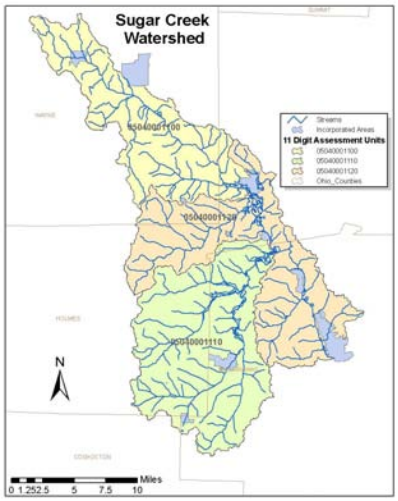
State of Ohio
Environmental Protection Agency

Division of Surface Water

Recreational Use Water Quality Survey of the Sugar Creek Watershed, 2005

Holmes, Stark, Tuscarawas and Wayne Counties, Ohio



Ohio EPA Technical Report NEDO/2006-02-01

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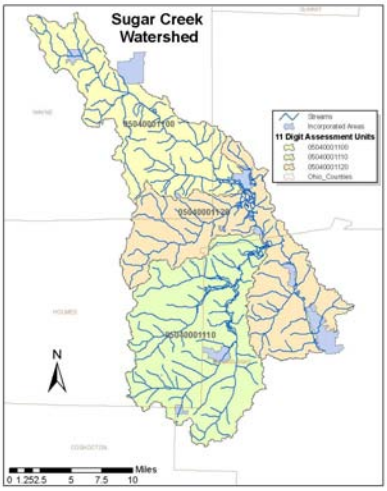

Ohio EPA Technical Report NEDO/2006-02-01

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SUMMARY AND RECOMMENDATIONS

1. Water samples were collected at 38 sites throughout the Sugar Creek watershed to determine the attainment status of designated water bodies within the watershed with respect to recreational uses and to support the development of a Total Maximum Daily Load (TMDL) for pathogen indicator bacteria (fecal coliform bacteria and *Escherichia coli)*. A previous study in 1998 found that streams within three water quality Assessment Units (05040001100, 05040001110, and 05040001120) were in NON-attainment for designated recreational uses.

2. Eight sentinel Sites were chosen where water samples for bacteriological analyses were collected on 10-15 dates during the recreation season (May-October). Stream flow, gage height, and water clarity measurements and were also taken in order to provide flow and loading estimates for bacteria and total suspended solids to support the development of a TMDL for bacteria in the watershed. Thirty additional Geometric Sites were also sampled on a less frequent basis to provide a spatial sampling design dividing the watershed into relatively equally sized sub-watershed units.

3. Results of the survey found that all three Assessment Units making up the Sugar Creek watershed are in NON-attainment for their designated Recreational Uses. Only 5 of the sampling sites used in the study were fully attaining the recreational use water quality criteria. The only site on the mainstem of Sugar Creek found to be in FULL attainment was the site near the mouth of the stream located at RM 0.63. The upper reaches of the North Fork Sugar Creek (05040001100 AU), showed marked improvement since 1998, with both sites in the vicinity of the Village of Kidron in FULL attainment for the recreational use criteria. Construction of a wastewater treatment plant serving the Village of Kidron appears to have successfully addressed bacteria pollution issues in this area.

4. Review of monthly operating reports for NPDES permitted dischargers in the watershed revealed temporal problems for individual facilities. However, the compliance rate among NPDES dischargers was high, especially when the data for 2005 is considered. NPDES regulated facilities are not responsible for the widespread violations of the water quality criteria for fecal coliform bacteria and *E. coli* noted in this study.

5. Farming represents a very high percentage of the land use and the economic base within the Sugar Creek watershed. Agricultural practices in the watershed, particularly relating to animal pasturing and animal waste management are the primary causes of NON-attainment of recreational use water quality criteria. Sources of bacteria and potential pathogens relating to the problem are poorly managed or uncontrolled runoff from animal rearing and feeding operations, barn yards and milk houses, spills or releases from manure handling operations, runoff from manure applied or used as fertilizer for farm fields, and direct access of streams by grazing animals.

6. Failing or improperly designed on-site wastewater systems can also result in significant loadings of bacteria to adjacent drainageways and streams, potentially carrying associated pathogenic organisms. It is recommended that additional studies be conducted to determine the relative contribution of on-site wastewater management to the overall bacterial pollution problem.

7. Areas experiencing high rates of construction starts are the northern part of the Sugar Creek headwaters along the State Route 30 corridor in Wayne County (AU 05040001100), and the western portion of Tuscarawas County in the triangle between Strasburg, Dover and Sugarcreek (AU 05040001120). Expansion and development of associated businesses to service the expanding resident population within the watershed, as well as the popular tourist industry in the area will require adequate planning for wastewater management in order to prevent the pollution problems noted during this study from becoming worse and to improve water quality throughout the watershed.

8. Altered stream channel morphology, poor floodplain quality, and disconnection of stream channels from their floodplains play an important part in the extremely high fecal coliform and *E. coli* densities observed in the study. Sediments in aquatic systems can be a significant reservoir for pathogenic organisms and indicator bacteria. Sediment resuspension can significantly increase bacteria counts in overlying waters. The linkage of TSS to bacterial counts indicates that pollution abatement efforts to reduce water column bacteria counts will also have to consider not only non-point loadings of TSS and bacteria (external loads to the stream) but also factors that entrap bacteria laden sediments within the stream channel (internal loading).

9. It is recommended that the recreational use TMDL process evaluate targets not only for bacteria loadings but also existing TMDL targets for sediment loading and habitat quality addressed in the 2002 Sugar Creek TMDL to determine if they are adequate to restore recreational uses to full attainment. Specific factors that should be evaluated are measurements of floodplain connectivity (either through entrenchment ratios or other measures relating to stream channel integrity), sediment loading and resuspension (TSS), and indicators of habitat quality (with an emphasis upon vegetative buffers within the stream corridor. Targets should be established that will improve the substrate quality within stream channels through reductions of both loadings from runoff and the impacts of sediment resuspension (perhaps using specific subsets of the QHEI metrics).

10. Flow data analysis using orthogonal polynomial techniques of curvilinear regression yielded quadratic equations to estimate stream flow from gage height measurements that resulted in very high coefficients of determination. Based upon this analysis, the resulting quadratic equations can be used to predict stream flows for sampling dates when flow measurements were not taken.

11. Median TSS concentrations were lower at the sentinel sites in the northern part of the watershed (AU's 05040001100 and 05040001120) than in the South Fork sub-watershed (AU 05040001110). Indicator bacteria counts at sentinel sites correlated well with estimated TSS concentrations from water clarity measurements.

INTRODUCTION

A 1998 water quality survey of the Sugar Creek watershed found that the bacteriological water quality criteria used to protect designated recreational beneficial stream uses were exceeded on numerous occasions and on a wide-spread basis (Ohio EPA, 1999). These findings were used as the basis to list the assessment units within the Sugar Creek watershed as impaired with respect to recreational uses on the Ohio 303(d) list (Ohio EPA, 2004). Fecal coliform and *Escherichia coli* bacteria are indicator organisms for the potential presence of pathogens in surface water resulting from the presence of untreated human or animal wastes, and they are the basis for recreational use water quality criteria in Rule 3745-1-07 of the Ohio Administrative Code (OAC).

In 2005, water samples were collected at sites throughout the Sugar Creek watershed for bacteriological analyses to determine the attainment status of designated water bodies within the watershed with respect to recreational uses and to support the development of a Total Maximum Daily Load (TMDL) for bacteria. Analyses included analysis for fecal coliform bacteria and for *E. coli*.

STUDY AREA

Sugar Creek drains a 365.2 square mile watershed in northeast Ohio (Figure 1). The watershed lies in two ecoregions that are roughly defined by the southern glacial boundary in the region. The northern half is in the glaciated Erie and Ontario Drift and Lake Plain (EOLP). The southern half of the watershed is in the non-glaciated Western Allegheny Plateau (WAP). The glaciated portion is characterized by rolling hills and valleys. The non-glaciated portion has steeper topography with coal and clay deposits. The watershed is divided among four counties Holmes (26% of the watershed area), Stark (11%), Tuscarawas (35%) and Wayne (28%). Incorporated communities within the watershed include Brewster, Dover, Orrville, Smithville, Strasburg and Sugar Creek. The mainstem of Sugar Creek is 45 miles long and flows in a northwest to southeast direction from the vicinity of Smithville in Wayne County to its confluence with the Tuscarawas River near Dover. Statistics regarding the physical attributes of Sugar Creek and its tributary network are listed in Table 1. A schematic of the drainage pattern of the streams is provided in Figure 2.

For purposes of water quality evaluation, the Ohio EPA utilizes assessment units (AU's) based upon the 11-digit watershed Hydrologic Unit Code (HUC) boundaries established by the Natural Resources Conservation Service (NRCS, www.oh.nrcs.usda.gov) (Ohio EPA, 2002). The Sugar Creek watershed is divided into three 11-digit AU's: Sugar Creek, Headwaters to upstream of the Middle Fork (05040001100); South fork sugar Creek (05040001110); and Sugar Creek, from Middle Fork to mouth, excluding South Fork (05040001120) (Figure 3). Each of the 11-digit AU's is further subdivided into

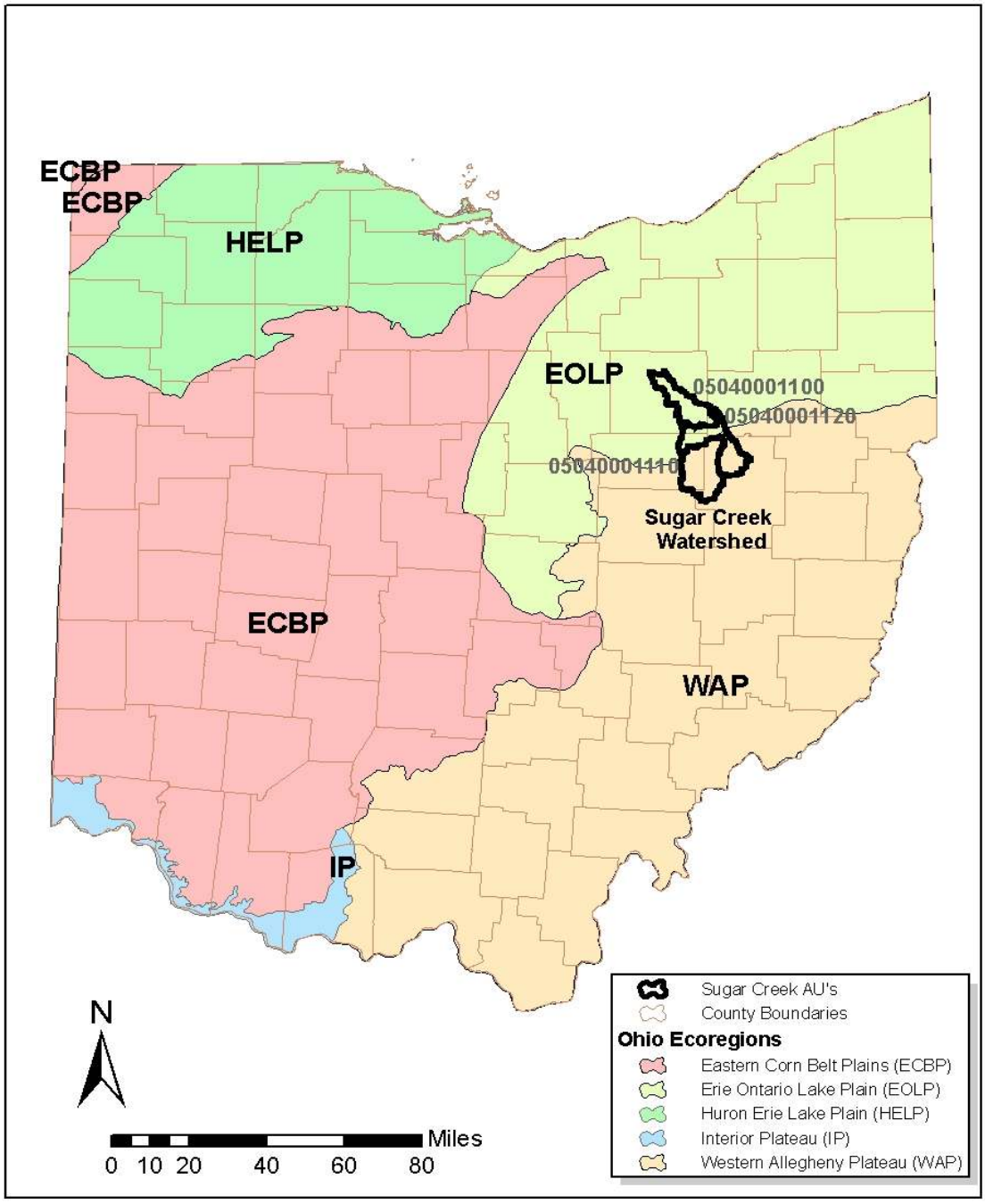
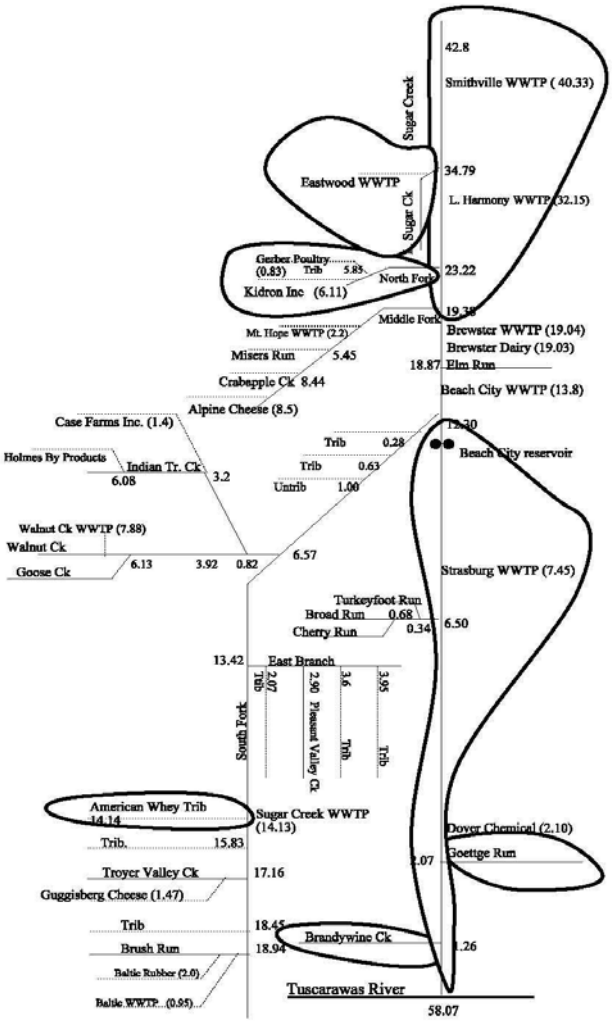


Figure 1. Location map of the Sugar Creek watershed.

Table 1.Stream characteristics for named streams within the Sugar Creek study area.

Stream Name	Length (miles)	AverageFall (ft/mile)	Drainage Area (mi^2)
Sugar Creek	45.0	6.3	356.2
Brandywine Creek	3.5	18.2	5.50
Broad Run	6.9	15.8	20.16
Turkeyfoot Run	3.3	28.8	4.28
South Fork	22.7	5.2	137.0
Walnut Creek	11.1	7.6	48.09
Indian Trail Creek	8.1	15.9	16.36
Goose Creek	4.7	9.1	6.26
East Branch	9.7	12.9	28.36
Pleasant Valley Creek	4.9	28.0	4.14
Troyer Valley Creek	3.2	20.3	2.96
Brush Run	2.8	25.4	5.23
Bean Creek	1.6	64.3	19.41
Elm Run	5.4	33.5	6.64
Middle Fork	23.0	9.1	65.80
Miser's Run	3.0	87.7	2.19
Crabapple Run	6.1	24.6	10.90
North Fork	6.8	6.8	17.62
Little Sugar Creek	10.6	28.7	18.71

Figure 2. Schematic of Sugar Creek and tributaries.



Numbers in parentheses indicate discharger river mile. Other numbers represent tributary or mainstem river miles

Source: Ohio EPA, 2002

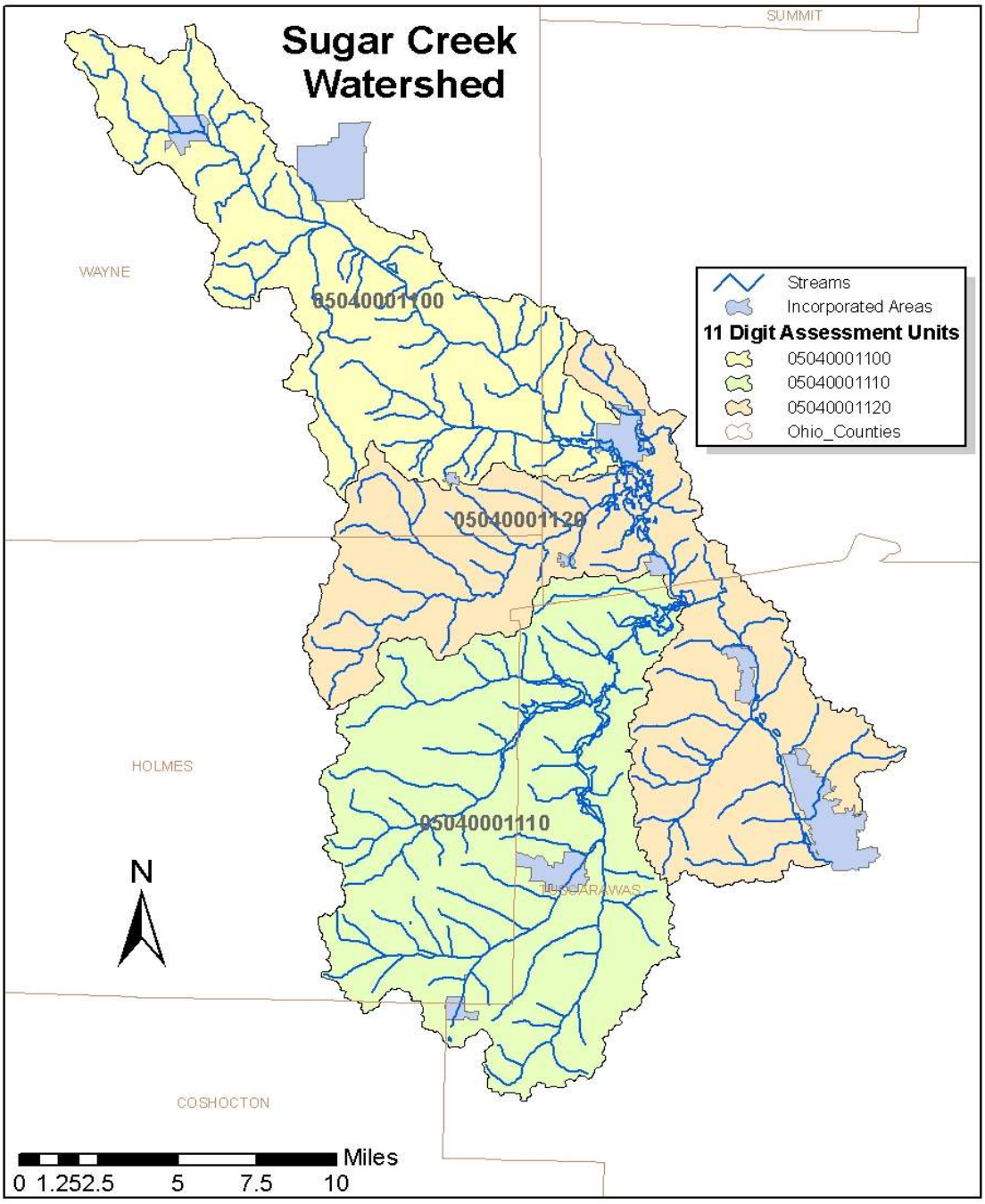


Figure 3. Assessment units within the Sugar Creek watershed.

14-digit HUC sub-watersheds (Table 2). Summaries of land use statistics within the Sugar Creek watershed AU's are found in Table 3 and Figures 4, 5, and 6.

Land cover in the Sugar Creek watershed is dominated by Agriculture/Open Urban Areas (72%) and Wooded (25%). Agriculture uses include: row crops, dairy cows, beef and poultry confined feeding operations, forage production, and fruit production. Farms within Holmes, Stark, Tuscarawas and Wayne Counties that incorporate the Sugar Creek watershed account for approximately 25 percent of the total milk production within the State of Ohio, averaging 1.19×10^9 pounds per year (USDA, 2005). The size of the dairy herd has averaged 69,136 head over the last 10 years, also 25 percent of the state total (Figure 7). Among the four counties, Wayne County has the highest density for all categories of livestock, with cattle constituting the majority of the livestock numbers. Although milk production, dairy cows, and total cattle herd sizes have remained relatively constant over the last ten years (Figures 7 and 8), there has been a significant decrease in hog production overall in the four county area (Figure 9), with the majority of the decrease observed in Holmes County.

Facilities with National Pollutant Discharge Elimination System (NPDES) permits to discharge wastewater within the Sugar Creek watershed include small to large publicly owned wastewater treatment facilities as well as industrial dischargers. Permitted industrial dischargers fall within several different categories including cheese manufacturing, poultry processing, meat packing, rendering, and chemical manufacturing. Information regarding the location, receiving streams, and design flows for NPDES permitted facilities within the watershed is provided in Table 4 and Figures 4, 5 and 6.

In 1998, the Ohio EPA conducted an intensive water quality survey that included assessments of the 76 sites within the Sugar Creek watershed (Ohio EPA, 1999). Fish and macroinvertebrate communities were assessed to determine attainment status with respect to Ohio's biological water quality criteria. The study also included assessments of habitat quality, water chemistry, bacteriological water quality, and sediment chemistry. Aquatic resource degradation from agriculture observed during the 1998 Ohio EPA water quality survey included: manure and urine discharge directly to streams, milking waste discharged by pipe to streams, failing on-site home sewage treatment systems, dumping of fruit processing waste into streams, stream channelization and dredging for agriculture, cattle in streams, and the lack of wooded riparian corridor. Strip mining of coal and clay has also had a negative impact on the aquatic resource as numerous small headwater streams are affected by acidic mine runoff. This process involves removing overbearing soil and minerals, removing the clay and or coal and replacing the overburden. Prior to the mid 1970's reclamation after mining was not required by law. Un-reclaimed mine land contributes sediments, metals and acid water to the streams.

Table 2. Assessment Unit (AU) and 14-Digit Hydrologic Unit Code (HUC) designations for the Sugar Creek Watershed.

11-Digit AU	14-Digit HUC	Narrative	Area (mi^2)
05040001100		**Sugar Creek (headwaters to above Middle Fork Sugar Creek)**	**97.33**
	010	Sugar Creek headwaters to above L. Sugar Cr.	28.17
	020	Little Sugar Creek	18.09
	030	Sugar Creek below L. Sugar Cr. to above Middle Fk. Sugar Cr. [except N. Fk.Sugar Cr.]	33.07
	040	North Fork Sugar Creek	18.00
05040001110		**South Fork Sugar Creek**	**137.69**
	010	South Fork Sugar Creek above E. Branch	34.99
	020	East Branch South Fork Sugar Creek	28.19
	030	South Fork Sugar Creek below E. Branch to above Walnut Cr.	12.66
	040	Walnut Creek [except Indian Trail Cr.]	31.65
	050	Indian Trail Creek	16.38
	060	South Fork Sugar Creek below Walnut Cr. to Sugar Cr.	13.82
05040001120		**Sugar Creek (above Middle Fork to Tuscarawas River [except South Fork])**	**121.32**
	010	Middle Fork Sugar Cr. above Crabapple Cr.	16.41
	020	Crabapple Creek	11.28
	030	Middle Fork Sugar Cr. below Crabapple Cr. to Sugar Cr.	19.52
	040	Sugar Creek below Middle Fk. Sugar Cr. to Beach City Reservoir [except S. Fk. Sugar Cr.]	17.57
	050	Sugar Creek below Beach City Reservoir to above Broad Run	13.44
	060	Broad Run	19.56
	070	Sugar Creek below Broad Run to Tuscarawas River	23.54

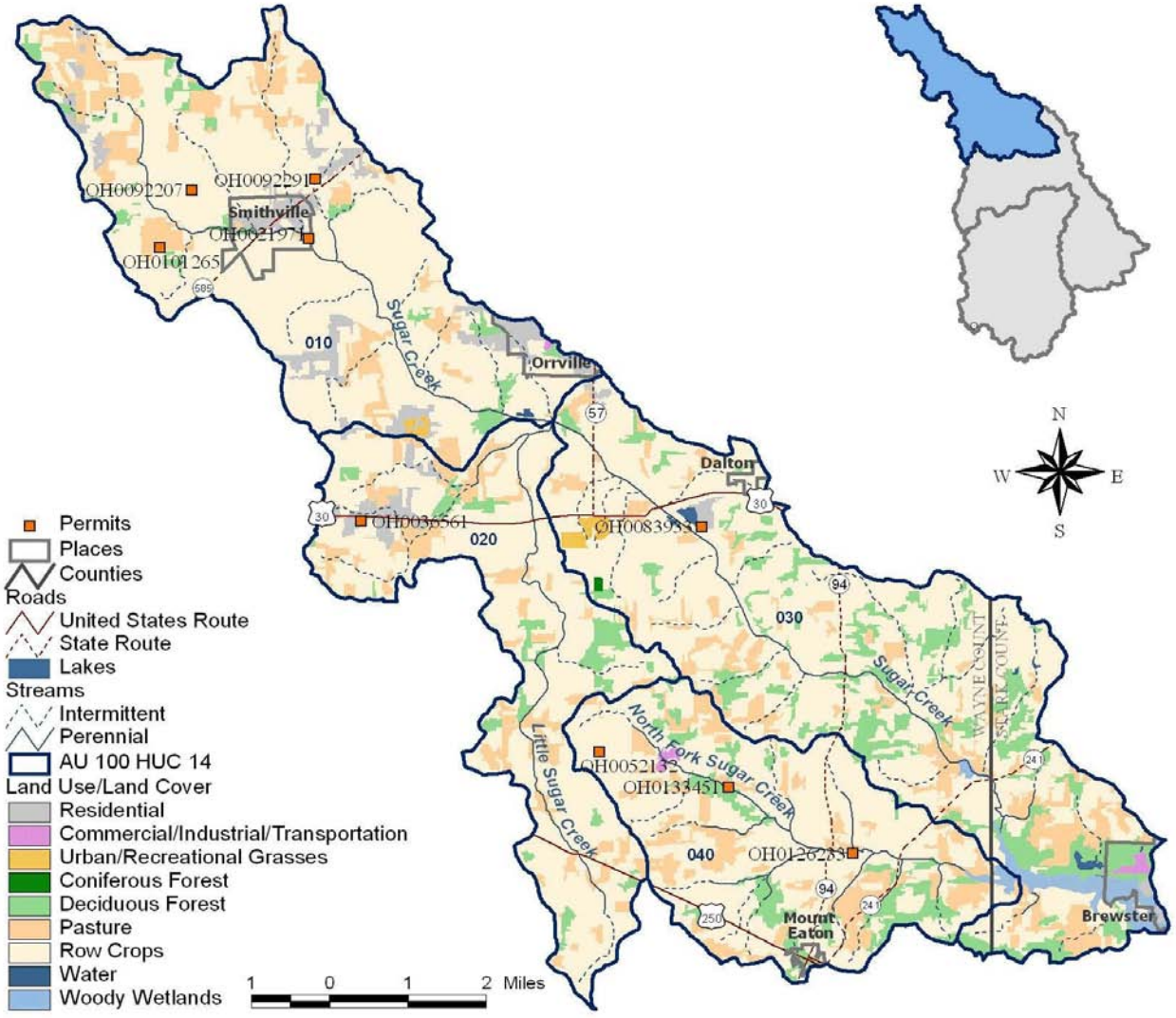


Figure 4. Land use pattern for AU 05040001100 (Sugar Creek, headwaters to above Middle Fork). Source: Tetra-Tech, Inc.

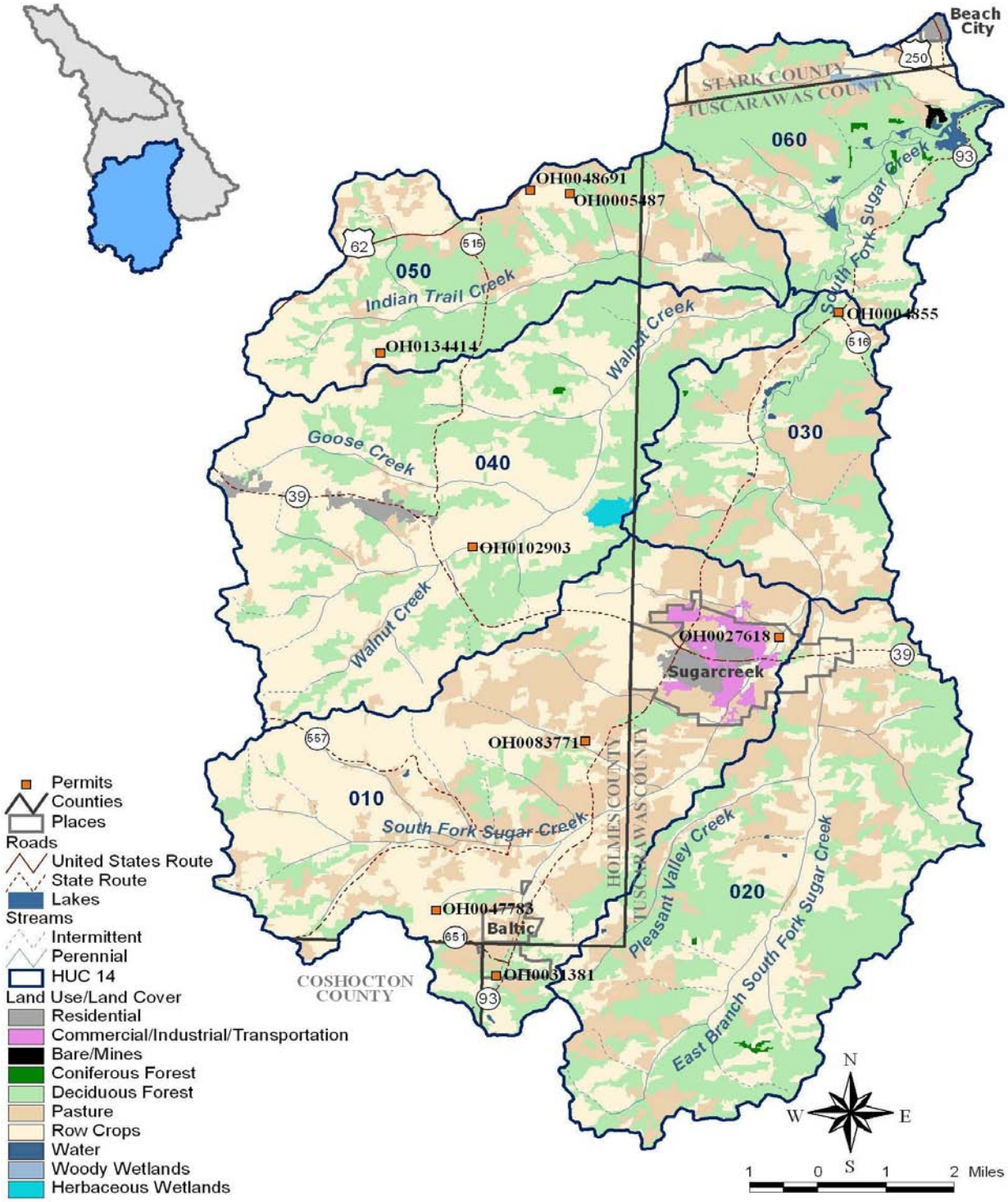


Figure 5. Land use pattern for AU 05040001110 (South Fork Sugar Creek). Source: Tetra-Tech, Inc.

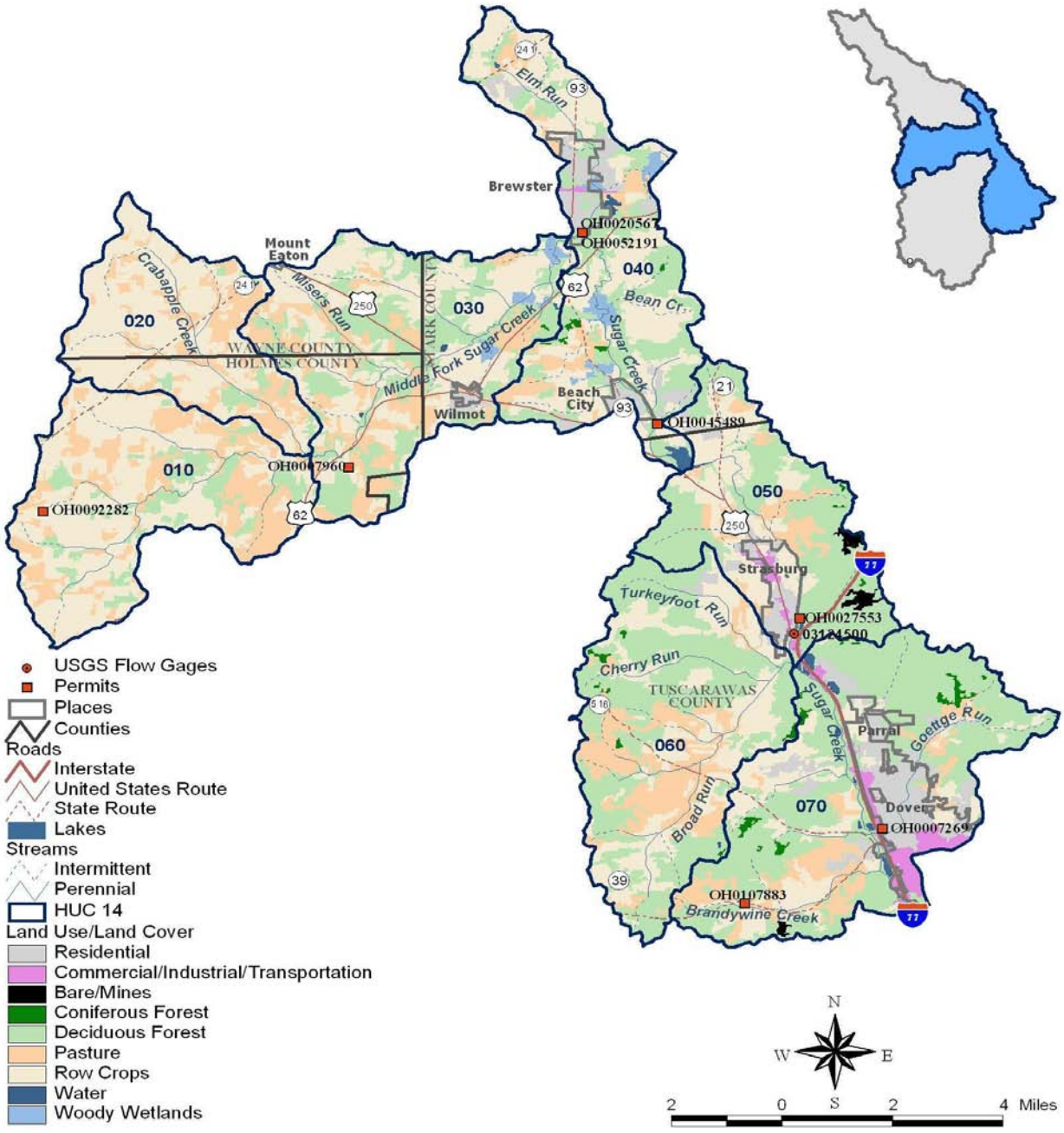


Figure 6. Land use pattern for AU 05040001120 (Sugar Creek, Middle Fork to mouth, excluding South Fork). Source: Tetra-Tech, Inc.

Table 3.Land use summary from 1994 Raster Map Data, provided by NRCS.

Watershed/ 11-Digit AU	Percent Land Use						
	Urban	Agriculture/ Open Urban Areas	Shrub/ Scrub	Wooded	Open Water	Wetlands Non-Forested	Barren
Sugar Creek (entire watershed)							
	1.48	71.89	0.35	24.87	0.17	0.81	0.42
Headwaters to Middle Fork/05040001100							
	1.49	83.19	0.22	14.29	0.19	0.54	0.06
South Fork/05040001110							
	0.96	70.67	0.36	26.42	0.09	0.93	0.56
Sugar Creek above Middle Fork to Tuscarawas River (Excluding South Fork)/05040001120							
	2.05	64.24	0.43	31.59	0.24	0.89	0.56

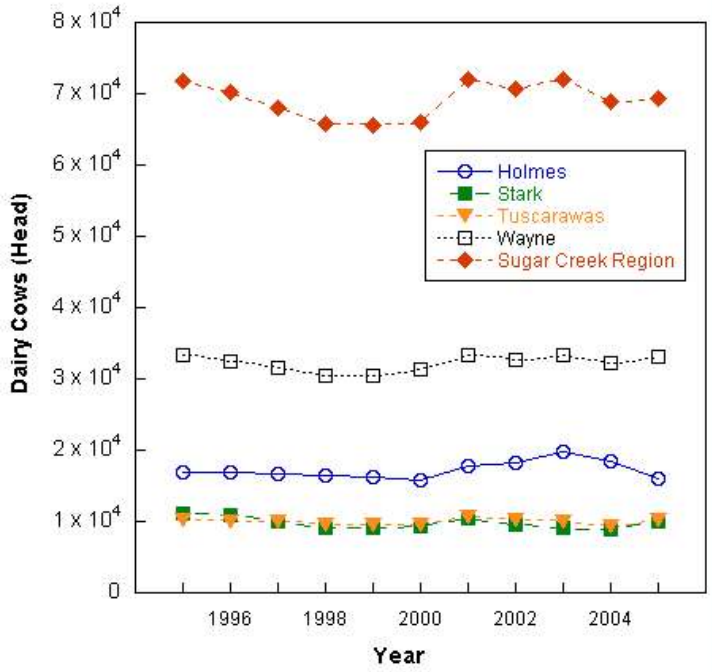


Figure 7. Dairy herd size within the Sugar Creek watershed region, 1995-2004. Source: USDA, 2005.

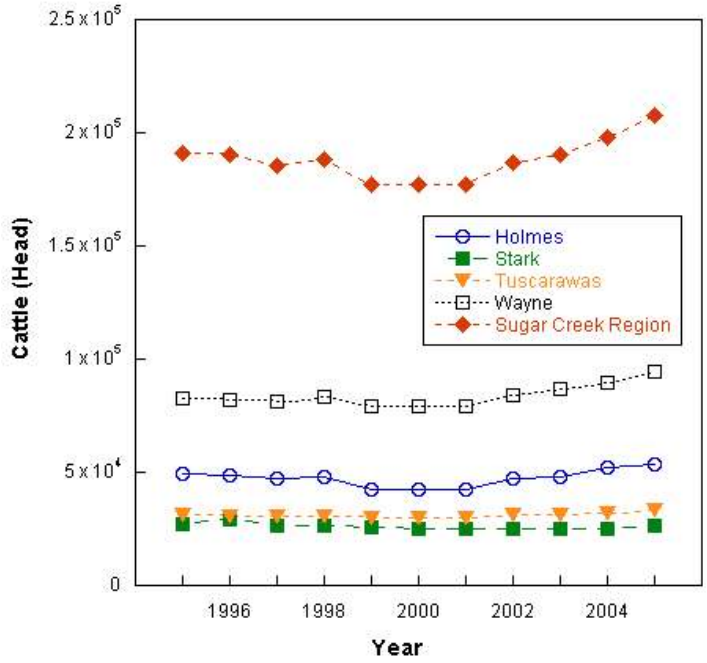


Figure 8. Total cattle herd size within the Sugar Creek watershed region, 1995-2004. Source: USDA, 2005.

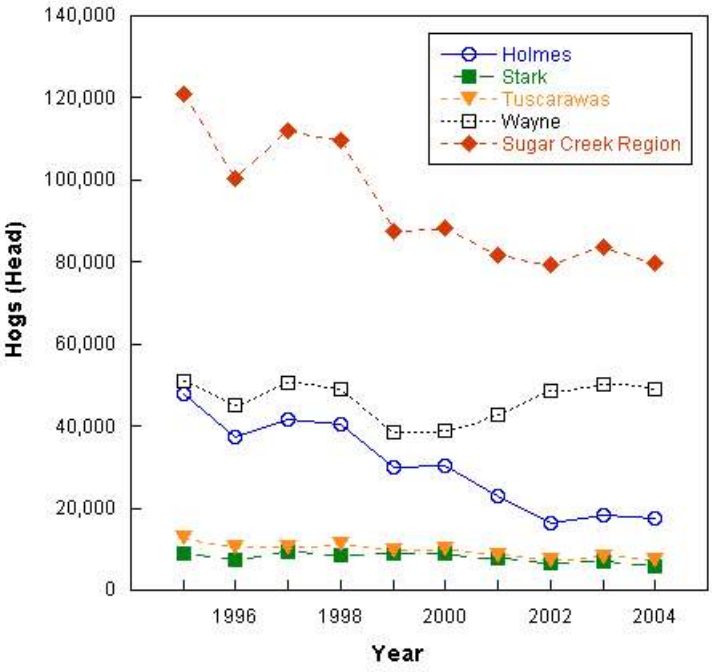


Figure 9. Hog numbers for farms within the Sugar Creek watershed region, 1985-2004. Source: USDA, 2005.

Table 4. NPDES permitted wastewater dischargers within the Sugar Creek watershed.

11-Digit AU/ Facility	County	Ohio Permit	USEPA ID	Expiration	Latitude	Longitude	Receiving Stream	River Mile	Sugar Creek RM	Design Flow (MGD)
05040001100										
Gerber's Poultry Inc	Wayne	3IH00049	OH0052132	1/31/2007	40.79500	-81.94000	RM 5.85 Trib. North Fork Sugar Creek	0.83	23.22	0.250
Kidron WWTP	Wayne	3PG00159	OH0133451	11/30/2008	40.73440	-81.72640	North Fork Sugar Creek	5.15	23.22	0.160
Lake Harmony Subdivision	Wayne	3PG00078	OH0083933	10/31/2005	40.79390	-81.73360	Sugar Creek	32.15	32.15	0.036
Mount Eaton WWTP	Wayne	3PA00033	OH0126233	11/30/2009	40.71910	-81.69020	North Fork Sugar Creek	2.90	23.22	0.045
Smithville Mobile Home Park	Wayne	3PG00139	OH0092291	7/31/2010	40.87380	-81.84600	RM 39.66 Trib. Sugar Creek	1.25	39.66	0.006
Smithville Western	Wayne	3PS00010	OH0101265	5/31/2006	40.85830	-81.89170	RM 0.31 Trib. To RM 42.42 Trib. Sugar Creek	0.20	42.42	0.090
Smithville WWTP	Wayne	3PB00046	OH0021971	5/31/2005	40.86030	-81.84810	Sugar Creek	40.33	40.33	0.300
Wayne Co Airport	Wayne	3PG00132	OH0092207	2/28/2010	40.87140	-81.88220	RM 41.85 Trib. Sugar Creek	0.70	41.85	0.002
Wayne Co. Eastwood Subdivision STP	Wayne	3PG00133	OH0036561	12/31/2007	40.79580	-81.83330	Little Sugar Creek	0.80	34.79	0.060
05040001110										
Baltic Rubber	Tuscarawas	NA	OH0031381	NA	40.43700	-81.70530	Brush Run	2.00	12.3	0.020
Baltic WWTP	Tuscarawas	0PB00067	OH0047783	5/31/2009	40.45190	-81.72180	Brush Run	0.95	12.3	0.010
Case Farms Inc Control Plant	Holmes	3IH00103	OH0005487	6/30/2007	40.61420	-81.68280	RM 3.2 Trib. Indian Trail Creek	1.40	12.3	0.500
Guggisberg Cheese Inc Sugarcreek WWTP	Holmes	3IH00065	OH0083771	7/28/2001	40.49000	-81.68000	Troyer Valley Creek	1.47	12.3	0.014
Holmes By-Products	Holmes	3IK00006	OH0134414	1/31/2010	40.57850	-81.73600	RM 6.08 Trib. Indian Trail Creek	0.60	12.3	NA
Holmes Cty Health	Holmes	3PG00138	OH0048691	1/31/2007	40.61510	-81.69370	RM 26.34 Trib. Indian Trail	1.30	12.3	0.015

Table 4. NPDES permitted wastewater dischargers within the Sugar Creek watershed.

11-Digit AU/ Facility	County	Ohio Permit	USEPA ID	Expiration	Latitude	Longitude	Receiving Stream	River Mile	Sugar Creek RM	Design Flow (MGD)
Dept Winesburg Area SD							Creek			
Sugarcreek WWTP	Tuscarawas	0PB00070	OH0027618	3/31/2006	40.51310	-81.62580	South Fork Sugar Creek	14.13	12.3	0.500
Troyer's Trail Bologna Inc	Holmes	3IH00104	OH0004855	9/30/2006	40.58670	-81.60830	RM 5.42 Trib. Indian Trail Creek	0.25	12.3	0.005
Walnut Creek WWTP	Holmes	3PH00058	OH0102903	10/31/2008	40.53420	-81.71080	Walnut Creek	7.88	12.3	0.090
05040001120										
Alpine Cheese Co	Holmes	3IH00100	OH0007960	1/28/2004	40.63580	-81.67560	Middle Fork Sugar Creek	8.50	19.38	0.220
Beach City Wilmot STP	Stark	3PB00036	OH0045489	12/31/2006	40.64720	-81.56940	Sugar Creek	13.80	13.8	0.200
Brewster Dairy Control Plant	Stark	3IH00051	OH0052191	2/28/2007	40.70070	-81.59440	Sugar Creek	19.04	19.04	0.300
Brewster STP	Stark	3PB00006	OH0020567	2/28/2007	40.70070	-81.59310	Sugar Creek	19.05	19.05	0.665
Dover Chemical Corporation	Tuscarawas	0IF00040	OH0007269	7/31/2006	40.53211	-81.49383	Sugar Creek	2.10	2.1	4.000
Kimble Sanitary Landfill	Tuscarawas	0IN00159	OH0107883	6/30/2006	40.51132	-81.54135	Brandywine Creek	2.00	1.26	NA
Mt Hope WWTP	Holmes	3PG00135	OH0092282	11/30/2004	40.62390	-81.78080	Middle Fork Sugar Creek	2.20	19.38	0.220
Strasburg WWTP	Tuscarawas	0PB00043	OH0027553	7/31/2006	40.59190	-81.52140	Sugar Creek	7.45	7.45	0.225

Many streams within the Sugar Creek watershed are highly impacted by modifications resulting from channelization, entrenchment (disconnection from the floodplain), farming practices, and riparian (stream side) deforestation (compare Figure 10 to Figures 11-13). Fish habitat assessments using the Qualitative Habitat Evaluation Index (QHEI) conducted in 1998 (Ohio EPA, 1999) found that 44 percent of the headwater streams (drainage areas <20 mi^2) had been either recently channelized or had no habitat recovery. This figure is much higher for surveyed stream reaches with drainage areas greater than 20 mi^2, where it was found that 73 percent of the sites fell into this category. The number of evaluated stream reaches that were deemed to be in a transition state where stream channel characteristics such as the development of riffle and pool sequences, point bars, and connection with the associated floodplain were recovering was low (4-6 percent). At the same time, 76 percent of the predominant land use immediately adjacent to the evaluated stream reaches was found to be open pasture or row crop agriculture for headwater stream sites and 29 percent for stream reaches with drainage areas greater than 20 mi^2.

The result of these channel modifications and riparian land use practices has been to create a stream network that is largely disconnected from its associated floodplain except under extreme flood conditions. Therefore, in relatively high gradient headwater catchments storm water flows, along with associated pollutant and sediment loads, are exported rather quickly to transitional and low gradient stream segments within the watershed, where flow velocities diminish and a significant amount of deposition occurs. In the Sugar Creek watershed, this process is magnified by the Beach City Dam, a flood control reservoir that controls flows from the entire upper Sugar Creek and South Fork Sugar Creek sub-watersheds (AU's 05040001100 and 05040001110) as well the Middle Fork Sugar Creek and Elm Run sub-watershed in AU 05040001120. The dam has created long reaches near the mouths of the major tributaries to Sugar Creek that are characterized by lower channel gradient, low water velocities and fine sediment particle size (Figure 13).

Disconnection of the stream channels from their associated floodplains through channelization and entrenchment results in storage of the fine sediments and silts within the stream channel itself, rather than deposition in adjacent flood terraces. Fifty percent of the stream reaches with drainage areas greater than 20 mi^2 evaluated using the QHEI were characterized as having heavy levels of siltation, and the number of sites where silt was determined to be a dominant substrate type was double in greater than 20 mi^2 sites as compared to headwater sites. There were a high percentage of sites under both drainage categories where stream substrate embededness, an additional measure of sediment aggradation, was deemed extensive (54% for sites greater than 20 mi^2, and 48% for headwater sites). The embededness scoring appeared to be closely associated with sand deposits, which was deemed a dominant substrate type at 21 percent of the greater than 20 mi^2 sites and at 24 percent of the headwater sites.

Figure 10. High gradient stream reach in the headwaters of the North Fork Sugar Creek. Riparian vegetation, active floodplains allow natural stream channels to maintain a balance between erosion and deposition resulting in excellent habitat for aquatic life and good water quality.

Figure 12. Stream channelization in the Little Sugar Creek watershed. These activities disconnect the stream from its floodplain and entrain fine sediments and pollutants in the stream channel.

Figure 13. A channelized reach of Brush Run. The entrenchment of the stream has disconnected the stream channel from the floodplain resulting in the deposition of sands and silts. The removal of woody vegetation from the stream banks and lack of buffer from nearby agricultural activities results in a highly enriched stream with poor water quality.

Figure 11. The mainstem of Sugar Creek at Alabama Ave. (Stark County). The stream channel characteristics and flow regime at this point are highly influenced by channelization (entrenchment) and backwater effects of the Beach City Dam.

RECREATIONAL USES

Water quality criteria for determining whether rivers and streams are suitable for recreational uses are established in the Ohio Water Quality Standards (Table 7-13 in OAC 3745-1-07) based upon the presence or absence of bacteria indicators in the water column. Indicator organisms used for these determinations are fecal coliform bacteria and *Escherichia coli*.

Fecal coliform bacteria are microscopic organisms that are present in large numbers in the feces and intestinal tracts of humans and other warm-blooded animals. *E. coli* typically comprises approximately 97 percent of the organisms found in the fecal coliform bacteria of human feces (Dufour, 1977), but there is currently no simple way to differentiate between human and animal sources of coliform bacteria in surface waters, although methodologies for this type of analysis are becoming more practicable. These microorganisms can enter water bodies where there is a direct discharge of human and animal wastes, or may enter water bodies along with runoff from soils where these wastes have been deposited.

Pathogenic (disease causing) organisms are typically present in the environment in such small amounts that it is impractical to monitor them directly. Fecal coliform bacteria, including *E. coli*, by themselves are usually not pathogenic. However, some strains of *E. coli* can be toxic, causing serious illness. Although not necessarily agents of disease, fecal coliform bacteria and *E. coli* may indicate the potential presence of pathogenic organisms that enter the environment through the same pathways. When fecal coliform bacteria or *E. coli* are present in high numbers in a water sample, it invariably means that the water has received fecal matter from one source or another. Swimming or other recreational-based contact with water having a high fecal coliform or *E. coli* count may result in ear, nose, and throat infections, as well as stomach upsets, skin rashes, and diarrhea. Young children, the elderly, and those with depressed immune systems are most susceptible to infection.

Designations of recreational uses for water bodies in the Sugar Creek watershed are listed in OAC Rule 3745-1-24. Water bodies with designated recreational use of Primary Contact Recreation (PCR) "...are waters that, during the recreation season, are suitable for full-body contact recreation such as ... swimming, canoeing, and SCUBA diving with minimal threat to public health as a result of water quality" [OAC 3745-1-07 (B)(4)(b)]. Water bodies designated for Secondary Contact Recreation (SCR) "... are waters that, during the recreation season, are suitable for partial body contact recreations such as, but not limited to, wading with minimal threat to public health as a result of water quality" [OAC 3745-1-07(B)(4)(c)]. The majority of the stream segments surveyed during the 2005 study are designated for the PCR use (Tables 5 and 6). The only exception was the lower reach (river mile 5.04 to the mouth) of the East Branch of the South Fork Sugar Creek which is

Table 5. Recreational Use Water Quality Critieria applicable to the Sugar Creek Study Area (Table 7-13 of OAC 3745-1-07). At least one of the two bacteriological standards (fecal coliform or *E. coli*) must be met. These criteria apply outside of the mixing zone.

Primary Contact

Fecal coliform - geometric mean fecal coliform content (either MPN or MF), based upon not less than five samples within a thirty-day period, shall not exceed 1,000 per 100 ml and fecal coliform content (either MPN or MF) shall not exceed 2,000 per 100 ml in more than ten percent of the samples taken during any thirty-day period.

E. coli - geometric mean *E. coli* content (either MPN or MF), based upon not less than five samples within a thirty-day period, shall not exceed 126 per 100 ml and *E. coli* content (either MPN or MF) shall not exceed 298 per 100 ml in more than ten percent of the samples taken during any thirty-day period.

Secondary Contact

Fecal coliform - shall not exceed 5,000 per 100 ml (either MPN or MF) in more than ten percent of the samples taken during any thirty-day period.

E. coli - shall not exceed 576 per 100 ml in more than ten percent of the samples taken during any thirty-day period.

designated for the SCR use. There are no designated bathing areas within the areas assessed for the Sugar Creek watershed in 2005. Applicable water quality criteria for the PCR and SCR uses within the Sugar Creek study area are listed in Table 5. Bacteriological results from environmental samples are typically reported as colony forming units (cfu) per 100 ml of water.

STUDY DESIGN

Sample Locations and Sampling Frequency

Sampling sites used for bacteriological sampling are listed in Table 6, and are depicted in Figure 14. Two types of sites were identified: Sentinel Sites and Geometric Sites. At Sentinel Sites, water samples for bacteria analysis were collected on 10-15 dates during the period of May 1 to October 15, 2005 (the recreation season as defined in OAC 3745-1-07). In addition, stream flow measurements were taken throughout the study period at the Sentinel Sites in order to provide loading estimates for the development of a TMDL for bacteria in the watershed. Total suspended solids (TSS) concentrations were estimated at sentinel sites by taking water transparency readings in the field simultaneously with the collection of water samples for bacteriological analysis.

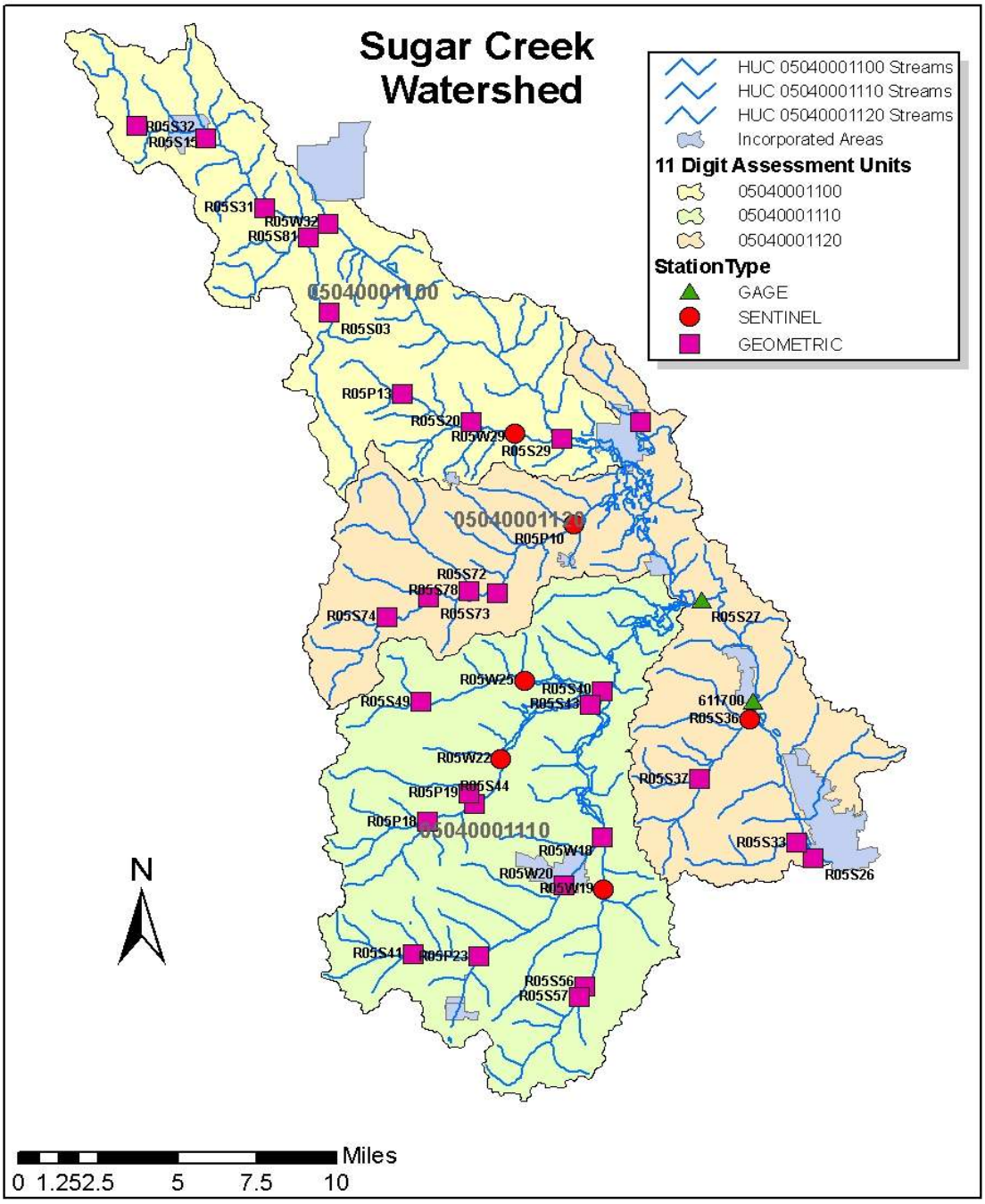


Figure 14. Sampling sites used in the Sugar Creek bacteriological survey, 2005

Table 6. Sentinel Site and Geometric Site sample locations for the Sugar Creek recreational use assessment, 2005.

STORET ID	Location	River Mile	Drainage Area (mi^2)	Geometric Site Category (mi^2)	County	USGS Quadrangle	Latitude	Longitude	HUC 11	HUC 14
Stream Name/River Code/Recreational Use Designation										
Sugar Creek (17-400) PCR										
R05S26	State Rt. 39	0.63	356	357	Tuscarawas	Dover	40.51250	-81.48861	05040001120	070
611700[U]	State Rt. 250	7.28	311	178	Tuscarawas	Strasburg	40.58750	-81.52333	05040001120	050
R05S27[G]	Dst Beach City Reservoir	12.07	300	178	Tuscarawas	Navarre	40.63583	-81.55333	05040001120	050
R05S29	Alabama Rd.	22.95	93	89	Stark	Wilmot	40.71390	-81.63640	05040001100	030
R05W32	Kansas Rd.	34.69	46	44	Wayne	Orrville	40.81750	-81.77500	05040001100	030
R05S31	Orr Rd.	36.88	25	22	Wayne	Orrville	40.82530	-81.81360	05040001100	010
R05S32	Co. Rd. 502	40.18	14.4	11	Wayne	Orrville	40.85890	-81.84810	05040001100	010
R05S15	Schellin Rd.	42.75	5.9	6	Wayne	Wooster	40.86520	-81.88940	05040001100	010
Brandywine Creek (17-401) PCR										
R05S33	Twp. Rd. 211	0.16	5.5	6	Tuscarawas	Dover	40.51972	-81.49806	05040001120	070
Broad Run (17-402) PCR										
R05S36[S]	Twp. Rd. 425	0.15	20	11	Tuscarawas	Strasburg	40.57920	-81.52560	05040001120	060
R05S37	Co. Rd. 80	2.8	8.2	6	Tuscarawas	Strasburg	40.55060	-81.55600	05040001120	060
Elm Run (17-405) PCR										
R05S71	Harmon St.	1.69	5.5	6	Stark	Navarre	40.72140	-81.58890	05040001120	040
Middle Fork Sugar Creek (17-406) PCR										
R05P10[S]	Northvale Ave.	3.16	41.9	44	Stark	Wilmot	40.67310	-81.62940	05040001120	030
R05S72	Twp. Rd. 606	7.58	30	22	Holmes	Wilmot	40.64060	-81.67560	05040001120	030
R05S73	Twp. Rd. 669	10.25	10.3	11	Holmes	Wilmot	40.63890	-81.71690	05040001120	010
R05S74	DST MT. HOPE WWTP	12	8	6	Holmes	Wilmot	40.62940	-81.74220	05040001120	010
Crabapple Creek (17-408) PCR										
R05S78	Twp. Rd. 606	0.31	10.8	11	Holmes	Wilmot	40.64170	-81.69280	05040001120	020
North Fork Sugar Creek (17-409) PCR										
R05W29[S]	W. Lebanon Rd.	1.35	16.5	11	Wayne	Wilmot	40.71670	-81.66420	05040001100	040
R05S20	Western Rd.	3.79	10.5	11	Wayne	Wilmot	40.72220	-81.69080	05040001100	040
R05P13	Zuercher Rd.	5.53	3.5	6	Wayne	Wilmot	40.73580	-81.73140	05040001100	040

Table 6. Sentinel Site and Geometric Site sample locations for the Sugar Creek recreational use assessment, 2005.

STORET ID	Location	River Mile	Drainage Area (mi^2)	Geometric Site Category (mi^2)	County	USGS Quadrangle	Latitude	Longitude	HUC 11	HUC 14
Stream Name/River Code/Recreational Use Designation										
South Fork Sugar Creek (17-410) PCR										
R05S40	Co. Rd. 94	6.43	124.0	89	Tuscarawas	Strasburg	40.59306	-81.61389	05040001110	060
R05W18	Winklepleck Rd.	13.28	63.3	44	Tuscarawas	Strasburg	40.52333	-81.61417	05040001110	030
R05W20	Co. Rd. 47	15.26	25.0	22	Tuscarawas	Sugarcreek	40.50083	-81.63750	05040001110	010
R05P23	Twp. Rd. 173	18.98	14.4	11	Holmes	Baltic	40.46694	-81.68889	05040001110	010
R05S41	Co. Rd. 114	21.11	5.9	6	Holmes	Baltic	40.46833	-81.72778	05040001110	010
Walnut Creek (17-411) PCR										
R05S43	Lane Near Mouth	0.56	48.0	44	Tuscarawas	Strasburg	40.58670	-81.62080	05040001110	040
R05W22[S]	Co. Rd. 172	4.49	22.0	22	Holmes	Sugarcreek	40.56140	-81.67470	05040001110	040
R05S44	Twp. Rd. 444	6.32	10.6	11	Holmes	Sugarcreek	40.53970	-81.69060	05040001110	040
R05P18	Old State Rt. 39	7.93	9.1	6	Holmes	Sugarcreek	40.53139	-81.71861	05040001110	040
Indian Trail Creek (17-412) PCR										
R05W25[S]	Twp. Rd. 66	2.56	13.4	11	Holmes	Sugarcreek	40.59860	-81.66020	05040001110	050
R05S49	Twp. Rd. 414	6.33	4.8	6	Holmes	Sugarcreek	40.58890	-81.72190	05040001110	050
Goose Creek (17-413) PCR										
R05P19	Twp. Rd. 419	0.35	6.0	6	Holmes	Sugarcreek	40.54490	-81.69390	05040001110	040
East Branch South Fork Sugar Creek (17-414) PCR/SCR										
R05W19[S]	Twp. Rd. 348[SCR]	1.7	25.4	22	Tuscarawas	Stone Creek	40.49833	-81.61417	05040001110	020
R05S56	Co. Rd. 52[SCR]	5.04	10.8	11	Tuscarawas	Baltic	40.45222	-81.62583	05040001110	020
R05S57	Co. Rd. 48[PCR]	5.47	10.0	6	Tuscarawas	Baltic	40.44722	-81.62944	05040001110	020
Brush Run (17-417) PCR										
R05P24	Twp. Rd. 173	0.09	5.0	6	Holmes	Baltic	40.46639	-81.68861	05040001110	010
Little Sugar Creek (17-418) PCR										
R05S81	McQuaid Rd..	0.85	13.3	11	Wayne	Orrville	40.81110	-81.78750	05040001100	020
R05S03	S. Kansas Rd.	4.2	9.0	6	Wayne	Orrville	40.77500	-81.77530	05040001100	020

[S] Sentinel site. Bridge mark stream level gage and flow monitoring location.

[U] Sentinel site. USGS gage location.

[G] USGS real-time stream level gaging location available via the internet.

Geometric Sites were positioned to provide a spatial sampling design for the Sugar Creek watershed which divides the watershed into relatively equally sized sub-watershed units. The sequential subdivision of the watershed is called geometric site selection, and was used during the 1998 Ohio EPA biological and water quality survey of the Sugar Creek Watershed (Ohio EPA, 1999). Spatial division of the watershed results in sites with approximate watershed areas of 357 mi^2, 178 mi^2, 89 mi^2, 44 mi^2, 22 mi^2, 11 mi^2, and 6 mi^2. As the watershed size decreases, the number of sites increases to reflect the apportionment of stream miles within the watershed as drainage area decreases. The 2005 bacteriological survey used the same geometric site locations as those used in the 1998 biological and water quality survey. In general, 5 samples were collected at each Geometric Site during the recreational season although some sites had fewer samples collected because of site-specific difficulties. Sampling events were scheduled in such a way that samples were collected from all Geometric Sites and Sentinel Sites within the same HUC 11 watershed on the same day.

Sample Collection and Analysis

Water samples were collected in accordance with the sampling protocols outlined in the Ohio EPA Division of Surface Water Manual of Ohio EPA Surveillance Methods and Quality Assurance Practices (Ohio EPA, 2003). Water samples were collected directly from the streams into sterilized polyethylene containers, cooled to 4°C, and transported to the Ohio EPA-NEDO contract laboratory for analysis within 6 hours of sample collection. All samples were analyzed for fecal coliform bacteria using U.S.EPA approved methods (STORET Parameter Code 31611). In addition, analysis for *E. coli* (STORET Parameter Code 31633) was conducted for all samples collected from sentinel sites and for approximately 50% of the samples collected from geometric sampling sites in order to provide supporting data with respect to these organisms.

Stream Gaging and Flow Monitoring

Provisional flow estimates and gage height readings for USGS stream gaging station 03124500 (Sugar Creek at Strasburg - STORET station number 611700) were obtained from the instruments at the gaging station on all sampling dates and dates when either gage readings or flow monitoring was conducted within the watershed. In addition, real-time stream stage measurements for USGS stream gaging station 03124000 (Sugar Creek below Beach City Dam) was obtained from the internet (http://waterdata.usgs.gov/oh/nwis/current/?type=flow) for all sampling and flow monitoring dates. The latest USGS rating table for Station 03124500 was used to obtain the provisional flow estimate for Sugar Creek at Strasburg. There is no updated rating table available for USGS gaging station 03124000 (Greg Koltun, USGS, pers. comm.). For other Sentinel Sites, bridge marks were established for the gaging of stream height, and water stage was measured by measuring the distance from the bridge mark to the water surface using a weighted tape measurer. Gage heights were measured in feet to the nearest 0.01

foot. Flow monitoring was conducted at all of the Sentinel Sites except for the site gaged by the USGS on a periodic basis (minimum of six occasions) across various flow conditions in order to develop regression relationships between stream flow and stream gage height. Flows were estimated for all sample collection dates using the gage height vs. stream flow relationship using linear regression techniques.

Stream flow monitoring was accomplished using either a Marsh-McBirney Model 201 or a SonTek Flow Tracker portable water current meter and following the procedures developed by the USGS (Buchanan and Somers, 1969) and the Ohio EPA (Ohio EPA, 2003).

Water Transparency Measurements

Transparency measurements and estimation of TSS concentrations followed the methodologies outlined in Anderson and Davic (2004). Water from the stream was either collected directly into a clear plastic sediment tube, with water added until a black and white target at the bottom of the tube just disappeared. Two readings were taken for each sample, and the average reading was recorded to the nearest centimeter (~0.25 inch). A regression equation correlating water transparency to TSS in mg/l was used to estimate TSS concentrations.

RESULTS

Ambient Bacteriological Water Quality

Fecal coliform bacteria results from the 2005 survey are summarized by sampling site in Figures 15 and 16 (see Appendix A for individual sample results, Appendix B for *E.coli* summary data, and Appendix C for summary statistics for each sampling station for fecal coliform). Extremely high bacteria counts were ubiquitous throughout the Sugar Creek watershed, confirming results of the more limited survey conducted by the Ohio EPA in 1998 (Ohio EPA, 1999). Of the 38 sites sampled in the survey, only 5 were fully attaining the recreational use water quality criteria. An additional 3 sites were partially attaining the water quality criteria. A particular bright spot is the upper reaches of the North Fork Sugar Creek (05040001100 AU), where both sites in the vicinity of the Village of Kidron were found to be in FULL attainment for the recreational use criteria for fecal coliform bacteria. The 1998 water quality survey found this reach to be one of the worst areas for bacteriological water quality (Ohio EPA, 1999). The construction and operation of a new wastewater treatment plant for the village appears to have alleviated much of the problems noted in the earlier survey.

In order to assess bacteriological data collected from the Sugar Creek Assessment Units (AU's), fecal coliform and *E. coli* results from ambient samples collected during

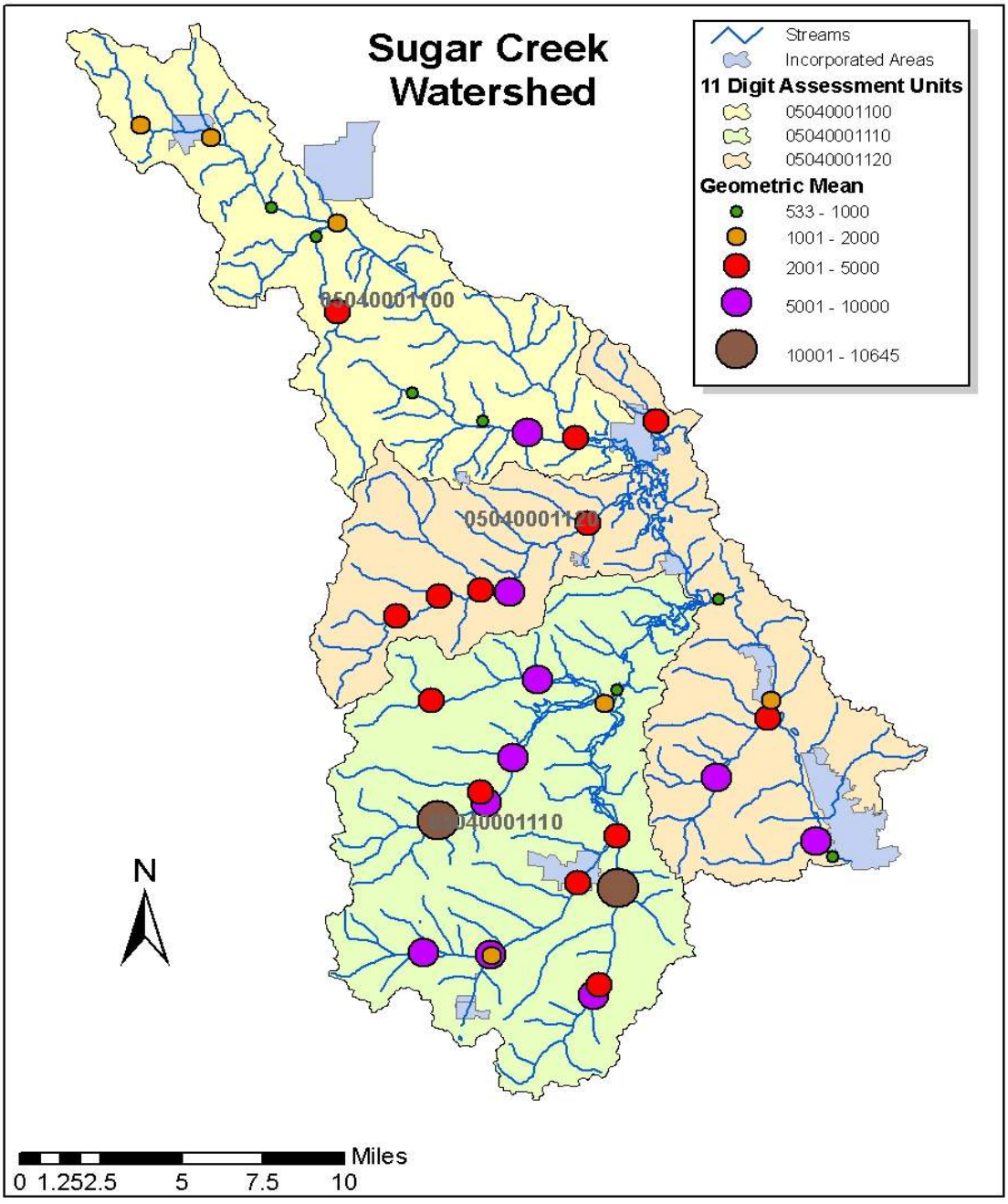


Figure 15. Fecal coliform geometric means for 2005 water quality survey sites within the Sugar Creek watershed.

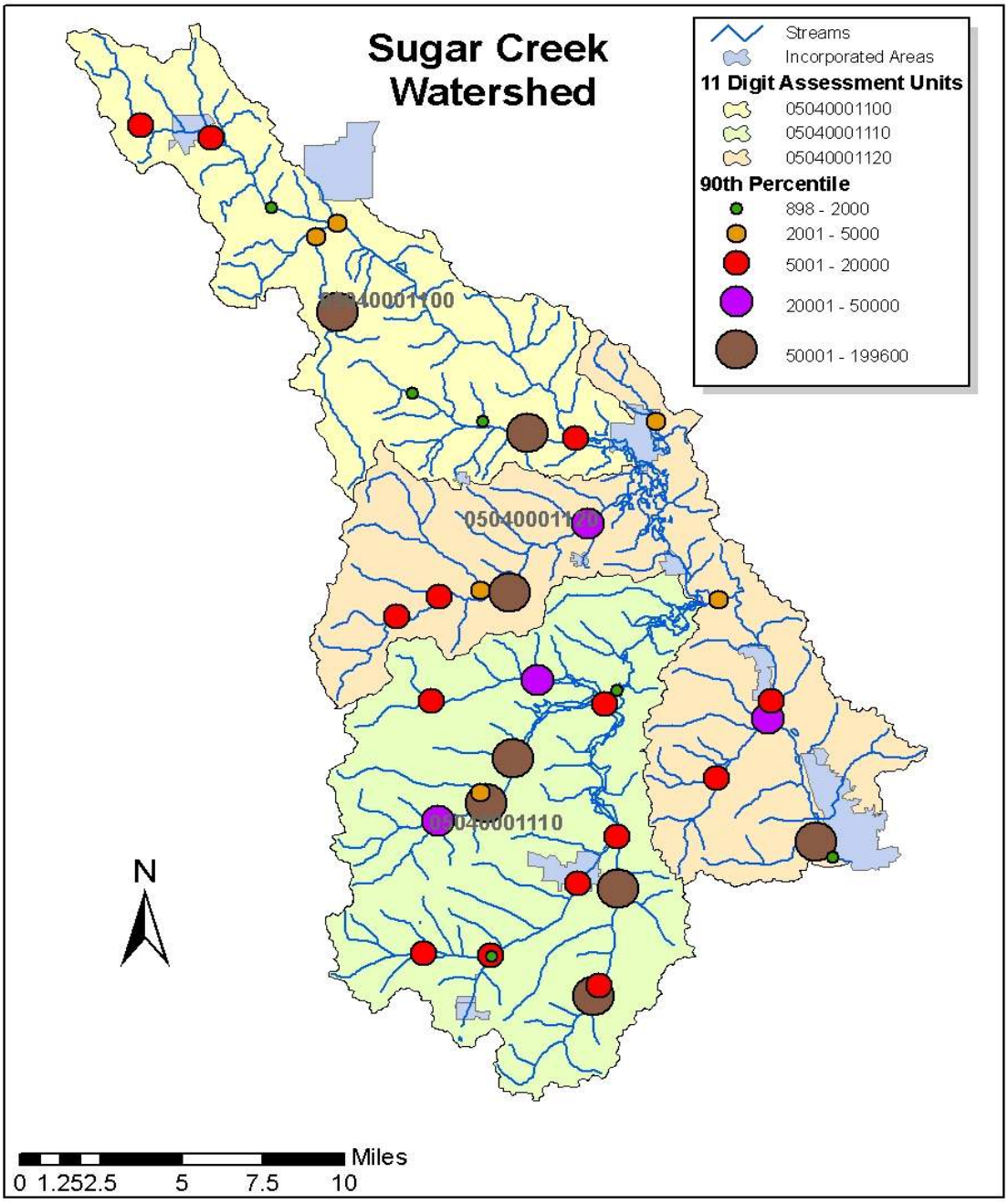


Figure 16. Fecal coliform 90th percentiles for 2005 water quality survey sites within the Sugar Creek watershed.

the 2005 survey were pooled in order to calculate geometric means and to determine the 90th percentile. Only data collected during the recreational season (May 1 through October 15) are used for the analysis. The results of the analyses are compared to the PCR use water quality criteria to determine the degree of attainment. Based upon the current rules, only one of the two indicators must be in attainment in order to meet the water quality criteria.

For purposes of reporting the attainment status for a particular Assessment Unit, the following protocol is followed:

1. Where sufficient data is available for direct comparison to the water quality criteria (5 samples collected within a thirty-day period), compliance with the criteria determines the attainment status. Violations of either the geometric mean or 10 percent criteria represents NON-Attainment and values below the criteria indicate FULL Attainment.

2. Where sufficient data is not available for direct comparison to the water quality criteria, pooled data for a period of record is compared to the water quality criteria as follows:

    A) NON-Attainment is assigned when both the geometric mean and the 90th percentile for the data exceed the applicable water quality criteria.

    B) PARTIAL Attainment is assigned when the geometric mean for the pooled data is less than the water quality criteria but the 90th percentile exceeds the water quality criteria.

    C) FULL Attainment is assigned when both the geometric mean and the 90th percentile for the pooled data are below the applicable water quality criteria.

Pooled fecal coliform results indicate that all three 11-digit AU's in the Sugar Creek watershed are in NON attainment for their designated Recreational Uses (Table 7). Of the 17 14-digit HUC sub-watersheds in the Sugar Creek basin, only 3 were found to be in PARTIAL attainment of the PCR criteria. The geometric means for fecal coliform from the pooled data for these 14-digit HUC's were below the PCR criterion of 1,000 cfu/100 ml, but the 90th percentile for the counts exceeded the PCR criterion. These results are not highly meaningful, however, since the geometric means for these sub-watersheds were either at or only slightly less than the PCR criterion. Analysis of *E. coli* data (See Appendix B) found that all 11-digit AU's and 14-digit sub-watersheds were in NON attainment for the PCR criteria.

Table 7. Summary fecal coliform bacteria data for 11-Digit HUC Assessment Units (AU's) and 14-Digit HUC watersheds within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml fecal coliform.

11-Digit AU 14-Digit HUC	Number of Samples	Geometric Mean	90th Percentile	Maximum	Minimum	Attainment Status
05040001100 (Pooled)	**58**	**1,930**	**10,230**	**290,000**	**270**	**NON**
05040001100010	15	1,000	6,460	11,000	310	PARTIAL
05040001100020	10	2,079	70,400	290,000	270	NON
05040001100030	10	2,165	4,850	6,200	880	NON
05040001100040	23	2,729	21,840	160,000	380	NON
05040001110 (Pooled)	**97**	**5,576**	**21,000**	**240,000**	**590**	**NON**
05040001110010	17	5,042	15,400	28,000	1,000	NON
05040001110020	22	8,528	74,700	240,000	2,400	NON
05040001110030	5	3,893	7,400	8,200	780	NON
05040001110040	31	6,070	24,000	200,000	650	NON
05040001110050	17	5,653	22,400	140,000	1,200	NON
05040001110060	5	978	1,720	2,200	590	PARTIAL
05040001120 (Pooled)	**88**	**2,643**	**20,300**	**240,000**	**200**	**NON**
05040001120010	10	3,425	6,660	18,000	1,700	NON
05040001120020	5	2,098	4,000	4,800	840	NON
05040001120030	18	5,492	77,200	240,000	900	NON
05040001120040	5	2,461	4,700	4,900	1,300	NON
05040001120050	22	966	5,590	21,000	200	PARTIAL
05040001120060	18	4,838	31,600	63,000	410	NON
05040001120070	10	1,986	27,690	240,000	400	NON

Analysis of the data collected in 2005 using the more natural breakdown of pooling data by the individual streams sampled within the watershed further confirmed the universal problem with respect to pathogens in the Sugar Creek watershed (Table 8). None of the streams sampled attained the PCR water quality criteria for fecal coliform or *E. coli*, nor did any or the streams achieve even partial attainment for bacteria. Stream catchments with particularly high bacteria counts were the East Fork South Branch Sugar Creek and Walnut Creek in the South Fork Sugar Creek AU (05040001110) and Brandywine Creek, Broad Run and the Middle Fork Sugar Creek in the lower Sugar Creek AU (05040001120). Although both sites in the upper reaches of the North Fork of Sugar Creek were in FULL attainment, the results from the most downstream location, a sentinel site, outweighed the upstream results in the analysis when the all of the results for the stream were pooled.

The only site on the mainstem of Sugar Creek found to be in FULL attainment was the site near the mouth of the stream located at RM 0.63. This site also constituted the only geometric drainage area category (357 mi^2) that fully met the recreational use water quality criteria in the watershed (Table 9). Pooled data from all of the drainage area categories

Table 8. Summary fecal coliform bacteria data for surveyed streams within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml fecal coliform.

Stream Name	Number of Samples	Geometric Mean	90th Percentile	Minimum	Maximum
Sugar Creek	52	1,076	5,590	200	21,000
Little Sugar Creek	10	2,079	70,400	270	290,000
North Fork Sugar Creek	23	2,729	21,840	380	160,000
Middle Fork Sugar Creek	28	4,618	44,600	900	240,000
Crabapple Creek	5	2,098	4,000	840	4,800
Elm Run	5	2,461	4,700	1,300	4,900
South Fork Sugar Creek	25	3,834	11,280	590	28,000
Walnut Creek	26	7,293	92,000	650	400,000
Indian Trail Creek	17	5,653	22,400	1,200	140,000
Goose Creek	5	2,336	4,460	1,300	5,700
E. Branch S. Fork Sugar Creek	22	8,528	74,700	2,400	240,000
Brush Run	2	1,342	1,720	1,000	1,800
Broad Run	17	4,838	31,600	410	63,000
Brandywine Creek	5	7,394	145,640	2,400	240,000

Table 9. Summary fecal coliform bacteria data for watershed drainage categories within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml fecal coliform.

Drainage Category	Number of Samples	Geometric Mean	90th Percentile	Minimum	Maximum
6 mi^2	62	3,747	19,800	310	290,000
11 mi^2	78	3,777	26,800	270	160,000
22 mi^2	39	6,211	200,000	310	240,000
46 mi^2	27	3,299	24,200	650	150,000
89 mi^2	10	1,687	4,850	590	6,200
178 mi^2	22	966	5,590	200	21,000
357 mi^2	5	533	920	400	1,200

less than 177 mi^2 exceeded both the geometric mean and 90th percentile PCR water quality criteria for fecal coliform bacteria. The geometric mean for fecal coliform at the 177 mi^2 stations met the PCR water quality criterion, but exceeded the 90th percentile criterion. Fecal coliform counts were the most elevated at the 22 mi^2 drainage area sites for both geometric mean and 90th percentile.

Point Sources

Effluent limitations for fecal coliform bacteria at all permitted point source dischargers in the Sugar Creek watershed (Table 4) are required to be maintained at or below the applicable PCR water quality criteria during the recreation season (May 1 - October 15). Therefore, if an NPDES regulated facility is meeting its effluent limitations, there should be no contribution to violations of the water quality criteria downstream of the discharge. Exceedances of effluent limitations for fecal coliform bacteria determined from monthly operating report data submitted to the Ohio EPA are summarized in Table 10. Although some temporal problems are noted for individual facilities, the compliance rate among NPDES dischargers is generally high, especially when the data for 2005 is considered. Analysis of the data supports a conclusion that NPDES regulated facilities are not responsible for the widespread violations of the water quality criteria for fecal coliform bacteria and *E. coli* noted in this study.

Stream Gaging and Flow Monitoring

Linear regression techniques were used to describe the relationship between stream gage heights and stream flows at the sentinel sites. Although coefficients of determination for the regressions of stream flows to gage height were high for all of the sites (r^2 values >0.90), the resulting linear equations did not provide adequate predictions of low flows. Predictions using gage heights measured under low flow conditions for several of the sites resulted in negative values using the linear equation. Further analysis using orthogonal polynomial techniques of curvilinear regression yielded quadratic equations to estimate stream flow from gage height measurements that resulted in very high coefficients of determination (r^2 values ranging from 0.966 to 0.999) (Figure 17) and no negative flow estimations. The quadratic equations were then used to predict stream flows for sampling dates when flow measurements were not taken.

Comparisons of estimated and actual stream flow measurements at the sentinel sites for dates when bacteria sampling was conducted are provided in Figure 18. Flows at the USGS gaging station (Sugar Creek at Strasburg, station 61170) were an order of magnitude higher than at the remainder of the sentinel sampling locations, reflective of the much larger drainage area of the stream at this location. Flow estimations reported here will be used as part of the modeling process for the development of total maximum daily loads (TMDL's) for bacteria.

Table 10. Summary of permit exceedances for NPDES permitted dischargers in the Sugar Creek watershed, 1998-2005. Values note the range for fecal coliform in samples exceeding the permit limits in cfu/100 ml with the number if exceedances of permit limits for the year in parentheses.

AU/Facility (Permit ID)	1998	1999	2000	2001	2002	2003	2004	2005
AU 05040001100								
Gerber's Poultry Inc. (3IH00049)	None	None	1400-3000 (2)	None	None	None	None	None
Kidron WWTP (3PG00159)	None	NA	NA	NA	NA	NA	NA	None
Lake Harmony Subdiv (3PG00078)	None	2000 (2)	2000 (1)	6300-12000 (2)	2400 (1)	1400 (1)	None	None
Mount Eaton WWTP (3PA00033)	None	None	None	None	None	None	1800 (1)	None
Smithville MHP (3PG00139)	NA	NA	NA	NA	NA	NA	NA	None
Smithville Western (3PS00010)	2900 (1)	None	None	None	8000 (1)	None	None	None
Smithville WWTP (3PB00046)	None	None	None	None	None	None	None	None
Wayne Co. Airport (3PG00132)	None	None	3300 (1)	2900-20000 (2)	2010-3500 (2)	None	2000 (2)	None
Wayne Co. Eastwood Subdivision STP (3PG00133)	None	None	2000-20000 (4)	2000-2200 (2)	7500 (1)	None	1100-3100 (3)	None
AU 05050001110								
Baltic Rubber (NA)	NA	NA	NA	NA	NA	NA	NA	NA
Baltic WWTP (0PB00067)	None	1025-22000 (8)	7000 (1)	12300-12500 (2)	1300 (1)	None	1296 (1)	None
Case Farms Inc Control Plant (3IH00103)	None	1166-6000 (5)	1554-6000 (4)	1430-6000 (5)	None	None	None	None
Guggisberg Cheese Inc Sugarcreek WWTP (3IH00065)	NA	NA	NA	NA	NA	NA	NA	NA
Holmes By-Products (3IK00006)	NA	NA	NA	NA	NA	NA	NA	NA

Table 10. Summary of permit exceedances for NPDES permitted dischargers in the Sugar Creek watershed, 1998-2005. Values note the range for fecal coliform in samples exceeding the permit limits in cfu/100 ml with the number if exceedances of permit limits for the year in parentheses.

AU/Facility (Permit ID)	1998	1999	2000	2001	2002	2003	2004	2005
AU 05050001110 (cont.)								
Holmes Cty Health Dept Winesburg Area SD (3PG00138)	None	None	None	None	None	None	650 (1)	None
Sugarcreek WWTP (0PB00070)	None	None	None	None	None	None	None	None
Troyer's Trail Bologna Inc (3IH00104)	None	None	768 (1)	692 (1)	500-2100 (3)	2800-3500 (2)	736-768 (2)	None
Walnut Creek WWTP (Holmes County) (3PH00058)	None	1600-1800 (2)	None	None	None	None	None	None
AU 05040001120								
Alpine Cheese Co. (3IH00100)	NA	NA	1900-17000 (2)	2800-6500 (3)	None	19600-21500 (2)	9800-20000 (9)	None
Beach City Wilmot STP (3PB00036)	None	None	None	None	None	7500 (1)	None	None
Brewster Dairy Control Plant (3IH00051)	NA	NA	NA	NA	NA	NA	NA	NA
Brewster STP (3PB00006)	None	1020-1175 (13)	1012-2275 (25)	1033-5800 (10)	1116 (1)	1584 (1)	1066 (1)	None
Dover Chemical Corporation (0IF00040)	None	None	None	None	None	None	None	None
Kimble Sanitary Landfill (0IN00159)	NA	NA	NA	NA	NA	NA	NA	NA
Mt Hope WWTP (3PG00135)	None	None	None	None	None	None	None	None
Strasburg WWTP (0PB00043)	None	1392-14000 (4)	2800-31800 (3)	None	2500-12100 (3)	3700 (1)	None	None

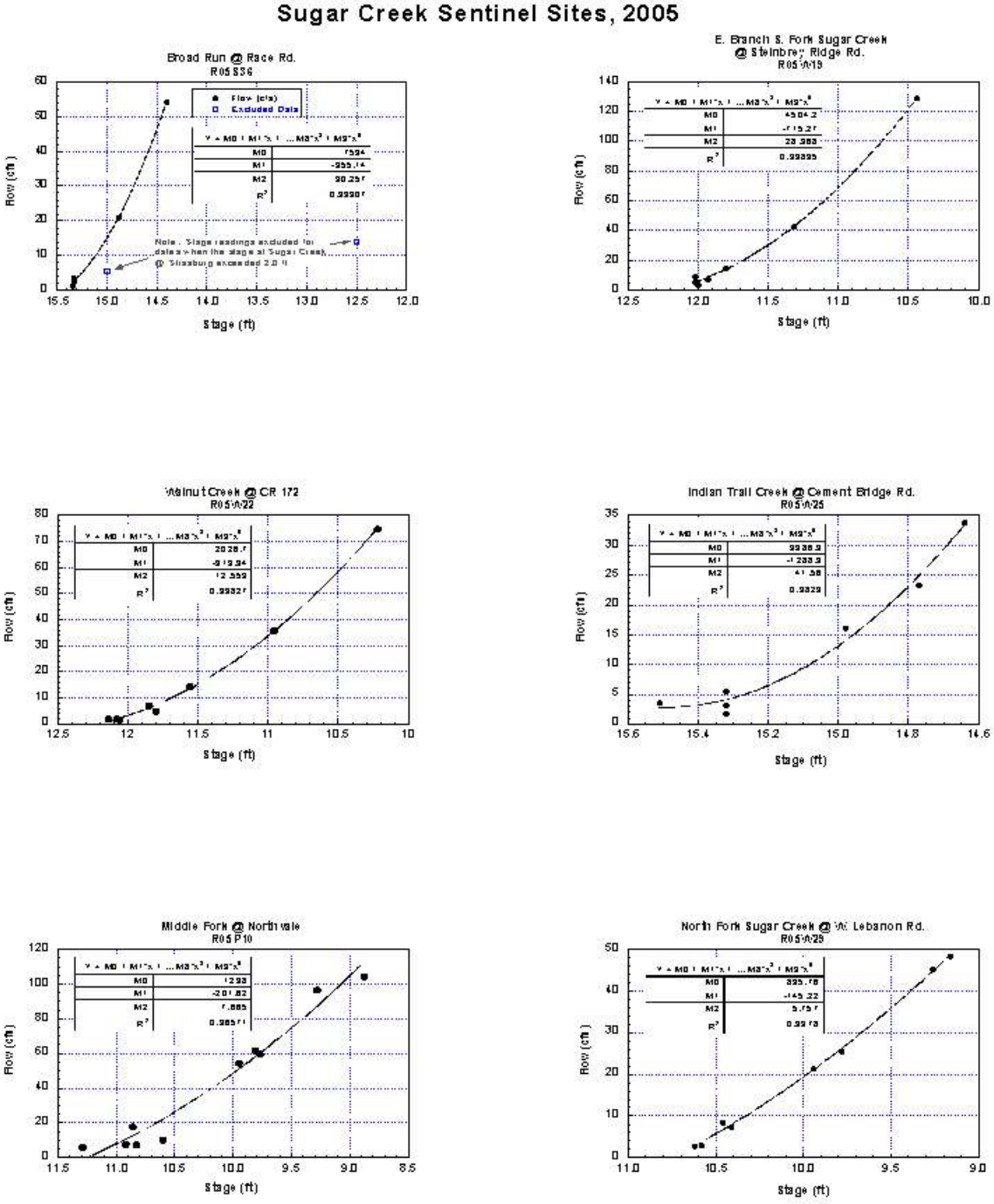


Figure 17. Correlations for gage height (stage) and stream flow for Sugar Creek watershed sentinel sites.

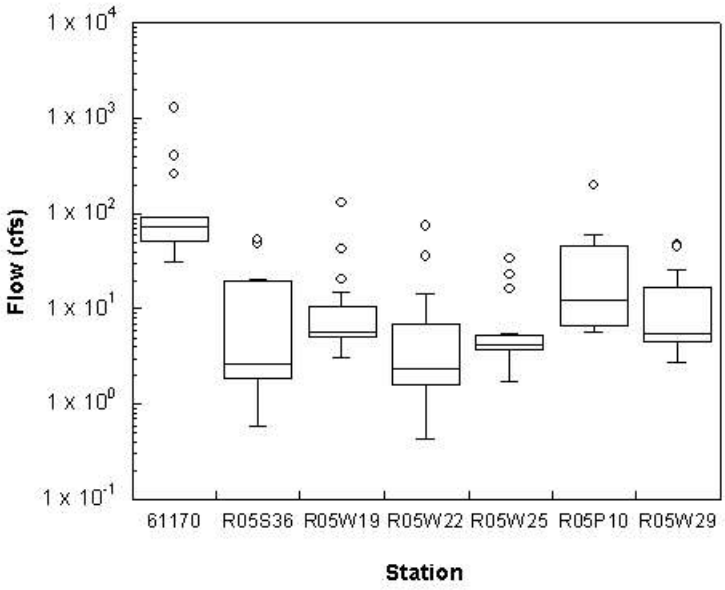


Figure 18. Comparison of stream flows at Sugar Creek sentinel sites on dates samples were collected in 2005.

Total Suspended Solids Estimations

Total suspended solids (TSS) concentrations were estimated for sentinel site samples from water clarity measurements taken at the time of sample collection. Conversion equations found in Anderson and Davic (2004) were used to estimate TSS to determine the degree of correlation between TSS and bacteria counts. Median TSS concentrations were much lower at the sentinel sites in the northern part of the watershed (AU's 05040001100 and 05040001120) than in the South Fork sub-watershed (AU 05040001110)(Figure 19). Median estimated TSS concentrations were 7 mg/l in the North Fork Sugar Creek (R05W29) and 8 mg/l in Indian Trail Creek (R05W25). The median TSS concentration was higher in the Middle Fork Sugar Creek (site R05P10, 16 mg/l). In contrast, median TSS concentrations were 2-3 times higher in the South Fork Sugar Creek AU, ranging between 30 and 32 mg/l in the East Fork South Branch Sugar Creek, Walnut Creek and Broad Run. The median TSS concentration in the mainstem of Sugar Creek at the stream gaging station in Strasburg (station 61170) was 28 mg/l.

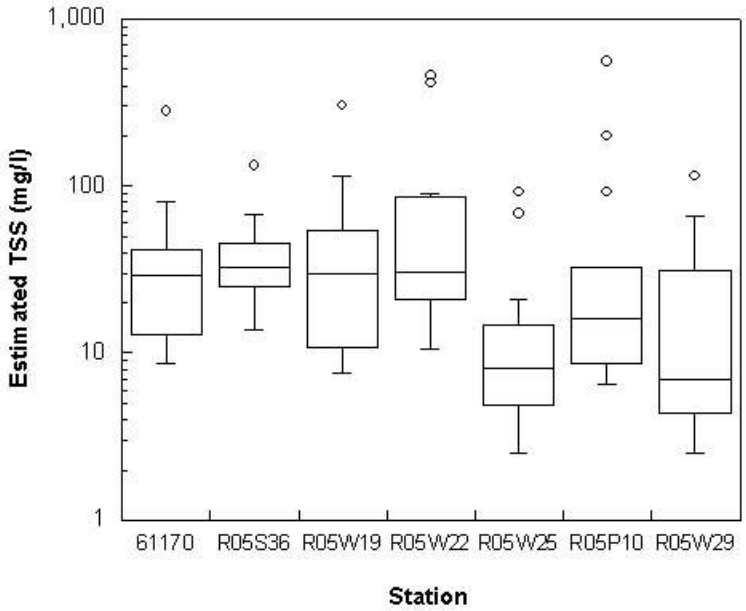


Figure 19. Estimated total suspended solids concentrations at sentinel sites for the 2005 Sugar Creek survey.

DISCUSSION

The widespread nature of bacterial pollution within the Sugar Creek watershed makes it impossible to analyze localized sources in detail within the limits of this report. However, given the scope of the problem it is possible to conclude that agricultural practices, particularly relating to animal pasturing and animal waste management are the primary causes of NON-attainment of recreational use water quality criteria in the watershed. Sources of bacteria and potential pathogens relating to the problem are poorly managed or uncontrolled runoff from animal rearing and feeding operations, barn yards and milk houses, spills or releases from manure handling operations, runoff from manure applied for use as fertilizer for farm fields, and direct access of streams by grazing animals (Figure 20).

The Sugar Creek watershed is the home of numerous dairy farms (Figure 21), resulting in very high densities of cattle with the potential to affect water quality in virtually all of the headwater streams within the drainage network. Particularly concentrated clusters of small dairy operations are found within the Amish communities, where herd sizes tend to be smaller, but where management practices rely more heavily upon pasturing with greater potential for impact to streams. Manure management practices associated with these operations often do not include adequate conservation practices, and tend to result in

Figure 20. Unrestricted access to streams by grazing animals can result in significant bacterial pollution of the stream and the re-suspension of bacteria-laden sediments.

greater non-point source loads to adjacent streams. Current trends for many Amish farms may be indicative of a greater potential for impact, as many of the Amish church districts are now allowing the use of automatic milking machines which will likely result in increases in dairy herd size on the associated farms (Dr. Richard Moore, Ohio State Univ., pers. comm.). Sub-watersheds with high densities of dairy operations are the mainstem of Sugar Creek downstream of Little Sugar Creek to the confluence of the North Fork, the upper portions of Little Sugar Creek, and the North Fork Sugar Creek in AU 05040001100; the upper portion of the South Fork Sugar Creek, Indian Trail Creek and Walnut Creek in AU 05040001110; and the Middle Fork Sugar Creek sub-watershed in AU 05040001120.

A secondary cause of bacterial pollution in the Sugar Creek watershed are failing or over-loaded on-site sewage handling or treatment systems. Evidence of the potential impacts from these systems is evident from a review of the history of bacterial concentrations in the North Fork of Sugar Creek before and after the installation of sewers and a wastewater treatment plant for the Village of Kidron (Wayne County). In 1998, the upper portions of the North Fork were found to be one of the most heavily polluted stream segments in the Sugar Creek watershed for bacterial indicators. In 2005, following the construction and

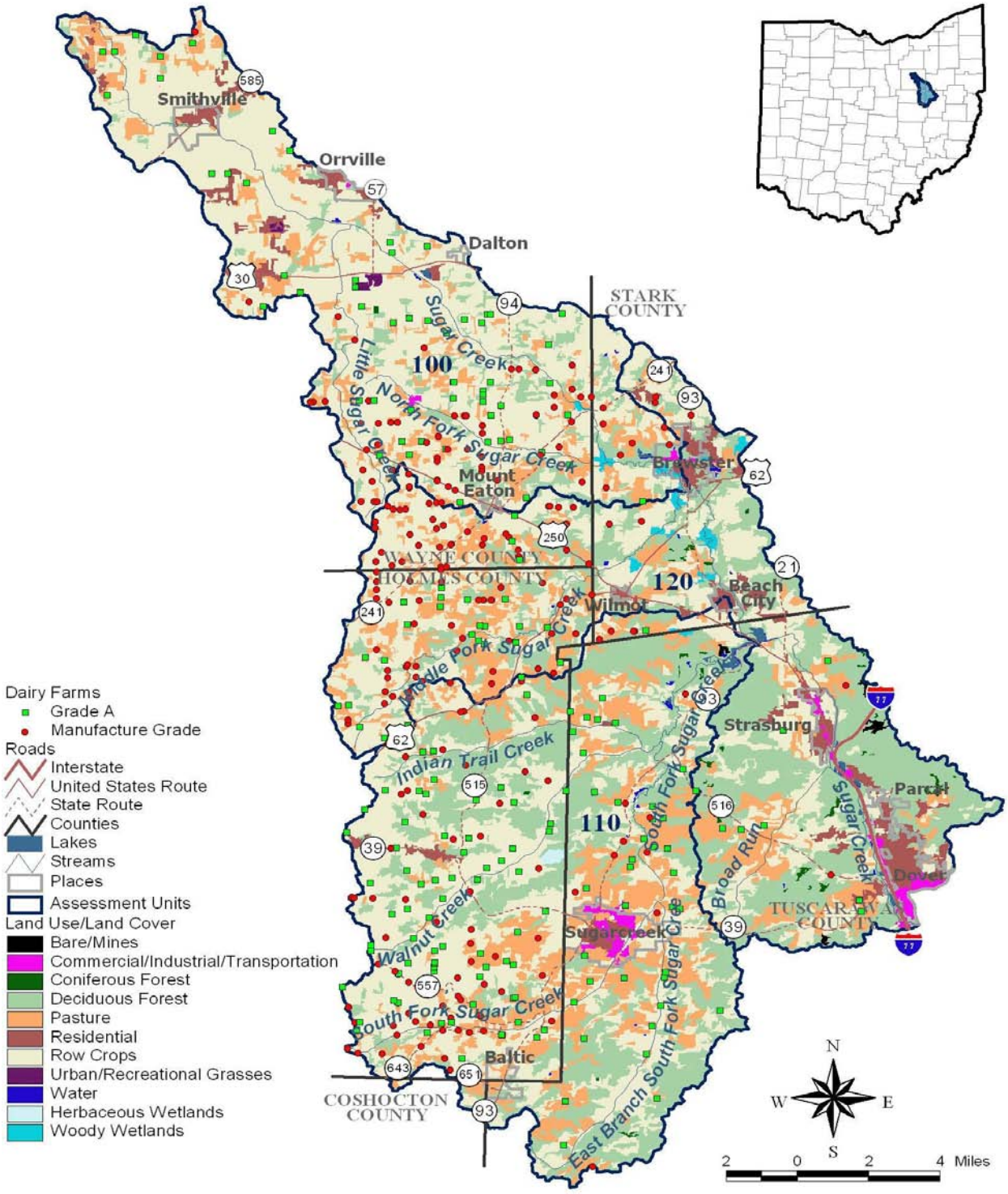


Figure 21. Distribution of licensed dairy farms within the Sugar Creek watershed.
Data source: Ohio Dept. Of Agriculture. Map produced by Tetra-Tech, Inc.

operation of the Kidron wastewater treatment plant, the upper North Fork was the only significant stream reach in the watershed which was in FULL attainment of the PCR water quality criteria.

Permitted NPDES wastewater treatment plants appear to be doing an adequate job of controlling effluent bacterial counts to acceptable levels. However, the great majority of the land area in the watershed is not served by central sewage systems. Failing or improperly designed on-site wastewater systems can result in significant loadings of bacteria to adjacent drainageways and streams, potentially carrying associated pathogenic organisms. This study did not attempt to quantify the nature and extent of this problem, but additional study to determine the relative contribution of on-site wastewater management to the overall bacterial pollution problem is essential to the implementation of a watershed pollution abatement effort. In many locales within the watershed, multiple-generation housing complexes have developed on small to medium sized farms (Figure 22), particularly in the Amish community. Small industrial operations employing both residents and non-residents are often associated with these farm complexes. Sanitary wastewater management at these complexes may range from dug pit toilets to septic systems.

Figure 22. Amish farm complex in Tuscarawas County. Large farm complexes such as this may house multiple generations of permanent residents as well as small industrial operations employing residents and non-residents. The overall impact of wastewater management on water quality in nearby streams is unknown.

In other areas of the Sugar Creek watershed, suburban development of single family homes on small to large lots is occurring at a rapid pace (Figure 23). Areas experiencing high rates of construction starts are the northern part of the Sugar Creek headwaters along the State Route 30 corridor in Wayne County (AU 05040001100), and the western portion of Tuscarawas County in the triangle between Strasburg, Dover and Sugarcreek (AU 05040001120). Expansion and development of associated businesses to service the expanding resident population within the watershed, as well as the popular tourist industry in the area will require adequate planning for wastewater management in order to prevent the pollution problems noted during this study from becoming worse and to improve water quality throughout the watershed.

Figure 23. New home construction in the Indian Trail Creek watershed. Residential and commercial development pressures within the Sugar Creek watershed will need to be carefully planned if water pollution problems are to be reversed.

Stream channel morphology and floodplain quality also play an important part in the extremely high fecal coliform and *E. coli* densities observed throughout the Sugar Creek watershed. It is well documented that pathogenic bacteria and viruses, as well as indicator fecal coliform bacteria and *E. coli* can survive and potentially reproduce within the sediments of aquatic ecosytems (Sayler, et al., 1975; Erkenbrecher, 1981; LaLiberte and Grimes, 1982; Craig et al., 2001). Concentrations of both indicator organisms and pathogens can be much higher in sediment than in overlying water, and survival of these

organisms can also be significantly prolonged in sediment, especially when fine grained sediments are abundant (Burton, et al., 1987; Craig et al., 2000; Craig et al., 2002). Therefore, sediments in aquatic systems can be a significant reservoir for pathogenic organisms and indicator bacteria, and resuspension of these sediments can significantly increase bacteria counts in overlying waters, making them unsuitable for contact recreation or drinking water uses (Craig et al., 2003; Gruber et al., 2005; Whitman and Nevers, 2003). Modeling and management efforts designed to control concentrations of pathogens and indicator bacteria must account not only to point and non-point sources of these organisms to the aquatic system, but must also account for internal loadings of viable organisms resulting from sediment resuspension or desorption (Byappanahalli, et al., 2003; Craig et al., 2003; Francy et al., 2003; Francy et al., 2005; Jamieson, et al., 2005).

Correlation of estimated TSS concentrations from water clarity measurements with indicator bacteria counts at sentinel sites within the Sugar Creek watershed (Figure 24) provide circumstantial evidence of the importance of sediment loadings and resuspension to the attainment of the recreational use criteria. In light of the stream channel characteristics of the majority of the streams in the watershed, the linkage of TSS to bacterial counts indicates that pollution abatement efforts to reduce water column bacteria counts will also have to consider not only non-point loadings of TSS and bacteria (external loads to the stream) but also factors that entrap bacteria laden sediments within the stream channel (internal loading).

It is recommended that the recreational use TMDL process evaluate targets not only for bacteria loadings but also existing TMDL targets for sediment loading and habitat quality addressed in the 2002 Sugar Creek TMDL (Ohio EPA, 2002) to determine if they are adequate to restore recreational uses to full attainment. Specific factors that should be evaluated are measurements of floodplain connectivity (either through entrenchment ratios or other measures relating to stream channel integrity), sediment loading and resuspension (TSS), and indicators of habitat quality (with an emphasis upon vegetative buffers within the stream corridor. Targets should be established that will improve the substrate quality within stream channels through reductions of both loadings from runoff and the impacts of sediment resuspension (perhaps using specific subsets of the QHEI metrics). Development of specific targets using this multi-faceted approach would also advance TMDL implementation to remedy causes and sources of biological non-attainment addressed in the existing TMDL.

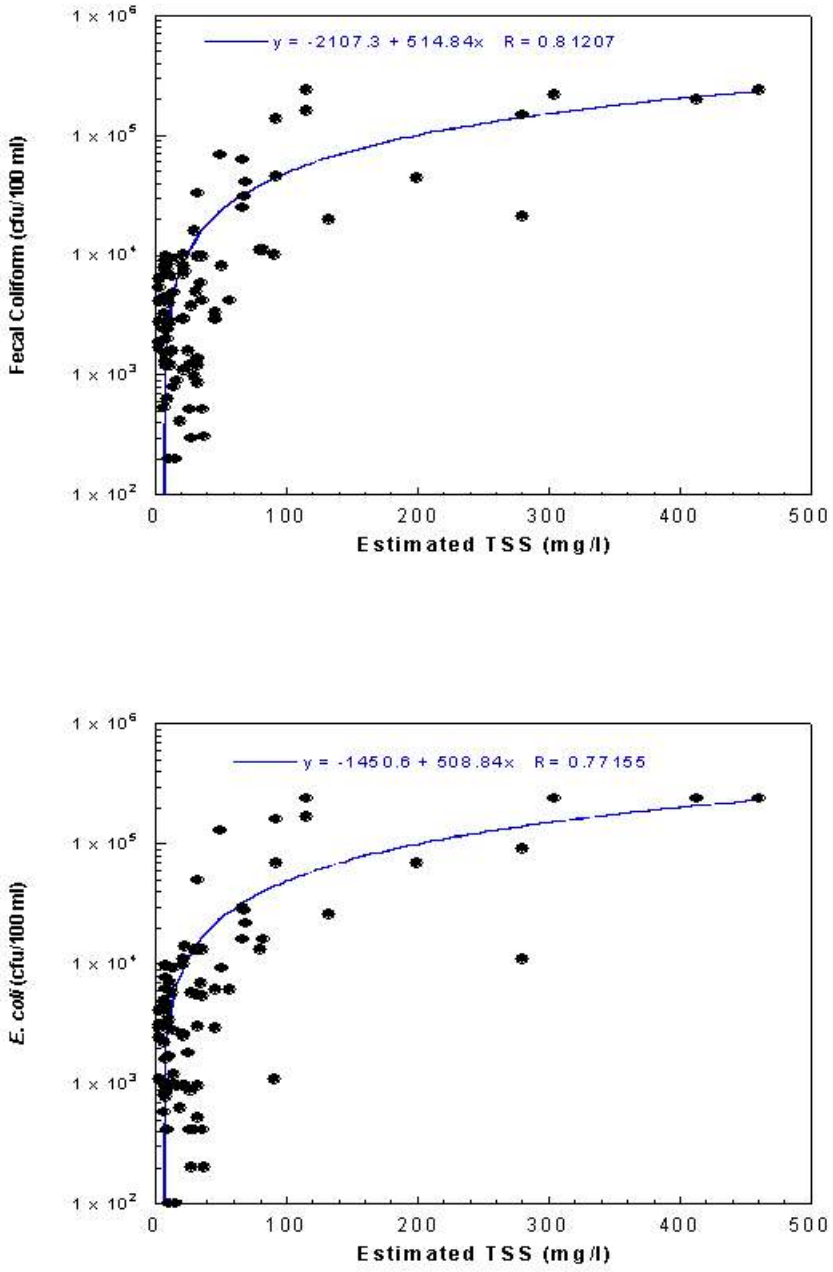


Figure 24. Relationship of total suspended solids to indicator bacteria counts at Sugar Creek watershed sentinel sites (2005 data).

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Appendix A.

Bacteria Count Data for the 2005 Sugar Creek Water Quality Survey

Stream Name	Storet Station ID	Location	River Mile	Date	Fecal Coliform (cfu/100 ml)	*E. Coli* (cfu/100ml)
Sugar Creek	R05S15	Schellin Rd.	42.75	7/26/2005	640	NA
				8/4/2005	360	NA
				8/9/2005	9,900	NA
				9/8/2005	690	NA
				9/13/2005	730	NA
	R05S32	Co. Rd. 502	40.18	7/26/2005	1,000	NA
				8/4/2005	1,200	NA
				8/9/2005	11,000	NA
				9/8/2005	560	510
				9/13/2005	440	NA
	R05S31	Orr Rd.	36.88	7/26/2005	1,560	NA
				8/4/2005	310	NA
				8/9/2005	1,300	NA
				9/8/2005	770	NA
				9/13/2005	1,100	1,300
	R05W32	Kansas Rd.	34.69	7/26/2005	4,300	NA
				8/4/2005	2,800	NA
				8/9/2005	1,100	NA
				9/8/2005	880	730
				9/13/2005	930	NA
	R05S29	Alabama Rd.	22.95	7/26/2005	6,200	6,800
				8/4/2005	2,600	3,400
				8/9/2005	4,700	NA
				9/8/2005	1,200	1,100
				9/13/2005	2,300	NA
	R05S27	St. Rt. 21	12.07	7/21/2005	1,000	840
				7/26/2005	700	740
				8/4/2005	800	NA
				8/9/2005	2,200	NA
				8/23/2005	200	100
				9/1/2005	5,500	7,700
				9/8/2005	520	410
				9/13/2005	410	NA
				9/19/2005	310	<100
	611700	St. Rt. 250	7.28	7/21/2005	200	100
				7/26/2005	2,000	950
				7/27/2005	21,000	11,000
				8/4/2005	300	200
				8/9/2005	630	410
				8/23/2005	200	<100
				9/1/2005	11,000	13,000
				9/8/2005	310	200
				9/13/2005	520	410
				9/19/2005	520	410
				9/23/2005	970	410

Stream Name	Storet Station ID	Location	River Mile	Date	Fecal Coliform (cfu/100 ml)	*E. Coli* (cfu/100ml)
Sugar Creek (cont.)	611700	St. Rt. 250 (cont.)	7.28	9/26/2005	3,300	2,900
				10/11/2005	5,600	5,600
	R05S26	St. Rt. 39	0.63	7/26/2005	1,200	520
				8/4/2005	900	1,200
				8/9/2005	1,000	NA
				9/8/2005	400	NA
				9/13/2005	400	350
Little Sugar Creek	R05S03	Kansas Rd.	4.20	7/26/2005	830	960
				8/4/2005	290,000	NA
				8/9/2005	46,000	65,000
				9/8/2005	540	520
				9/13/2005	310	NA
Little Sugar Creek	R05S81	McQuaid Rd.	0.85	7/26/2005	6,200	NA
				8/4/2005	270	NA
				8/9/2005	1,100	NA
				9/8/2005	690	NA
				9/13/2005	640	270
North Fork Sugar Creek	R05P13	Zuercher Rd.	5.53	7/26/2005	740	NA
				8/4/2005	690	870
				8/9/2005	2,300	1,800
				9/8/2005	730	680
				9/13/2005	380	540
	R05S20	Western Rd.	3.79	7/26/2005	880	NA
				8/4/2005	820	730
				8/9/2005	910	810
				9/8/2005	460	NA
				9/13/2005	670	NA
	R05W29	W. Lebanon Rd.	1.35	7/21/2005	4,100	4,100
				7/26/2005	5,400	3,100
				7/27/2005	25,000	16,000
				8/4/2005	3,200	2,400
				8/9/2005	2,800	4,100
				8/23/2005	1,200	970
				38595	9,200	9,200
				9/8/2005	2,400	2,200
				9/13/2005	4,400	4,900
				9/19/2005	3,200	4,000
				9/23/2005	160,000	170,000
				9/26/2005	69,000	130,000
				10/11/2005	15,800	14,800
Middle Fork Sugar Creek	R05S74	Twp. Rd. 654	12.00	7/26/2005	18,000	8,600
				8/3/2005	1,700	NA
				8/8/2005	4,100	NA
				9/7/2005	3,200	3,800
				9/12/2005	2,900	3,400

Stream Name	Storet Station ID	Location	River Mile	Date	Fecal Coliform (cfu/100 ml)	*E. Coli* (cfu/100ml)
Middle Fork Sugar Creek (cont.)	R05S73	Twp. Rd. 669	10.25	7/26/2005	5,400	46
				8/3/2005	5,200	NA
				8/8/2005	2,100	NA
				9/7/2005	1,800	4,100
				9/12/2005	1,800	NA
	R05S72	Twp. Rd. 606	7.58	7/26/2005	4,700	NA
				8/3/2005	2,400	NA
				8/8/2005	4,000	NA
				9/7/2005	240,000	240,000
				9/12/2005	2,400	3,400
	R05P10	Northvale Ave	3.16	7/21/2005	2,130	1,350
				7/26/2005	7,000	2,600
				7/27/2005	150,000	92,000
				8/4/2005	900	960
				8/9/2005	1,600	980
				8/23/2005	1,100	960
				9/1/2005	9,900	13,000
				9/8/2005	9,000	9,600
				9/13/2005	1,300	840
				9/19/2005	1,200	770
				9/23/2005	44,000	69,000
				9/26/2005	46,000	69,000
				10/11/2005	2,800	2,900
Crabapple Creek	R05S78	Twp. Rd. 606	0.31	7/26/2005	4,800	NA
				8/3/2005	840	NA
				8/8/2005	1,500	NA
				9/7/2005	2,400	NA
				9/12/2005	2,800	2,700
Elm Run	R05S71	Harmon St.	1.69	7/26/2005	4,400	5,100
				8/4/2005	2,300	2,200
				8/9/2005	4,900	3,300
				9/8/2005	1,400	1,600
				9/13/2005	1,300	930
South Fork Sugar Creek	R05S41	Co. Rd. 114	21.11	7/26/2005	5,200	5,800
				8/3/2005	4,200	NA
				8/8/2005	4,800	4,600
				9/7/2005	28,000	28,000
				9/12/2005	3,300	NA
	R05P23	Twp. Rd. 173	18.98	7/26/2005	6,200	NA
				8/3/2005	7,200	2,300
				8/8/2005	19,000	NA
				38601	13,000	12,000
				9/12/2005	3,300	3,300

Stream Name	Storet Station ID	Location	River Mile	Date	Fecal Coliform (cfu/100 ml)	*E. Coli* (cfu/100ml)
South Fork Sugar Creek (cont.)	R05W20	Co. Rd. 47	15.26	7/26/2005	6,500	NA
				8/3/2005	2,900	2,200
				8/8/2005	4,700	4,900
				9/7/2005	8,700	NA
				9/12/2005	1,800	1,200
	R05W18	Winklepleck Rd.	13.28	7/26/2005	6,200	4,400
				8/3/2005	4,900	6,900
				8/8/2005	8,200	5,600
				9/7/2005	780	1,100
				9/12/2005	4,600	NA
	R05S40	Co. Rd. 94	6.43	7/26/2005	1,000	NA
				8/3/2005	590	NA
				8/8/2005	800	NA
				9/7/2005	2,200	2,200
				9/12/2005	860	520
Walnut Creek	R05P18	Old State Route 39	7.93	7/26/2005	7,800	NA
				8/3/2005	15,000	NA
				8/8/2005	6,200	5,700
				9/7/2005	24,000	24,000
				9/12/2005	7,000	NA
	R05S44	Twp. Rd. 444	6.32	7/26/2005	4,900	2,800
				8/3/2005	970	NA
				8/8/2005	11,000	6,300
				9/7/2005	160,000	140,000
				9/12/2005	4,300	NA
	R05W22	Co. Rd. 172	4.49	7/21/2005	6,600	5,700
				7/26/2005	4,000	1,700
				8/3/2005	1,200	870
				8/8/2005	3,800	5,700
				8/23/2005	4,400	6,300
				9/1/2005	11,000	16,000
				9/7/2005	15,000	5,000
				9/12/2005	8,200	11,000
				9/19/2005	5,900	6,800
				9/23/2005	>240,000	>240,000
				9/26/2005	200,000	240,000
				10/11/2005	10,000	1,100
	R05S43	Lane near Mouth	0.56	8/3/2005	650	NA
				8/8/2005	980	NA
				9/7/2005	2,100	NA
				9/12/2005	11,000	NA
Indian Trail Creek	R05S49	Twp. Rd. 414	6.33	7/26/2005	10,000	7,900
				8/3/2005	2,400	NA
				8/8/2005	3,500	NA
				9/7/2005	1,600	NA

Stream Name	Storet Station ID	Location	River Mile	Date	Fecal Coliform (cfu/100 ml)	*E. Coli* (cfu/100ml)
Indian Trail Creek (cont.)	R05S49	Twp. Rd. 414	6.33	9/12/2005	3,700	NA
	R05W25	Cement Bridge Rd Rd. (Twp. 66)	2.56	7/21/2005	1,900	2,900
				7/26/2005	6,400	2,400
				8/3/2005	1,700	1,100
				8/8/2005	5,000	1,600
				8/23/2005	5,700	6,600
				9/1/2005	10,000	10,000
				9/7/2005	1,200	1,000
				9/12/2005	9,800	9,800
				9/19/2005	6,900	7,700
				9/23/2005	41,000	22,000
				9/26/2005	140,000	160,000
				10/11/2005	9,000	6,200
Goose Creek	R05P19	Twp. Rd. 419	0.35	7/26/2005	2,600	NA
				8/3/2005	1,900	NA
				8/8/2005	1,300	NA
				9/7/2005	5,700	NA
				9/12/2005	1,900	1,700
E. Branch S. Fork Sugar Creek	R05S57	Co. Rd. 48	5.47	7/26/2005	81,000	20,000
				8/3/2005	4,400	1,500
				8/8/2005	8,700	NA
				9/7/2005	3,900	2,900
				9/12/2005	4,400	NA
	R05S56	Co. Rd. 52	5.04	7/26/2005	6,200	NA
				8/3/2005	2,700	3,700
				8/8/2005	18,000	11,000
				9/7/2005	>2,400	NA
				9/12/2005	3,700	4,000
	R05W19	Twp. Rd. 348	1.70	7/21/2005	4,200	6,100
				7/26/2005	2,400	1,600
				8/3/2005	4,600	3,400
				8/8/2005	7,700	4,400
				8/23/2005	2,800	6,900
				9/1/2005	8,100	9,300
				9/7/2005	16,000	13,000
				9/12/2005	12,500	24,000
				9/19/2005	9,900	13,000
				9/23/2005	240,000	240,000
				9/26/2005	220,000	240,000
				10/11/2005	5,000	5,600
Brush Run	R05P24	Twp. Rd. 173	0.09	9/7/2005	1,000	NA
				9/12/2005	1,800	2,900
Broad Run	R05S37	Co. Rd. 80	2.8	7/26/2005	9,300	NA
				8/3/2005	27,000	18,300

Stream Name	Storet Station ID	Location	River Mile	Date	Fecal Coliform (cfu/100 ml)	*E. Coli* (cfu/100ml)
Broad Run (cont.)	R05S37	Co. Rd. 80	2.8	8/8/2005	>20,000	>2,400
				9/7/2005	>2,400	NA
				9/12/2005	9,800	12,000
	R05S36	Twp. Rd. 425	0.15	7/21/2005	1,200	3,000
				7/26/2005	3,000	2,500
				7/27/2005	63,000	29,000
				8/4/2005	800	1,200
				8/9/2005	410	630
				8/23/2005	1,400	520
				9/1/2005	2,900	6,100
				9/8/2005	33,000	50,000
				9/13/2005	860	960
				9/19/2005	1,600	1,800
				9/23/2005	31,000	28,000
				9/26/2005	20,000	26,000
				10/11/2005	4,200	5,400
Brandywine Creek	R05S33	Twp. Rd. 211	0.16	7/26/2005	3,600	2,800
				8/4/2005	2,600	NA
				8/9/2005	4,100	3,000
				9/8/2005	>240,000	200,000
				9/13/2005	>2,400	NA

Appendix B.

E. coli Data for the 2005 Sugar Creek Water Quality Survey

Table B-1. Summary *E. coli* bacteria data for sampling sites within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml *E. coli* .

HUC 11 / ***HUC 14*** / **STORET Station ID**	**Stream Name**	**Location**	**River Mile**	**Number of Samples**	**Geometric Mean**	**90th Percentile**	**Minimum**	**Maximum**
5040001100								
5040001100010								
R05S15	Sugar Creek	Schellin Rd.	42.75	0				
R05S32	Sugar Creek	Co. Rd. 502	40.18	1	510	510	510	510
R05S31	Sugar Creek	Orr Rd.	36.88	1	1,300	1,300	1,300	1,300
5040001100010								
R05S03	Little Sugar Creek	Kansas Rd.	4.20	3	3,190	52,192	520	65,000
R05S81	Little Sugar Creek	McQuaid Rd.	0.85	1	270	270	270	270
5040001100030								
R05W32	Sugar Creek	Kansas Rd.	34.69	1	730	730	730	730
R05S29	Sugar Creek	Alabama Rd.	22.95	3	2,941	6,120	1,100	6,800
5040001100040								
R05P13	North Fork Sugar Creek	Zuercher Rd.	5.53	4	871	1,521	540	1,800
R05S20	North Fork Sugar Creek	Western Rd.	3.79	2	769	802	730	810
R05W29	North Fork Sugar Creek	W. Lebanon Rd.	1.35	13	7,143	107,200	970	170,000
5040001110								
5040001110010								
R05P24	Brush Run	Twp. Rd. 173	0.09	1	2,900	2,900	2,900	2,900
R05S41	South Fork Sugar Creek	Co. Rd. 114	21.11	3	9,074	23,560	4,600	28,000
R05P23	South Fork Sugar Creek	Twp. Rd. 173	18.98	3	4,499	10,260	2,300	12,000
R05W20	South Fork Sugar Creek	Co. Rd. 47	15.26	3	2,347	4,360	1,200	4,900
5040001110020								
R05S57	E. Branch S. Fork Sugar Creek	Co. Rd. 48	5.47	3	4,431	16,580	1,500	20,000
R05S56	E. Branch S. Fork Sugar Creek	Co. Rd. 52	5.04	3	5,460	9,600	3,700	11,000
R05W19	E. Branch S. Fork Sugar Creek	Twp. Rd. 348	1.70	12	11,631	217,300	1,600	240,000

Table B-1. Summary *E. coli* bacteria data for sampling sites within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml *E. coli* .

HUC 11	**Stream Name**	**Location**	**River Mile**	**Number of Samples**	**Geometric Mean**	**90th Percentile**	**Minimum**	**Maximum**
HUC 14								
STORET Station ID								
5040001110030								
R05W18	South Fork Sugar Creek	Winklepleck Rd.	13.28	4	3,698	6,510	1,100	6,900
5040001110040								
R05P19	Goose Creek	Twp. Rd. 419	0.35	1	1,700	1,700	1,700	1,700
R05P18	Walnut Creek	Old State Route 39	7.93	2	11,696	22,170	5,700	24,000
R05S44	Walnut Creek	Twp. Rd. 444	6.32	3	13,517	113,260	2,800	140,000
R05W22	Walnut Creek	Co. Rd. 172	4.49	12	7,881	217,600	870	240,000
R05S43	Walnut Creek	Lane near Mouth	0.56	0				
5040001110050								
R05S49	Indian Trail Creek	Twp. Rd. 414	6.33	1	7,900	7,900	7,900	7,900
R05W25	Indian Trail Creek	Cement Bridge Rd (Twp. Rd. 66)	2.56	12	5,759	20,800	1,000	160,000
5040001110060								
R05S40	South Fork Sugar Creek	Co. Rd. 94	6.43	2	1,070	2,032	520	2,200
5040001120								
5040001120010								
R05S74	Middle Fork Sugar Creek	Twp. Rd. 654	12.00	3	4,808	7,640	3,400	8,600
R05S73	Middle Fork Sugar Creek	Twp. Rd. 669	10.25	2	4,343	4,550	4,100	4,600
5040001120020								
R05S78	Crabapple Creek	Twp. Rd. 606	0.31	1	2,700	2,700	2,700	2,700
5040001120030								
R05S72	Middle Fork Sugar Creek	Twp. Rd. 606	7.58	2	28,566	216,340	3,400	240,000
R05P10	Middle Fork Sugar Creek	Northvale Ave.	3.16	13	4,059	69,000	675	92,000
5040001120040								
R05S71	Elm Run	Harmon St.	1.69	5	2,230	4,380	930	5,100

Table B-1. Summary *E. coli* bacteria data for sampling sites within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml *E. coli* .

HUC 11	**Stream Name**	**Location**	**River Mile**	**Number of Samples**	**Geometric Mean**	**90th Percentile**	**Minimum**	**Maximum**
HUC 14								
STORET Station ID								
5040001120050								
R05S27	Sugar Creek	St. Rt. 21	12.07	6	519	4,270	100	7,700
611700	Sugar Creek	St. Rt. 250	7.28	13	753	9,920	100	13,000
5040001120060								
R05S37	Broad Run	Co. Rd. 80	2.80	3	6,611	11,430	2,400	12,000
R05S36	Broad Run	Twp. Rd. 425	0.15	13	4,310	28,800	520	50,000
5040001120070								
R05S33	Brandywine Creek	Twp. Rd. 211	0.16	3	11,888	160,600	2,800	200,000
R05S26	Sugar Creek	St. Rt. 39	0.63	3	478	584	350	600

Table B-2. Summary *E. coli* bacteria data for 11 digit HUC Assessment Units (AU's) and 14 digit HUC watersheds within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml *E. coli*.

11 Digit AU 14 Digit HUC	Number of Samples	Geometric Mean	90th Percentile	Maximum	Minimum	Attainment Status
05040001100 (Total)	**29**	**2,733**	**25,800**	**170,000**	**270**	**NON**
5040001100010	2	814	1,221	1,300	510	NON
5040001100020	4	1,720	45,788	65,000	270	NON
5040001100030	4	2,076	5,780	6,800	730	NON
5040001100040	19	3,627	38,800	170,000	540	NON
05040001110 (Total)	**65**	**6,358**	**26,400**	**240,000**	**520**	**NON**
5040001110010	10	4,372	13,600	28,000	1,200	NON
5040001110020	18	8,730	86,000	240,000	1,500	NON
5040001110030	4	3,698	6,510	6,900	1,100	NON
5040001110040	18	8,273	170,000	240,000	870	NON
5040001110050	13	5,901	19,600	160,000	1,000	NON
5040001110060	2	1,070	2,032	2,200	520	NON
05040001120 (Total)	**67**	**2,439**	**28,400**	**240,000**	**100**	**NON**
5040001120010	5	4,616	7,000	8,600	3,400	NON
5040001120020	1	2,700	2,700	2,700	2,700	NON
5040001120030	15	5,265	82,800	240,000	770	NON
5040001120040	5	2,230	4,380	5,100	930	NON
5040001120050	19	670	8,360	13,000	100	NON
5040001120060	16	4,643	28,500	50,000	520	NON
5040001120070	6	2,384	101,500	200,000	350	NON

Table B-3. Summary *E. coli* bacteria data for surveyed streams within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml *E. coli* .

Stream Name	Number of Samples	Geometric Mean	90th Percentile	Minimum	Maximum
Sugar Creek	28	770	7,070	13,000	100
Little Sugar Creek	4	1,720	45,788	65,000	270
North Fork Sugar Creek	19	3,627	38,800	170,000	540
Middle Fork Sugar Creek	20	5,095	71,300	240,000	675
Crabapple Creek	1	2,700	2,700	2,700	2,700
Elm Run	5	2,230	4,380	5,100	930
South Fork Sugar Creek	15	3,562	9,960	28,000	520
Walnut Creek	17	9,080	180,000	240,000	870
Indian Trail Creek	13	5,901	19,600	160,000	1,000
Goose Creek	1	1,700	1,700	1,700	1,700
E. Branch S. Fork Sugar Creek	18	8,730	86,000	240,000	1,500
Brush Run	1	2,900	2,900	2,900	2,900
Broad Run	16	4,643	28,500	50,000	520
Brandywine Creek	3	11,888	160,600	200,000	2,800

Table B-4. Summary *E. coli* bacteria data for watershed drainage categories within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml *E. coli*.

Drainage Category	Number of Samples	Geometric Mean	90th Percentile	Minimum	Maximum
6 mi^2	32	3,993	23,600	520	200,000
11 mi^2	54	4,773	28,700	270	170,000
22 mi^2	30	8,371	240,000	870	240,000
46 mi^2	18	3,614	69,000	675	92,000
89 mi^2	5	1,962	5,440	520	6,800
178 mi^2	19	670	8,360	100	13,000
357 mi^2	3	478	584	600	350

Appendix C

Summary Statistics for Fecal Coliform Data by Station

Table C-1. Summary fecal coliform bacteria data for sampling sites within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml fecal coliform.

HUC 11 / *HUC 14* / STORET Station ID	Stream Name	Location	River Mile	Number of Samples	Geometric Mean	90th Percentile	Minimum	Maximum
5040001100								
5040001100010								
R05S15	Sugar Creek	Schellin Rd.	42.75	5	1,028	6,232	360	9,900
R05S32	Sugar Creek	Co. Rd. 502	40.18	5	1,266	7,080	440	11,000
R05S31	Sugar Creek	Orr Rd.	36.88	5	767	1,220	310	1,300
5040001100020								
R05S03	Little Sugar Creek	Kansas Rd.	4.2	5	4,504	192,400	310	290,000
R05S81	Little Sugar Creek	McQuaid Rd.	0.85	5	959	4,160	270	6,200
5040001100030								
R05W32	Sugar Creek	Kansas Rd.	34.69	5	1,611	3,700	880	4,300
R05S29	Sugar Creek	Alabama Rd.	22.95	5	2,911	5,600	1,200	6,200
5040001100040								
R05P13	North Fork Sugar Creek	Zuercher Rd.	5.53	5	799	1,676	380	2,300
R05S20	North Fork Sugar Creek	Western Rd.	3.79	5	726	898	460	910
R05W29	North Fork Sugar Creek	W. Lebanon Rd.	1.35	13	7,280	60,200	1,200	160,000
5040001110								
5040001110010								
R05P24	Brush Run	Twp. Rd. 173	0.09	2	1,342	1,720	1,000	1,800
R05S41	South Fork Sugar Creek	Co. Rd. 114	21.11	5	6,270	18,880	3,300	28,000
R05P23	South Fork Sugar Creek	Twp. Rd. 173	18.98	5	8,169	16,600	3,300	19,000
R05W20	South Fork Sugar Creek	Co. Rd. 47	15.26	5	4,251	7,820	1,800	8,700

Table C-1. Summary fecal coliform bacteria data for sampling sites within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml fecal coliform.

HUC 11 / *HUC 14* / STORET Station ID	Stream Name	Location	River Mile	Number of Samples	Geometric Mean	90th Percentile	Minimum	Maximum
05040001110 (cont.)								
5040001110020								
R05S57	E. Branch S. Fork Sugar Creek	Co. Rd. 48	5.47	5	8,814	52,080	3,900	81,000
R05S56	E. Branch S. Fork Sugar Creek	Co. Rd. 52	5.04	5	4,847	13,280	2,400	18,000
R05W19	E. Branch S. Fork Sugar Creek	Twp. Rd. 348	1.7	12	10,645	199,600	2,400	240,000
5040001110030								
R05W18	South Fork Sugar Creek	Winklepeck Rd.	13.28	5	3,893	7,400	780	8,200
5040001110040								
R05P19	Goose Creek	Twp. Rd. 419	0.35	5	2,336	4,460	1,300	5,700
R05P18	Walnut Creek	Old State Route 39	7.93	5	10,403	20,400	6,200	24,000
R05S44	Walnut Creek	Twp. Rd. 444	6.32	5	8,151	100,400	970	160,000
R05W22	Walnut Creek	Co. Rd. 172	4.49	12	9,308	181,500	1,200	200,000
R05S43	Walnut Creek	Lane near Mouth	0.56	4	1,959	8,330	650	11,000
5040001110050								
R05S49	Indian Trail Creek	Twp. Rd. 414	6.33	5	3,462	7,480	1,600	10,000
R05W25	Indian Trail Creek	Cement Bridge Rd (Twp. Rd. 66)	2.56	12	6,934	37,900	1,200	140,000
5040001110060								
R05S40	South Fork Sugar Creek	Co. Rd. 94	6.43	5	978	1,720	590	2,200

Table C-1. Summary fecal coliform bacteria data for sampling sites within the Sugar Creek watershed, 2005. All values expressed as cfu/100 ml fecal coliform.

HUC 11 / *HUC 14* / STORET Station ID	Stream Name	Location	River Mile	Number of Samples	Geometric Mean	90th Percentile	Minimum	Maximum
5040001120								
5040001120010								
R05S74	Middle Fork Sugar Creek	Twp. Rd. 654	12	5	4,104	12,440	1,700	18,000
R05S73	Middle Fork Sugar Creek	Twp. Rd. 669	10.25	5	2,859	5,320	1,800	5,400
5040001120020								
R05S78	Crabapple Creek	Twp. Rd. 606	0.31	5	2,098	4,000	840	4,800
5040001120030								
R05S72	Middle Fork Sugar Creek	Twp. Rd. 606	7.58	5	7,638	145,880	2,400	240,000
R05P10	Middle Fork Sugar Creek	Northvale Ave.	3.16	13	4,789	45,600	900	150,000
5040001120040								
R05S71	Elm Run	Harmon St.	1.69	5	2,461	4,700	1,300	4,900
5040001120050								
R05S27	Sugar Creek	St. Rt. 21	12.07	9	765	2,860	200	5,500
611700	Sugar Creek	St. Rt. 250	7.28	13	1,136	9,920	200	21,000
5040001120060								
R05S37	Broad Run	Co. Rd. 80	2.8	5	9,000	17,400	2,400	20,000
R05S36	Broad Run	Twp. Rd. 425	0.15	13	3,811	32,600	410	63,000
5040001120070								
R05S33	Brandywine Creek	Twp. Rd. 211	0.16	5	7,394	145,920	2,400	240,000
R05S26	Sugar Creek	St. Rt. 39	0.63	5	533	920	400	1,200

Appendix D

Supplemental Data
(Flow Measurements, Gage Height Measurements, Water Clarity Readings, and Estimated Total Suspended Solids Concentrations)

Table D-1. Flow measurements, gage height readings, and water clarity data for sentinel sites used in the Sugar Creek water quality survey, 2005.

Sentinel Site/STORET ID Date	Gage Height (ft)	Measured Flow (cfs)	Calculated Flow (cfs)[a]	Water Clarity (cm)	Estimated TSS (mg/l)
Broad Run @ Race Rd. / R05S36					
6/30/2005	15.33	3.39			
7/6/2005	15.00	5.66			
7/14/2005	15.33	2.42			
7/20/2005	15.38	2.19			
7/21/2005	15.30		3.22	26.0	33
7/26/2005	15.33		2.37	36.8	21
7/27/2005	14.44		50.77	15.2	66
8/4/2005	14.48		47.57	50.2	14
8/9/2005	15.32		2.65	39.4	19
8/23/2005	15.34	1.17		26.0	33
9/1/2005	12.50	14.10		20.1	46
9/8/2005	15.40		0.59	26.4	32
9/12/2005	15.40		0.59		
9/13/2005	15.35		1.83	26.3	32
9/19/2005	15.40		0.59	31.8	25
9/23/2005	14.88	20.82		15.0	68
9/26/2005	14.40	54.09		9.0	133
10/11/2005	14.90		19.77	24.2	36
E. Branch S. Fork Sugar Creek @ TR 348 / R05W19					
6/22/2005	11.93	6.94			
6/30/2005	12.01	5.21			
7/6/2005	12.02	5.42			
7/14/2005	12.02	8.77			
7/20/2005	12.05	10.52			
7/21/2005	12.02		5.27	17.2	57
7/26/2005	12.06		3.99	78.7	8
8/3/2005	12.09		3.08	62.9	10
8/8/2005	12.07		3.68	72.4	8
8/23/2005	12.00	3.52		58.4	11
9/1/2005	11.32	42.61		18.6	51
9/7/2005	11.96		7.37	28.0	30
9/12/2005	12.01		5.61	34.7	22
9/19/2005	12.01		5.61	24.4	36
9/23/2005	11.80	14.77		10.0	115
9/26/2005	10.44	128.70		4.8	303
10/11/2005	11.67		20.41	27.4	31

Table D-1. Flow measurements, gage height readings, and water clarity data for sentinel sites used in the Sugar Creek water quality survey, 2005.

Sentinel Site/STORET ID Date	Gage Height (ft)	Measured Flow (cfs)	Calculated Flow (cfs)[a]	Water Clarity (cm)	Estimated TSS (mg/l)
Indian Trail Creek @ Cement Bridge Rd. (TR 66) / R05W25					
6/22/2005	15.32	3.09			
6/30/2005	15.32	1.74			
7/6/2005	15.32	5.42			
7/14/2005	15.33	3.55			
7/21/2005	15.32		4.38	>91.4	3
7/26/2005	15.33		4.23	>91.4	3
8/3/2005	15.33		4.23	>91.4	3
8/8/2005	15.36		3.85	73.7	8
9/1/2005	14.98	16.04		36.4	21
9/7/2005	15.33		4.23	76.8	8
9/12/2005	15.36		3.85	80.6	7
9/19/2005	15.38		3.63	74.3	8
9/23/2005	14.77	23.34		14.8	69
9/26/2005	14.64	33.77		11.9	92
10/11/2005	15.28		5.04	74.9	8
Middle Fork Sugar Creek@ Northvale Ave. / R05P10					
6/21/2005	10.83	7.26			
38523	10.92	7.54			
7/6/2005	10.60	10.17			
7/14/2005	10.86	17.81			
7/21/2005	11.03		6.66	88.9	6
7/26/2005	10.83		13.47	36.2	21
7/27/2005	8.88	104.29		5.1	280
7/27/2005	9.28	96.46		5.1	280
8/4/2005	11.05		6.01	44.5	16
8/9/2005	11.02		6.99	53.3	13
8/23/2005	11.29	5.97		35.2	22
9/1/2005	9.77	59.69		26.0	33
9/8/2005	10.88		11.71	71.8	9
9/13/2005	11.03		6.66	79.4	8
9/19/2005	11.06		5.69	82.6	7
9/23/2005	9.95	54.42		6.6	199
9/26/2005	9.81	61.48		11.8	93
10/11/2005	10.23		37.59	66.7	9

Table D-1. Flow measurements, gage height readings, and water clarity data for sentinel sites used in the Sugar Creek water quality survey, 2005.

Sentinel Site/STORET ID Date	Gage Height (ft)	Measured Flow (cfs)	Calculated Flow (cfs)[a]	Water Clarity (cm)	Estimated TSS (mg/l)
North Fork Sugar Creek @ W. Lebanon Rd. / R05W29					
6/21/2005	10.58	2.83			
7/6/2005	10.41	7.29			
7/14/2005	10.46	8.41			
7/21/2005	10.53		4.93	>91.4	3
7/26/2005	10.55		4.46	>91.4	3
7/27/2005	9.16	48.30		15.2	66
8/9/2005	10.59		3.52	>91.4	3
8/23/2005	10.62	2.72		59.7	11
9/1/2005	9.94	21.28		52.0	13
9/8/2005	10.51		5.42	85.1	7
9/13/2005	10.55		4.46	87.6	7
9/19/2005	10.55		4.46	83.2	7
9/23/2005	9.78	25.46		10.0	115
9/26/2005	9.26	45.15		19.0	49
10/11/2005	10.25		12.10	91.4	6
Sugar Creek @ US 250 (USGS gage) / 611700[b]					
7/6/2005	2.30		258.00		
7/14/2005	1.31		78.00		
7/20/2005	1.22		67.10		
7/21/2005	1.08		51.80	64.1	10
7/26/2005	1.12		56.00	71.8	9
7/27/2005	2.84		408.00	5.1	280
8/3/2005	0.85		31.10		
8/4/2005	0.99		43.10	29.2	28
8/8/2005	1.35		83.20		
8/9/2005	1.18		62.50	66.0	10
8/23/2005	0.92		36.80	45.7	16
9/1/2005	4.71		1300.00	13.2	80
9/7/2005	1.40		89.80		
9/8/2005	1.31		78.00	23.6	37
9/12/2005	1.10		53.90		
9/13/2005	1.06		49.80	24.1	36
9/19/2005	1.14		91.20	30.6	26
9/23/2005	1.06		49.80	28.0	30
9/26/2005	1.34		81.90	20.4	45
10/11/2005	2.32		263.00		

Table D-1. Flow measurements, gage height readings, and water clarity data for sentinel sites used in the Sugar Creek water quality survey, 2005.

Sentinel Site/STORET ID Date	Gage Height (ft)	Measured Flow (cfs)	Calculated Flow (cfs)[a]	Water Clarity (cm)	Estimated TSS (mg/l)
Walnut Creek @ Co. Rd. 172 / R05W22					
6/22/2005	11.80	4.93			
6/30/2005	12.06	1.60			
7/6/2005	11.85	6.89			
7/14/2005	12.08	1.97			
7/21/2005	12.09		1.60	54.6	12
7/26/2005	12.13		1.00	61.0	11
8/3/2005	12.17		0.43	30.5	27
8/8/2005	12.13		1.00	29.2	28
8/23/2005	12.14	1.86		36.8	21
9/1/2005	11.56	14.28		13.0	82
9/8/2005	12.05		2.25	25.8	33
9/12/2005	12.04		2.42	36.0	21
9/19/2005	12.00		3.12	25.0	34
9/23/2005	10.96	35.78		3.5	460
9/26/2005	10.22	74.69		3.8	413
10/11/2005	11.80		7.20	12.0	91

a. Calculated flows based upon regression equations developed for each station (see Figure 17 of report) unless otherwise noted.

b. Stream flow calculated from USGS rating table dated 7/5/2005.