Appendix A: Streamflow Estimation Techniques

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A-1Introduction

Flow data are not available for the listed section 303(d) segments; although, there is one active USGS gage in the watershed. Thus, a streamflow estimation technique is necessary to create flow duration curves at the assessment points for each impaired waterbody. Additionally, streamflow estimates are also needed as part of the data assessment process using a duration curve framework.

Three streamflow estimation techniques were analyzed for this report: drainage area weighting, linear regression, and ILSAM. The results showed that only the ILSAM method yielded acceptable results.

A-2Drainage Area Weighting

Drainage area weighting is a widely used technique in many cases where limited streamflow monitoring data are available. This method is most valid in situations where watersheds are of similar size, land use, soil types, and experience similar precipitation patterns. Discharge is estimated by drainage area weighting using the following equation:

$$Q_{ungaged} = \frac{A_{ungaged}}{A_{gaged}} \times Q_{gaged}$$

where

$Q_{ungaged}$: Flow at the ungaged location
Q_{gaged}: Flow at surrogate USGS gage station
$A_{ungaged}$: Drainage area of the ungaged location
A_{gaged}: Drainage area at surrogate USGS gage station

A-2.1.Data

The accuracy of this method was tested using the instantaneous discharge data collected by Ohio EPA at stations X02W06 and 300057 (Figure A-1) during the summer of 2006. The drainage areas of the two stations are 29.7 and 53.6 square miles (mi^2), respectively (Table A-1).

Table A-1. Ohio EPA sample stations with instantaneous discharge data

Station ID	Station name	Stream name	River mile (miles)	Drainage area ($mile^2$)	Number of discharge samples
300057	@ CR-24B (Tri-County Hwy)	North Fork White Oak Creek	1.48	53.6	10
X02W06	@ Sterling Road at South Ford	Sterling Run	0.59	29.7	12

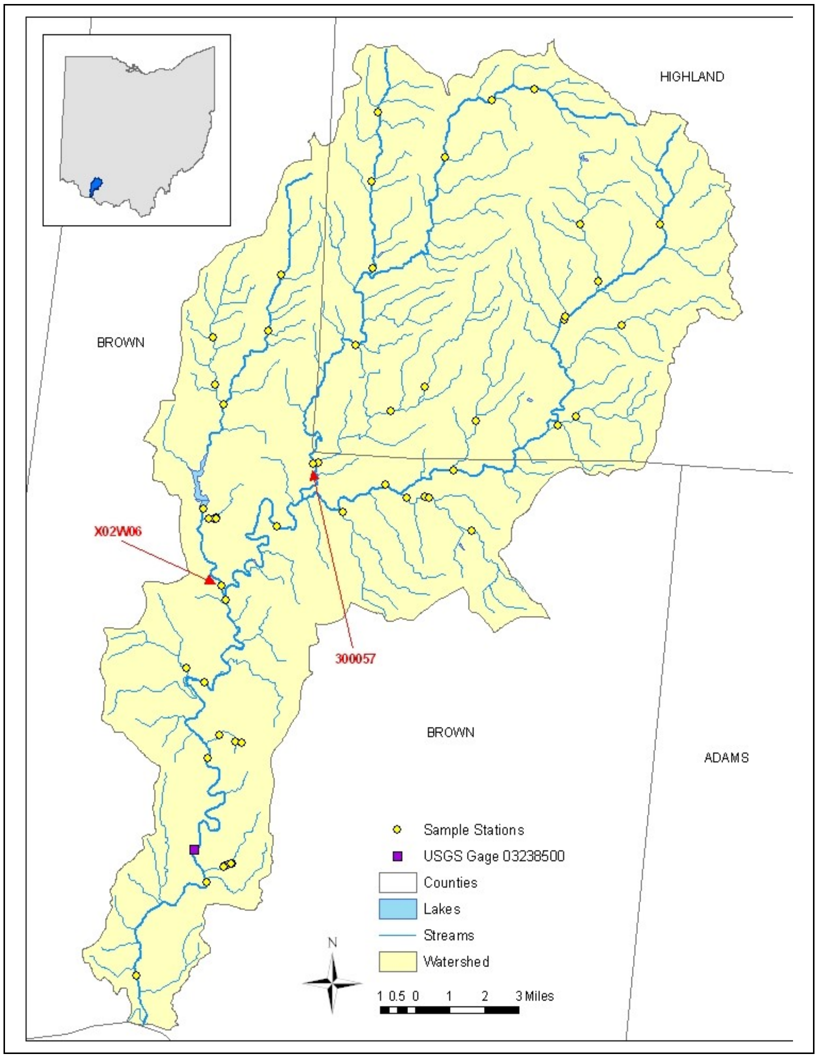

Figure A-1. Station locations.

USGS operates a gage on White Oak Creek (03238500) near Georgetown (Figure A-1). The gage has a drainage area of 218 square miles and a period of record of October 1923 to November 1935 and October 1939 to present. Mean daily discharges were downloaded from the National Water Information System (USGS 2008b). Hourly data at this gage were downloaded from Instantaneous Discharge Archive (USGS 2008a).

Hourly data for 03238500 were not available on August 7, 2006, August 9, 2006, and September 8, 2006, because the gage was not operating properly (Koltun, hydrologist, USGS, email correspondance, June 2008). Mean daily discharges for these dates are available and were used as surrogates for the instantaneous data to be paired with the Ohio EPA data.

A-2.2.Analysis

For rural, unregulated streams in Ohio, it is recommended that the drainage area ratio method be applied only if the drainage area of the ungaged site is between 50 and 150 percent of the gaged site (Koltun and Whitehead 2002; Koltun 2003). Both stations have a drainage area of less than 50 percent of USGS gage 03238500 (White Oak Creek near Georgetown OH).

The observed discharges at station 300057 ranged from 0.164 to 26.606 cubic feet per second (cfs) with an average of 5.714 cfs. The predicted discharges at station 300057, using the drainage area ratio method, ranged from 0.8 to 34.4 cfs with an average of 7.6 cfs. The percent error (observed minus expected, quantity divided by observed) ranged from -859 percent to 8 percent with an average error of -262 percent. The largest percent errors are for low-flow predictions. The data are displayed in Table A-2.

Table A-2. Drainage area ratio method prediction for station 300057

Observed					Estimated	
Station date	**Station time**	**Station discharge (cfs)**	**Gage date and time**	**Gage discharge (cfs)**	**Station discharge (cfs)**	**% Error**
4/10/06	1:30 PM	26.606	4/10/06 13:00	140	34.42	29%
5/18/06	10:20 AM	8.69	5/18/06 10:00	46	11.31	30%
7/18/06	2:42 PM	1.3884	7/18/06 15:00	12	2.95	113%
7/27/06	10:20 AM	0.497	7/27/06 10:00	10	2.46	395%
8/3/06	9:45 AM	0.415	8/3/06 10:00	6.9	1.70	309%
8/7/06	1:05 PM	0.1639	8/7/06 0:00	3.4	0.84	410%
8/31/06	9:00 AM	0.282	8/31/06 9:00	11	2.70	859%
9/8/06	11:11 AM	0.1795	9/8/06 0:00	3.3	0.81	352%
9/20/06	2:45 PM	1.273	9/20/06 15:00	12	2.95	132%
12/14/06	1:30 PM	17.647	12/10/06 14:00	66	16.23	-8%

The observed discharges at station X02W06 ranged from 0.218 to 14.094 cfs with an average of 3.175 cfs. The predicted discharges at station X02W06 ranged from 0.4 to 20.2 cfs with an average of 4.0 cfs. The percent error ranged from -227 percent to 26 percent with an average error of -64 percent. The largest percent errors are for low-flow predictions. The data are displayed in Table A-3 and Figure A-2.

Table A-3. Drainage area ratio method prediction for station X02W06

Observed					Estimated	
Station date	**Station time**	**Station discharge (cfs)**	**Gage date and time**	**Gage discharge (cfs)**	**Station discharge (cfs)**	**% Error**
4/10/06	9:45 AM	14.094	4/10/06 10:00	148	20.16	43%
5/18/06	12:15 PM	8.453	5/18/06 12:00	46	6.27	-26%
7/18/06	1:38 PM	0.9665	7/18/06 14:00	12	1.63	69%
7/26/06	12:55 PM	0.556	7/26/06 13:00	11	1.50	170%
8/2/06	10:55 AM	0.38	8/2/06 11:00	4	0.54	43%
8/7/06	1:05 PM	0.4241	8/7/06 0:00	3.4	0.46	9%
8/9/06	1:05 PM	0.2552	8/9/06 0:00	3.2	0.44	71%
8/30/06	11:40 AM	0.459	8/30/06 12:00	11	1.50	226%
9/8/06	1:05 PM	0.2178	9/8/06 0:00	3.3	0.45	106%
9/20/06	10:50 AM	1.803	9/20/06 11:00	13	1.77	-2%
9/27/06	11:30 AM	2.904	9/27/06 12:00	30	4.09	41%
12/14/06	11:30 AM	7.577	12/10/06 12:00	66	8.99	19%

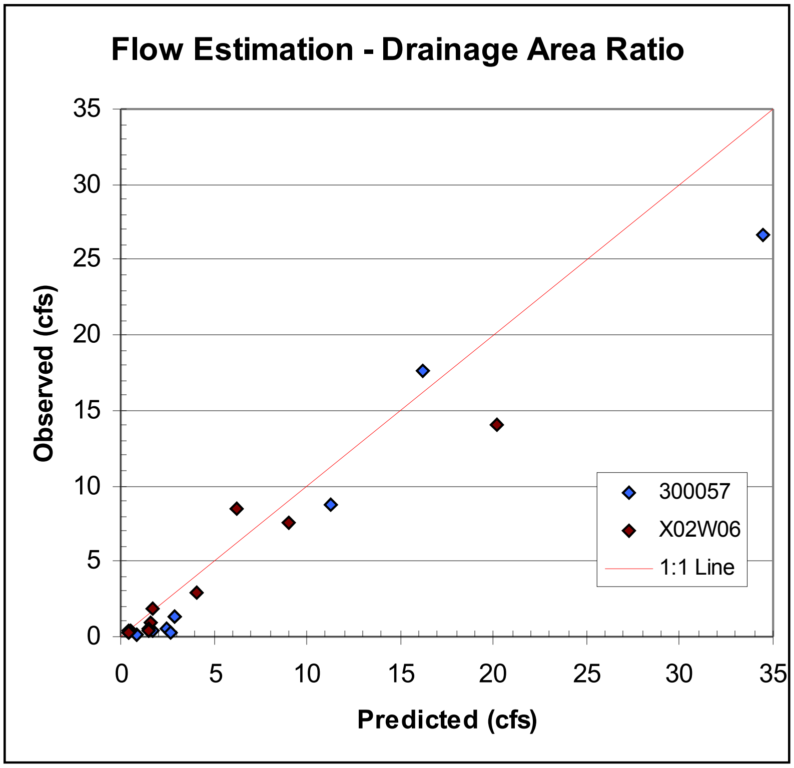

Figure A-2. Predicted versus observed data at stations 300057 and X02W06.

A-3Linear Regression

Linear regression has been used to interpolate and extrapolate discharge data at ungaged and gaged sites. The discharge at an ungaged site with limited data can be estimated by performing a regression on the limited data and a gaged site. Regression can also be used to interpolate missing data from a gaged site by using that gaged site's data or another gaged sites' data.

Linear regression of data from ungaged sites and gaged sites is a more accurate method to predict discharge at ungaged sites. However, the regression will be least accurate during low and high flows (Koltun, hydrologist, USGS, email correspondance, June 2008). Numerous studies have found that predicting low flows is difficult because different factors affect low flows. For example, groundwater has a greater relative effect during low flows than at mid-range flows (Koltun, hydrologist, USGS, email correspondance, June 2008). Additionally, the distance between the ungaged sites and gaged sites affects the regression because of the *lag effect*. Data from the ungaged sites are compared to data at the gage collected at relatively the same time; in actuality, it takes time for flows from the tributaries to flow downstream and reach the gage.

If instantaneous discharge data were available at each water-quality sample station, linear regressions would be developed for each station. However, instantaneous discharge data are available at only two stations; therefore, the data were standardized by drainage area. This allows a comparison of data from different subwatersheds. In standardizing the data by drainage area, it was assumed that the subwatersheds are hydrologically similar. Additionally, data from both stations were combined and randomly divided to calibrate and test the regression.

A-3.1.Data Preprocessing

Ohio EPA provided the exact day and time of each instantaneous discharge, whereas USGS reports only instantaneous discharge at the beginning of each hour (i.e., 24 measurements per day). For each instantaneous discharge collected by Ohio EPA, the instantaneous discharge at the gage at the closest hour was chosen (i.e., Ohio EPA data at 2:42 p.m. was paired with USGS data at 3:00 p.m.). When the Ohio EPA data was reported at an even half hour, the USGS data chosen was at the larger hour (i.e., Ohio EPA data at 1:30 p.m. was paired with USGS data at 2:00 p.m.)

A-3.2.Developing a Linear Regression

A preliminary linear regression was performed using data from station X02W06 (Figure A-3); the regression yielded the following equation:

$$Y = 0.1019x + 0.1949 \quad (R^2 = 0.9249)$$

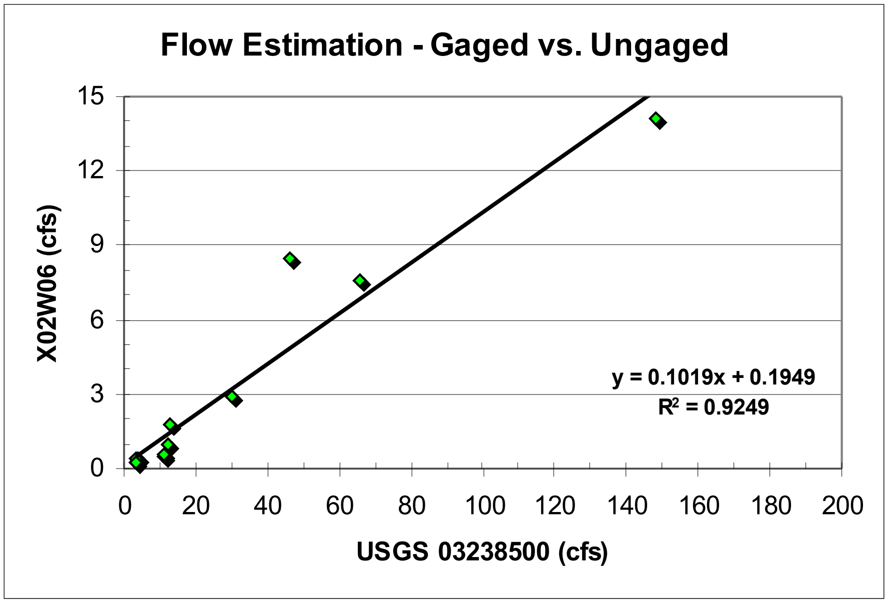

Figure A-3. Linear regression of discharge data.

Two issues were identified with the preliminary linear regression. First, this regression was unique to station X02W06. Second, scaling issues were present, and the regression was least accurate in the low-flow range.

A second linear regression was performed using discharge data standardized by drainage area (Figure A-4). The standardization allowed the regression to be used to estimate discharge at other stations and will allow for the inclusion of additional future discharge data. The standardization was performed because the two stations are in hydrologically similar areas. Standardization is not permissible when two subwatersheds are not hydrologically similar.

$$Y = 0.7478x + 0.0066 \quad (R^2 = 0.9249)$$

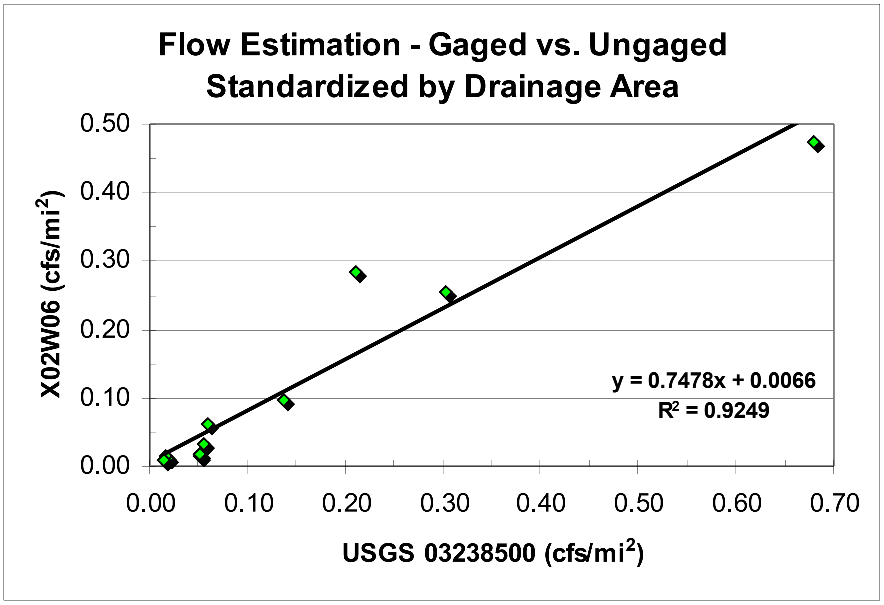

Figure A-4. Linear regression of standardized discharge data.

The linear regressions were then used to estimate flows at the locations with discharge data. The percent error of the preliminary linear regression ranged from -30 to 733 percent with an average of 262 percent. The standardization by drainage area had little effect on the accuracy of the regression (~20 percent improvement to the mean percent error). This was likely because the second linear regression was performed on data from only one station and was tested with data from an additional station. Additionally, the low-flow and scaling issues were not resolved with the second linear regression.

For the final linear regression, data from both stations were combined into one data set. One-half of the data were used to calibrate the regression and one-half of the data were used to test the accuracy of the regression. To mitigate scaling effects and the issues involving low flows, the logs of the discharge data were calculated. The log data were standardized via drainage area and were plotted with the USGS data as the independent variable and the Ohio EPA data as the dependent variable. A linear regression was performed on the calibration data set (the data are displayed in Table A-4 and the regression is displayed in Figure A-5), yielding the following equation:

$$Y = 6.9445x - 0.0336 \quad (R^2 = 0.8946)$$

Table A-4. Standardized log data for the final linear regression

Observed						Log of Discharge		Drainage Area Standardization	
Date and time	**Gage discharge (cfs)**	**Station discharge (cfs)**	**Station ID**	**Station drainage area (mi^2)**	**Station analysis type**	**Gage discharge (log cfs)**	**Station discharge (log cfs)**	**Gage discharge ((log cfs)/mi^2)**	**Station discharge ((log cfs)/mi^2)**
4/10/06 13:00	140	26.606	300057	53.6	Calibration	2.146	1.425	0.00984	0.02659
5/18/06 12:00	46	8.453	X02W06	29.7	Calibration	1.663	0.927	0.00763	0.03121
7/18/06 14:00	12	0.9665	X02W06	29.7	Calibration	1.079	-0.015	0.00495	-0.00050
7/27/06 10:00	10	0.497	300057	53.6	Calibration	1.000	-0.304	0.00459	-0.00566
8/2/06 11:00	4	0.38	X02W06	29.7	Calibration	0.602	-0.420	0.00276	-0.01415
8/7/06 0:00	3.4	0.4241	X02W06	29.7	Calibration	0.531	-0.373	0.00244	-0.01254
8/9/06 0:00	3.2	0.2552	X02W06	29.7	Calibration	0.505	-0.593	0.00232	-0.01997
8/31/06 9:00	11	0.282	300057	53.6	Calibration	1.041	-0.550	0.00478	-0.01026
9/8/06 0:00	3.3	0.1795	300057	53.6	Calibration	0.519	-0.746	0.00238	-0.01392
9/20/06 15:00	12	1.273	300057	53.6	Calibration	1.079	0.105	0.00495	0.00196
12/10/06 12:00	66	7.577	X02W06	29.7	Calibration	1.820	0.879	0.00835	0.02961

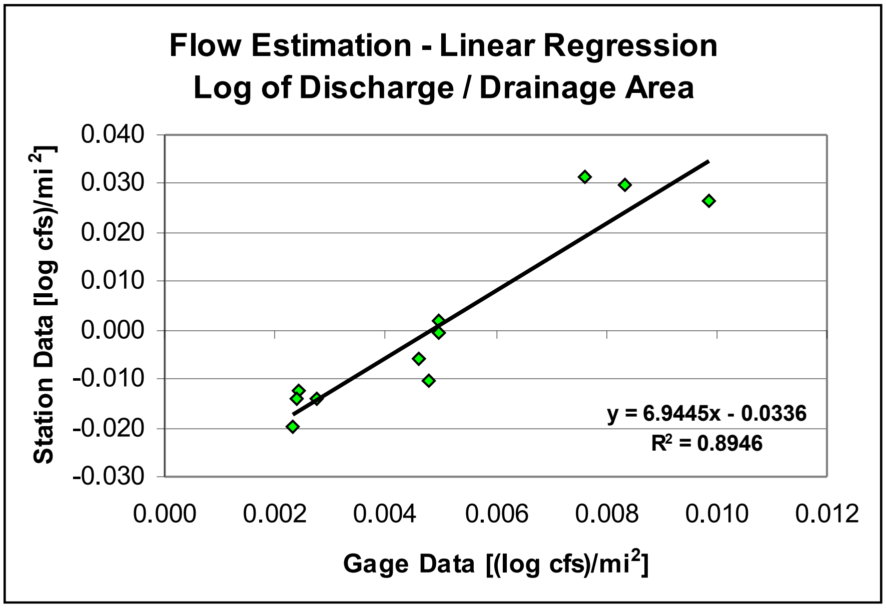

Figure A-5. Linear regression of standardized instantaneous discharge data.

This equation can be used to predict the log of instantaneous discharge per drainage area ((log cfs)/mi^2) at any water-quality sample station in the watershed by using the data at the USGS gage on White Oak Creek.

A-3.3.Testing the Final Linear Regression

The test data set was used to test the accuracy of the linear regression. The previously discussed equation was used to estimate the instantaneous discharges per drainage area for the 11 samples collected by Ohio EPA. The predicted and observed data were plotted and are displayed in Table A-5.

Table A-5. Estimating instantaneous discharge with the linear regression

Observed						Estimated					Testing
Date and time	**Gage (cfs)**	**Station (cfs)**	**Station ID**	**Station drainage area (mi^2)**	**Station analysis type**	**Gage discharge (log cfs)**	**Gage discharge ((log cfs)/mi^2)**	**Station discharge ((log cfs)/mi^2)**	**Station discharge (log cfs)**	**Station discharge (cfs)**	**% Error**
4/10/06 10:00	148	14.094	X02W06	29.7	Test	2.170	0.010	0.036	1.055	11.360	-19.397
5/18/06 10:00	46	8.69	300057	53.6	Test	1.663	0.008	0.019	1.038	10.918	25.633
7/18/06 15:00	12	1.3884	300057	53.6	Test	1.079	0.005	0.001	0.042	1.101	-20.717
7/26/06 13:00	11	0.556	X02W06	29.7	Test	1.041	0.005	0.000	-0.013	0.971	74.693
8/3/06 10:00	6.9	0.415	300057	53.6	Test	0.839	0.004	-0.007	-0.369	0.428	3.107
8/7/06 0:00	3.4	0.1639	300057	53.6	Test	0.531	0.002	-0.017	-0.893	0.128	-22.028
8/30/06 12:00	11	0.459	X02W06	29.7	Test	1.041	0.005	0.000	-0.013	0.971	111.611
9/8/06 0:00	3.3	0.2178	X02W06	29.7	Test	0.519	0.002	-0.017	-0.507	0.311	42.755
9/20/06 11:00	13	1.803	X02W06	29.7	Test	1.114	0.005	0.002	0.056	1.138	-36.905
9/27/06 12:00	30	2.904	X02W06	29.7	Test	1.477	0.007	0.013	0.400	2.510	-13.583
12/10/06 14:00	66	17.647	300057	53.6	Test	1.820	0.008	0.024	1.306	20.222	14.593

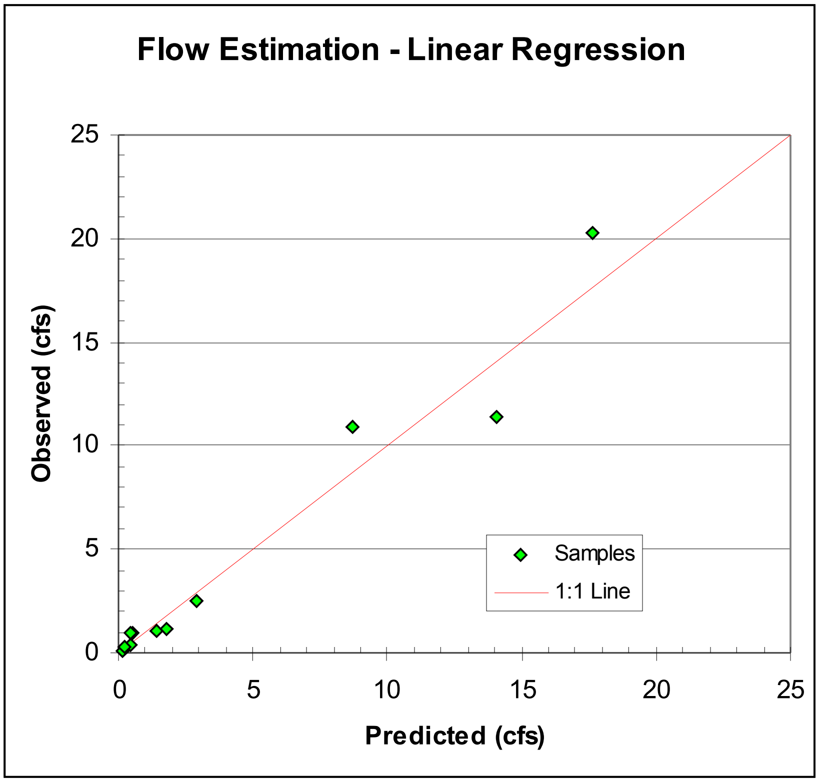

Figure A-6. Accuracy testing of the linear regression.

The percent error (observed minus predicted, divided by observed) ranged from -36.9 percent to 112 percent with an average of 14.5 percent. The average and maximum of the predicted discharges (4.6 and 20.2 cfs, respectively) overestimated the average and maximum of the observed discharges (4.4 and 17.6 cfs, respectively). The minimum of the predicted discharges (0.13 cfs) underestimated the minimum of the observed discharges (0.16 cfs). The linear regression method was least accurate during the summer months (Figure A-7).

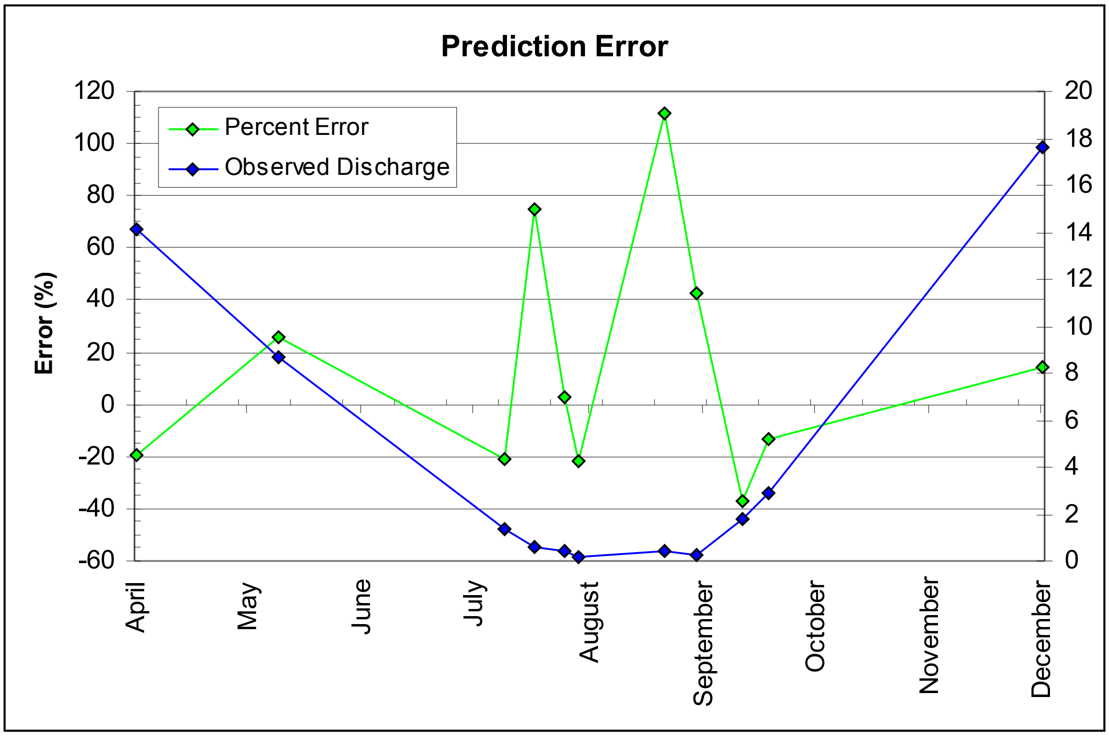

Figure A-7. Linear regression estimation error.

A-4ILSAM

The Illinois State Water Survey developed the Illinois Streamflow Assessment Model (ILSAM) for 10 watersheds in Illinois. The Illinois Water Survey (ILSAM 2008) describes ILSAM as follows:

> ILSAM produces statistical estimates of flow quantity in Illinois streams. The ILSAM flow estimates are representative of long-term climatic conditions, with base periods covering the past 50 years or more, but also account for recent man-made modifications to the flow amount such as have been caused by reservoirs, water-supply withdrawals, and discharges from wastewater treatment plants. Flow estimates may be obtained for thousands of stream locations within each major watershed.

Equations were developed for numerous percentile flows, low flows at certain recurrence intervals, and for various periods. The equations of interest for this project are the percentile flows, which can be used to develop a flow duration curve. Equations were developed for the following percentiles: 1, 2, 5, 10, 25, 40, 50, 60, 75, 85, 90, 95, 98, and 99. Although developed for rivers in Illinois, ILSAM was considered a potentially appropriate tool for estimating flow in the White Oak Creek watershed. The sections below describe the results.

A-4.1.Little Wabash River

The Little Wabash River watershed is one of the 10 ILSAM watersheds and is hydrologically similar to the White Oak Creek watershed. A full discussion of the Little Wabash River subwatershed is presented in Knapp and Myers (2001). Both watersheds are relatively flat in the headwaters regions and have broad valleys and mature drainage in the downstream regions. The annual precipitation ranges from 39 to 45 inches in the Little Wabash River watershed and from 41 to 43 inches in the White Oak Creek watershed. In southern Ohio, the average unit streamflow is 1.0 cfs/mi^2, which is slightly larger than that of the Little Wabash River watershed, 0.9 cfs/mi^2.

A-4.2.Equation Parameters for White Oak Creek

ILSAM estimates flow duration intervals on the basis of the following general equation:

$$Q_x = \min\{Q_{mean} [a + b \times DA + c \times K] - 0.05, 0\}$$

where Q_x is the flow at the particular flow duration interval at the ungaged site (in cfs), Q_{mean} is the mean annual flow at the ungaged site (in cfs), *DA* is the drainage area (mi^2), *K* is the subsoil permeability (inches per hour), and the coefficients *a*, *b*, and *c* are regression coefficients unique to each flow duration interval. Q_{mean} can be calculated from the following equation:

$$Q_{mean} = 0.0738 \times DA \times (P - ET)$$

where *P* is the precipitation (inches) and *ET* is evapotranspiration (inches). ($P - ET$) is referred to as the net precipitation factor.

The drainage area (*DA*) for most stations was provided by Ohio EPA. USGS StreamStats (USGS 2008c) was used to calculate the drainage area for the remaining sites. The net precipitation factor was calculated at the USGS gage and applied to the equations for all stations in the watershed. The value used was 16.6 inches.

The subsoil permeability (*K*) was calculated using geographic information system (GIS) and SSURGO data. SSURGO reports three Ksat (hydraulic conductivity at saturation) data sets: minimum, representative, and maximum. The average Ksat for the greatest depth of each soil group was queried from the SSURGO database for each of the three data sets and saved in DBF format. The data were converted from micrometers per second to inches per hour before they were added to the GIS and joined to the soil polygons, also provided by SSURGO (Figure A-8). The area of each soil polygon was calculated in the Attribute Table by inserting a new field and using the *Calculate Geometry* tool using the UTM NAD 1983 Zone 11 projection. The *Summarize* tool was used to generate another DBF that displayed the area and Ksat for each soil polygon. The area-weighted average was calculated in Excel using only the soil polygons with a reported Ksat. The representative Ksat data set yielded an area-weighted average of 0.51 inch per hour. The resultant flow-duration curves do not align with the field measurements (discussed in Section 4.3) and the data set has limited accuracy. For example, the percent error from the ILSAM estimations for the dry-conditions zone for the USGS gage data ranges from -34 percent to -60 percent. The SSURGO GIS analysis was re-performed using the maximum Ksat data set (Figure A-11), and the resultant area-weighted average is 0.98 inch per hour. Section 4.3 discusses the accuracy of the ILSAM equations using a K of 0.98 inch per hour.

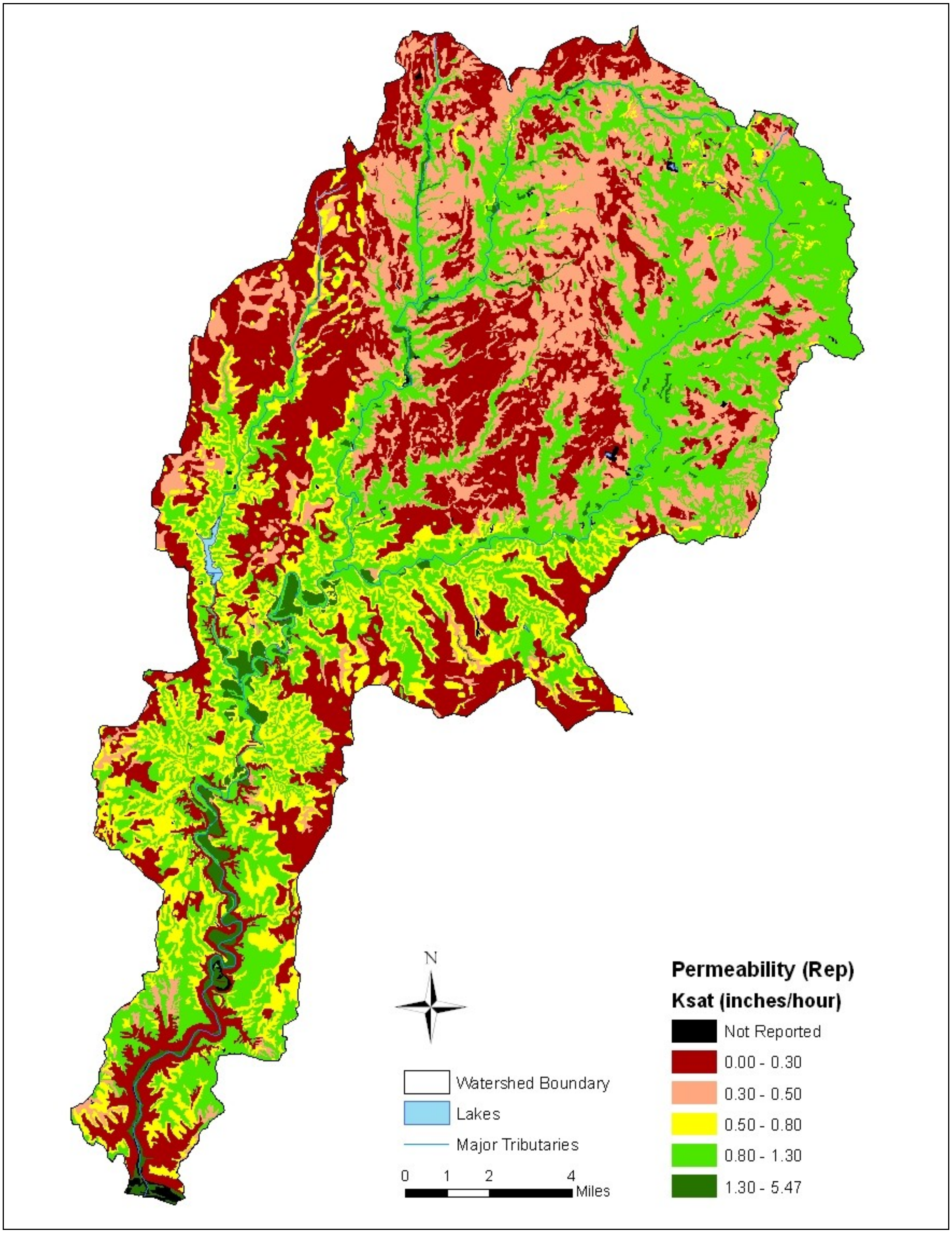

Figure A-8. SSURGO representative hydraulic conductivity at saturation at maximum depth.

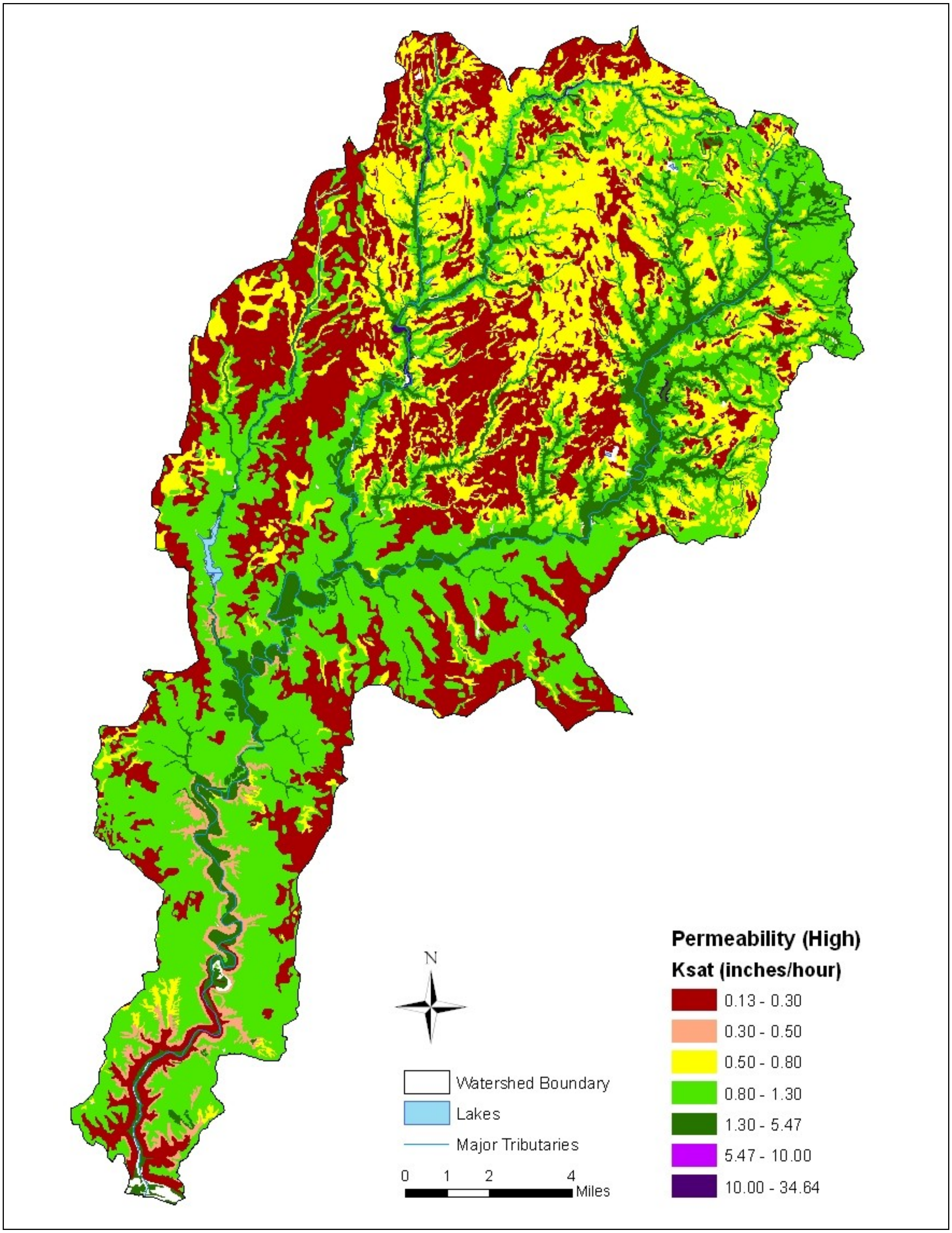

Figure A-9. SSURGO maximum hydraulic conductivity at saturation at maximum depth.

A-4.3.Analysis

The ILSAM method was tested using the instantaneous discharge data from the USGS gage, stations 300057 and X02W06 (see Section 2.1), and with field measurements collected during the summer of 2008 from stations X02K15, X02K17, and X02W05.

The most complete streamflow data set in the White Oak Creek watershed is for the USGS gage. ILSAM was used to estimate streamflow using the gage's drainage area of 218 square miles and the soil permeability and net precipitation values discussed in Section 4.2. The data from the gage and ILSAM were plotted together in a flow duration curve (Figure A-10). ILSAM was most accurate with estimating streamflow in the categories of high flows and moist conditions; it was least accurate estimating streamflow in the low flows and dry conditions categories (Table A-6). The average percent error—excluding the 98th and 99th percentiles in which the USGS flows drop to zero—was 4 percent.

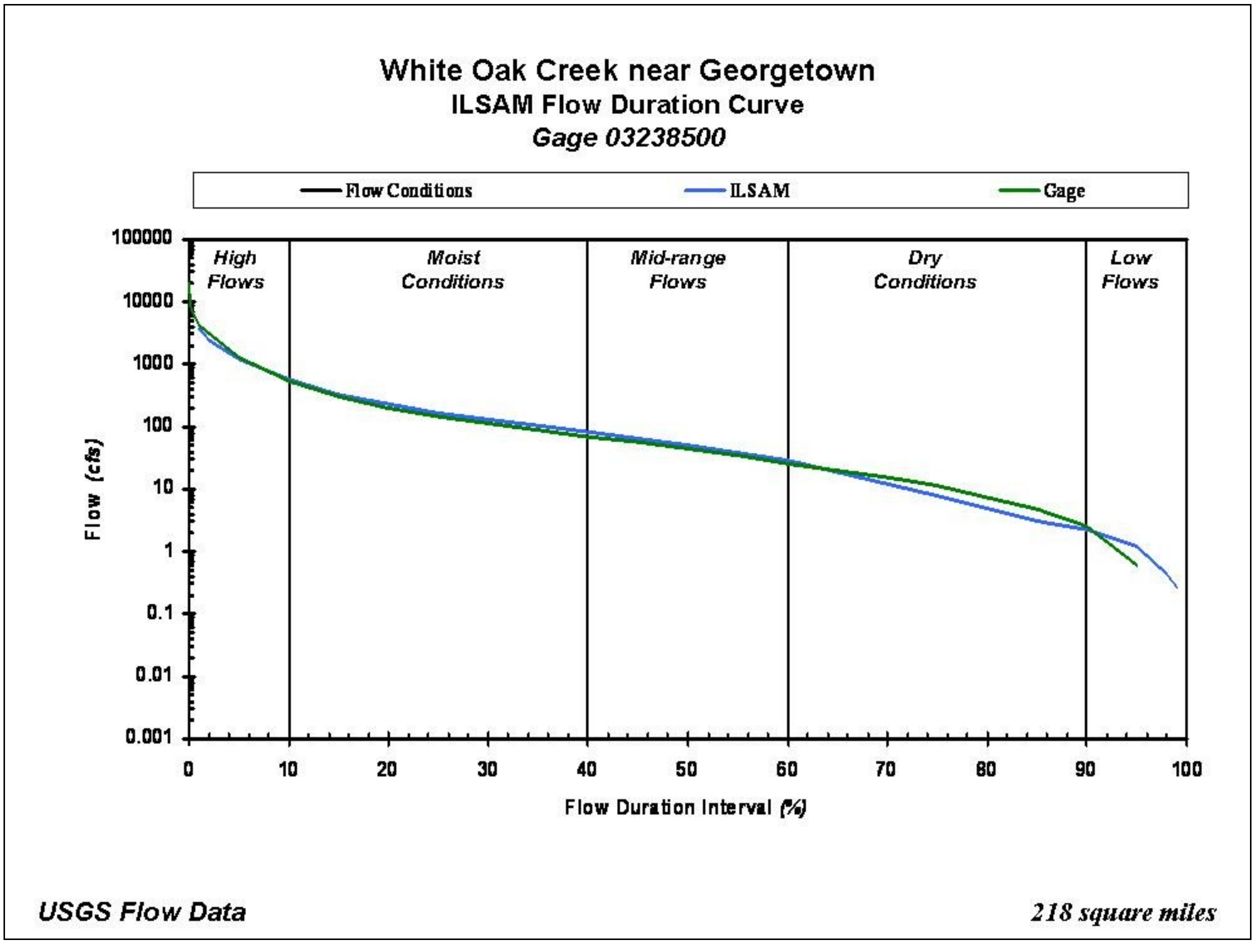

Figure A-10. ILSAM at USGS gage 03238500.

Table A-6. ILSAM estimation accuracy at gage 03238500

ILSAM percentile	ILSAM estimation	USGS gage	% Error
1	3,724	4,274.8	-13%
2	2,429	2,809.6	-14%
5	1,179	1,290.0	-8.6%
10	565.6	543.8	4.0%
15	331.3	304.0	9.0%
25	164.4	146.0	13%
40	82.70	70.0	18%
50	50.00	44.0	14%
60	28.62	26.0	10%
75	7.584	11.0	-31%
85	3.099	4.6	-32%
90	2.184	2.5	-13%
95	1.178	0.6	96%
98	0.436	0.0	
99	0.265	0.0	

Station 300057 is the only sample station with instantaneous discharge data that is not in the Sterling Run subwatershed. Figure A-11 displays the ILSAM-estimated flow duration curve with field-collected instantaneous discharge data, and Table A-7 shows the ILSAM prediction errors at station 300057. Note that the field-collected data is instantaneous discharge, whereas the ILSAM predictions are mean daily discharges. The instantaneous discharge might not be representative of mean daily flows because of the variation of flow over the course of a day.

Table A-7. ILSAM estimation accuracy at station 300057

ILSAM-interpolated percentile	ILSAM-interpolated estimation (cfs)	Field measurement (cfs)	% error
26.0	34.209	26.606	-29
49.4	11.97	8.69	-38
74.1	1.8128	1.3884	-31
76.2	1.398	0.497	-181
80.8	0.955	0.415	-130
80.6	0.3455	0.1639	-111
75.4	1.475	0.282	-423
88.0	0.4410	0.1795	-146
74.1	1.813	1.273	-42
41.7	17.775	17.647	-1

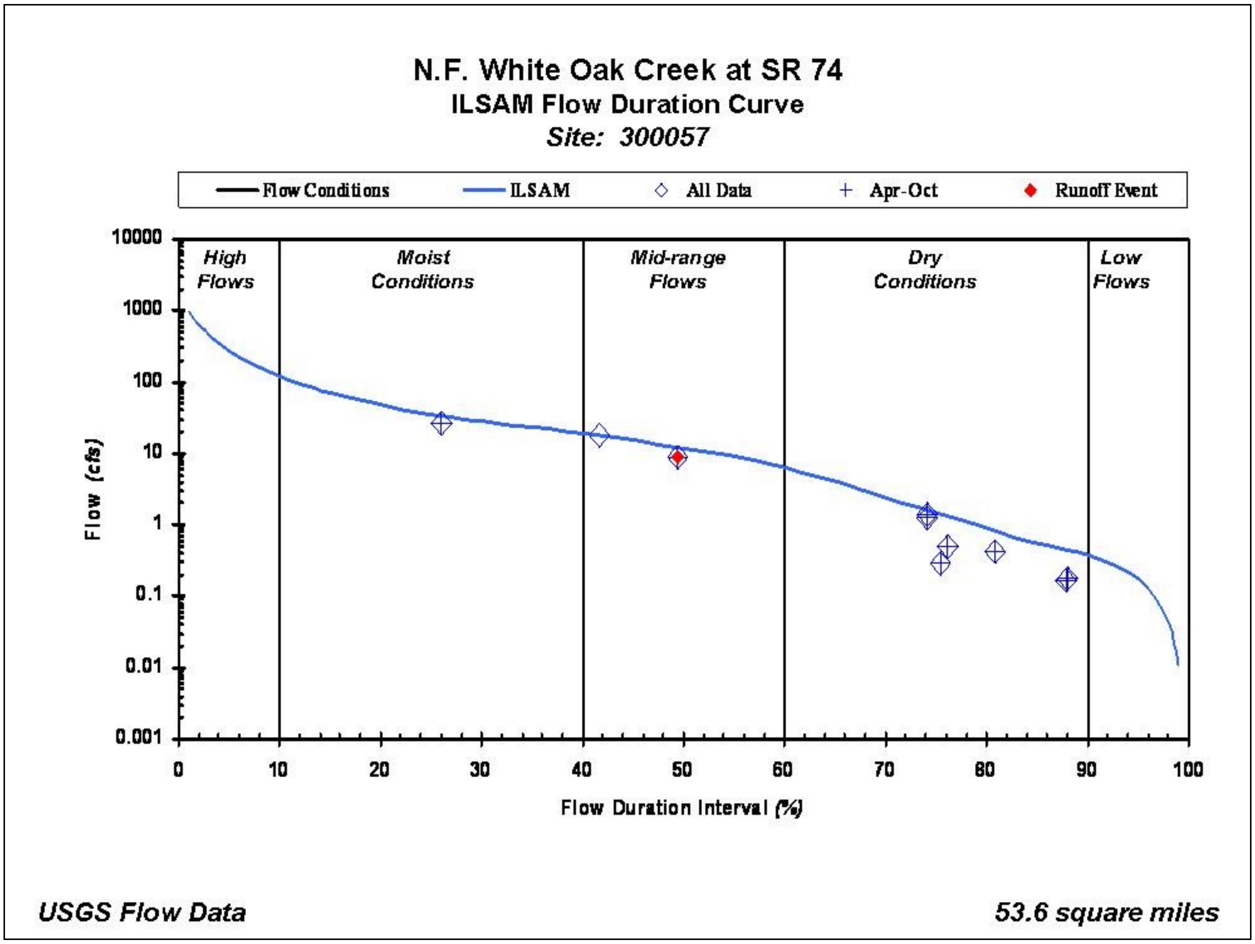

Figure A-11. ILSAM flow-duration curve for station 300057.

ILSAM estimates flows in virgin, or naturally flowing, streams. Table A-8 displays the ILSAM-estimate flow duration curve and the field-collected instantaneous discharge data. The ILSAM estimation for Sterling Run (Figure A-12) appears to be accurate even though this stream is affected by two significant factors: a public water supply (PWS) and Grant Lake.

Table A-8. ILSAM estimation accuracy at station X02W06

ILSAM-interpolated percentile	ILSAM-interpolated estimation (cfs)	Field measurement (cfs)	% error
25.0	19.122	14.094	-36%
49.4	6.546	8.453	23%
74.1	0.9561	0.9665	1%
75.4	0.771	0.556	-39%
86.5	0.24	0.38	37%
90.6	0.1591	0.4241	63%
91.3	0.1451	0.2552	43%
75.4	0.771	0.459	-68%
88.0	0.2101	0.2178	4%
73.0	1.157	1.803	36%
57.6	4.198	2.904	-45%
41.7	9.734	7.577	-29%

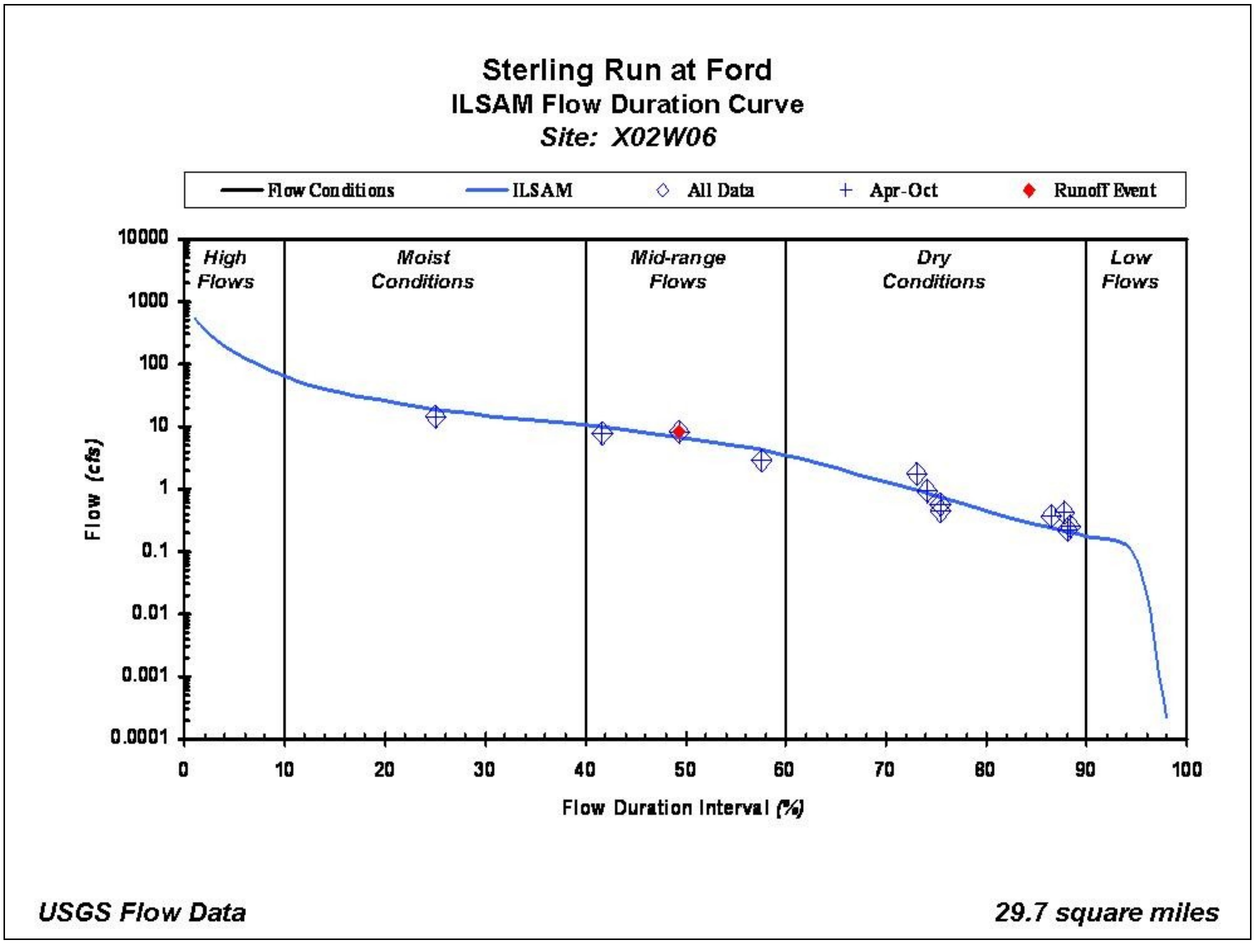

Figure A-12. ILSAM flow-duration curve for station X02W06.

The PWS is the Mount Orab water treatment plant (WTP) and its intake is at rivermile 6.47. The pump at the intake operates at approximately 1,000 gallons per minute (gpm) with a maximum design capacity of 1,100 gpm. The pump is manually activated; however, it deactivates automatically when the depth above the intake pipe in Sterling Run becomes too shallow. Neither this depth nor the streamflow at this depth is known. WTP personnel log the days that they activate the pump, but they do not log how long the pump is active. Under certain conditions, the pump might run 24 hours per day; in other conditions, it might run for part of the day or not at all (Van Harlingen, Mount Orab WTP, telephone conversation and email correspondance, August 2008). Furthermore, the pump is deactivated when in-stream atrazine levels exceed 0.3 ppm. WTP personnel collect weekly water-quality samples at the intake pipe and submit them to Sygenta, who then has the samples analyzed. The WTP personnel do not record the days that the pump is not active because of atrazine. Additionally, a low-head dam is approximately one-eighth of a mile downstream of the PWS intake (Van Harlingen, Mount Orab WTP, telephone conversation and email correspondance, August 2008).

Grant Lake is in the Grant Lake Wildlife area, and both are owned by the Ohio Department of Natural Resources Division of Wildlife. The dam on Grant Lake was constructed in 1948, and the pipe drain was HDPE slip-lined in 2004. It is an earthen-filled dam that is 600 feet long, 32 feet high, and 40 feet wide at the crest. Water drains from the lake via a 130-foot-wide concrete weir. The dam is inspected by the Division of Water, with the last inspection in June 2008. There are no reported dam breaches or failures.

The ILSAM flow duration curve for Sterling Run at the PWS intake and at other locations (Figure A-13, Figure A-14, and Figure A-15) appear to be accurate; thus, no modification of the ILSAM equations are necessary. At each of these three stations, one of the field-collected samples corresponded to a percentile of less than one in the high-flows zone. ILSAM can be extrapolated (for a discussion of extrapolation in the low flow zone, see Appendix C); however, a technique was not developed to extrapolate for these three samples. The percent errors for the ILSAM estimations for the other three samples at stations X02W05, X02K17, and X02K15 are -53 percent, -59 percent, and -30 percent, respectively.

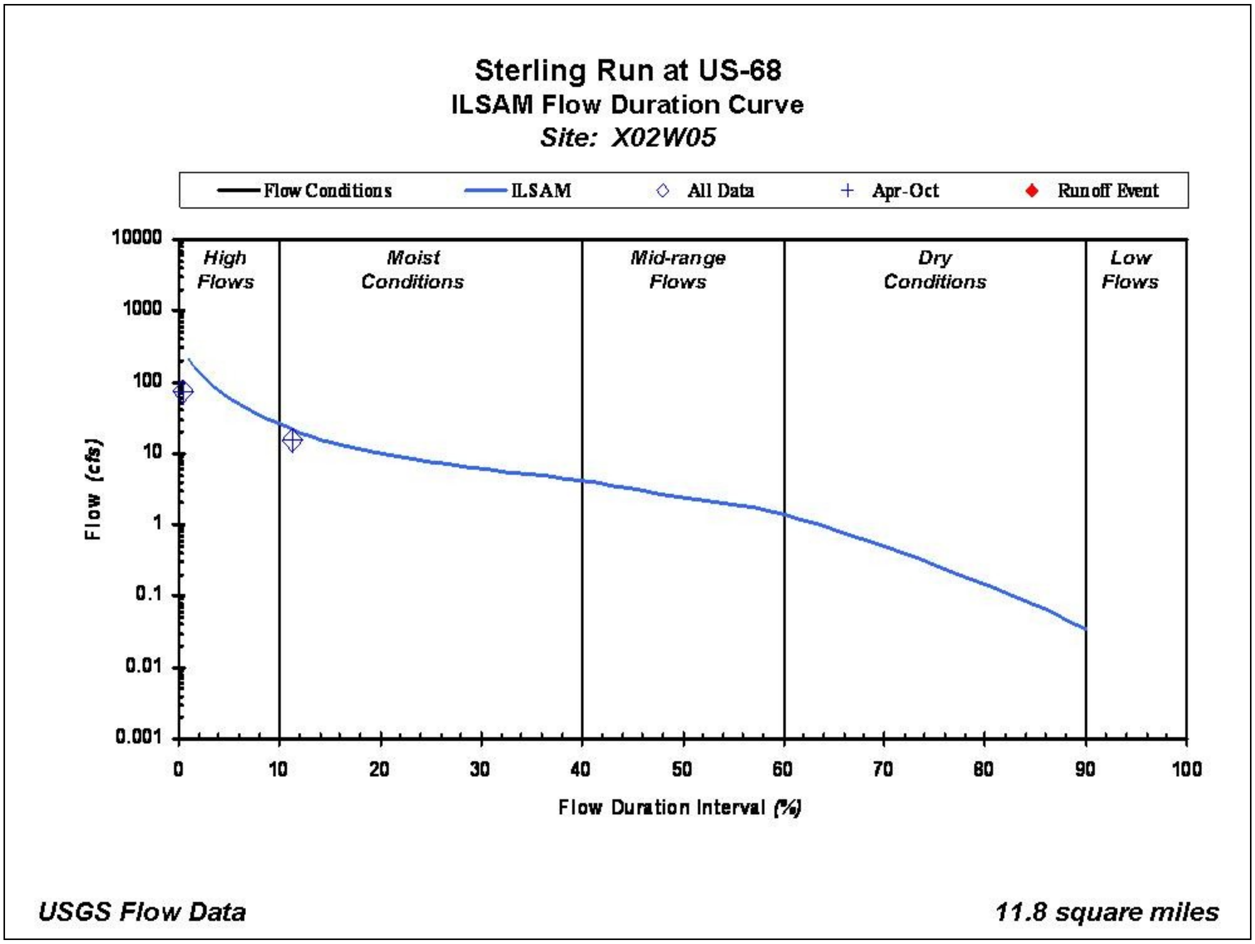

Figure A-13. ILSAM flow duration curve for station X02W05.

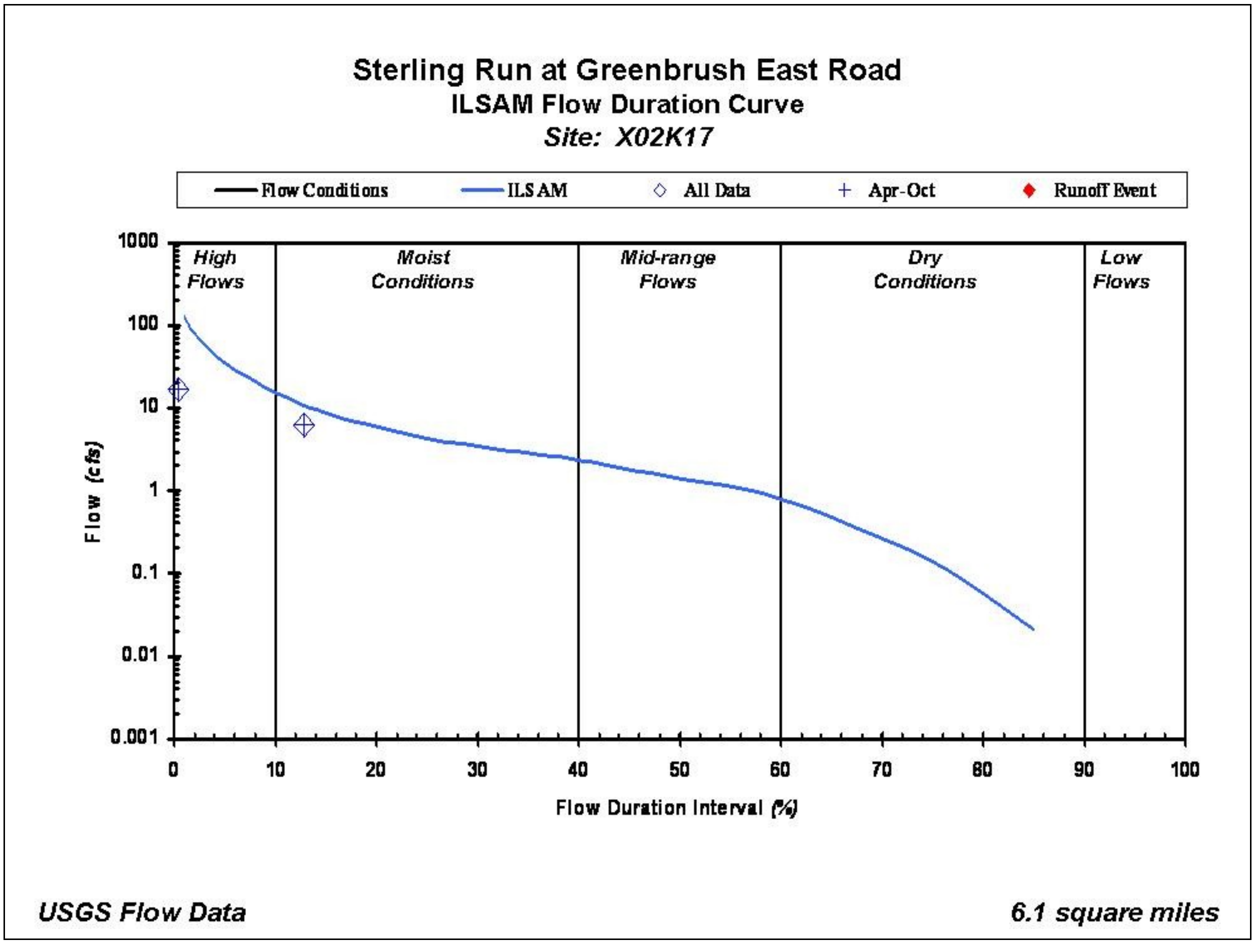

Figure A-14. ILSAM flow duration curve for station X02K17.

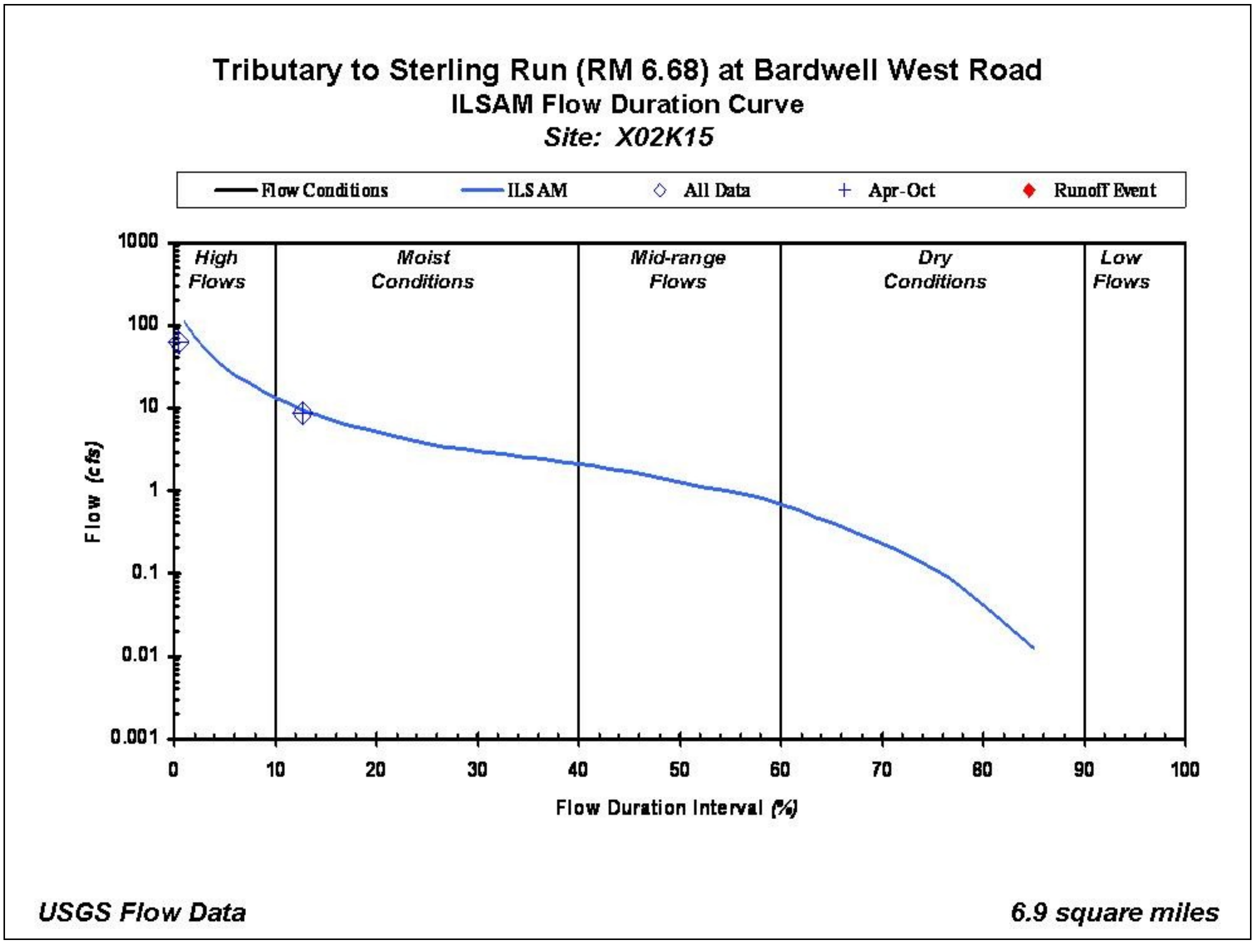

Figure A-15. ILSAM flow duration curve for station X02K15.

A-5Summary

The most accurate streamflow estimation technique for the White Oak Creed watershed is the ILSAM method. For this watershed, the drainage area ratio method yields instantaneous discharge estimations that are inaccurate. This is likely due to a number of factors, including the fact that the drainage areas of the ungaged sites are much smaller than the drainage area of the gaged site. The linear regression method was slightly more accurate but was also limited by the lack of data at additional sites. The linear regression performed in this project was least accurate during low flows that occurred during the summer (see Figure A-7); however, most of the Ohio EPA data was collected during the summer. Thus, the ILSAM method, with an average error of 4 percent at the gage, will be used to estimate streamflow for this project.

A-6References

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