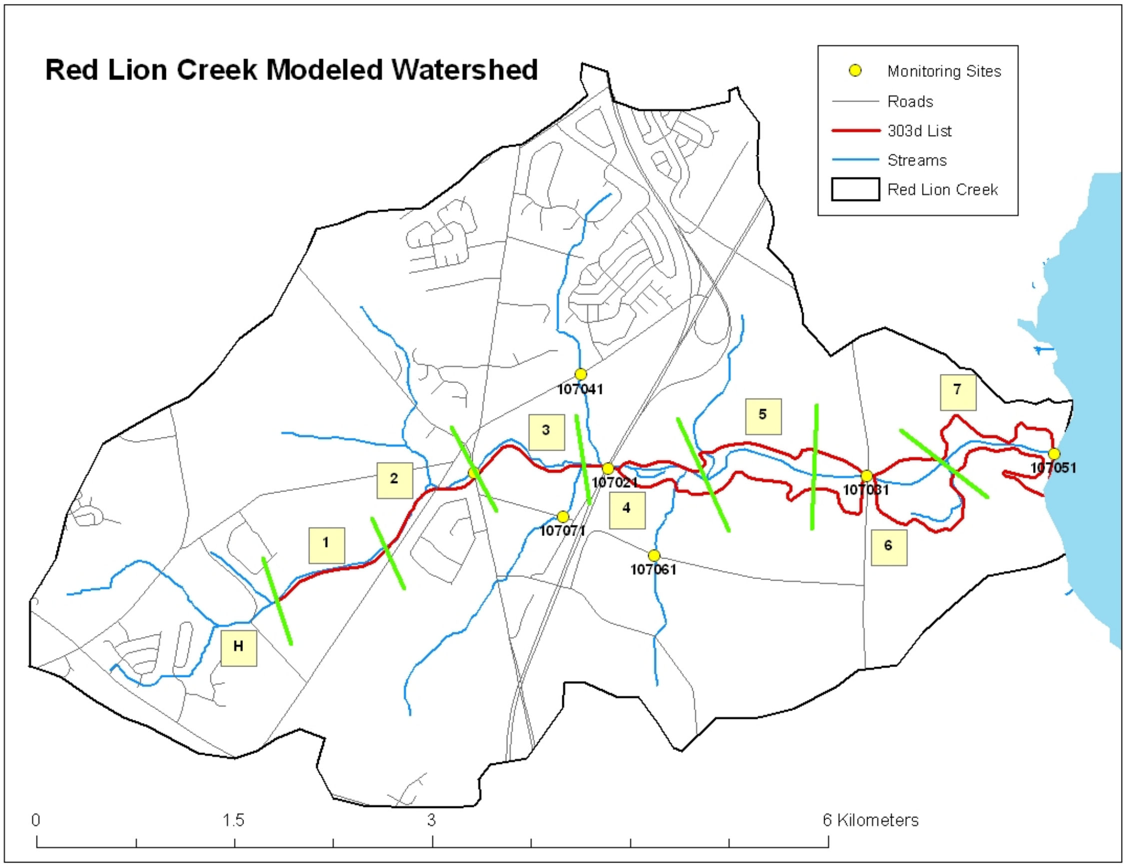


Figure 2- 3 Reaches of Red Lion Creek Qual2K Model

2.3.2 Flow Balance

A gauge (USGS 01482298) (11), which was in operation from August 4, 1978 through September 30, 1981, was situated midway on Red Lion Creek between the headwaters and outlet to the Delaware River. This gauge drained an area of 7.98 km^2 and had an average flow rate of 0.101 cms, producing a runoff rate of 0.013 $m^3/km^2/sec$. However, since no gauge was in place on Red Lion Creek during the water quality monitoring period (2002-2005), discharge data for that period must be estimated.

The gauge data from the Christina River station at Cooches Bridge (USGS 01478000) (11) was also considered reasonable for estimating flow for Red Lion Creek, as it was for Army Creek (see page 29 on the Army Creek Qual2K Model for more details) (Figure 2-4).

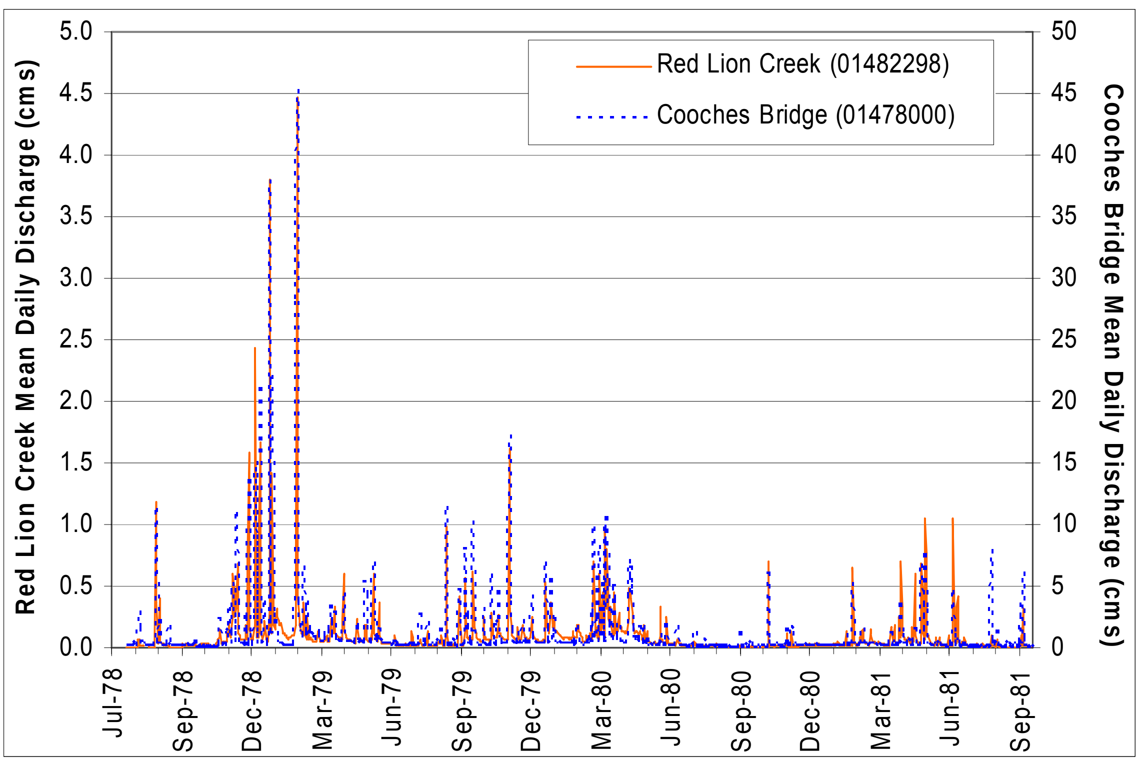


Figure 2- 4 Mean Daily Discharge at the Red Lion Creek and Cooches Bridge Gauging Stations

As with Army Creek, the Red Lion Creek and Cooches Bridge discharge data from 1978 to 1981 were correlated with an R2 of 0.8221 (see page 29 on the

Army Creek Qual2K Model for more details). The Cooches Bridge discharge record for October 2000 through September 2005 was averaged and the regression equation was used to estimate the annual average discharge at the location of the old Red Lion Creek gauge. The Cooches Bridge-Red Lion regression was also used to determine the 7Q10 for Red Lion Creek.

Table 2-10 lists the Red Lion Creek sub-watershed drainage areas as well as the estimated annual average and 7Q10 flows, which were computed using a ratio of flow to drainage area.

Table 2- 10 Red Lion Creek Qual2K Model Discharge Data

Description of Drainage Area	Drainage Area	Annual Average		Critical Condition	
	km^2	ft^3/s	m^3/s	ft^3/s	m^3/s
Headwater	3.83	1.76	0.0500	0.40	0.0113
Reach 1 diffuse inflow	0.99	0.46	0.0129	0.10	0.0029
Tributary 1, Reach 2	2.83	1.30	0.0369	0.29	0.0083
Reach 2 diffuse inflow	0.55	0.25	0.0071	0.06	0.0016
Tributary 2 (Doll Run), Reach 3	3.57	1.65	0.0466	0.37	0.0105
Reach 3 diffuse inflow	1.06	0.49	0.0138	0.11	0.0031
Tributary 3, Reach 4	3.57	1.64	0.0465	0.37	0.0105
Tributary 4, Reach 4	1.51	0.69	0.0196	0.16	0.0044
Reach 4 diffuse inflow	0.44	0.20	0.0057	0.05	0.0013
Tributary 5, Reach 5	1.68	0.77	0.0219	0.18	0.0050
Tributary 6, Reach 5	1.21	0.56	0.0158	0.13	0.0036
Reach 5 diffuse inflow	0.81	0.37	0.0106	0.08	0.0024
Reach 6 diffuse inflow	2.14	0.99	0.0279	0.22	0.0063
Reach 7 diffuse inflow	1.52	0.70	0.0198	0.16	0.0045
Red Lion Creek Total	25.72	11.84	0.3352	2.675	0.0757

Additionally, the Valero Energy Corporation Refinery in Delaware City has a permitted withdrawal on Red Lion Creek (permit number 8013). The pump is situated at the Route 1 road crossing (same location as monitoring station 107021 in Figure 2-3), which is located just below Tributary 3 in Reach 4 of the model framework. The permit allows the refinery to withdrawal 0.0568 cms from this location. However, the refinery has not utilized this withdrawal in recent years.

2.3.3 Hydraulic Characteristics

The Red Lion Creek Qual2K Model also uses the Manning equation to describe stream hydraulic characteristics (see page 32 under the Army Creek Qual2K Model for more details). The Manning Equation factors input into the Red Lion Creek Model for the headwater and model reaches are displayed in Table 2-11.

Table 2- 11 Red Lion Creek Qual2K Model Manning Equation Parameters

	Channel Slope	Manning n	Bottom Width (m)	
			Annual Average	Critical Condition
Headwater	0.0060	0.12	1.0	1.0
Reach 1	0.0040	0.12	2.0	1.0
Reach 2	0.0030	0.12	3.0	2.0
Reach 3	0.0020	0.12	4.0	3.0
Reach 4	0.0005	0.12	8.0	6.0
Reach 5	0.0002	0.12	10.0	8.0
Reach 6	0.0002	0.12	12.0	10.0
Reach 7	0.0001	0.12	25.0	15.0

2.3.4 System Parameters

The various rates used in the Red Lion Creek Qual2K Model are listed in Tables 2-12 and 2-13. The Red Lion Creek Qual2K Model used the same light and heat rates as the Army Creek Qual2K Model (Table 2-6, page 37).

Table 2- 12 Red Lion Creek Qual2K Model Climatic Rate Input Parameters

Parameter	Value		Unit
	Annual Average	Critical Condition	
Air Temperature	16	25	Degrees C
Dew Point Temperature	10	20	Degrees C
Wind Speed	3	3	m/s
Cloud Cover	50	50	%
Shade	50	50	%

Table 2- 13   Red Lion Creek Qual2K Model Water Column Rates

Parameter	Value	Unit	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	0.1	m/d	v_i
Oxygen:			
Reaeration model	Tsivoglou-Neal, 0.5		
Temperature correction	1.024		q_a
Reaeration wind effect	None		
O_2 for C oxidation	2.67	gO_2/gC	r_{oc}
O_2 for NH_4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhibition CBOD oxidation model	Exponential		
Oxygen inhibition CBOD oxidation parameter	0.60	L/mgO_2	K_{socf}
Oxygen inhibition nitrification model	Exponential		
Oxygen inhibition nitrification parameter	0.60	L/mgO_2	K_{sona}
Oxygen enhancement denitrification model	Exponential		
Oxygen enhancement denitrification parameter	0.60	L/mgO_2	K_{sodn}
Oxygen inhibition phytoplankton respiration model	Exponential		
Oxygen inhibition phytoplankton respiration parameter	0.60	L/mgO_2	K_{sop}
Oxygen enhancement bottom algae respiration model	Exponential		
Oxygen enhancement bottom algae respiration parameter	0.60	L/mgO_2	K_{sob}
Bottom sediment oxygen demand coverage	100	%	
Prescribed sediment oxygen demand	0.0-0.4	$gO_2/m^2/d$	
Slow CBOD:			

Hydrolysis rate	1	/d	k_{hc}
Temperature correction	1.05		q_{hc}
Oxidation rate	0	/d	k_{dcs}
Temperature correction	1.05		q_{dcs}
Fast CBOD:			
Oxidation rate	0.2	/d	k_{dc}
Temperature correction	1.05		q_{dc}
Organic Nitrogen:			
Hydrolysis rate	0.4	/d	k_{hn}
Temperature correction	1.05		q_{hn}
Settling velocity	0.025	m/d	v_{on}
Ammonium:			
Nitrification rate	4	/d	k_{na}
Temperature correction	1.05		q_{na}
Prescribed NH_4 flux	200	$mgN/m^2/d$	
Nitrate:			
Denitrification rate	0	/d	k_{dn}
Temperature correction	1.05		q_{dn}
Sediment denitrification transfer coefficient	0	m/d	v_{di}
Temperature correction	1.05		q_{di}
Organic Phosphorus:			
Hydrolysis rate	1	/d	k_{hp}
Temperature correction	1.05		q_{hp}
Settling velocity	0.025	m/d	v_{op}
Inorganic Phosphorus:			
Settling velocity	0	m/d	v_{ip}
Inorganic P sorption coefficient	0	L/mgD	K_{dpi}
Sediment P oxygen attenuation half saturation constant	0.05	mgO_2/l	k_{spi}
Prescribed inorganic P flux	25	$mgP/m^2/d$	
Phytoplankton:			
Maximum growth rate	2	/d	k_{gp}
Temperature correction	1.066		q_{gp}
Respiration rate	0.275	/d	k_{rp}
Temperature correction	1.05		q_{rp}
Death rate	0	/d	k_{dp}
Temperature correction	1.05		q_{dp}
N half saturation constant	155	ugN/l	k_{sPp}
P half saturation constant	26	ugP/l	k_{sNp}
Inorganic C half saturation constant	1.30E-05	moles/l	k_{sCp}
Light model	Half saturation		
Light constant	57.6	Langley's/d	K_{Lp}

Ammonia preference	25	ugN/l	k_{hnxp}
Settling velocity	0.1	m/d	v_a
Bottom Algae:			
Growth model	First-order		
Maximum growth rate	2	mgA/m^2/d or /d	C_{gb}
Temperature correction	1.066		q_{gb}
First-order model carrying capacity	100	mgA/m^2	$a_{b,max}$
Respiration rate	0.275	/d	k_{rb}
Temperature correction	1.05		q_{rb}
Excretion rate	0	/d	k_{eb}
Temperature correction	1.05		q_{db}
Death rate	0	/d	k_{db}
Temperature correction	1.05		q_{db}
External N half saturation constant	300	ugN/l	k_{sPb}
External P half saturation constant	50	ugP/l	k_{sNb}
Inorganic C half saturation constant	1.30E-05	moles/l	k_{sCb}
Light model	Half saturation		
Light constant	50	Langley's/d	K_{Lb}
Ammonia preference	25	ugN/l	k_{hnxb}
Subsistence quota for N	7.2	mgN/mgA	q_{0N}
Subsistence quota for P	1	mgP/mgA	q_{0P}
Maximum uptake rate for N	720	mgN/mgA/d	r_{mN}
Maximum uptake rate for P	100	mgP/mgA/d	r_{mP}
Internal N half saturation constant	9	mgN/mgA	K_{qN}
Internal P half saturation constant	1.3	mgP/mgA	K_{qP}
Bottom algae coverage	50	%	
Detritus (POM):			
Dissolution rate	0.2	/d	k_{dt}
Temperature correction	1.05		q_{dt}
Fraction of dissolution to fast CBOD	0.00		F_f
Settling velocity	0.1	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temperature correction	1.07		q_{dx}
Settling velocity	1	m/d	v_x
Light efficiency factor	0.00		a_{path}
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

2.3.5 Boundary Conditions

The headwater and tributary conditions of the Red Lion Creek Qual2K Model were defined by monitoring data collected at stations 107041, 107061, and 107071. Data from these stations, which are located on tributaries to Red Lion Creek, were combined together. Table 2-14 lists the annual average and critical condition model input values. For more information on how boundary condition data is utilized in the model, see page 38 under the Army Creek Qual2K Model. The option of internally calculating the downstream boundary conditions was selected for the Red Lion Creek Qual2K Model.

Table 2- 14 Red Lion Creek Qual2K Model Headwater/Tributary Source Input Values

Parameter	Value		Unit
	Annual Average	Critical Condition	
Temperature	15.68	19.03	Degrees C
Conductivity	219.50	239.74	umhos
Inorganic Solids	2.40	4.28	mgD/l
Dissolved Oxygen	8.44	6.98	mgO_2/l
CBODslow	1.24	1.56	mgO_2/l
CBODfast	2.48	3.12	mgO_2/l
Organic Nitrogen	551.00	646.26	ugN/l
NH4-Nitrogen	72.00	97.26	ugN/l
NO3-Nitrogen	2,304.00	2,279.42	ugN/l
Organic Phosphorus	49.00	56.67	ugP/l
Inorganic Phosphorus (SRP)	5.00	7.50	ugP/l
Phytoplankton	2.00	3.62	ugA/l
Detritus (POM)	5.60	9.98	mgD/l
Pathogen	NA	NA	cfu/100 mL
Alkalinity	28.90	33.62	$mgCaCO_3/l$
pH	6.80	6.88	s.u.

2.3.6 Diffuse Sources

Nutrient concentrations for diffuse source waters in the Red Lion Creek Qual2K Model were estimated by beginning with the same values used for the headwater/tributary sources (described above under Boundary Conditions). These values were then adjusted, if necessary, to account for groundwater inputs (Table 2-15). For a more detailed description on diffuse sources, see page 39 in the Army Creek Qual2K Model section.

Table 2- 15 Red Lion Creek Qual2K Model Diffuse Source Input Values

Parameter	Value		Unit
	Annual Average	Critical Condition	
Temperature	15.68	19.03	Degrees C
Conductivity	315.00	315.00	umhos
Inorganic Solids	7.00	7.00	mgD/l
Dissolved Oxygen	4.86-5.89	4.86-5.89	mgO_2/l
CBODslow	1.60	1.60	mgO_2/l
CBODfast	3.20	3.20	mgO_2/l
Organic Nitrogen	2,000.00	2,000.00	ugN/l
NH4-Nitrogen	250.00	250.00	ugN/l
NO3-Nitrogen	1,000.00	1,000.00	ugN/l
Organic Phosphorus	150.00	150.00	ugP/l
Inorganic Phosphorus (SRP)	50.00	50.00	ugP/l
Phytoplankton	5.00	5.00	ugA/l
Detritus (POM)	15.00	15.00	mgD/l
Pathogen	NA	NA	cfu/100 mL
Alkalinity	40.00	40.00	$mgCaCO_3/l$
pH	6.95	6.95	s.u.

2.4 Dragon Run Creek Qual2K Model Input Data

The major input data groups for the Dragon Run Creek Qual2K Model are summarized below.

2.4.1 Model Segmentation

The Dragon Run Creek Qual2K Model consists of nine model reaches starting from its headwater to the sluice gate situated at the Route 9 bridge in Delaware City. The model covers approximately 9 km of stream length. Figure 2-5 displays the reaches on the watershed map. Each reach is further divided into computational elements with a length of 1.0 km. A summary of reach lengths and the number of computational elements per reach is presented in Table 2-16.

Table 2- 16 Dragon Run Creek Qual2K Model Reaches

Reach Number	Description	Reach Length (km)	Number of Computational Elements
1	Upper reach from headwaters to above McCoy Road	1.0	10
2	Middle reach above and below McCoy Road	1.0	10
3	Middle reach above and below Route 1	1.0	10
4	Middle reach above and below Route 13	1.0	10
5	Middle reach below Route 13	1.0	10
6	Middle reach above and below Clarks Corner Road	1.0	10
7	Middle reach below Clarks Corner Road	1.0	10
8	Middle reach above Route 9	1.0	10
9	Lower reach above Route 9 to sluice gate	1.0	10
Total Dragon Run Creek		9.0	90

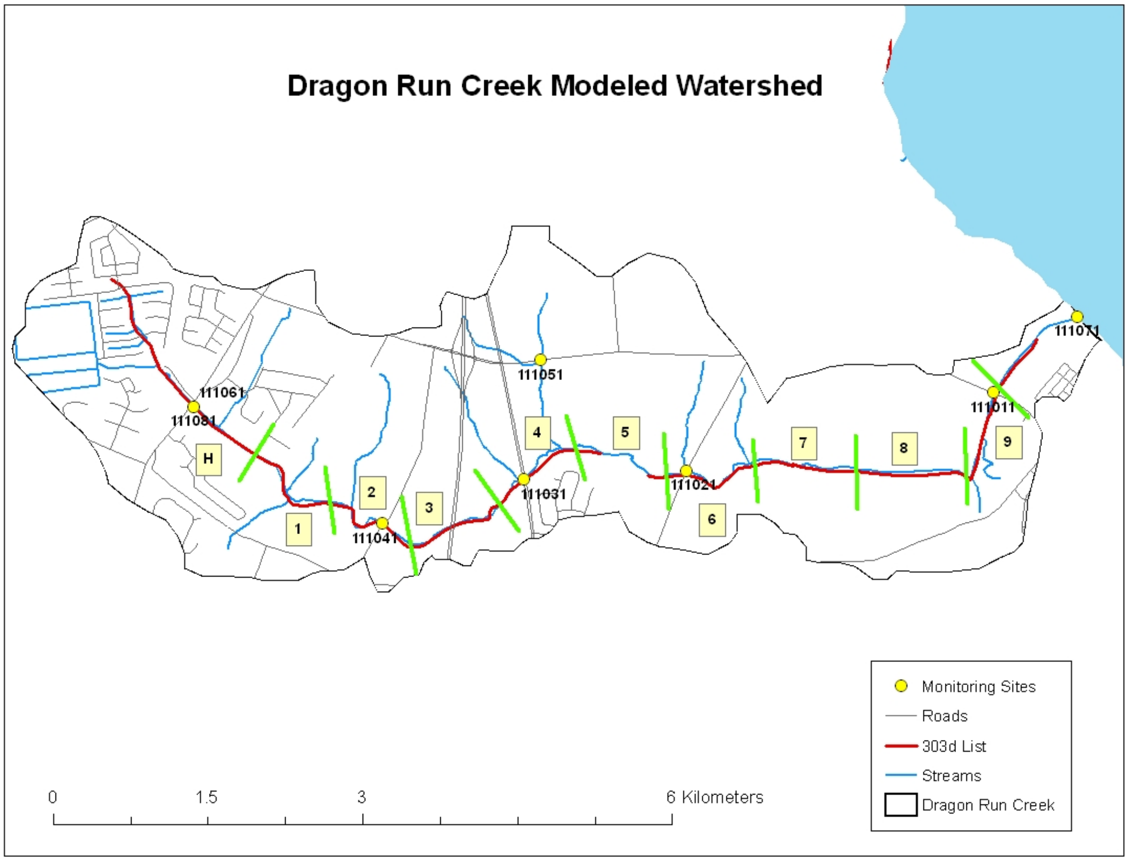


Figure 2- 5 Reaches of Dragon Run Creek Qual2K Model

2.4.2 Flow Balance

Since there is no USGS discharge gauge on Dragon Run Creek, values have been estimated using Red Lion Creek discharge data (see the discussion beginning on page 42 above) and a ratio of flow to drainage area. Table 2-17 lists the Dragon Run Creek sub-watershed drainage areas as well as the estimated annual average and 7Q10 flows, which were also computed using a ratio of flow to drainage area.

Table 2- 17 Dragon Run Creek Qual2K Model Discharge Data

Description of Drainage Area	Drainage Area	Annual Average		Critical Condition	
	km^2	ft^3/s	m^3/s	ft^3/s	m^3/s
Headwater	5.24	2.41	0.0684	0.55	0.0154
Tributary 1, Reach 1	0.16	0.07	0.0020	0.02	0.0005
Tributary 2, Reach 1	0.82	0.38	0.0107	0.09	0.0024
Reach 1 diffuse inflow	0.91	0.42	0.0118	0.09	0.0027
Tributary 3, Reach 2	1.37	0.63	0.0178	0.14	0.0040
Reach 2 diffuse inflow	0.65	0.30	0.0084	0.07	0.0019
Reach 3 diffuse inflow	1.06	0.49	0.0138	0.11	0.0031
Tributary 4, Reach 4	0.92	0.42	0.0120	0.10	0.0027
Tributary 5, Reach 4	1.90	0.88	0.0248	0.20	0.0056
Reach 4 diffuse inflow	0.54	0.25	0.0070	0.06	0.0016
Reach 5 diffuse inflow	2.17	1.00	0.0283	0.23	0.0064
Tributary 6, Reach 6	0.68	0.31	0.0089	0.07	0.0020
Tributary 7, Reach 6	0.33	0.15	0.0043	0.03	0.0010
Reach 6 diffuse inflow	0.89	0.41	0.0116	0.09	0.0026
Reach 7 diffuse inflow	1.54	0.71	0.0201	0.16	0.0045
Reach 8 diffuse inflow	2.05	0.95	0.0268	0.21	0.0061
Reach 9 diffuse inflow	1.17	0.54	0.0152	0.12	0.0034
Dragon Run Creek Total	22.40	10.31	0.2920	2.33	0.0660

Additionally, the Valero Energy Corporation Refinery in Delaware City has a permitted withdrawal on Dragon Run Creek (permit number 8014). The pump is situated at the Clarks Corner Road crossing (same location as monitoring station 111021 in Figure 2-5), which is located just below Tributary 6 in Reach 6 of the model framework. The permit allows the refinery to withdrawal 0.0820 cms from this location. However, the refinery has not utilized this withdrawal to its maximum extent allowable in recent years. The annual water use reports from the refinery indicate that the average withdrawal between 2003-2005 (no data was reported in 2002) was 0.0405 cms, with a maximum abstraction of 0.0664 cms.

2.4.3 Hydraulic Characteristics

The Dragon Run Creek Qual2K Model also uses the Manning equation to describe stream hydraulic characteristics (see page 32 under the Army Creek Qual2K Model for more details). The Manning Equation factors input into the Dragon Run Creek Model for the headwater and model reaches are displayed in Table 2-18.

Table 2- 18 Dragon Run Creek Qual2K Model Manning Equation Parameters

	Channel Slope	Manning n	Bottom Width (m)	
			Annual Average	Critical Condition
Headwater	0.0050	0.12	1.0	1.0
Reach 1	0.0040	0.12	2.0	2.0
Reach 2	0.0030	0.12	2.3	2.3
Reach 3	0.0020	0.12	2.5	2.5
Reach 4	0.0010	0.12	2.8	2.8
Reach 5	0.0005	0.12	3.0	3.0
Reach 6	0.0004	0.12	3.5	3.5
Reach 7	0.0003	0.12	4.0	4.0
Reach 8	0.0002	0.12	5.0	5.0
Reach 9	0.0001	0.12	6.0	6.0

2.4.4 System Parameters

The various rates used in the Dragon Run Creek Qual2K Model are listed in Tables 2-6, 2-12, and 2-13. The only differences to note are that the Dragon Run Qual2K Model utilized the O'Connor Dobbins formula to calculate the reaeration rate in the first reach, with a reaeration of 1.5 /d prescribed for the remaining reaches and the prescribed sediment oxygen demand ranged from 0.5 – 2.0 $gO_2/m^2/d$.

2.4.5 Boundary Conditions

The headwater and tributary conditions of the Dragon Run Creek Qual2K Model were defined by monitoring data collected at station 111081. Table 2-19 lists the annual average and critical condition model input values. For more information on how boundary condition data is utilized in the model, see page 38 under the Army Creek Qual2K Model. The option of internally calculating the downstream boundary conditions was selected for the Dragon Run Creek Qual2K Model.

Table 2- 19 Dragon Run Creek Qual2K Model Headwater/Tributary Source Input Values

Parameter	Value		Unit
	Annual Average	Critical Condition	
Temperature	16.14	20.20	Degrees C
Conductivity	163.50	164.00	umhos
Inorganic Solids	1.80	1.50	mgD/l
Dissolved Oxygen	9.20 / 4.50	7.50 / 2.00	mgO_2/l
CBODslow	1.20	1.20	mgO_2/l
CBODfast	2.40	2.40	mgO_2/l
Organic Nitrogen	530.00	567.00	ugN/l
NH4-Nitrogen	68.00	81.00	ugN/l
NO3-Nitrogen	900.00	1,183.50	ugN/l
Organic Phosphorus	48.00	48.00	ugP/l
Inorganic Phosphorus (SRP)	9.50	12.00	ugP/l
Phytoplankton	2.00	1.00	ugA/l
Detritus (POM)	4.90	3.50	mgD/l
Pathogen	NA	NA	cfu/100 mL
Alkalinity	25.25	37.00	$mgCaCO_3/l$
pH	6.79	6.98	s.u.

2.4.6 Diffuse Sources

Nutrient concentrations for diffuse source waters in the Dragon Run Creek Qual2K Model were estimated by beginning with the same values used for the headwater/tributary sources (described above under Boundary Conditions). These values were then adjusted, if necessary, to account for groundwater inputs (Table 2-20). For a more detailed description on diffuse sources, see page 39 in the Army Creek Qual2K Model section.

Table 2- 20 Dragon Run Creek Qual2K Model Diffuse Source Input Values

Parameter	Value		Unit
	Annual Average	Critical Condition	
Temperature	19.00	22.00	Degrees C
Conductivity	320.00	320.00	umhos
Inorganic Solids	2.50	2.50	mgD/l
Dissolved Oxygen	4.00	4.00	mgO_2/l
CBODslow	1.60	1.60	mgO_2/l
CBODfast	3.20	3.20	mgO_2/l
Organic Nitrogen	2,000.00	2,000.00	ugN/l
NH4-Nitrogen	250.00	250.00	ugN/l
NO3-Nitrogen	1,000.00	1,000.00	ugN/l
Organic Phosphorus	150.00	150.00	ugP/l
Inorganic Phosphorus (SRP)	50.00	50.00	ugP/l
Phytoplankton	8.00	8.00	ugA/l
Detritus (POM)	6.00	6.00	mgD/l
Pathogen	NA	NA	cfu/100 mL
Alkalinity	65.00	65.00	$mgCaCO_3/l$
pH	6.90	6.90	s.u.

3.0 Model Calibrations and Scenario Analyses

3.1 Army Creek Qual2K Model

3.1.1 Model Calibration / Annual Average Baseline

The Army Creek Qual2K Model was calibrated to reproduce average water quality conditions observed during 2002-2005. Qual2K requires the user to input a date in order to calculate the photoperiod, or the amount of time within a day that photosynthesis can occur. In order to simulate an average day during the water quality monitoring period, a day with an average number of daylight hours should be chosen. An arbitrary date of April 21, 2002 was selected. Average annual flows and median water quality concentrations for headwater, tributary, and diffuse source inputs, which were presented in Chapter 2, were used in the model calibration. System parameters, also presented in Chapter 2, were adjusted to be consistent with other models, literature values, and best professional judgment.

Figures 3-1 and 3-2 display the model calibration results for several water quality constituents including water temperature, total suspended solids, biochemical oxygen demand, nutrient species, phytoplankton chlorophyll-*a*, and dissolved oxygen under average conditions during 2002-2005. The daily simulated mean concentrations are presented as a solid line while the predicted minimum and maximum daily concentrations are shown as dashed lines. The observed data from the monitoring sites (114011 and 114021 on the mainstem, and 114051 on the unnamed tributary), which the model was calibrated against, are shown as symbols with mean, maximum, and minimum values of all samples collected between 2002-2005.

The calibration results show that temperature, dissolved oxygen, nitrogen, phosphorus, and chlorophyll-*a* have been reproduced reasonably well. The calibrated models for the average conditions during 2002 – 2005 constitute the baseline conditions for Army Creek.

In Figures 3-1 and 3-2, the State of Delaware standards for dissolved oxygen (5.5 mg/l daily average and 4.0 mg/l instantaneous minimum) and target nutrient values (3.0 mg/l (3,000 ug/l) for total nitrogen and 0.2 mg/l (200 ug/l) for total phosphorus) are shown as dashed green lines. These figures show that the modeled dissolved oxygen levels meet the standards in all portions of Army Creek on an annual average basis. Additionally, under average conditions, the modeled total nitrogen and total phosphorus concentrations achieve the target values.

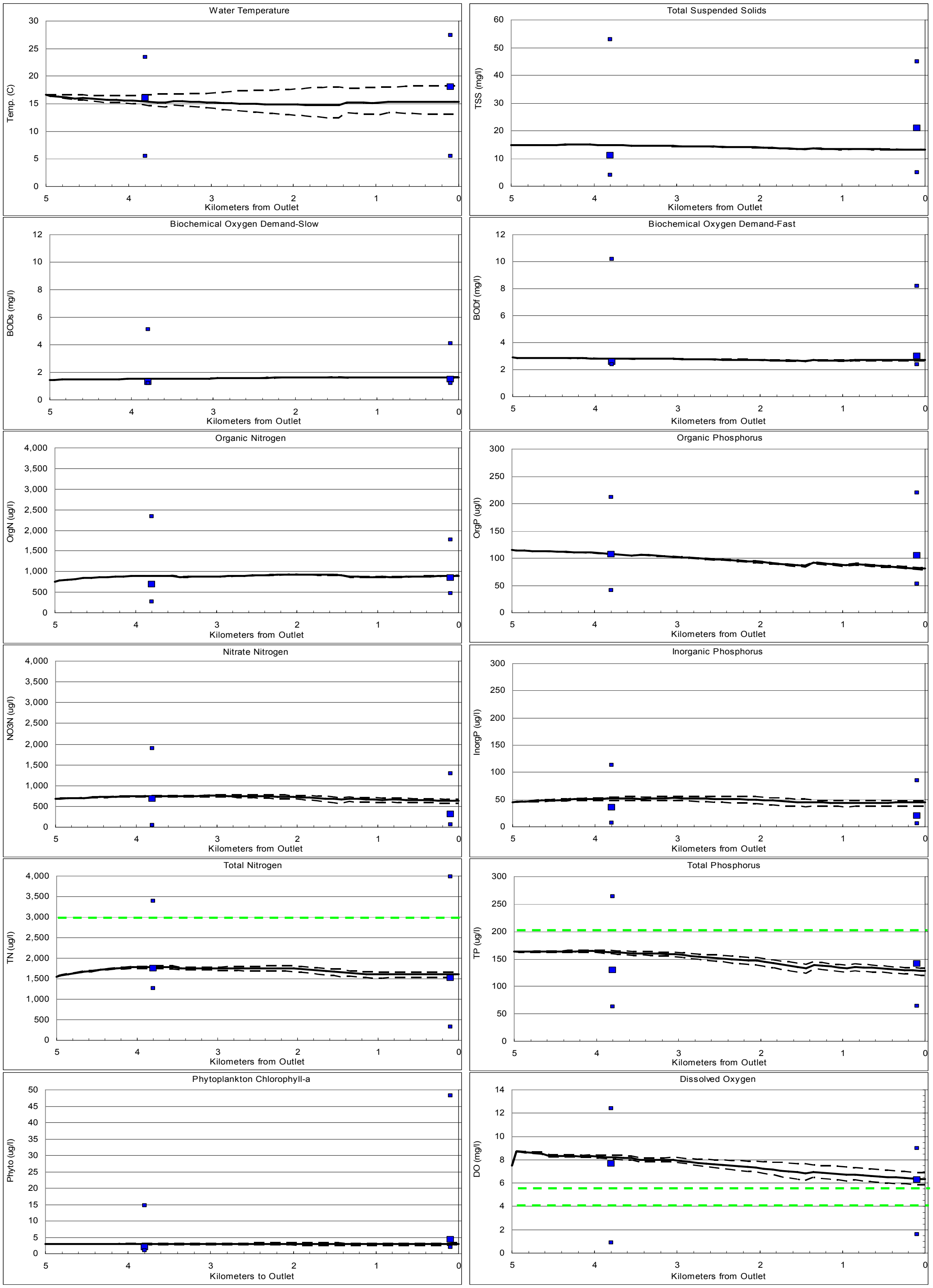


Figure 3- 1 Army Creek Qual2K Model Calibration/Annual Average Baseline Results in the Mainstem

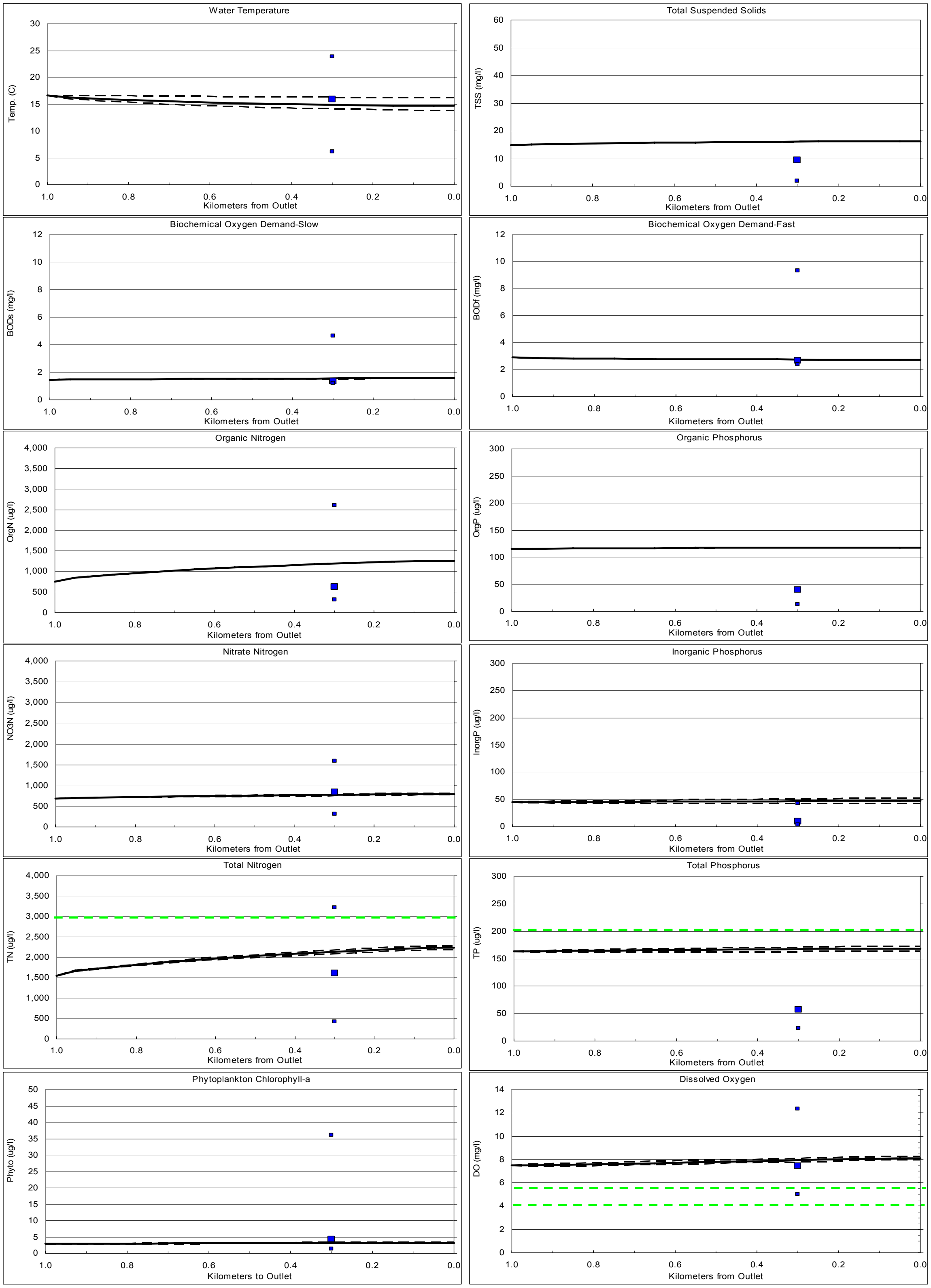


Figure 3- 2 Army Creek Qual2K Model Calibration/Annual Average Baseline Results in the Unnamed Tributary

3.1.2 Critical Condition Baseline

Low flows coupled with warm temperatures are observed during the months of June, July, August, and September in Army Creek. Monitoring data showed that violation of the dissolved oxygen standard happened more frequently during summer months than other months of the year. The water quality conditions in the summer were simulated to form the critical baseline conditions during summer time. Water quality data collected between June and September were considered summer month samples. The median summer concentrations between 2002-2005 were used to define the headwater conditions and tributary input conditions of the model. The median summer concentrations were coupled with the 7Q10 flow to simulate the summer critical condition. The arbitrary date chosen for the critical condition scenario was July 21, 2002.

The modeled total nitrogen and total phosphorus concentrations again meet the target values of 3.0 mg/l (3,000 ug/l) and 0.2 mg/l (200 ug/l), respectively, during the critical condition scenario. However, the modeled dissolved oxygen levels fall below both the 5.5 mg/l daily average standard and the 4.0 mg/l instantaneous minimum standard. The daily simulated mean, maximum, and minimum concentrations for this critical condition day are presented in Figures 3-3 and 3-4 for several parameters.

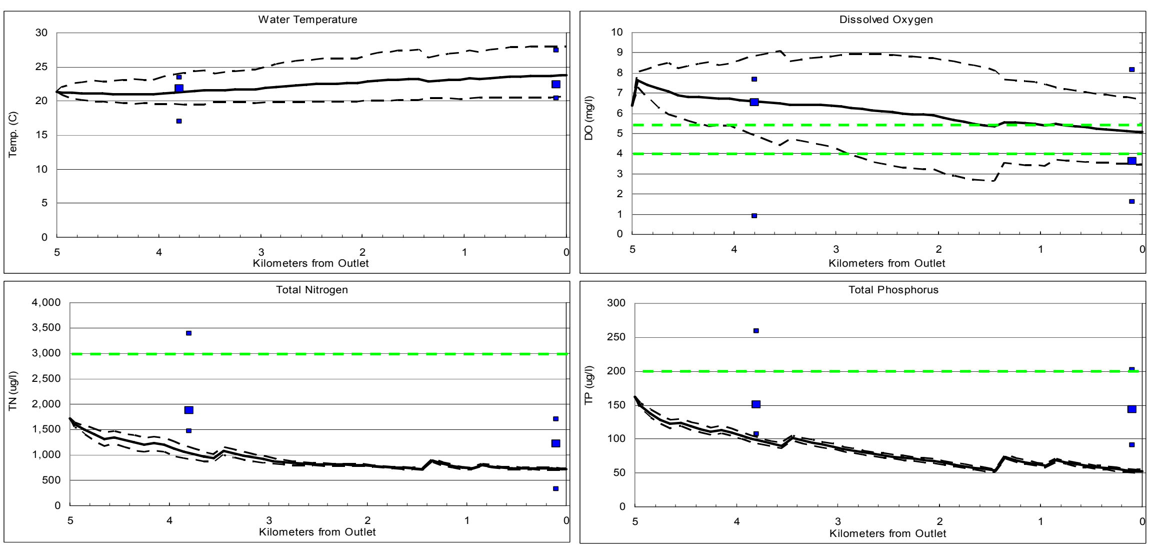


Figure 3- 3 Army Creek Qual2K Model Critical Condition Baseline Results in the Mainstem

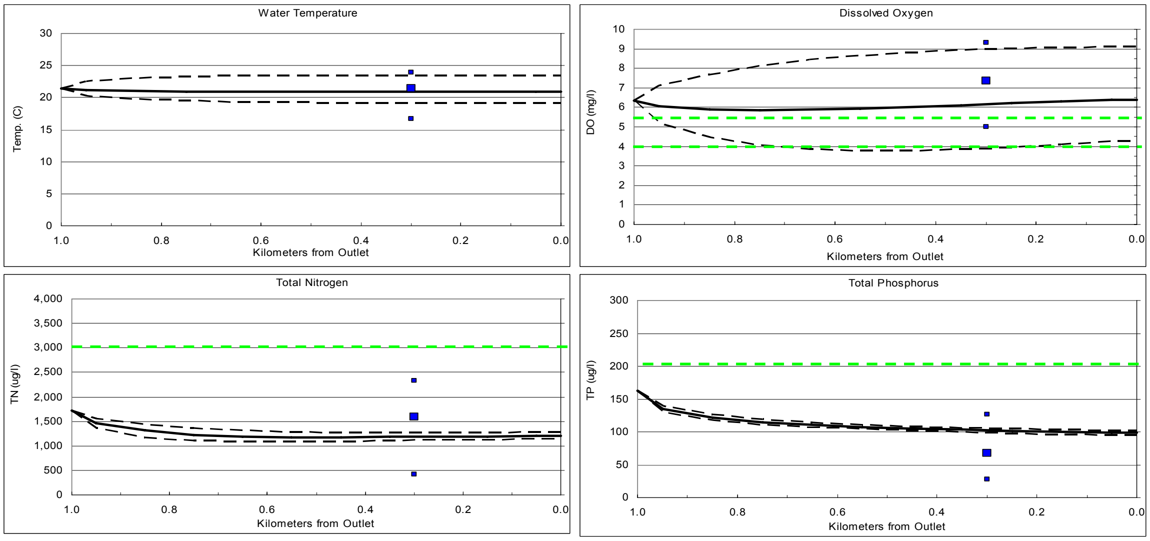


Figure 3- 4 Army Creek Qual2K Model Critical Condition Baseline Results in the Unnamed Tributary

3.1.3 Load Reductions on the Annual Average and Critical Condition Baseline

The nonpoint source loads are considered implicitly in the Qual2K model. They are used in the model through user-defined boundary conditions including headwater conditions, tributary inflow conditions, and diffuse inflow conditions. Water quality concentrations used to define these boundary conditions for the Army Creek Qual2K Model were discussed in Chapter 2 of this report.

Load reduction scenarios, in which pollutant loads were reduced from the headwater, tributary, and diffuse sources, were conducted and several are summarized in Table 3-1. The minimum dissolved oxygen concentration and maximum total nitrogen and total phosphorus concentrations observed in the modeled segments of the stream are presented for each reduction scenario under both annual average (AA) and critical conditions (CC). Cells within the table are colored green if the concentration meets the dissolved oxygen standards or nutrient target, where as if the standard or target is not met, the cell is colored orange. In the scenario that was ultimately chosen (#5, bold font in Table 3-1), nitrogen, phosphorus, and biochemical oxygen demand concentrations were reduced by 40% and the sediment fluxes were adjusted accordingly to account for the reduced nutrient inputs. It was also assumed that these reductions will allow for the dissolved oxygen concentration of the incremental inflow waters to meet the 5.5 mg/l standard. The results are presented as a dashed red line in Figures 3-5 and 3-6 for the reductions to the annual average baseline and Figures 3-7 and 3-8 for reductions to the critical condition baseline. It is apparent that this scenario will result in daily average dissolved oxygen concentrations above the State of Delaware’s 5.5 mg/l standard and minimum concentrations above the 4.0 mg/l instantaneous minimum standard.

Table 3- 1 Results of Load Reduction Scenarios in Army Creek under Annual Average (AA) and Critical Conditions (CC)

Scenario #	Load Reduction N% / BOD%	Load Reduction P%		DO (mg/l) Daily Inst. Min.	DO (mg/l) Daily Ave. Min.	Daily Maximum TN (mg/l)	Daily Maximum TP (mg/l)
Army Creek Baseline			AA	5.9	6.4	2.3	0.17
			CC	3.0	5.2	1.7	0.16
1	0%	40%	AA	6.0	6.4	2.3	0.10
			CC	3.2	5.4	1.7	0.10
2	40%	0%	AA	6.5	7.0	1.3	0.17
			CC	3.9	6.0	1.0	0.16
3	20%	40%	AA	6.3	6.7	1.8	0.10
			CC	3.7	5.9	1.4	0.10
4	40%	20%	AA	6.5	7.0	1.3	0.14
			CC	3.9	6.1	1.0	0.13
5	**40%**	**40%**	**AA**	**6.5**	**7.0**	**1.3**	**0.10**
			CC	**4.1**	**6.1**	**1.0**	**0.10**

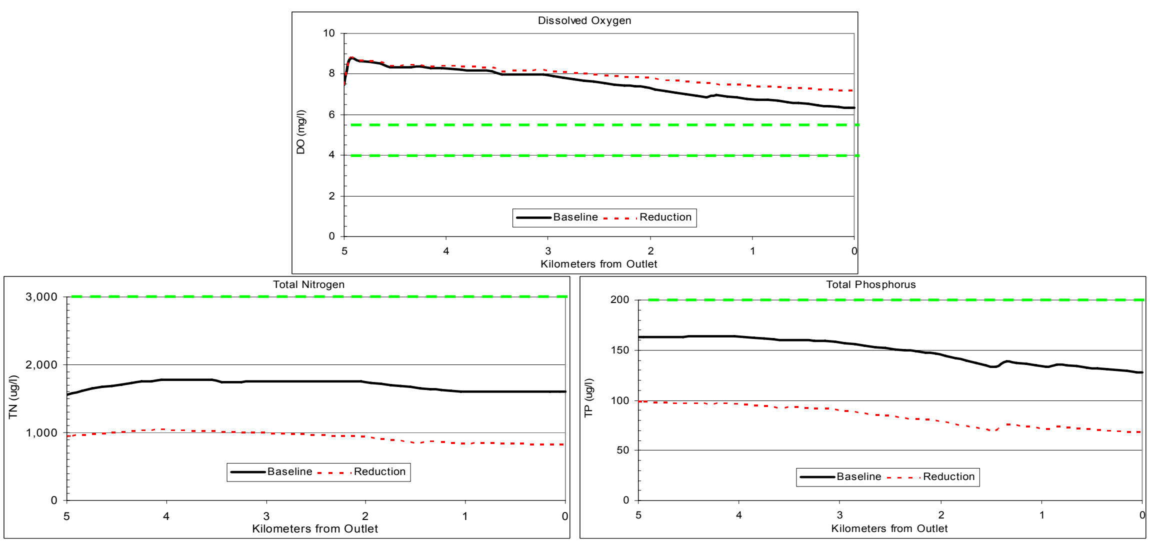


Figure 3- 5 Results of Load Reduction Scenario on Annual Average Baseline Daily Mean Concentrations in the Mainstem of Army Creek

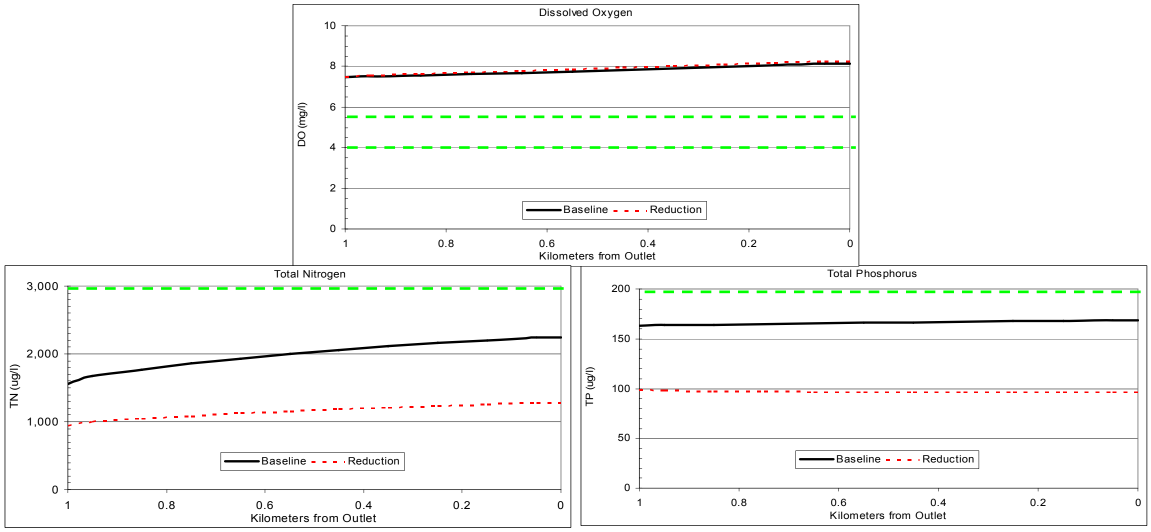


Figure 3- 6 Results of Load Reduction Scenario on Annual Average Baseline Daily Mean Concentrations in the Unnamed Tributary of Army Creek

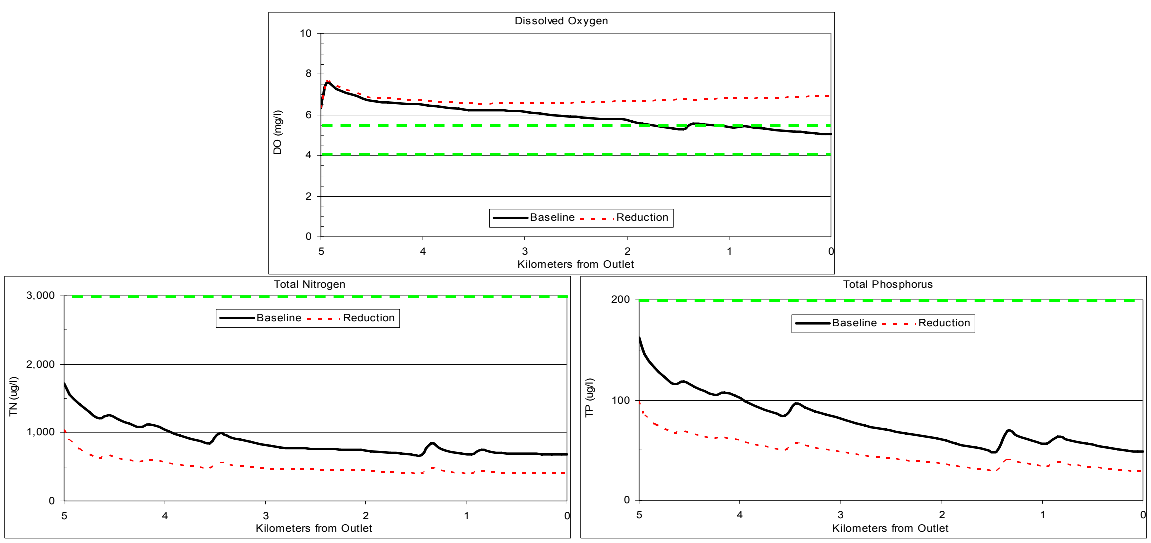


Figure 3- 7 Results of Load Reduction Scenario on Critical Condition Baseline Daily Mean Concentrations in the Mainstem of Army Creek

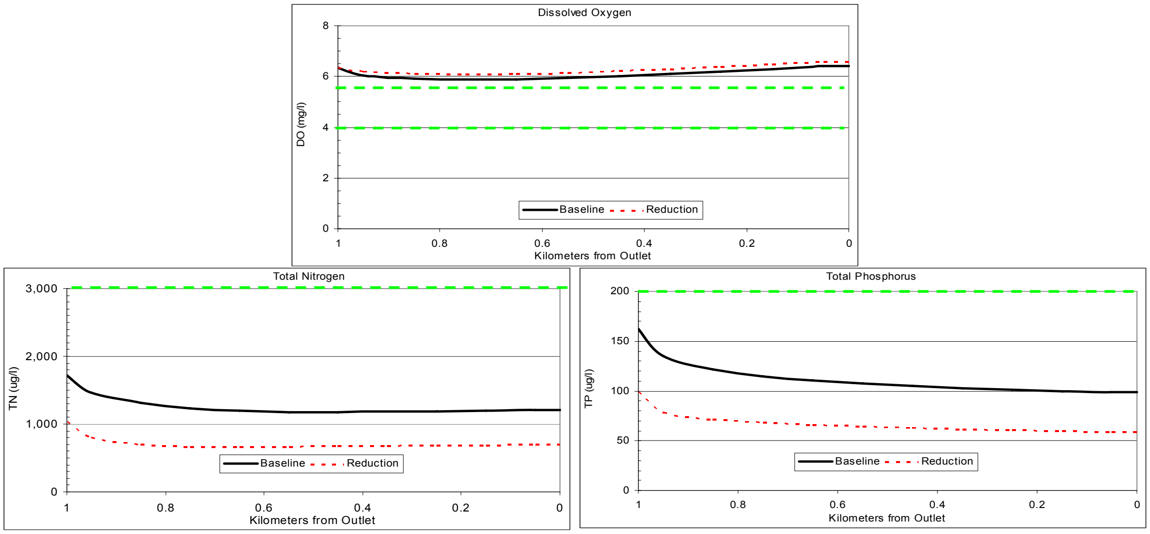


Figure 3- 8 Results of Load Reduction Scenario on Critical Condition Baseline Daily Mean Concentrations in the Unnamed Tributary of Army Creek

3.2 Red Lion Creek Qual2K Model

3.2.1 Model Calibration / Annual Average Baseline

The Red Lion Creek Qual2K Model was calibrated to reproduce average water quality conditions observed during 2002-2005. Qual2K requires the user to input a date in order to calculate the photoperiod, or the amount of time within a day that photosynthesis can occur. In order to simulate an average day during the water quality monitoring period, a day with an average number of daylight hours should be chosen. An arbitrary date of April 21, 2002 was selected. Average annual flows and median water quality concentrations for headwater, tributary, and diffuse source inputs, which were presented in Chapter 2, were used in the model calibration. Since the Valero Delaware City Refinery reported that they did not utilize their permitted intake during the water quality monitoring period, a zero abstraction has been included in the baseline model. System parameters, also presented in Chapter 2, were adjusted to be consistent with other models, literature values, and best professional judgment.

Figure 3-9 displays the model calibration results for several water quality constituents including water temperature, total suspended solids, biochemical oxygen demand, nutrient species, phytoplankton chlorophyll-*a*, and dissolved oxygen under average conditions during 2002-2005. The daily simulated mean concentrations are presented as a solid line while the predicted minimum and maximum daily concentrations are shown as dashed lines. The observed data from the monitoring sites (107011 and 107031), which the model was calibrated against, are shown as symbols with mean, maximum, and minimum values of all samples collected between 2002-2005.

The calibration results show that temperature, dissolved oxygen, nitrogen, phosphorus, and chlorophyll-*a* have been reproduced reasonably well. The calibrated models for the average conditions during 2002 – 2005 constitute the baseline conditions for Red Lion Creek.

In Figure 3-9 the State of Delaware standards for dissolved oxygen (5.5 mg/l daily average and 4.0 mg/l instantaneous minimum) and target nutrient values (3.0 mg/l (3,000 ug/l) for total nitrogen and 0.2 mg/l (200 ug/l) for total phosphorus) are shown as dashed green lines. These figures show that the modeled dissolved oxygen levels meet the standards in all portions of Red Lion Creek on an annual average basis. Additionally, under average conditions, the modeled total nitrogen and total phosphorus concentrations achieve the target values, except for a very slight exceedance of total nitrogen.

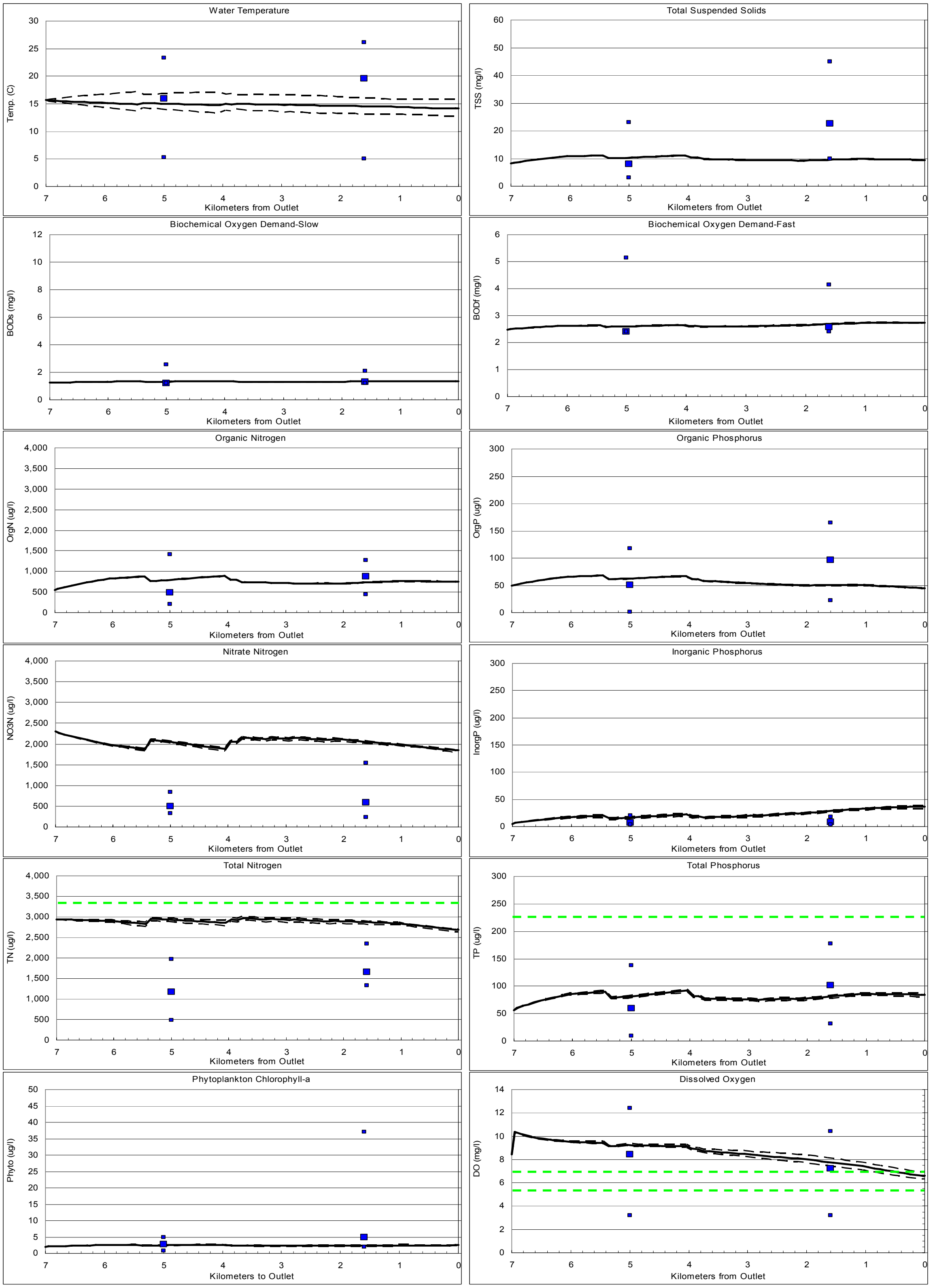


Figure 3- 9 Red Lion Creek Qual2K Model Calibration/Annual Average Baseline Results

3.2.2 Critical Condition Baseline

Low flows coupled with warm temperatures are observed during the months of June, July, August, and September in Red Lion Creek. Monitoring data showed that violation of the dissolved oxygen standard happened more frequently during summer months than other months of the year. The water quality conditions in the summer were simulated to form the critical baseline conditions during summer time. Water quality data collected between June and September were considered summer month samples. The median summer concentrations between 2002-2005 were used to define the headwater conditions and tributary input conditions of the model. The median summer concentrations were coupled with 7Q10 low flows to simulate the summer critical condition. Again, since the Valero Delaware City Refinery did not utilize their permitted withdrawal during the monitoring period, a zero abstraction has been included in the baseline model. The arbitrary date chosen for the critical condition scenario was July 21, 2002.

The modeled total nitrogen and total phosphorus concentrations again meet the target values of 3.0 mg/l (3,000 ug/l) and 0.2 mg/l (200 ug/l), respectively, during the critical conditions, except for a slight nitrogen exceedence at the headwaters. However, the modeled dissolved oxygen levels fall below both the 5.5 mg/l daily average standard and the 4.0 mg/l instantaneous minimum standard. The daily simulated mean, maximum, and minimum concentrations for this critical condition day are presented in Figure 3-10 for several parameters.

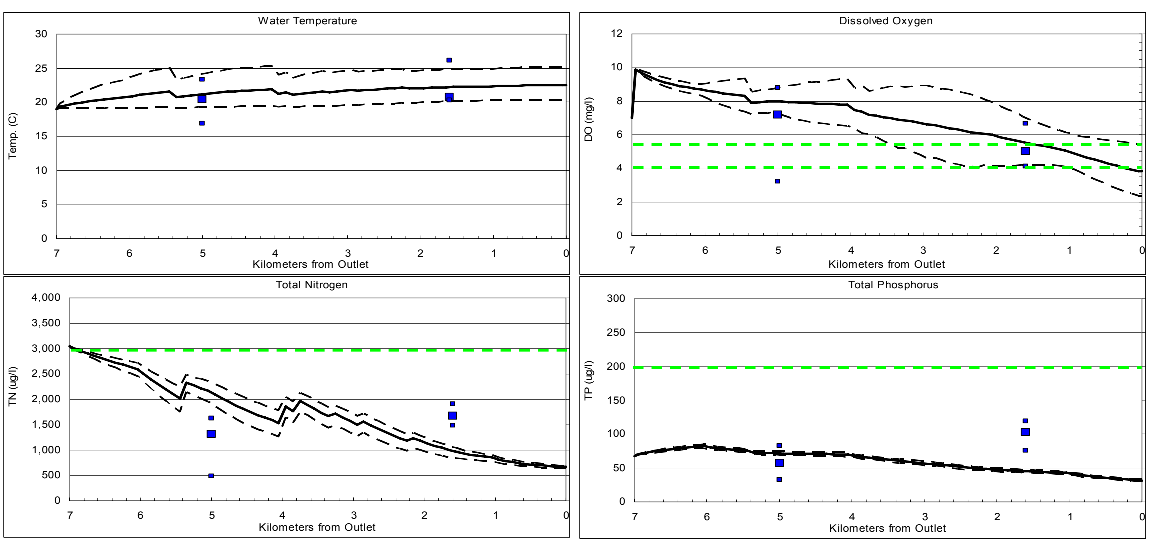


Figure 3- 10 Red Lion Creek Qual2K Model Critical Condition Baseline Results

3.2.3 Load Reductions on the Annual Average and Critical Condition Baseline

The nonpoint source loads are considered implicitly in the Qual2K model. They are used in the model through user-defined boundary conditions including headwater conditions, tributary inflow conditions, and diffuse inflow conditions. Water quality concentrations used to define these boundary conditions for the Red Lion Creek Qual2K Model were discussed in Chapter 2 of this report.

The Valero Delaware City Refinery's permitted intake of 0.0568 cms was included as an abstraction in annual average load reduction scenarios, which is a conservative assumption, since the refinery currently reports that they have not been using this pump for several years now. Load reduction scenarios on the critical condition assumed that the refinery would not withdrawal stream water due to the extremely low water levels that would be present at 7Q10 conditions.

Load reduction scenarios, in which pollutant loads were reduced from the headwater, tributary, and diffuse sources, were conducted and several are summarized in Table 3-2. The minimum dissolved oxygen concentration and maximum total nitrogen and total phosphorus concentrations observed in the modeled segments of the stream are presented for each reduction scenario under both annual average (AA) and critical conditions (CC). Cells within the table are colored green if the concentration meets the dissolved oxygen standards or nutrient target, where as if the standard or target is not met, the cell is colored orange. In the scenario that was ultimately chosen (#5, bold font in Table 3-2), nitrogen, phosphorus, and biochemical oxygen demand concentrations were reduced by 40% and the sediment fluxes were adjusted accordingly to account for the reduced nutrient inputs. The results are presented as a dashed red line in Figure 3-11 for the reductions to the annual average baseline and Figure 3-12 for reductions to the critical condition baseline. It is apparent that this scenario will result in daily average dissolved oxygen concentrations above the State of Delaware's 5.5 mg/l standard and minimum concentrations above the 4.0 mg/l instantaneous minimum standard.

Table 3- 2 Results of Load Reduction Scenarios in Red Lion Creek under Annual Average (AA) and Critical Conditions (CC)

Scenario #	Load Reduction			DO (mg/l)		Daily Maximum TN (mg/l)	Daily Maximum TP (mg/l)
	N% / BOD%	P%		Daily Inst. Min.	Daily Ave. Min.		
Red Lion Creek Baseline			AA	6.3	6.6	3.0	0.09
			CC	2.4	3.8	3.0	0.09
1	0%	40%	AA	6.2	6.5	3.0	0.06
			CC	3.1	4.4	3.0	0.05
2	40%	0%	AA	6.7	7.1	1.8	0.09
			CC	3.8	5.2	1.8	0.09
3	20%	40%	AA	6.6	6.9	2.4	0.06
			CC	3.7	5.0	2.4	0.05
4	40%	20%	AA	6.9	7.2	1.8	0.07
			CC	4.1	5.4	1.8	0.07
5	**40%**	**40%**	**AA**	**7.0**	**7.3**	**1.8**	0.06
			CC	**4.4**	**5.6**	**1.8**	0.05

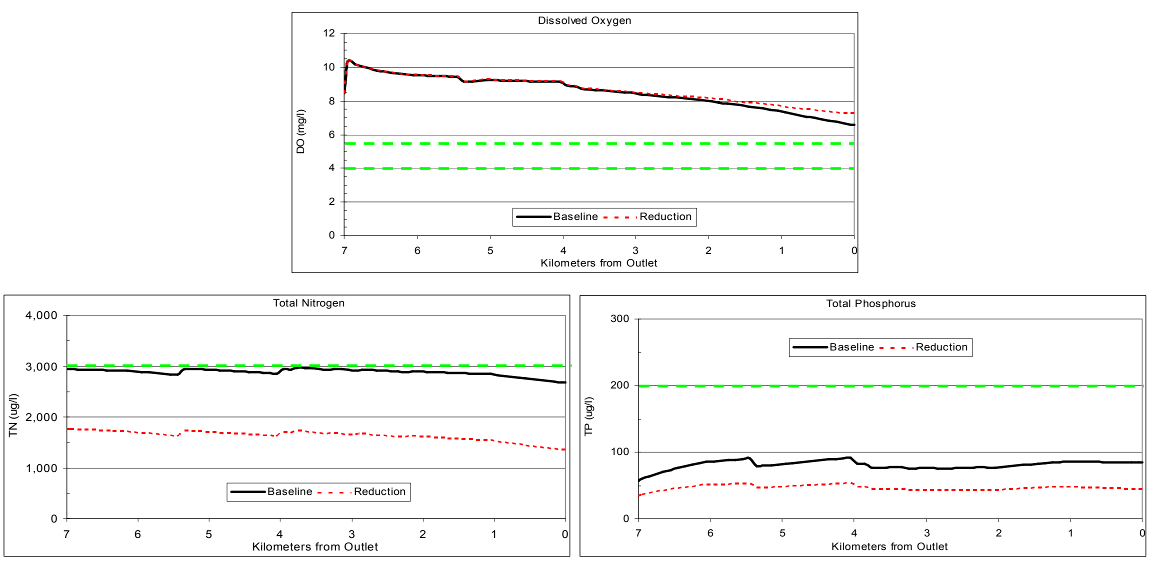


Figure 3- 11 Results of Load Reduction Scenario on Annual Average Baseline Daily Mean Concentrations in Red Lion Creek

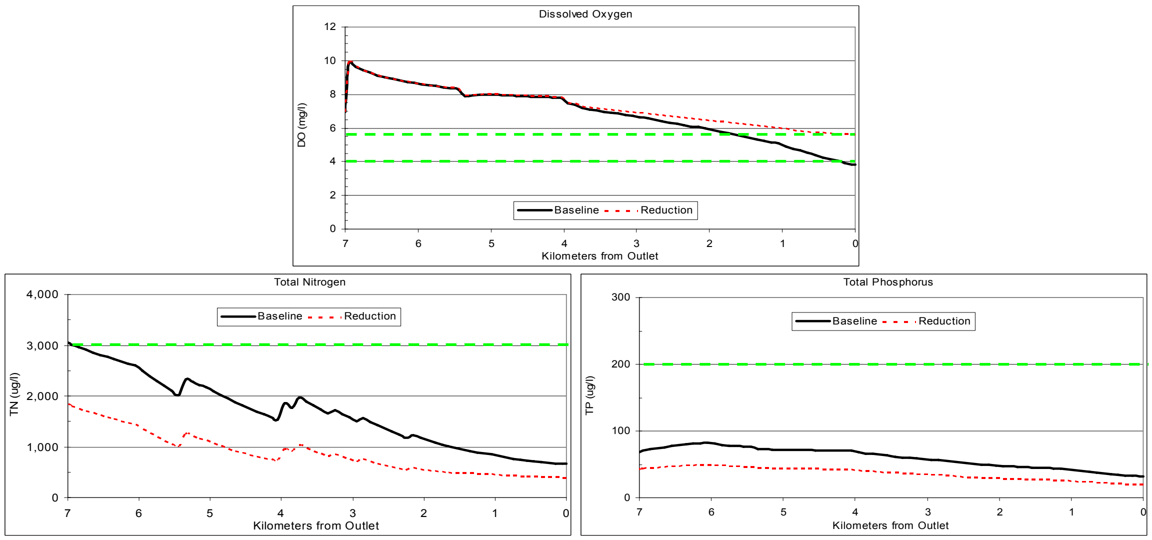


Figure 3- 12 Results of Load Reduction Scenario on Critical Condition Baseline Daily Mean Concentrations in Red Lion Creek

3.3 Dragon Run Creek Qual2K Model

3.3.1 Model Calibration / Annual Average Baseline

The Dragon Run Creek Qual2K Model was calibrated to reproduce average water quality conditions observed during 2002-2005. Qual2K requires the user to input a date in order to calculate the photoperiod, or the amount of time within a day that photosynthesis can occur. In order to simulate an average day during the water quality monitoring period, a day with an average number of daylight hours should be chosen. An arbitrary date of April 21, 2002 was selected. Average annual flows and median water quality concentrations for headwater, tributary, and diffuse source inputs, which were presented in Chapter 2, were used in the model calibration. The average withdrawal (0.0405 cms) reported by the Valero Delaware City Refinery for the period of 2003-2005 was input into the annual average baseline scenario. System parameters, also presented in Chapter 2, were adjusted to be consistent with other models, literature values, and best professional judgment.

Figure 3-13 displays the model calibration results for several water quality constituents including water temperature, total suspended solids, biochemical oxygen demand, nutrient species, phytoplankton chlorophyll-*a*, and dissolved oxygen under average conditions during 2002-2005. The daily simulated mean concentrations are presented as a solid line while the predicted minimum and maximum daily concentrations are shown as dashed lines. The observed data from the monitoring sites (111011, 111021, 111031, and 111041), which the model was calibrated against, are shown as symbols with mean, maximum, and minimum values of all samples collected between 2002-2005.

The calibration results show that temperature, dissolved oxygen, nitrogen, phosphorus, and chlorophyll-*a* have been reproduced reasonably well. The calibrated models for the average conditions during 2002 – 2005 constitute the baseline conditions for Dragon Run Creek.

In Figure 3-13 the State of Delaware standards for dissolved oxygen (5.5 mg/l daily average and 4.0 mg/l instantaneous minimum) and target nutrient values (3.0 mg/l (3,000 ug/l) for total nitrogen and 0.2 mg/l (200 ug/l) for total phosphorus) are shown as dashed green lines. These figures show that, on an annual average basis, the modeled dissolved oxygen levels meet the standards in the upper portions of Dragon Run Creek, but fall below the daily average standard in the lower portions. Additionally, under average conditions, the modeled total nitrogen and total phosphorus concentrations achieve the target values.

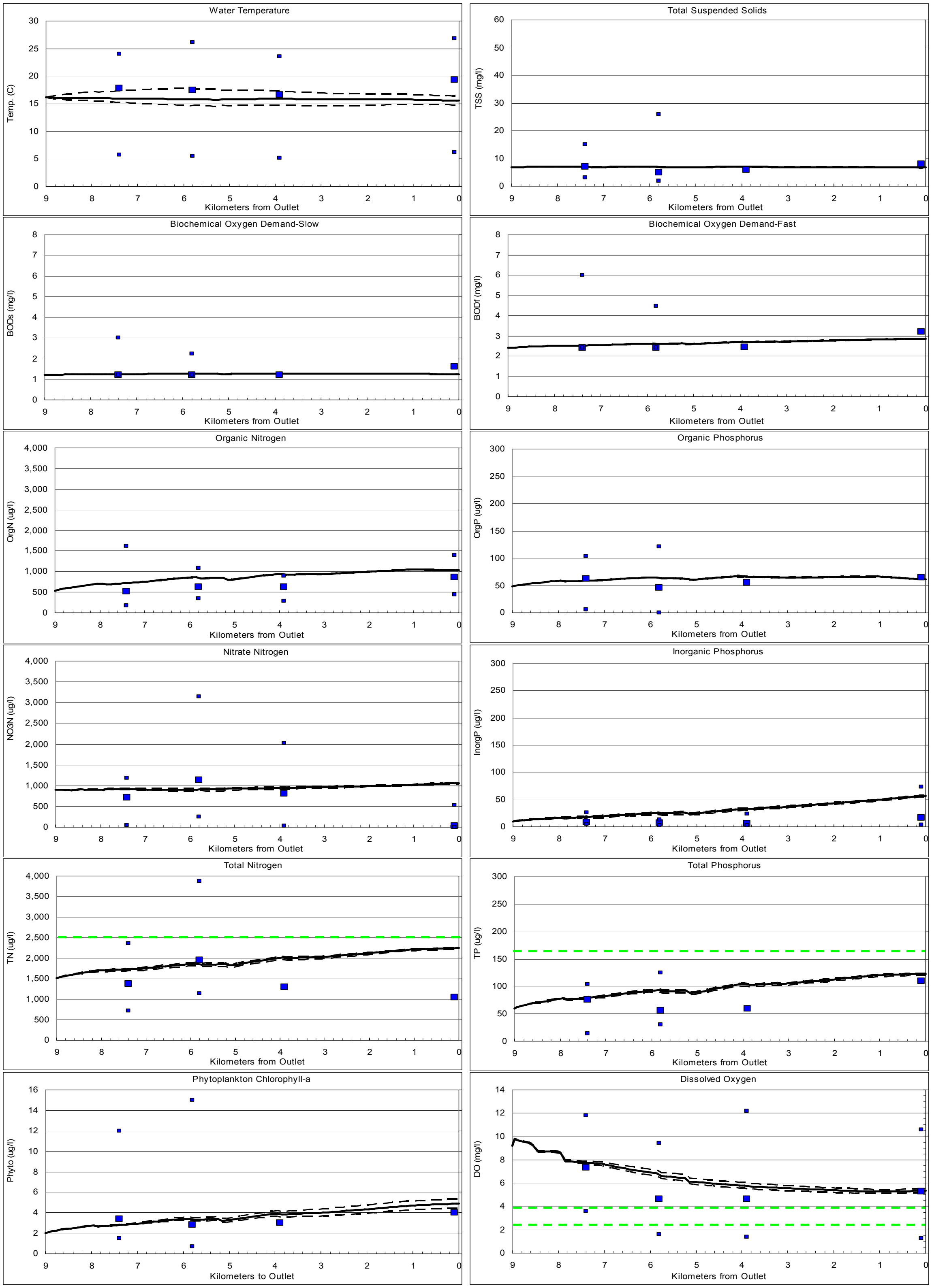


Figure 3- 13 Dragon Run Creek Qual2K Model Calibration/Annual Average Baseline Results

3.3.2 Critical Condition Baseline

Low flows coupled with warm temperatures are observed during the months of June, July, August, and September in Dragon Run Creek. Monitoring data showed that violation of the dissolved oxygen standard happened more frequently during summer months than other months of the year. The water quality conditions in the summer were simulated to form the critical baseline conditions during summer time. Water quality data collected between June and September were considered summer month samples. The median summer concentrations between 2002-2005 were used to define the headwater conditions and tributary input conditions of the model. The median summer concentrations were coupled with 7Q10 low flows to simulate the summer critical condition. It was assumed that the Valero Delaware City Refinery would not utilize their withdrawal pump during critical 7Q10 conditions due to the extremely low water levels that would be present in the stream and a zero abstraction was therefore utilized in the critical condition baseline. The arbitrary date chosen for the critical condition scenario was July 21, 2002.

The modeled total nitrogen and total phosphorus concentrations again meet the target values of 3.0 mg/l (3,000 ug/l) and 0.2 mg/l (200 ug/l), respectively, during the critical conditions. However, the modeled dissolved oxygen levels fall below both the 5.5 mg/l daily average standard and the 4.0 mg/l instantaneous minimum standard. The daily simulated mean, maximum, and minimum concentrations for this critical condition day are presented in Figure 3-14 for several parameters.

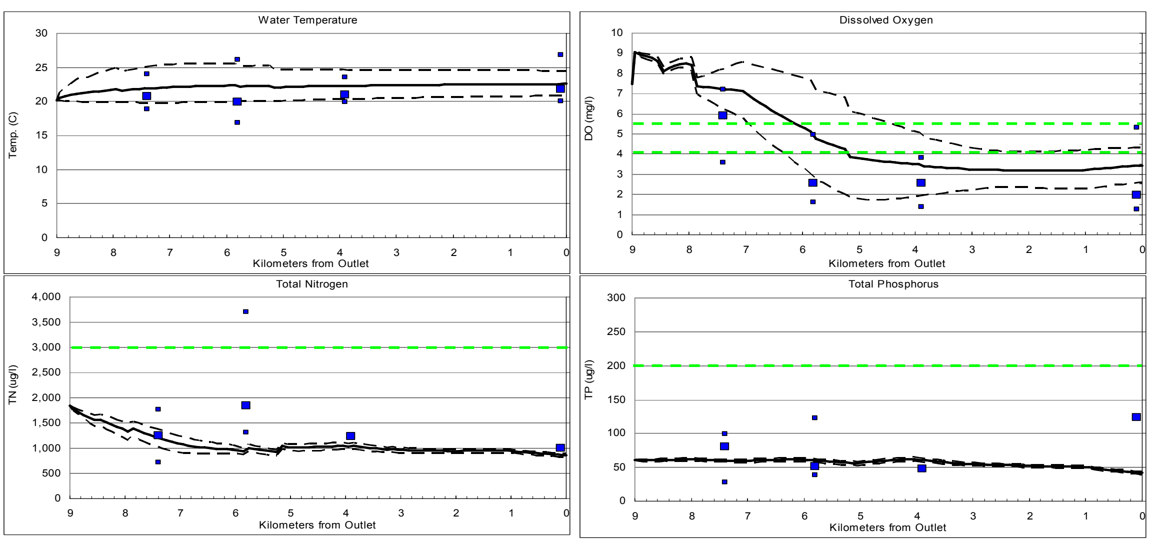


Figure 3- 14 Dragon Run Creek Qual2K Model Critical Condition Baseline Results

3.3.3 Load Reductions on the Annual Average and Critical Condition Baseline

The nonpoint source loads are considered implicitly in the Qual2K model. They are used in the model through user-defined boundary conditions including headwater conditions, tributary inflow conditions, and diffuse inflow conditions. Water quality concentrations used to define these boundary conditions for the Dragon Run Creek Qual2K Model were discussed in Chapter 2 of this report.

The Valero Delaware City Refinery's permitted intake of 0.0820 cms was included as an abstraction in annual average load reduction scenarios, which is a conservative assumption, since the refinery currently reports that they have not utilized this pump to its maximum permitted level for the last several years. Load reduction scenarios on the critical condition assumed that the refinery would not withdrawal stream water due to the extremely low water levels that would be present at 7Q10 conditions.

Load reduction scenarios, in which pollutant loads were reduced from the headwater, tributary, and diffuse sources, were conducted and several are summarized in Table 3-3. The minimum dissolved oxygen concentration and maximum total nitrogen and total phosphorus concentrations observed in the modeled segments of the stream are presented for each reduction scenario under both annual average (AA) and critical conditions (CC). Cells within the table are colored green if the concentration meets the dissolved oxygen standards or nutrient target, where as if the standard or target is not met, the cell is colored orange. In the scenario that was ultimately chosen (#5, bold font in Table 3-3), nitrogen, phosphorus, and biochemical oxygen demand concentrations were reduced by 40% and the sediment fluxes were adjusted accordingly to account for the reduced nutrient inputs. It was also assumed that these reductions will allow for the dissolved oxygen concentration of the incremental inflow waters and tributary waters to meet the 5.5 mg/l standard in critical condition scenarios. The results are presented as a dashed red line in Figure 3-15 for the reductions to the annual average baseline and Figure 3-16 for reductions to the critical condition baseline. It is apparent that this scenario will result in daily average dissolved oxygen concentrations above the State of Delaware's 5.5 mg/l standard and minimum concentrations above the 4.0 mg/l instantaneous minimum standard.

Table 3- 3 Results of Load Reduction Scenarios in Dragon Run Creek under Annual Average (AA) and Critical Conditions (CC)

Scenario #	Load Reduction			DO (mg/l)		Daily Maximum TN (mg/l)	Daily Maximum TP (mg/l)
	N% / BOD%	P%		Daily Inst. Min.	Daily Ave. Min.		
Dragon Run Creek Baseline			AA	5.1	5.3	2.3	0.12
			CC	1.7	3.2	1.8	0.07
1	0%	40%	AA	5.1	5.3	2.3	0.07
			CC	3.5	4.4	1.8	0.04
2	40%	0%	AA	5.5	5.7	1.2	0.13
			CC	3.7	4.9	1.1	0.07
3	20%	40%	AA	5.5	5.6	1.8	0.07
			CC	3.9	5.0	1.5	0.04
4	40%	20%	AA	5.7	5.9	1.3	0.10
			CC	4.0	5.2	1.1	0.05
5	**40%**	**40%**	**AA**	**5.8**	**6.0**	**1.3**	**0.07**
			CC	**4.4**	**5.5**	**1.1**	**0.04**

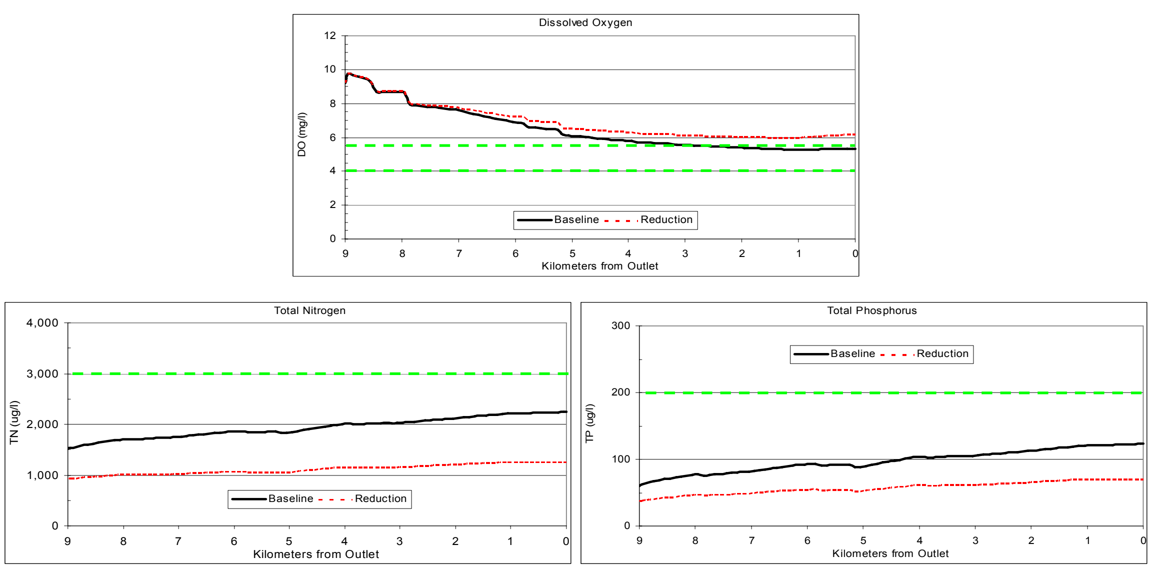


Figure 3- 15 Results of Load Reduction Scenario on Annual Average Baseline Daily Mean Concentrations in Dragon Run Creek

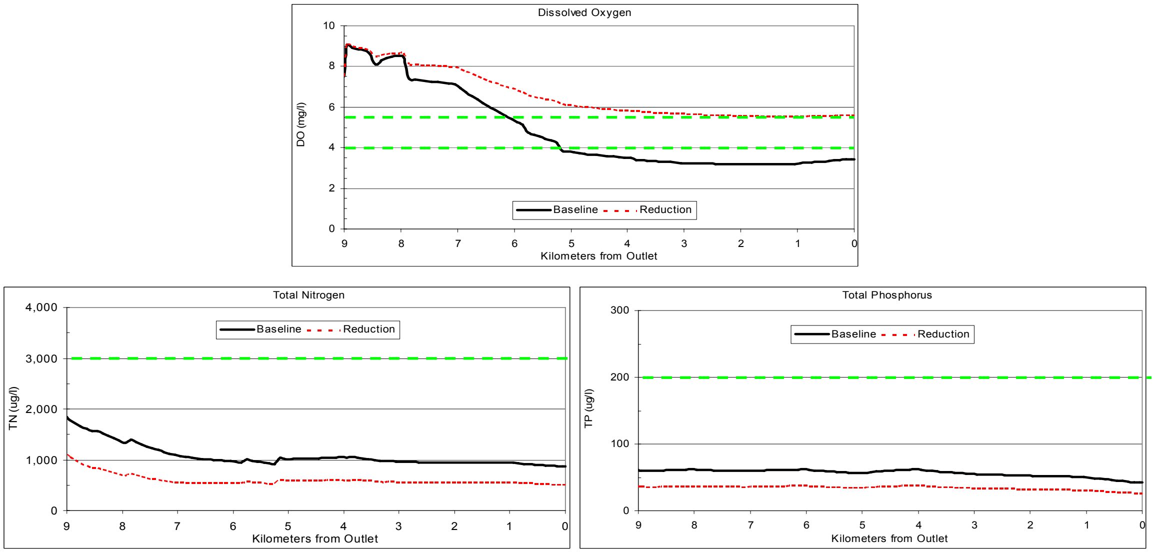


Figure 3- 16 Results of Load Reduction Scenario on Critical Condition Baseline Daily Mean Concentrations in Dragon Run Creek

3.4 Sensitivity Analysis

In order to assess the sensitivity to changes in various environmental parameters used in the Army Creek, Red Lion Creek, and Dragon Run Creek models, a sensitivity analysis was performed. Since dissolved oxygen concentrations tend to be lowest during summer critical periods, the critical condition baseline scenario for Army Creek, Red Lion Creek, and Dragon Run Creek were evaluated to determine which tributary experienced the most critical conditions (lowest dissolved oxygen concentrations and highest total nitrogen and total phosphorus concentrations). It was determined that the most critical conditions occurred in Dragon Run Creek (Appendix A, Table A-1).

For this analysis, one parameter was changed at a time and the percentage of change in dissolved oxygen concentration, as well as total nitrogen and total phosphorus concentrations, were recorded. The percent change in concentration was evaluated on a model-average basis (average change in all model computation elements) and with respect to the two computation elements with the lowest dissolved oxygen concentrations. The elements in the Dragon Run critical condition baseline scenario with the most critical dissolved oxygen levels occurred in Reach 5 (Figure 3-14). The sensitivity analysis results are provided in Table A-2 in Appendix A.

The results of this analysis showed that the dissolved oxygen concentrations predicted by the Qual2K model are most sensitive to changes in the sediment oxygen demand rate, the percentage of bottom area where SOD can take place, and the oxygen reaeration rate. The total nitrogen and total phosphorus concentrations are most sensitive to changes in bottom algae related parameters, such as the death rate, excretion rate, the in internal half saturation constants for nitrogen and phosphorus.

4.0 Nutrient Total Maximum Daily Loads and Allocations

As was stated in Chapter 1, the applicable State of Delaware water quality standards for dissolved oxygen are 5.5 mg/l for freshwater streams on a daily average basis and 4.0 mg/l on an instantaneous minimum basis. The TMDL nutrient targets are 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorous. The results of load reduction scenarios, as discussed in Chapter 3, show that under summer critical conditions as well as average conditions, the dissolved oxygen standards and nutrient targets are met along all simulated reaches of Army Creek, Red Lion Creek, and Dragon Run Creek. Therefore, it can be concluded that the nonpoint source load reduction rates listed below in Table 4-1 are sufficient to achieve water quality standards in the impaired segments of the Army Creek, Red Lion Creek, and Dragon Run Creek.

Table 4- 1 Nonpoint Source Nutrient Reductions Required for the Army Creek, Red Lion Creek, and Dragon Run Creek Watersheds

	TN	TP
Army Creek	40%	40%
Red Lion Creek	40%	40%
Dragon Run Creek	40%	40%

A TMDL is defined as:

$$TMDL = WLA + LA + MOS$$

Where,

WLA = waste load allocation for point sources
LA = load allocation for nonpoint sources
MOS = margin of safety to account for uncertainties and lack of data

As discussed previously, there are no active point sources discharging nutrients into Army Creek, Red Lion Creek, or Dragon Run Creek. However, New Castle County, in its entirety, has been issued by a Municipal Separate Storm Sewer System (MS4) permit (NPDES Permit # DE 0051071). EPA guidelines require that nonpoint source loads for MS4 permitted areas be considered as WLAs instead of LAs. Therefore, all nonpoint source nutrient loads generated from these three watersheds are allocated to an MS4 WLA, with no loadings allocated to nonpoint source LAs. Specific WLAs were not designated for stormwater outfalls discharging to Red Lion Creek or Dragon Run Creek because their contributions are already represented within the nonpoint source loads assigned to the MS4 WLA, as discussed above. EPA's policy memo of Nov. 22, 2002

indicates that for regulatory purposes, stormwater loads from facilities that are not covered by Phase I or Phase II of the NPDES storm water program can be considered as part of nonpoin source load (LA, or in this case MS4 WLA). The NPDES facilities within these watersheds are not covered by the Phase I or Phase II of the NPDES stormwater program. For these TMDLs, an implicit margin of safety has been considered through the use of conservative assumptions.

The baseline loads and TMDLs for Army Creek, Red Lion Creek, and Dragon Run Creek are calculated using scenario results discussed in Chapter 3. The loads are calculated as the product of headwater, tributary, and diffuse concentrations and the respective discharges. The baseline loads were estimated from the model results of the baseline scenario. The TMDL loads were estimated from the model results of the load reduction scenarios that applied the various necessary reduction rates mentioned above. Table 4-2 presents the MS4 waste load allocations for total nitrogen and total phosphorous.

Under average conditions in Army Creek, total nitrogen should be reduced from the baseline level of 18.4 kg/day (40.5 lb/day) to the level of 11.0 kg/day (24.3 lb/day), and total phosphorous should be reduced from the baseline of 1.54 kg/day (3.40 lb/day) to the level of 0.93 kg/day (2.04 lb/day).

Under average conditions in Red Lion Creek, total nitrogen should be reduced from the baseline level of 91.7 kg/day (202 lb/day) to the level of 55.0 kg/day (121 lb/day), and total phosphorous should be reduced from the baseline of 2.80 kg/day (6.17 lb/day) to the level of 1.68 kg/day (3.70 lb/day).

Under average conditions in Dragon Run Creek, total nitrogen should be reduced from the baseline of 60.3 kg/day (133 lb/day) to the level of 36.2 kg/day (79.7 lb/day), and total phosphorous should be reduced from the baseline of 3.21 kg/day (7.08 lb/day) to the level of 1.93 kg/day (4.25 lb/day).

Table 4- 2 MS4 Waste Load Allocations of the Army Creek, Red Lion Creek, and Dragon Run Creek Watershed TMDLs

	Flow (m^3/s)	TN Load (kg/day)		TP Load (kg/day)	
		Baseline	TMDL	Baseline	TMDL
Army Creek	0.10	18.4	11.0	1.54	0.93
Red Lion Creek	0.33	91.7	55.0	2.80	1.68
Dragon Run Creek	0.29	60.3	36.2	3.21	1.93

5.0 Establishment of the Bacteria TMDL for the Army Creek, Red Lion Creek, and Dragon Run Creek Watersheds

Bacteria impairments were not included in the QUAL2K modeling but were evaluated using the Cumulative Distribution Function Method to determine the reductions required in the Army Creek, Red Lion Creek, and Dragon Run Creek Watersheds to achieve water quality standards (100 CFU enterococci/100mL geometric mean). This approach was developed by Lee Dunbar at the Connecticut Department of Environmental Protection and much of the following text is based upon or copied directly from documentation provided by the Connecticut Department of Environmental Protection

Overall reductions of 37%, 38%, and 15% in the bacteria loading for the Army Creek, Red Lion Creek, and Dragon Run Creek Watersheds are required for the water quality to meet the geometric mean of 100CFU/100 mL.

5.1 Overview of Cumulative Distribution Function Method

This analytical methodology provides a defensible scientific and technical basis for establishing TMDLs to address recreational use impairments in urban watersheds. Representative ambient water quality monitoring data for a minimum of 21 sampling dates is required for the analysis. The reduction in bacteria density from current levels needed to achieve consistency with the criteria is quantified by calculating the difference between the cumulative relative frequency of the sample data set and the criteria adopted by Delaware to support recreational use. Delaware's adopted water quality criteria for the indicator bacteria fecal enterococci (geometric mean 100 CFU/100mL) is represented by a statistical distribution of geometric mean 100 and log standard deviation 0.4 for purposes of TMDL calculations.

The geometric mean criterion was derived by the EPA scientists from epidemiological studies at beaches where the incidence of swimming related health effects (gastrointestinal illness rate) could be correlated with indicator bacteria densities. Delaware's recommended criteria reflect an average illness rate of 12.5 illnesses per 1000 swimmers exposed. This condition was predicted to exist based on studies cited in the federal guidance when the steady-state geometric mean density of fecal enterococci was 100 col/100mL. The distribution of individual sample results around the geometric mean is such that approximately half of all individual samples are expected to exceed the geometric mean and half will be below the geometric mean.

EPA also derived a formula to calculate single sample maximum criteria from this same database to support decisions by public health officials regarding the closure of beaches when an elevated risk of illness exists. Because

approximately half of all individual sample results for a beach where the risk of illness is considered "acceptable" are expected to exceed the geometric mean criteria of 100CFU/100mL, an upper boundary to the range of individual sample results was statistically derived that will be exceeded at frequencies less than 50% based on the variability of sample data. The mean log standard deviation for fecal enterococci densities at the freshwater beach sites studied by EPA was 0.4. Using these values, 457 CFU/100mL was calculated to represent the 95th percentile upper confidence limit (5% exceedance frequency) for this statistical distribution of data and was used as the acceptable, risk based upper boundary.

TMDLs developed using this approach are expressed as the average percentage reduction from current conditions required to achieve consistency with criteria. The procedure partitions the TMDL into regulated point source wasteload allocation (WLA) and non-point source load allocation (LA) components by quantifying the contribution of ambient monitoring data collected during periods of high storm water influence and minimal storm water influence to the current condition. TMDLs developed using this analytical approach provide an ambient monitoring benchmark ideally suited for quantifying progress in achieving water quality goals as a result of TMDL implementation.

5.2 TMDL End Point Determination

The criteria can be expressed as a cumulative frequency distribution or "criteria curve" as shown in Figure 5.1.

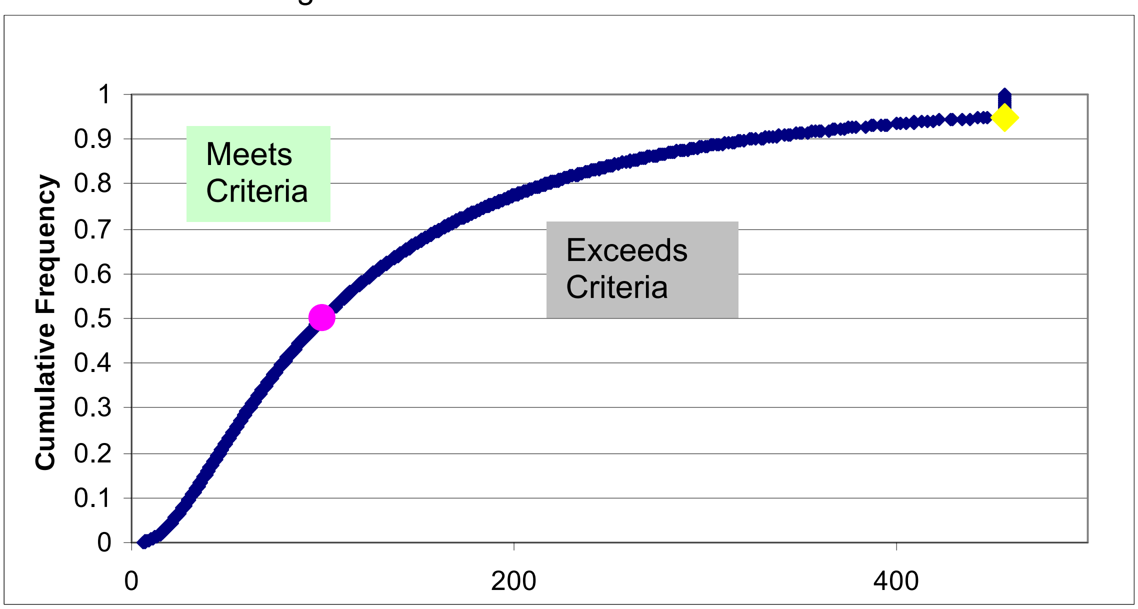


Figure 5-0-1 Cumulative Relative Frequency Distribution representing Delaware Water Quality Standards

As with the cumulative relative frequency curve representing the criteria shown in Figure 1, a cumulative relative frequency curve can be prepared using site-specific sample data to represent current conditions at the TMDL monitoring sites. The TMDL for the monitored segments are derived by quantifying the difference between these two distributions as shown conceptually in Figure 2. This is accomplished by calculating the reduction required at representative points on the sample data cumulative frequency distribution curve and then averaging the reduction needed across the entire range of sampling data. This procedure allows the contribution of each individual sampling result to be considered when estimating the percent reduction needed to meet a criterion that is expressed as a geometric mean.

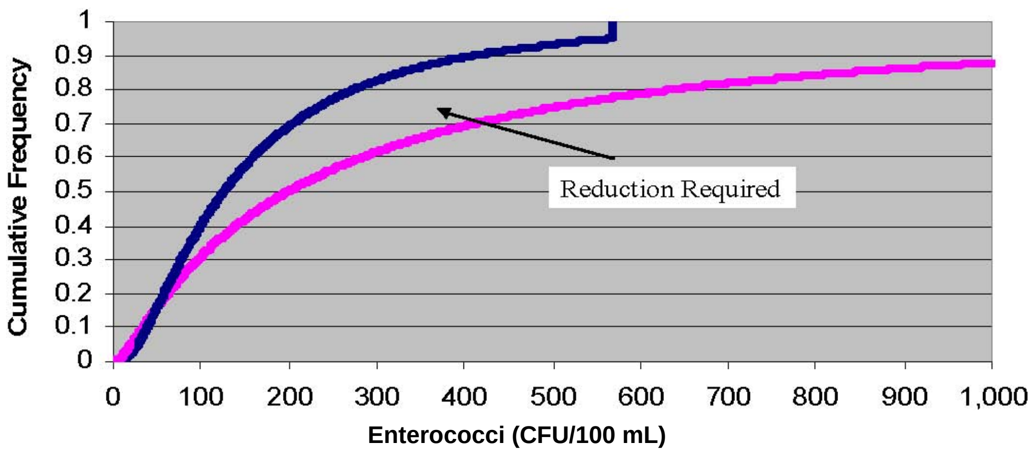


Figure 5-0-2 Reduction in indicator bacteria density needed from current condition (magenta line) to meet criteria (blue line) based on cumulative relative frequency distribution.

WLA and LA

Stormwater runoff in an urbanized area is considered a point source subject to regulation under the NPDES permitting program. TMDLs for indicator bacteria in waters draining urbanized areas must therefore be partitioned into a WLA to accommodate point source stormwater loadings of indicator bacteria and a LA to accommodate non-point loadings from unregulated sources. This is accomplished using the same ambient monitoring data used to establish the TMDL.

One common characteristic of urbanized areas is the high percentage of impervious surface. Much of the impervious surface is directly connected to nearby surface waters through stormwater drainage systems. As a result, runoff is rapid following rain events and flow in urban streams is typically dominated by stormwater runoff during these periods. Monitoring results for samples collected under these conditions are strongly influenced by stormwater quality. During dry conditions, urban streams contain little stormwater since urban watersheds

drain quickly and baseflows are reduced due to lower infiltration rates and reduced recharge of groundwater. At baseflow, urban stream water quality is dominated by non-point sources of indicator bacteria since stormwater outfalls are inactive.

The relative contribution of indicator bacteria loadings occurring during periods of high or low stormwater influence to the geometric mean indicator density is estimated by calculating separate averages of the reduction needed to achieve consistency with criteria under “wet” and “dry” conditions. The reduction needed under “wet” conditions is assigned to the WLA and the reduction needed under “dry” conditions is assigned to the LA. Separate reduction goals are established for baseflow and stormwater dominated periods that can assist local communities in selection of best management practices to improve water quality. The technique also facilitates the use of ambient stream monitoring data to track future progress in meeting water quality goals.

5.3 Analytical Procedure – TMDL

1. The fecal enterococcus monitoring data is ranked from lowest to highest. In the event of ties, monitoring results are assigned consecutive ranks in chronological order of sampling date. The sample proportion (p) is calculated for each monitoring result by dividing the assigned rank (r) for each sample by the total number of sample results (n): $p = r / n$

2. Next, a single sample criteria reference value is calculated for each monitoring result from the statistical distribution used to represent the criteria following the procedure described in steps 3-6 below:

3. If the sample proportion is equal to or greater than 0.95, the single sample criteria reference value is equivalent to the maximum value of 457 CFU/mL.

4. If the sample proportion is less than 0.95, and greater than 0.50, the single sample criteria reference value is calculated as:

criteria reference value = antilog_{10} [$\log_{10}$ 100 CFU/100mL + {F x 0.4}]

> Note: 100 CFU/100mL is the geometric mean indicator bacteria criterion adopted into Delaware’s Water Quality Standards, F is a factor determined from areas under the Normal probability curve for a probability level equivalent to the sample proportion, 0.4 is the $\log_{10}$ standard deviation used by EPA in deriving the national guidance criteria recommendations.

5. If the sample proportion is equal to 0.50, the single sample reference criteria value is equal to the geometric mean criterion adopted into the Water Quality Standards (100 CFU/100mL).

6. If the sample proportion is less than 0.50, the single sample reference criteria value is calculated as:
criteria reference value = antilog_{10} [$\log_{10}$ 100 CFU/100mL - {F x 0.4}]

7. The percent reduction necessary to achieve consistency with the criteria is then calculated following the procedure described in steps 8-9 below:

8. If the monitoring result is less than the single sample reference criteria value, the percent reduction is zero.

9. If the monitoring result exceeds the single sample criteria reference value, the percent reduction necessary to meet criteria on that sampling date is calculated as:
percent reduction = ((monitoring result – criteria reference value)/monitoring result)x100

10. The TMDL, expressed as the average percent reduction to meet criteria, is then calculated as the arithmetic average of the percent reduction calculated for each sampling date.

11. Precipitation data is reviewed and each sampling date is designated as a “dry” or “wet” sampling event. Although a site-specific protocol may be specified in an individual TMDL analysis, typically samples collected within 48 hours of a precipitation event of 0.25 inches or greater are designated as “wet”.

12. The average percent reduction for all sampling events used to derive the TMDL that are designated as “wet” is computed and established as the WLA.

13. The average percent reduction for all sampling events used to derive the TMDL that are designated as “dry” is computed and established as the LA.

5.4 TMDL Reductions

	Waste Load Allocation reduction	**Load Allocation reduction**	**Overall TMDL reductions**
Army Creek	54%	24%	**37%**
Red Lion	48%	31%	**38%**
Dragon Run	22%	10%	**15%**

Table 5 -1 TMDL allocations for Army Creek, Red Lion and Dragon Run Watersheds.

5.4.1 Army Creek

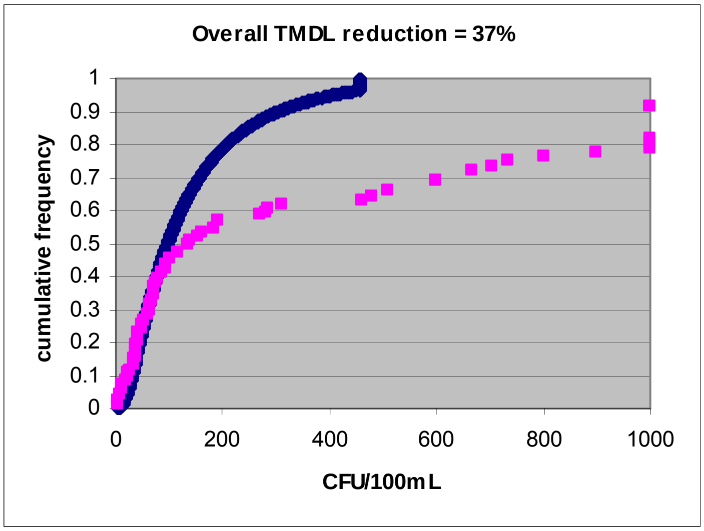


Figure 5-0-3 Army Creek, Overall TMDL needed from current condition (magenta squares) to meet criteria (blue line). Current condition based on dry and wet weather data.

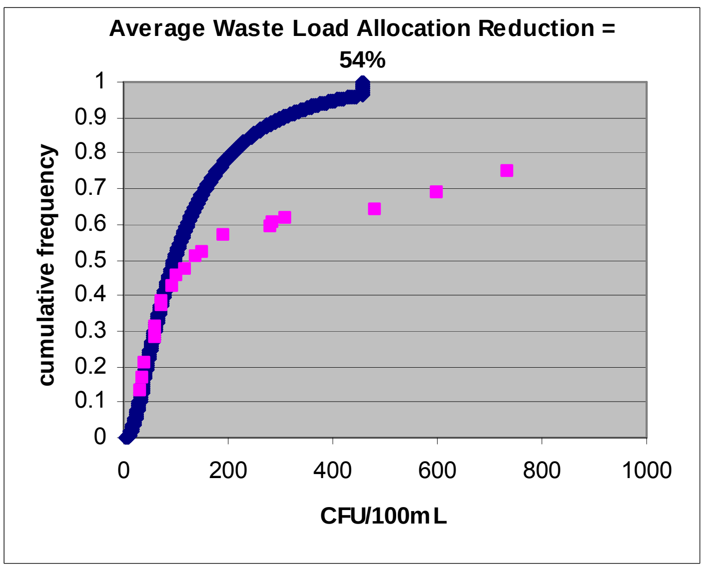


Figure 5-0-4 Army Creek, Waste Load Allocation (WLA) needed from current condition (magenta squares) to meet criteria (blue line). Current condition based on wet weather data.

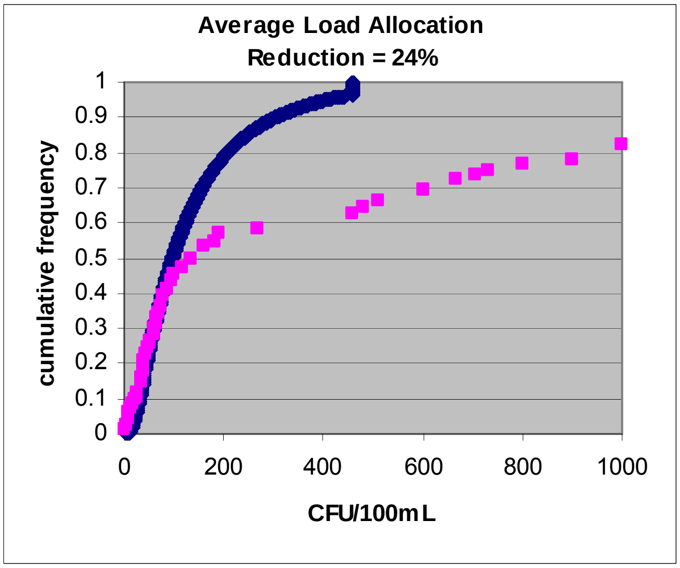


Figure 5-0-5 Army Creek, Load Allocation (LA) needed from current condition (magenta squares) to meet criteria (blue line). Current condition based on dry weather data.

5.4.2 Red Lion

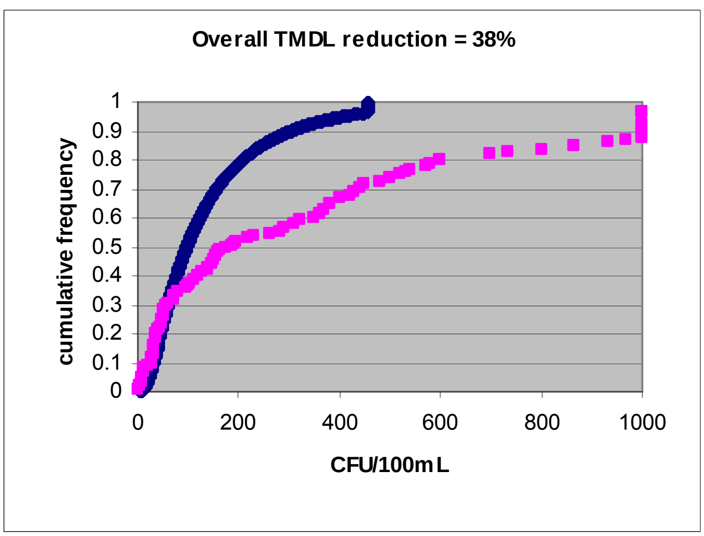


Figure 5-0-6 Red Lion, Overall TMDL needed from current condition (magenta squares) to meet criteria (blue line). Current condition based on dry and wet weather data.

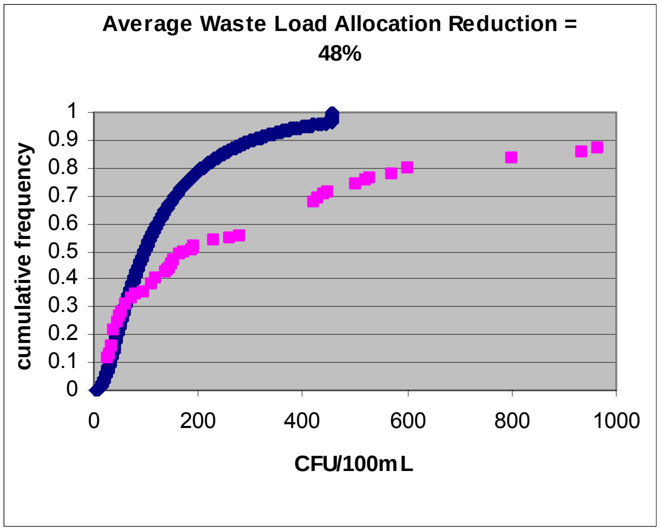


Figure 5-0-7 Red Lion, Waste Load Allocation (WLA) needed from current condition (magenta squares) to meet criteria (blue line). Current condition based on wet weather data.

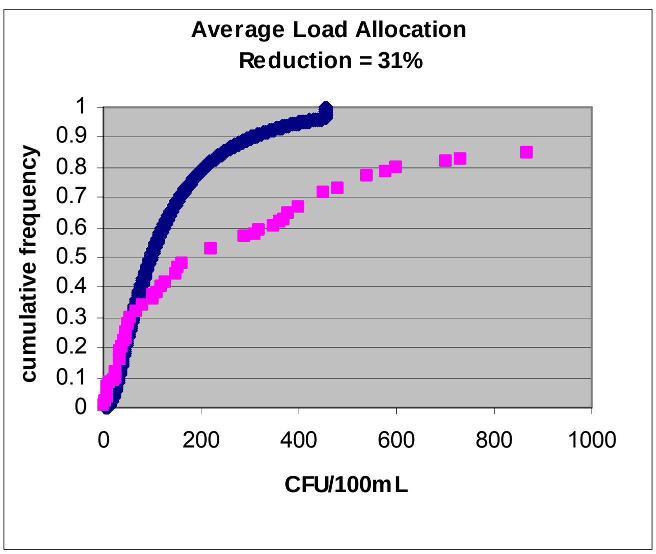


Figure 5-0-8 Red Lion, Load Allocation (LA) needed from current condition (magenta squares) to meet criteria (blue line). Current condition based on dry weather data.

5.4.3 Dragon Run

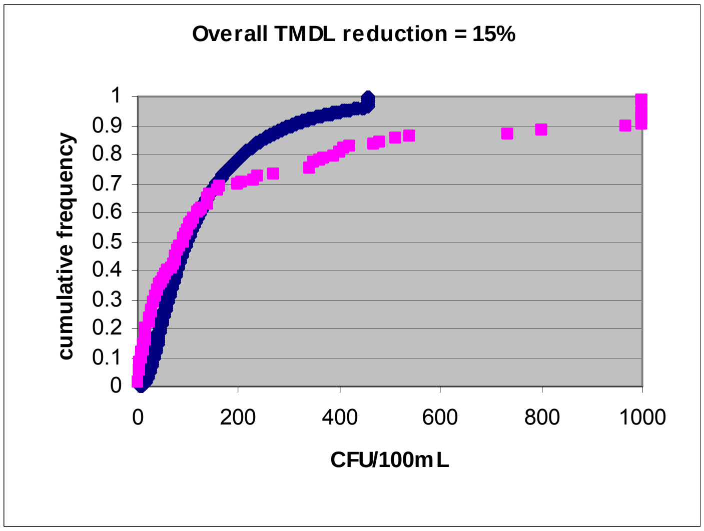


Figure 5-0-9 Dragon Run, Overall TMDL needed from current condition (magenta squares) to meet criteria (blue line). Current condition based on dry and wet weather data.

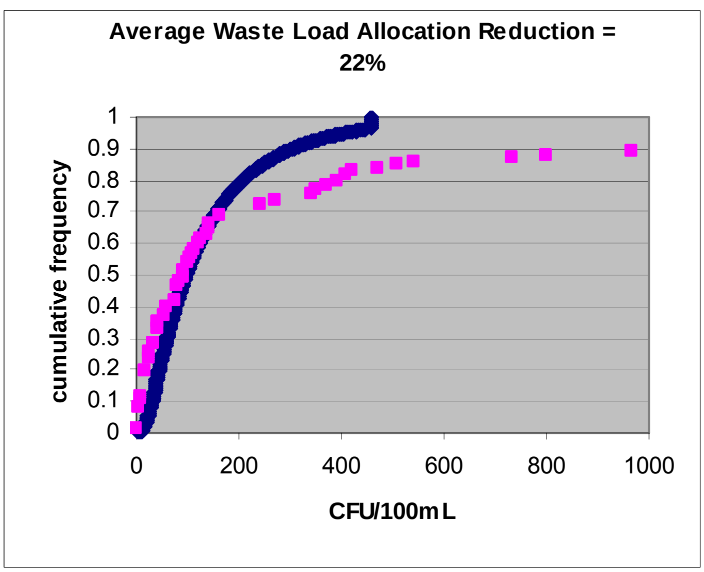


Figure 5-0-10 Dragon Run, Waste Load Allocation (WLA) needed from current condition (magenta squares) to meet criteria (blue line). Current condition based on wet weather data.

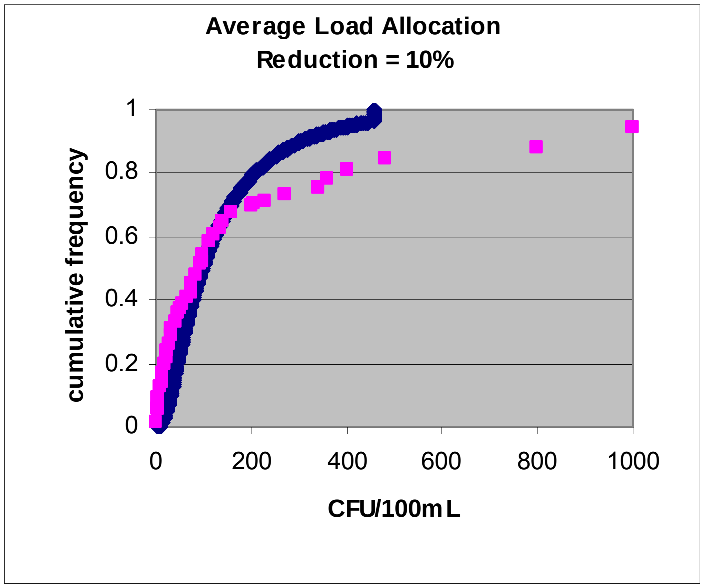


Figure 5-0-11 Dragon Run, Load Allocation (LA) needed from current condition (magenta squares) to meet criteria (blue line). Current condition based on dry weather data.

5.5 Daily Loading

With respect to bacteria, the total maximum daily load can be considered in many different ways because the water quality standard is not expressed in daily terms but as a geometric mean over time, typically a period of 30 days. A theoretical maximum, albeit an unrealistic scenario, can be calculated so that the entire loading over the 30-day period occurs in one day. A more practical approach would be to calculate the maximum load at a level corresponding to the appropriate confidence interval and risk level, e.g. a 95% confidence interval and its related single sample value. However, this approach is problematic, as it does not ensure that the geometric mean will be equal to or below the water quality standard.

An average daily maximum, calculated by multiplying the average daily flow times the water quality standard would arguably be the most appropriate measure of a daily maximum with respect to TMDL requirements. Table illustrates all of the above maximum daily loading calculations.

Table 5-2 Flow and Daily Loading

	Flow (m³/day)	Current loading – wet weather (CFU/day)	Current loading – dry weather (CFU/day)	Theoretical Maximum Daily Load (CFU/day)	95% Confidence Interval Daily Load (CFU/day)	Average Daily Maximum Load (CFU/day)
Army Creek	9,046	3.0E+10	1.5E+10	9.0E+67	4.9E+10	9.0E+09
Red Lion	28,961	6.5E+10	4.6E+10	2.9E+68	1.6E+11	2.9E+10
Dragon Run	25,229	3.8E+10	3.1E+10	2.5E+68	1.4E+11	2.5E+10

5.6 Source Tracking Adjustment Factor

The Source Tracking Adjustment Factor (STAF) is a multiplier used to normalize human health risk associated with total fecal enterococci counts to enterococci counts derived exclusively from human sources. Bacteria source tracking (BST) data and the STAF, when available, will be used throughout the State to determine the sources of fecal contamination and in the development of pollution control strategies (PCSs).

6.0 Discussion of Regulatory Requirements for TMDLs

Federal regulations of 40 CFR Section 130 require that TMDLs must meet the following eight minimum regulatory requirements:

1. The TMDLs must be designed to achieve applicable water quality standards.
2. The TMDLs must include a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources.
3. The TMDLs must consider the impact of background pollutants.
4. The TMDLs must consider critical environmental conditions.
5. The TMDLs must consider seasonal variations.
6. The TMDLs must include a margin of safety.
7. The TMDLs must have been subject to public participation.
8. There should be a reasonable assurance that the TMDLs can be met.

As will be discussed in the following, the TMDLs for Army Creek, Red Lion Creek, and Dragon Run Creek meet the above eight minimum regulatory requirements.

6.1 The TMDLs must be designed to achieve applicable water quality standards.

The water quality standards for dissolved oxygen and bacteria and nutrient guidelines for total nitrogen and total phosphorus applicable to the Army Creek, Red Lion Creek, and Dragon Run Creek watersheds were described in Chapter 1. The State of Delaware dissolved oxygen criteria for fresh water streams is 5.5 mg/l on a daily average basis and 4.0 mg/l on an instantaneous minimum basis; the enterococcus criteria is 100 CFU/100 mL as a 30 day geometric mean; and the TMDL nutrient target levels are 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus. The analyses show that for Army Creek, the standards will be met by reducing the total nitrogen and total phosphorus loads by 40% from the baseline levels, and reducing the bacteria load by 39% from the 1997 – 2005 baseline level. For Red Lion Creek, the standards will be met by reducing the total nitrogen and total phosphorus loads by 40% from the baseline levels, and reducing the bacteria load by 40% from the 1997 – 2005 baseline level. For Dragon Run Creek, the standards will be met by reducing the total nitrogen and total phosphorus loads by 40% from the baseline levels, and reducing the bacteria load by 19% from the 1997 – 2005 baseline level. Therefore, it can be concluded that the proposed TMDLs meet the applicable water quality criteria and target values.

6.2 The TMDLs must include a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources.

The total allowable loads have been calculated and are presented in Table 4-2 for nutrients and Table 5-1 for bacteria. The proposed TMDLs allocate all of the nonpoint source nutrient loads and bacteria waste load allocations to the New Castle County MS4 permit, as EPA guidelines suggest. The entire waste load allocation is from the MS4 land area since no other point sources discharge nutrients or bacteria to the creeks and the load allocations are zero. Therefore, it can be concluded that the proposed TMDLs include allocations for point and nonpoint sources.

6.3 The TMDLs must consider the impact of background pollutants.

The TMDL analyses for the Army Creek, Red Lion Creek, and Dragon Run Creek were based on calibrated Qual2K water quality models and/or water quality data collected in the watershed. Since background conditions are reflected in the calibrated models and the monitoring data, it can be concluded that the impact of background pollutants is accounted in these TMDL analyses.

6.4 The TMDLs must consider critical environmental conditions.

Low stream flow during summer months coupled with high water temperatures constitute critical conditions for Army Creek, Red Lion Creek, and Dragon Run Creek and has been recognized and simulated in the nutrient analyses. A scenario that incorporated 7Q10 flow with high water temperature was considered in each case. Headwater conditions and tributary inflow conditions were defined using data collected during summer months (June, July, August, and September). Details of the nutrient model inputs and results of the model runs are discussed in Chapters 2 and 3 and showed that implementing nonpoint source reductions of 40% nitrogen and 40% phosphorus in Army Creek, Red Lion Creek, and Dragon Run Creek would result in achieving water quality standards and nutrient targets. For bacteria, concentrations and loadings were analyzed during wet and dry conditions, which include any critical conditions. Therefore, the critical conditions of Army Creek, Red Lion Creek, and Dragon Run Creek were considered in this analysis.

6.5 The TMDLs must consider seasonal variations.

Seasonal variations are considered in the Army Creek, Red Lion Creek, and Dragon Run Creek Qual2K Models as the models were calibrated to the average flow and water quality conditions. The data used to define the model inputs were collected during 2002-2005 at different months (see Surface Water Quality Monitoring Program FY2001 (9)), which reflected the seasonal variations in the models. In addition, the models were also run under summer critical condition of 7Q10 flow coupled with high temperature as well as summer water quality concentrations. The data used for the bacteria analyses was collected over a ten year period, with each season represented in the data set. Therefore, seasonal variations have been considered for these analyses.

6.6 The TMDLs must include a margin of safety.

EPA's technical guidance allows consideration of a margin of safety as implicit or as explicit. An implicit margin of safety considers the conservative assumptions for model development and TMDL establishment. An explicit margin of safety reserves a specified percentage of assimilative capacity unassigned to account for uncertainties, lack of sufficient data, or future growth.

An implicit margin of safety has been considered for the Army Creek, Red Lion Creek, and Dragon Run Creek nutrient analyses. The Qual2K models were calibrated using conservative assumptions, which include but are not limited to:

- Choosing a conservative option for estimating oxygen reaeration rate,
- Applying conservative values for sediment oxygen demand and sediment nutrient fluxes,
- Assigning sediment oxygen demand to 100% of the stream bottom,
- Assigning conservative values for cloud cover and stream shading,
- Utilizing median values of dissolved oxygen data for calibration and headwater input stations, as opposed to less conservative average values,
- Utilizing the method detection limit for BOD20 rather than zero when sample values at calibration and headwater input stations were below the method detection limit,
- Utilizing the permitted Valero intakes during annual average TMDL scenarios rather than the lesser reported usage values.

Consideration of these conservative assumptions contributes to the implicit margin of safety and therefore an adequate margin of safety is included in the nutrient TMDLs.

For bacteria, the indicator bacteria criteria used in this TMDL analysis were developed exclusively from data derived from studies conducted at high use public bathing areas of which half were affected by point source discharges (12). Therefore, the criteria provide an additional level of protection when applied to

water not designated for high use bathing and without point sources such as those within these watersheds. As a result, achieving the criteria results in an "implicit" MOS. A portion of this "implicit" MOS will be removed via use of the Source Tracking Adjustment Factor (STAF), a tool that will be used in the implementation and best management practice designs during development of the Pollution Control Strategies (PCS) following the adoption of the TMDL. However, the STAF incorporates an explicit margin of safety so that a portion of the "implicit" MOS remains intact. Therefore, an adequate margin of safety is included in the bacteria TMDLs.

6.7 The TMDLs must have been subject to public participation.

The proposed TMDLs for the Army Creek, Red Lion Creek, and Dragon Run Creek were presented at a public workshop on May 16, 2006 at DNREC's Lukens Drive office in New Castle, Delaware. The workshop was advertised in local and regional newspapers, on the State of Delaware and DNREC websites, as well as in the May 1, 2006 edition of the Delaware Register of Regulations. The public was invited to submit comments on the draft TMDLs during the entire month of May 2006. All comments received were considered and this report has been updated to address several comments.

A public hearing will also be held where comments can again be entered into public record. It is currently scheduled for August 29, 2006 also at DNREC's Lukens Drive office. Notices advertising the public workshops and hearing will be published in local and regional newspapers and on internet sites. In addition, notice of the public hearing and proposed regulations has been published in the Delaware Register of Regulations. Considering these opportunities, it can be concluded that the TMDLs for the Army Creek, Red Lion Creek, and Dragon Run Creek will have been subject to significant public participation.

6.8 There should be a reasonable assurance that the TMDLs can be met.

The TMDLs for the Army Creek, Red Lion Creek, and Dragon Run Creek require reduction of nutrients and bacteria from nonpoint sources. As a result of these reductions, water quality standards with regard to dissolved oxygen and enterococcus bacteria will be met in all segments of these three water bodies. Following adoption of these TMDLs, the Delaware DNREC in association with local citizen groups and other affected parties, will implement the requirements of these TMDLs through development of Pollution Control Strategies. Therefore, it can be concluded that there is a reasonable assurance that the TMDLs for the Army Creek, Red Lion Creek, and Dragon Run Creek will be met.

7.0 References

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12. United States Environmental Protection Agency, 1986*. Ambient Water Quality Criteria for Bacteria -1986.* EPA 440/5-84-002

Appendix A Sensitivity Analyses

Table A- 1 Critical Condition Baseline Concentrations in Army Creek, Red Lion Creek, and Dragon Run Creek Qual2K Models

	Model Average			Most Critical Element				2nd Most Critical Element			
	DO Min (mg/l)	TN Max (ug/l)	TP Max (ug/l)	R# E#	DO Min (mg/l)	TN Max (ug/l)	TP Max (ug/l)	R# E#	DO Min (mg/l)	TN Max (ug/l)	TP Max (ug/l)
Army Creek	3.76	929.3	82.36	R4 E5	2.39	698.4	52.64	R4 E6	2.391	688.3	50.67
Red Lion Creek	5.74	1,795	61.97	R7 E10	2.37	691.2	33.44	R7 Outlet	2.367	691.2	33.44
Dragon Run Creek	3.67	1,147	58.65	R5 E3	1.74	1,082	61.27	R5 E4	1.739	1,086	61.98

Table A- 2 Summary of Sensitivity Analysis for Dragon Run Creek Qual2K Model

Parameter	Unit	Symbol	Value	Input Change	Percent Change from Baseline								
					Model Average			Reach 5, Element 3			Reach 5, Element 4		
					DO	TN	TP	DO	TN	TP	DO	TN	TP
ISS settling velocity	m/d	*vi*	0.100	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O_2 reaeration			0.500	50	18.9	0.9	1.0	35.6	0.9	0.8	36.3	1.0	0.8
				-50	-41	-2.7	-2.7	-154	-1.9	-1.4	-166	-2.1	-1.6
O_2 for C oxidation	gO_2/gC	r_{OC}	2.670	50	-10	-0.2	0.0	-42	-0.5	-0.3	-40	-0.4	-0.2
				-50	9.5	0.3	0.0	30.1	0.2	0.2	29.2	0.2	0.2
O_2 for NH_4 nitrification	gO_2/gN	r_{ON}	4.570	50	-2.4	-0.2	-0.2	-4.0	-0.1	-0.1	-4.1	-0.1	-0.1
				-50	2.3	0.1	0.2	3.8	0.1	0.1	3.9	0.1	0.1
O inhibition CBOD oxidation parameter	L/mgO_2	K_{socf}	0.600	50	-0.2	0.0	0.0	-0.4	0.0	0.0	-0.4	0.0	0.0
				-50	0.4	0.0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
O inhibition nitrification parameter	L/mgO_2	K_{sona}	0.600	50	-0.4	0.0	0.0	-0.8	0.0	0.0	-0.9	0.0	0.0
				-50	1.0	0.1	0.1	1.9	0.0	0.0	1.9	0.1	0.0
O enhance. Denitrify. parameter	L/mgO_2	K_{sodn}	0.600	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O inhibition phyto. respiration parameter	L/mgO_2	K_{sop}	0.600	50	0.0	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0	0.0
				-50	0.1	0.0	0.1	0.2	0.0	0.1	0.2	0.0	0.1
O enhance. bottom algae resp. parameter	L/mgO_2	K_{sob}	0.600	50	-0.9	1.6	1.3	-3.3	2.1	1.3	-3.4	2.2	1.4
				-50	2.7	-5.1	-3.2	6.9	-6.3	-3.3	7.0	-6.5	-3.4
Bottom SOD coverage	%		100.000	NA									
				-50	31.0	-0.5	-2.5	53.9	-0.2	-1.7	54.2	-0.2	-1.7
Prescribed SOD	$gO_2/m^2/d$		0.0-0.4	50	-41	-2.9	-2.6	-231	-4.1	-2.7	-233	-4.4	-2.8
				-50	25.3	1.3	1.4	46.0	1.6	1.3	46.3	1.7	1.4
Slow CBOD hydrolysis rate	/d	k_{hc}	1.000	50	-1.3	-0.1	-0.1	-3.0	-0.1	-0.1	-3.0	-0.1	-0.1
				-50	1.7	0.1	0.1	3.4	0.1	0.1	3.5	0.1	0.1
Slow CBOD oxidation rate	/d	k_{dcs}	0.000	1	-4.5	-0.3	-0.3	-11	-0.4	-0.3	-11	-0.5	-0.3
				NA									
Fast CBOD oxidation rate	/d	*kdcs*	0.200	50	-0.7	-0.1	0.0	-1.4	-0.1	-0.1	-1.4	-0.1	-0.1
				-50	0.8	0.1	0.0	1.4	0.1	0.1	1.4	0.1	0.1

ON hydrolysis rate	/d	k_{hn}	0.400	50	-0.3	-3.6	0.0	-0.4	-2.7	0.0	-0.5	-2.8	0.0
				-50	0.4	4.1	0.0	0.5	2.9	0.0	0.6	3.0	0.0
ON settling rate	m/d	v_{on}	0.025	50	-0.5	-1.6	0.0	-0.9	-1.7	0.0	-0.9	-1.7	0.0
				-50	0.5	1.7	0.0	1.0	1.7	0.0	1.0	1.7	0.0
NH_4 nitrification rate	/d	k_{na}	4.000	50	-1.6	-0.1	-0.1	-3.2	-0.1	-0.1	-3.2	-0.1	-0.1
				-50	1.9	0.1	0.1	3.4	0.1	0.1	3.5	0.1	0.1
Prescribed NH_4 flux	mgN/m^2/d		200.000	50	-1.2	8.7	-0.2	-2.0	9.5	-0.1	-2.2	9.4	-0.1
				-50	1.5	-8.3	0.1	2.2	-8.5	0.1	2.4	-8.6	0.1
NO_3 denitrific. rate	/d	dn_{hc}	0.000	1	0.1	-0.4	0.0	0.2	-0.6	0.0	0.2	-0.7	0.0
				NA									
Sediment denitrific. transfer coefficient	m/d	v_{di}	0.000	1	-3.0	-19	-0.4	-5.3	-12	-0.4	-5.2	-12	-0.4
				NA									
OP hydrolysis rate	/d	k_{hp}	1.000	50	-0.1	-0.6	-12	-0.8	-0.7	-11	-0.7	-0.7	-11
				-50	0.2	0.9	12.9	1.0	1.1	11.0	1.0	1.1	11.1
OP settling velocity	m/d	v_{op}	0.025	50	0.0	0.0	-2.1	0.0	0.0	-2.3	0.0	0.0	-2.3
				-50	0.0	0.0	2.1	0.0	0.0	2.3	0.0	0.0	2.3
InorgP settling velocity	m/d	v_{ip}	0.000	1	0.5	2.4	-3.6	2.6	2.6	-3.1	2.4	2.6	-3.2
				NA									
InorgP sorption coefficient	L/mgD	K_{dpi}	0.000	1	0.0	0.2	-0.3	0.2	0.2	-0.2	0.2	0.2	-0.2
				NA									
Sediment P O atten. half sat. constant	mgO$_2$/l	k_{spi}	0.050	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prescribed InorgP flux	mgP/m^2/d		25.000	50	-0.5	-2.3	7.7	-3.0	-2.6	6.9	-2.7	-2.5	6.9
				-50	1.0	4.4	-6.5	5.0	5.3	-5.8	4.7	5.1	-5.9
Phytoplank. max growth rate	/d	k_{gp}	2.000	50	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
Phytoplank. respiration rate	/d	k_{rp}	0.275	50	-0.2	-0.1	-0.2	-0.3	-0.1	-0.1	-0.3	-0.1	-0.1
				-50	0.2	0.1	0.2	0.3	0.1	0.1	0.3	0.1	0.1
Phytoplank. death rate	/d	k_{dp}	0.000	1	0.1	0.0	-0.2	0.1	0.0	0.0	0.1	0.0	0.0
				NA									
Phytoplank. N half saturation constant	ugN/l	k_{sNp}	155.000	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Phytoplank. P half saturation constant	ugP/l	k_{sPp}	26.000	50	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Phyto. InorgC half saturation constant	moles/l	k_{sCp}	0.000	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phytoplank. light constant	Langley's/d	K_{Lp}	57.600	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phytoplank. NH3 preference	ugN/l	k_{hnxp}	25.000	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phytoplank. settling velocity	m/d	v_a	0.100	50	-0.4	-0.2	-0.4	-0.7	-0.2	-0.4	-0.7	-0.2	-0.4
				-50	0.4	0.2	0.5	0.9	0.2	0.4	0.9	0.2	0.4
Bottom algae max growth rate	$mgA/m^2/d$	C_{gb}	2.000	50	-5.9	-20	-8.9	-29	-18	-8.2	-27	-18	-8.4
				-50	-2.5	42.7	38.6	16.0	46.7	38.0	14.0	46.7	37.9
Bottom alg. 1st order model carry. cap.	mgA/m^2	$a_{b,max}$	100.000	50	0.3	-8.9	-4.2	-7.5	-8.4	-3.9	-6.3	-8.6	-4.0
				-50	0.8	23.2	14.4	14.1	27.4	13.1	12.8	27.3	13.2
Bottom algae respiration rate	/d	k_{rb}	0.275	50	-2.7	19.0	11.7	-2.2	22.3	10.2	-2.9	22.0	10.3
				-50	6.9	-16	-7.1	13.7	-14	-6.3	13.9	-14	-6.5
Bottom algae excretion rate	/d	k_{eb}	0.000	1	-21	43.0	37.6	-51	46.4	35.1	-54	46.2	35.1
				NA									
Bottom algae death rate	/d	k_{db}	0.000	1	-27	58.6	67.8	-26	60.1	65.0	-30	60.3	65.2
				NA									
Bottom alg. external N half sat. constant	ugN/l	k_{sNb}	300.000	50	0.3	4.8	0.0	0.7	5.7	0.0	0.7	5.7	0.0
				-50	-0.1	-6.8	0.0	-0.6	-8.6	0.0	-0.5	-8.7	0.0
Bottom alg. external P half sat. constant	ugP/l	k_{sPb}	50.000	50	0.2	0.8	5.7	0.7	0.6	5.1	0.6	0.6	5.2
				-50	-0.2	-0.9	-7.2	-0.7	-0.7	-6.6	-0.7	-0.7	-6.8
Bottom alg. InorgC half saturation constant	moles/l	k_{sCb}	0.000	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bottom algae light constant	Langley's/d	K_{Lb}	50.000	50	0.9	7.9	4.5	5.7	8.6	4.0	5.0	8.5	4.0
				-50	-0.9	-8.2	-4.2	-6.2	-7.7	-3.7	-5.2	-7.8	-3.9
Bottom algae NH3 preference	ugN/l	k_{hnxb}	25.000	50	-1.5	-0.1	-0.1	-3.3	-0.1	-0.1	-3.3	-0.1	-0.1
				-50	2.1	0.1	0.1	3.9	0.1	0.1	4.0	0.1	0.1
Bottom algae subsistence quota for N	mgN/mgA	q_{0N}	7.200	50	-33	57.4	63.6	-48	59.1	61.8	-53	59.3	61.9
				-50	0.1	0.6	0.0	0.2	0.6	0.0	0.1	0.7	0.0

Bottom algae subsistence quota for P	mgP/mgA	q_{0P}	1.000	50	-30	56.0	66.2	-38	58.1	63.5	-43	58.2	63.6
				-50	-1.6	-6.0	-2.3	-7.5	-6.0	-2.2	-7.0	-6.0	-2.2
Bottom algae max uptake rate for N	mgN/mgA/d	r_{mN}	720.000	50	-0.5	-9.2	0.0	-1.3	-8.8	0.0	-1.1	-9.0	0.0
				-50	1.3	16.8	0.0	3.0	19.3	0.0	2.8	19.1	0.0
Bottom algae max uptake rate for P	mgP/mgA/d	r_{mP}	100.000	50	-0.2	-0.7	-5.2	-0.5	-0.5	-4.7	-0.5	-0.6	-4.8
				-50	0.6	2.2	13.1	1.9	1.8	11.5	1.7	1.8	11.7
Bottom alg. internal N half sat. constant	mgN/mgA	K_{qN}	9.000	50	-0.5	-8.6	0.0	-1.3	-8.2	0.0	-1.1	-8.4	0.0
				-50	-33	57.4	63.6	-48	59.1	61.8	-53	59.3	61.9
Bottom alg. internal P half sat. constant	mgP/mgA	qP_{dpi}	1.300	50	-0.1	-0.5	-4.4	-0.4	-0.4	-4.0	-0.4	-0.4	-4.1
				-50	-30	56.0	66.2	-38	58.1	63.5	-43	58.2	63.6
Bottom algae coverage	%		50.000	50	-2.1	-13	-6.7	-16	-13	-6.2	-14	-13	-6.4
				-50	3.4	27.3	20.7	18.9	31.0	18.9	17.7	30.8	19.0
POM dissolution rate	/d	k_{dt}	0.200	50	0.1	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0
				-50	-0.1	0.0	0.0	-0.3	0.0	0.0	-0.3	0.0	0.0
Fraction of dissolution to fast CBOD		F_f	0.000	1	-1.8	-0.1	-0.1	-3.9	-0.1	-0.1	-3.9	-0.1	-0.1
				NA									
POM settling velocity	m/d	v_{dt}	0.100	50	-4.3	-0.6	-0.3	-11	-0.6	-0.4	-10	-0.7	-0.4
				-50	5.7	0.8	0.5	13.1	0.7	0.5	13.0	0.8	0.5
Partial pressure of carbon dioxide	ppm	p_{CO2}	347.000	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Photosynth. available radiation			0.470	50	-0.6	-5.4	-2.8	-4.2	-5.1	-2.5	-3.5	-5.2	-2.6
				-50	1.6	15.1	9.1	10.2	17.4	8.1	9.2	17.2	8.2
Backg. light extinction	/m	k_{eb}	0.200	50	0.0	0.3	0.2	0.2	0.3	0.2	0.2	0.3	0.2
				-50	0.0	-0.3	-0.2	-0.2	-0.3	-0.2	-0.1	-0.3	-0.2
Linear chlorophyll light extinction	1/m-(ugA/l)	a_p	0.009	50	0.0	0.8	0.6	0.5	0.7	0.4	0.4	0.8	0.5
				-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nonlinear chlorophyll light extinction	1/m-(ugA/l)2/3	a_{pn}	0.054	50	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
				-50	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
ISS light extinction	1/m-(mgD/l)	a_i	0.052	50	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
				-50	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
POM light extinction	1/m-(mgD/l)	a_o	0.174	50	0.1	0.7	0.5	0.5	0.7	0.4	0.4	0.7	0.4
				-50	-0.1	-0.7	-0.4	-0.5	-0.7	-0.4	-0.4	-0.7	-0.4

Bras solar param. atmos. turbid. coef.		n_{fac}	2.000	5	3.0	19.3	12.5	14.2	22.6	11.0	12.9	22.4	11.2
				1	-1.3	-5.8	-3.3	-5.7	-5.6	-2.8	-5.0	-5.7	-2.9
Sediment thermal thickness	cm	H_s	10.000	50	0.3	-0.2	-0.1	0.4	-0.3	-0.2	0.4	-0.3	-0.2
				-50	0.2	-0.3	0.0	0.4	-0.3	0.2	0.3	-0.3	0.2
Sediment thermal diffusivity	cm^2/s	a_s	0.005	50	-0.2	0.1	0.1	-0.3	0.2	0.1	-0.3	0.2	0.1
				-50	0.3	-0.4	-0.1	0.6	-0.5	-0.1	0.6	-0.5	-0.1
Sediment density	g/cm^3	r_s	1.600	50	-0.3	0.4	0.1	-0.4	0.5	0.0	-0.4	0.5	0.0
				-50	0.3	-0.5	-0.1	0.6	-0.6	0.0	0.6	-0.6	0.0
Water density	g/cm^3	r_w	1.000	50	-3.6	-1.6	-1.9	-10	-2.7	-2.8	-9.8	-2.7	-2.9
				-50	1.3	-1.3	-0.2	2.5	-0.5	0.6	2.4	-0.5	0.5
Sediment heat capacity	cal/(g^{o}C)	c_{ps}	0.400	50	-0.3	0.4	0.1	-0.4	0.5	0.0	-0.4	0.5	0.0
				-50	0.3	-0.5	-0.1	0.6	-0.6	0.0	0.6	-0.6	0.0
Water heat capacity	cal/(g^{o}C)	c_{pw}	1.000	50	-3.6	-1.6	-1.9	-10	-2.7	-2.8	-9.8	-2.7	-2.9
				-50	1.3	-1.3	-0.2	2.5	-0.5	0.6	2.4	-0.5	0.5

Appendix B Bacteria Data and Analyses

Army Creek

Statistics

# Samples DRY	**54**
# Samples WET	**40**
# Samples Total	**94**
Geomean	**176**
Log std deviation	**0.77**

Avg % Reduction

Wet (WLA)	**54**
Dry (LA)	**24**
Total (TMDL)	**37**

Date	Precip.(in)[1] 24h	48h	96h	Condition[2] (WET/DRY)	enterococcus (CFU/100 mL)	Rank	Proportion	Criteria Value	% Reduction
9/22/97	0.00	0.00	0.23	DRY	87	38.5	0.4096	81	7
9/22/97	0.00	0.00	0.23	DRY	705	69.0	0.7340	178	75
12/9/97	0.01	0.01	0.01	DRY	50	24.0	0.2553	55	0
12/9/97	0.01	0.01	0.01	DRY	10	5.5	0.0585	24	0
4/6/98	0.00	0.00	0.07	DRY	17	8.0	0.0851	28	0
4/6/98	0.00	0.00	0.07	DRY	190	53.5	0.5691	117	38
8/17/98	0.06	0.06	0.07	DRY	53	25.0	0.2660	56	0
8/17/98	0.06	0.06	0.07	DRY	1733	77.0	0.8191	232	87
9/1/98	0.00	0.00	0.00	DRY	40	19.5	0.2074	47	0
9/1/98	0.00	0.00	0.00	DRY	480	60.5	0.6436	140	71
12/1/98	0.00	0.00	0.00	DRY	70	32.5	0.3457	69	1
12/1/98	0.00	0.00	0.00	DRY	72	34.0	0.3617	72	0
4/28/99	0.00	0.00	0.00	DRY	2	1.0	0.0106	12	0
4/28/99	0.00	0.00	0.00	DRY	38	17.0	0.1809	43	0
8/2/99	0.00	0.00	0.00	DRY	35	14.0	0.1489	38	0
11/17/99	0.00	0.00	0.00	DRY	133	46.5	0.4947	99	26
11/17/99	0.00	0.00	0.00	DRY	183	51.5	0.5479	112	39
3/1/00	0.00	0.00	0.20	DRY	600	65.0	0.6915	158	74
3/1/00	0.00	0.00	0.20	DRY	600	65.0	0.6915	158	74
5/23/00	0.02	0.23	0.38	DRY	36	15.0	0.1596	40	0
5/23/00	0.02	0.23	0.38	DRY	600	65.0	0.6915	158	74
7/5/00	0.00	0.05	0.09	DRY	67	31.0	0.3298	67	1

7/5/00	0.00	0.05	0.09	DRY	800	72.0	0.7660	195	76
11/15/00	0.00	0.39	0.39	**WET**	600	65.0	0.6915	158	74
11/15/00	0.00	0.39	0.39	**WET**	600	65.0	0.6915	158	74
4/30/01	0.00	0.00	0.00	DRY	8	4.0	0.0426	20	0
4/30/01	0.00	0.00	0.00	DRY	133	46.5	0.4947	99	26
6/26/01	0.00	0.00	0.20	DRY	70	32.5	0.3457	69	1
6/26/01	0.00	0.00	0.20	DRY	510	62.0	0.6596	146	71
9/24/01	0.53	0.53	0.68	**WET**	37	16.0	0.1702	42	0
9/24/01	0.53	0.53	0.68	**WET**	190	53.5	0.5691	117	38
11/6/01	0.00	0.00	0.04	DRY	63	29.5	0.3138	64	0
11/6/01	0.00	0.00	0.04	DRY	3	2.5	0.0266	17	0
5/7/02	0.00	0.00	0.00	DRY	62	28.0	0.2979	61	1
5/7/02	0.00	0.00	0.00	DRY	733	70.5	0.7500	186	75
6/12/02	0.19	0.19	0.19	**WET**	285	57.0	0.6064	128	55
6/12/02	0.19	0.19	0.19	**WET**	100	42.5	0.4521	90	10
8/6/02	0.00	0.00	0.00	DRY	24	10.0	0.1064	32	0
8/6/02	0.00	0.00	0.00	DRY	47	23.0	0.2447	53	0
8/6/02	0.00	0.00	0.00	DRY	117	44.5	0.4734	94	20
11/13/02	0.07	0.87	1.22	**WET**	1215	76.0	0.8085	223	82
11/13/02	0.07	0.87	1.22	**WET**	2000	86.0	0.9149	354	82
11/13/02	0.07	0.87	1.22	**WET**	480	60.5	0.6436	140	71
4/1/03	0.00	0.00	0.63	DRY	100	42.5	0.4521	90	10
4/1/03	0.00	0.00	0.63	DRY	60	26.5	0.2819	59	2
4/1/03	0.00	0.00	0.63	DRY	183	51.5	0.5479	112	39
6/11/03	0.21	0.21	0.22	**WET**	94	40.0	0.4255	84	11
6/11/03	0.21	0.21	0.22	**WET**	33	12.5	0.1330	36	0
6/11/03	0.21	0.21	0.22	**WET**	33	12.5	0.1330	36	0
6/11/03	0.21	0.21	0.22	**WET**	117	44.5	0.4734	94	20
8/12/03	0.00	0.91	1.12	**WET**	2000	86.0	0.9149	354	82
8/12/03	0.00	0.91	1.12	**WET**	2000	86.0	0.9149	354	82
8/12/03	0.00	0.91	1.12	**WET**	2000	86.0	0.9149	354	82
8/12/03	0.00	0.91	1.12	**WET**	2000	86.0	0.9149	354	82
10/15/03	0.09	1.18	1.19	**WET**	2000	86.0	0.9149	354	82
10/15/03	0.09	1.18	1.19	**WET**	2000	86.0	0.9149	354	82
10/15/03	0.09	1.18	1.19	**WET**	2000	86.0	0.9149	354	82
10/15/03	0.09	1.18	1.19	**WET**	2000	86.0	0.9149	354	82
3/10/04	0.05	0.05	0.17	DRY	39	18.0	0.1915	45	0
3/10/04	0.05	0.05	0.17	DRY	43	21.5	0.2287	50	0
3/10/04	0.05	0.05	0.17	DRY	27	11.0	0.1170	33	0
3/10/04	0.05	0.05	0.17	DRY	10	5.5	0.0585	24	0
5/11/04	0.00	0.31	0.90	**WET**	137	48.0	0.5106	102	25
5/11/04	0.00	0.31	0.90	**WET**	153	49.0	0.5213	105	31
5/11/04	0.00	0.31	0.90	**WET**	2000	86.0	0.9149	354	82
5/11/04	0.00	0.31	0.90	**WET**	2000	86.0	0.9149	354	82
8/16/04	0.14	0.14	0.63	**WET**	1155	75.0	0.7979	216	81
8/16/04	0.14	0.14	0.63	**WET**	2000	86.0	0.9149	354	82
8/16/04	0.14	0.14	0.63	**WET**	280	56.0	0.5957	125	55

8/16/04	0.14	0.14	0.63	**WET**	2000	86.0	0.9149	354	82
9/13/04	0.00	0.00	0.00	DRY	43	21.5	0.2287	50	0
9/13/04	0.00	0.00	0.00	DRY	1100	74.0	0.7872	208	81
9/13/04	0.00	0.00	0.00	DRY	460	59.0	0.6277	135	71
10/13/04	0.00	0.00	0.00	DRY	3	2.5	0.0266	17	0
10/13/04	0.00	0.00	0.00	DRY	13	7.0	0.0745	26	0
10/13/04	0.00	0.00	0.00	DRY	667	68.0	0.7234	173	74
3/30/05	0.00	0.00	2.27	**WET**	733	70.5	0.7500	186	75
3/30/05	0.00	0.00	2.27	**WET**	2000	86.0	0.9149	354	82
3/30/05	0.00	0.00	2.27	**WET**	310	58.0	0.6170	132	58
3/30/05	0.00	0.00	2.27	**WET**	73	35.0	0.3723	74	0
5/2/05	0.01	0.10	0.98	DRY	900	73.0	0.7766	202	78
5/2/05	0.01	0.10	0.98	DRY	270	55.0	0.5851	122	55
5/2/05	0.01	0.10	0.98	DRY	160	50.0	0.5319	108	33
5/2/05	0.01	0.10	0.98	DRY	95	41.0	0.4362	86	9
8/9/05	0.19	0.20	0.21	**WET**	60	26.5	0.2819	59	2
8/9/05	0.19	0.20	0.21	**WET**	2000	86.0	0.9149	354	82
8/9/05	0.19	0.20	0.21	**WET**	2000	86.0	0.9149	354	82
8/9/05	0.19	0.20	0.21	**WET**	2000	86.0	0.9149	354	82
9/26/05	0.19	0.19	0.19	**WET**	40	19.5	0.2074	47	0
9/26/05	0.19	0.19	0.19	**WET**	63	29.5	0.3138	64	0
9/26/05	0.19	0.19	0.19	**WET**	75	36.0	0.3830	76	0
10/3/05	0.00	0.00	0.00	DRY	23	9.0	0.0957	30	0
10/3/05	0.00	0.00	0.00	DRY	87	38.5	0.4096	81	7
10/3/05	0.00	0.00	0.00	DRY	80	37.0	0.3936	78	3

Red Lion

Statistics

# Samples DRY	66
# Samples WET	55
# Samples Total	121
Geomean	164
Log std deviation	0.71

Avg % Reduction

Wet (WLA)	48
Dry (LA)	31
Total (TMDL)	38

Date	Precip.(in)[1]			Condition[2]	enterococcus	Rank	Proportion	Criteria	%
	24h	48h	96h	(WET/DRY)	(CFU/100 mL)			Value	Reduction
9/22/97	0.00	0.00	0.23	DRY	600	97.0	0.8017	218	64
9/22/97	0.00	0.00	0.23	DRY	160	58.0	0.4793	95	40
12/9/97	0.01	0.01	0.01	DRY	100	44.0	0.3636	73	27
12/9/97	0.01	0.01	0.01	DRY	350	73.0	0.6033	127	64
4/6/98	0.00	0.00	0.07	DRY	1	1.0	0.0083	11	0
4/6/98	0.00	0.00	0.07	DRY	34	22.5	0.1860	44	0
8/17/98	0.06	0.06	0.07	DRY	733	100.0	0.8264	238	68
8/17/98	0.06	0.06	0.07	DRY	450	86.5	0.7149	169	63
9/1/98	0.00	0.00	0.00	DRY	867	102.5	0.8471	257	70
9/1/98	0.00	0.00	0.00	DRY	47	30.0	0.2479	53	0
12/1/98	0.00	0.00	0.00	DRY	70	38.5	0.3182	65	8
12/1/98	0.00	0.00	0.00	DRY	600	97.0	0.8017	218	64
4/28/99	0.00	0.00	0.00	DRY	21	11.0	0.0909	29	0
4/28/99	0.00	0.00	0.00	DRY	26	12.0	0.0992	31	0
8/3/99	0.00	0.57	1.05	**WET**	500	89.5	0.7397	181	64
8/3/99	0.00	0.57	1.05	**WET**	27	14.0	0.1157	33	0
11/17/99	0.00	0.00	0.00	DRY	34	22.5	0.1860	44	0
11/17/99	0.00	0.00	0.00	DRY	400	81.0	0.6694	150	63
3/1/00	0.00	0.00	0.20	DRY	9	6.0	0.0496	22	0
3/1/00	0.00	0.00	0.20	DRY	220	64.0	0.5289	107	51
5/23/00	0.02	0.23	0.38	DRY	580	95.0	0.7851	207	64
5/23/00	0.02	0.23	0.38	DRY	120	48.5	0.4008	79	34
7/5/00	0.00	0.05	0.09	DRY	700	99.0	0.8182	231	67
7/5/00	0.00	0.05	0.09	DRY	27	14.0	0.1157	33	0

11/15/00	0.00	0.39	0.39	**WET**	260	66.0	0.5455	111	57
11/15/00	0.00	0.39	0.39	**WET**	600	97.0	0.8017	218	64
4/30/01	0.00	0.00	0.00	DRY	44	27.0	0.2231	50	0
4/30/01	0.00	0.00	0.00	DRY	10	8.0	0.0661	25	0
6/26/01	0.00	0.00	0.20	DRY	480	88.0	0.7273	175	64
6/26/01	0.00	0.00	0.20	DRY	46	28.0	0.2314	51	0
9/24/01	0.53	0.53	0.68	**WET**	230	65.0	0.5372	109	53
9/24/01	0.53	0.53	0.68	**WET**	137	51.0	0.4215	83	39
11/6/01	0.00	0.00	0.04	DRY	370	76.0	0.6281	135	63
11/6/01	0.00	0.00	0.04	DRY	2000	117.0	0.9669	457	77
5/7/02	0.00	0.00	0.00	DRY	867	102.5	0.8471	257	70
5/7/02	0.00	0.00	0.00	DRY	27	14.0	0.1157	33	0
5/7/02	0.00	0.00	0.00	DRY	37	24.5	0.2025	46	0
5/7/02	0.00	0.00	0.00	DRY	110	46.5	0.3843	76	31
5/7/02	0.00	0.00	0.00	DRY	147	53.5	0.4421	87	41
6/12/02	0.19	0.19	0.19	**WET**	430	83.5	0.6901	158	63
6/12/02	0.19	0.19	0.19	**WET**	80	41.5	0.3430	69	14
6/12/02	0.19	0.19	0.19	**WET**	110	46.5	0.3843	76	31
6/12/02	0.19	0.19	0.19	**WET**	193	63.0	0.5207	105	46
8/6/02	0.00	0.00	0.00	DRY	380	78.5	0.6488	142	63
8/6/02	0.00	0.00	0.00	DRY	70	38.5	0.3182	65	8
8/6/02	0.00	0.00	0.00	DRY	540	93.0	0.7686	197	64
8/6/02	0.00	0.00	0.00	DRY	1470	109.5	0.9050	334	77
11/13/02	0.07	0.87	1.22	**WET**	430	83.5	0.6901	158	63
11/13/02	0.07	0.87	1.22	**WET**	2000	117.0	0.9669	457	77
11/13/02	0.07	0.87	1.22	**WET**	1470	109.5	0.9050	334	77
11/13/02	0.07	0.87	1.22	**WET**	190	62.0	0.5124	103	46
11/13/02	0.07	0.87	1.22	**WET**	440	85.0	0.7025	163	63
4/1/03	0.00	0.00	0.63	DRY	53	34.0	0.2810	59	0
4/1/03	0.00	0.00	0.63	DRY	7	4.5	0.0372	19	0
4/1/03	0.00	0.00	0.63	DRY	10	8.0	0.0661	25	0
4/1/03	0.00	0.00	0.63	DRY	33	19.0	0.1570	40	0
6/11/03	0.21	0.21	0.22	**WET**	33	19.0	0.1570	40	0
6/11/03	0.21	0.21	0.22	**WET**	53	34.0	0.2810	59	0
6/11/03	0.21	0.21	0.22	**WET**	50	32.0	0.2645	56	0
6/11/03	0.21	0.21	0.22	**WET**	47	30.0	0.2479	53	0
6/11/03	0.21	0.21	0.22	**WET**	30	16.0	0.1322	36	0
8/12/03	0.00	0.91	1.12	**WET**	530	92.0	0.7603	192	64
8/12/03	0.00	0.91	1.12	**WET**	1530	111.0	0.9174	359	77
8/12/03	0.00	0.91	1.12	**WET**	173	60.0	0.4959	99	43
8/12/03	0.00	0.91	1.12	**WET**	450	86.5	0.7149	169	63
8/12/03	0.00	0.91	1.12	**WET**	60	37.0	0.3058	63	0
10/15/03	0.09	1.18	1.19	**WET**	2000	117.0	0.9669	457	77
10/15/03	0.09	1.18	1.19	**WET**	520	91.0	0.7521	187	64
10/15/03	0.09	1.18	1.19	**WET**	1570	112.0	0.9256	378	76
10/15/03	0.09	1.18	1.19	**WET**	1400	108.0	0.8926	313	78
10/15/03	0.09	1.18	1.19	**WET**	2000	117.0	0.9669	457	77

3/10/04	0.05	0.05	0.17	DRY	33	19.0	0.1570	40	0
3/10/04	0.05	0.05	0.17	DRY	380	78.5	0.6488	142	63
3/10/04	0.05	0.05	0.17	DRY	37	24.5	0.2025	46	0
3/10/04	0.05	0.05	0.17	DRY	10	8.0	0.0661	25	0
3/10/04	0.05	0.05	0.17	DRY	7	4.5	0.0372	19	0
5/11/04	0.00	0.31	0.90	**WET**	800	101.0	0.8347	245	69
5/11/04	0.00	0.31	0.90	**WET**	570	94.0	0.7769	202	65
5/11/04	0.00	0.31	0.90	**WET**	97	43.0	0.3554	71	27
5/11/04	0.00	0.31	0.90	**WET**	187	61.0	0.5041	101	46
5/11/04	0.00	0.31	0.90	**WET**	153	56.5	0.4669	93	39
8/16/04	0.14	0.14	0.63	**WET**	420	82.0	0.6777	153	64
8/16/04	0.14	0.14	0.63	**WET**	147	53.5	0.4421	87	41
8/16/04	0.14	0.14	0.63	**WET**	280	67.0	0.5537	113	60
8/16/04	0.14	0.14	0.63	**WET**	500	89.5	0.7397	181	64
8/16/04	0.14	0.14	0.63	**WET**	967	105.0	0.8678	279	71
9/13/04	0.00	0.00	0.00	DRY	360	74.5	0.6157	131	64
9/13/04	0.00	0.00	0.00	DRY	290	68.5	0.5661	117	60
9/13/04	0.00	0.00	0.00	DRY	320	71.5	0.5909	124	61
9/13/04	0.00	0.00	0.00	DRY	380	78.5	0.6488	142	63
9/13/04	0.00	0.00	0.00	DRY	127	50.0	0.4132	82	36
10/13/04	0.00	0.00	0.00	DRY	53	34.0	0.2810	59	0
10/13/04	0.00	0.00	0.00	DRY	153	56.5	0.4669	93	39
10/13/04	0.00	0.00	0.00	DRY	3	2.5	0.0207	15	0
10/13/04	0.00	0.00	0.00	DRY	3	2.5	0.0207	15	0
10/13/04	0.00	0.00	0.00	DRY	13	10.0	0.0826	28	0
3/30/05	0.00	0.00	2.27	**WET**	33	19.0	0.1570	40	0
3/30/05	0.00	0.00	2.27	**WET**	73	40.0	0.3306	67	9
3/30/05	0.00	0.00	2.27	**WET**	2000	117.0	0.9669	457	77
3/30/05	0.00	0.00	2.27	**WET**	2000	117.0	0.9669	457	77
3/30/05	0.00	0.00	2.27	**WET**	120	48.5	0.4008	79	34
5/2/05	0.01	0.10	0.98	DRY	57	36.0	0.2975	61	0
5/2/05	0.01	0.10	0.98	DRY	80	41.5	0.3430	69	14
5/2/05	0.01	0.10	0.98	DRY	103	45.0	0.3719	74	28
5/2/05	0.01	0.10	0.98	DRY	47	30.0	0.2479	53	0
5/2/05	0.01	0.10	0.98	DRY	33	19.0	0.1570	40	0
8/9/05	0.19	0.20	0.21	**WET**	1030	106.0	0.8760	290	72
8/9/05	0.19	0.20	0.21	**WET**	1070	107.0	0.8843	301	72
8/9/05	0.19	0.20	0.21	**WET**	933	104.0	0.8595	270	71
8/9/05	0.19	0.20	0.21	**WET**	2000	117.0	0.9669	457	77
8/9/05	0.19	0.20	0.21	**WET**	2000	117.0	0.9669	457	77
9/26/05	0.19	0.19	0.19	**WET**	163	59.0	0.4876	97	40
9/26/05	0.19	0.19	0.19	**WET**	40	26.0	0.2149	48	0
9/26/05	0.19	0.19	0.19	**WET**	140	52.0	0.4298	85	39
9/26/05	0.19	0.19	0.19	**WET**	2000	117.0	0.9669	457	77
9/26/05	0.19	0.19	0.19	**WET**	150	55.0	0.4545	90	40
10/3/05	0.00	0.00	0.00	DRY	320	71.5	0.5909	124	61
10/3/05	0.00	0.00	0.00	DRY	380	78.5	0.6488	142	63

10/3/05	0.00	0.00	0.00	DRY	290	68.5	0.5661	117	60
10/3/05	0.00	0.00	0.00	DRY	360	74.5	0.6157	131	64
10/3/05	0.00	0.00	0.00	DRY	310	70.0	0.5785	120	61

Dragon Run

Statistics

# Samples DRY	**62**
# Samples WET	**60**
# Samples Total	**122**
Geomean	**82**
Log std deviation	**0.78**

Avg % Reduction

Wet (WLA)	**22**
Dry (LA)	**10**
Total (TMDL)	**15**

Date	Precip.(in)[1]			Condition[2]	enterococcus	Rank	Proportion	Criteria	%
	24h	48h	96h	(WET/DRY)	(CFU/100 mL)			Value	Reduction
4/16/97	0.00	0.00	0.00	DRY	1	2.0	0.0164	14	0
4/16/97	0.00	0.00	0.00	DRY	1	2.0	0.0164	14	0
9/23/97	0.01	0.36	1.10	**WET**	8	13.0	0.1066	32	0
9/23/97	0.01	0.36	1.10	**WET**	270	89.5	0.7336	178	34
11/19/97	0.00	0.00	0.00	DRY	7	11.5	0.0943	30	0
11/19/97	0.00	0.00	0.00	DRY	75	53.0	0.4344	86	0
4/7/98	0.00	0.36	1.15	**WET**	4	10.0	0.0820	28	0
4/7/98	0.00	0.36	1.15	**WET**	43	42.5	0.3484	70	0
8/17/98	0.06	0.06	0.07	DRY	360	95.0	0.7787	203	44
8/17/98	0.06	0.06	0.07	DRY	800	107.5	0.8811	297	63
9/29/98	0.00	0.01	0.02	DRY	77	55.0	0.4508	89	0
9/29/98	0.00	0.01	0.02	DRY	1333	115.5	0.9467	442	67
10/27/98	0.00	0.00	0.00	DRY	10	15.5	0.1270	35	0
10/27/98	0.00	0.00	0.00	DRY	140	79.0	0.6475	142	0
4/29/99	0.00	0.39	1.37	**WET**	1	2.0	0.0164	14	0
4/29/99	0.00	0.39	1.37	**WET**	240	88.0	0.7213	172	28
8/3/99	0.00	0.57	1.05	**WET**	17	24.0	0.1967	46	0
11/17/99	0.00	0.00	0.00	DRY	15	20.0	0.1639	41	0
11/17/99	0.00	0.00	0.00	DRY	207	86.0	0.7049	164	21
3/29/00	0.00	0.18	1.04	DRY	35	38.0	0.3115	64	0
3/29/00	0.00	0.18	1.04	DRY	230	87.0	0.7131	168	27
5/9/00	0.00	0.00	0.00	DRY	16	21.0	0.1721	42	0
5/9/00	0.00	0.00	0.00	DRY	77	55.0	0.4508	89	0
7/5/00	0.00	0.05	0.09	DRY	22	27.0	0.2213	49	0

11/15/00	0.00	0.39	0.39	**WET**	26	31.0	0.2541	54	0
11/15/00	0.00	0.39	0.39	**WET**	350	94.0	0.7705	198	43
4/30/01	0.00	0.00	0.00	DRY	14	19.0	0.1557	39	0
4/30/01	0.00	0.00	0.00	DRY	77	55.0	0.4508	89	0
6/26/01	0.00	0.00	0.20	DRY	12	17.0	0.1393	37	0
9/24/01	0.53	0.53	0.68	**WET**	9	14.0	0.1148	33	0
9/24/01	0.53	0.53	0.68	**WET**	1333	115.5	0.9467	442	67
11/6/01	0.00	0.00	0.04	DRY	3	6.5	0.0533	23	0
11/6/01	0.00	0.00	0.04	DRY	200	85.0	0.6967	161	20
5/7/02	0.00	0.00	0.00	DRY	10	15.5	0.1270	35	0
5/7/02	0.00	0.00	0.00	DRY	73	51.5	0.4221	83	0
5/7/02	0.00	0.00	0.00	DRY	113	71.0	0.5820	121	0
5/7/02	0.00	0.00	0.00	DRY	137	76.5	0.6270	135	2
5/7/02	0.00	0.00	0.00	DRY	1300	114.0	0.9344	402	69
6/18/02	0.24	0.53	0.54	**WET**	33	35.0	0.2869	60	0
6/18/02	0.24	0.53	0.54	**WET**	370	96.0	0.7869	208	44
6/18/02	0.24	0.53	0.54	**WET**	40	40.0	0.3279	66	0
6/18/02	0.24	0.53	0.54	**WET**	120	73.0	0.5984	126	0
6/18/02	0.24	0.53	0.54	**WET**	420	101.0	0.8279	239	43
8/6/02	0.00	0.00	0.00	DRY	97	64.0	0.5246	106	0
8/6/02	0.00	0.00	0.00	DRY	57	47.0	0.3852	76	0
8/6/02	0.00	0.00	0.00	DRY	400	98.5	0.8074	222	44
8/6/02	0.00	0.00	0.00	DRY	83	58.5	0.4795	95	0
8/6/02	0.00	0.00	0.00	DRY	1200	111.5	0.9139	352	71
11/13/02	0.07	0.87	1.22	**WET**	90	60.5	0.4959	99	0
11/13/02	0.07	0.87	1.22	**WET**	163	84.0	0.6885	157	4
11/13/02	0.07	0.87	1.22	**WET**	1070	110.0	0.9016	328	69
11/13/02	0.07	0.87	1.22	**WET**	1200	111.5	0.9139	352	71
11/13/02	0.07	0.87	1.22	**WET**	1230	113.0	0.9262	380	69
4/1/03	0.00	0.00	0.63	DRY	3	6.5	0.0533	23	0
4/1/03	0.00	0.00	0.63	DRY	17	24.0	0.1967	46	0
4/1/03	0.00	0.00	0.63	DRY	23	29.0	0.2377	52	0
4/1/03	0.00	0.00	0.63	DRY	23	29.0	0.2377	52	0
4/1/03	0.00	0.00	0.63	DRY	17	24.0	0.1967	46	0
6/11/03	0.21	0.21	0.22	**WET**	33	35.0	0.2869	60	0
6/11/03	0.21	0.21	0.22	**WET**	90	60.5	0.4959	99	0
6/11/03	0.21	0.21	0.22	**WET**	33	35.0	0.2869	60	0
6/11/03	0.21	0.21	0.22	**WET**	410	100.0	0.8197	232	43
6/11/03	0.21	0.21	0.22	**WET**	143	81.0	0.6639	148	0
8/12/03	0.00	0.91	1.12	**WET**	137	76.5	0.6270	135	2
8/12/03	0.00	0.91	1.12	**WET**	127	75.0	0.6148	131	0
8/12/03	0.00	0.91	1.12	**WET**	100	66.0	0.5410	110	0
8/12/03	0.00	0.91	1.12	**WET**	23	29.0	0.2377	52	0
8/12/03	0.00	0.91	1.12	**WET**	470	102.0	0.8361	246	48
10/15/03	0.09	1.18	1.19	**WET**	80	57.0	0.4672	93	0
10/15/03	0.09	1.18	1.19	**WET**	510	104.0	0.8525	262	49
10/15/03	0.09	1.18	1.19	**WET**	1730	117.0	0.9590	457	74

10/15/03	0.09	1.18	1.19	**WET**	2000	120.0	0.9836	457	77
10/15/03	0.09	1.18	1.19	**WET**	2000	120.0	0.9836	457	77
3/10/04	0.05	0.05	0.17	DRY	3	6.5	0.0533	23	0
3/10/04	0.05	0.05	0.17	DRY	3	6.5	0.0533	23	0
3/10/04	0.05	0.05	0.17	DRY	27	32.0	0.2623	56	0
3/10/04	0.05	0.05	0.17	DRY	7	11.5	0.0943	30	0
3/10/04	0.05	0.05	0.17	DRY	47	44.0	0.3607	72	0
5/11/04	0.00	0.31	0.90	**WET**	17	24.0	0.1967	46	0
5/11/04	0.00	0.31	0.90	**WET**	140	79.0	0.6475	142	0
5/11/04	0.00	0.31	0.90	**WET**	540	105.0	0.8607	271	50
5/11/04	0.00	0.31	0.90	**WET**	113	71.0	0.5820	121	0
8/16/04	0.14	0.14	0.63	**WET**	73	51.5	0.4221	83	0
8/16/04	0.14	0.14	0.63	**WET**	103	68.0	0.5574	114	0
8/16/04	0.14	0.14	0.63	**WET**	100	66.0	0.5410	110	0
8/16/04	0.14	0.14	0.63	**WET**	390	97.0	0.7951	214	45
8/16/04	0.14	0.14	0.63	**WET**	340	92.0	0.7541	188	45
9/13/04	0.00	0.00	0.00	DRY	33	35.0	0.2869	60	0
9/13/04	0.00	0.00	0.00	DRY	140	79.0	0.6475	142	0
9/13/04	0.00	0.00	0.00	DRY	93	62.5	0.5123	103	0
9/13/04	0.00	0.00	0.00	DRY	123	74.0	0.6066	128	0
9/13/04	0.00	0.00	0.00	DRY	340	92.0	0.7541	188	45
10/13/04	0.00	0.00	0.00	DRY	3	6.5	0.0533	23	0
10/13/04	0.00	0.00	0.00	DRY	17	24.0	0.1967	46	0
10/13/04	0.00	0.00	0.00	DRY	67	50.0	0.4098	81	0
10/13/04	0.00	0.00	0.00	DRY	40	40.0	0.3279	66	0
10/13/04	0.00	0.00	0.00	DRY	3	6.5	0.0533	23	0
3/30/05	0.00	0.00	2.27	**WET**	2000	120.0	0.9836	457	77
3/30/05	0.00	0.00	2.27	**WET**	53	45.5	0.3730	74	0
3/30/05	0.00	0.00	2.27	**WET**	60	48.5	0.3975	79	0
3/30/05	0.00	0.00	2.27	**WET**	107	69.0	0.5656	116	0
3/30/05	0.00	0.00	2.27	**WET**	40	40.0	0.3279	66	0
5/2/05	0.01	0.10	0.98	DRY	13	18.0	0.1475	38	0
5/2/05	0.01	0.10	0.98	DRY	160	82.5	0.6762	152	5
5/2/05	0.01	0.10	0.98	DRY	113	71.0	0.5820	121	0
5/2/05	0.01	0.10	0.98	DRY	100	66.0	0.5410	110	0
5/2/05	0.01	0.10	0.98	DRY	53	45.5	0.3730	74	0
8/9/05	0.19	0.20	0.21	**WET**	800	107.5	0.8811	297	63
8/9/05	0.19	0.20	0.21	**WET**	2000	120.0	0.9836	457	77
8/9/05	0.19	0.20	0.21	**WET**	2000	120.0	0.9836	457	77
8/9/05	0.19	0.20	0.21	**WET**	733	106.0	0.8689	281	62
8/9/05	0.19	0.20	0.21	**WET**	967	109.0	0.8934	315	67
9/26/05	0.19	0.19	0.19	**WET**	33	35.0	0.2869	60	0
9/26/05	0.19	0.19	0.19	**WET**	43	42.5	0.3484	70	0
9/26/05	0.19	0.19	0.19	**WET**	83	58.5	0.4795	95	0
9/26/05	0.19	0.19	0.19	**WET**	93	62.5	0.5123	103	0
9/26/05	0.19	0.19	0.19	**WET**	60	48.5	0.3975	79	0
10/3/05	0.00	0.00	0.00	DRY	160	82.5	0.6762	152	5

10/3/05	0.00	0.00	0.00	DRY	340	92.0	0.7541	188	45
10/3/05	0.00	0.00	0.00	DRY	270	89.5	0.7336	178	34
10/3/05	0.00	0.00	0.00	DRY	400	98.5	0.8074	222	44
10/3/05	0.00	0.00	0.00	DRY	480	103.0	0.8443	254	47