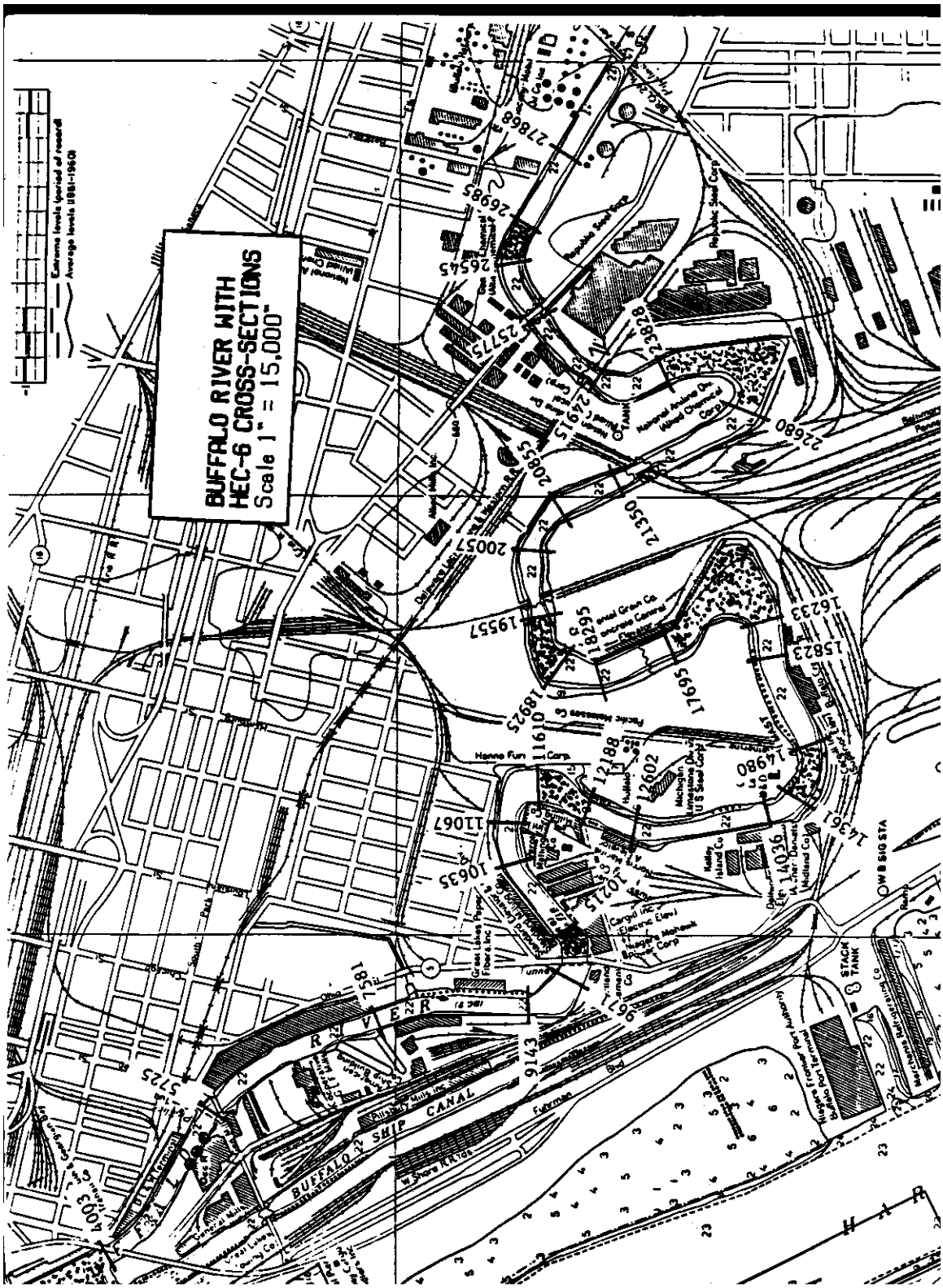

BUFFALO RIVER WITH
HEC-6 CROSS-SECTIONS
Scale 1" = 15,000"
Extreme levels (period of record)
Average levels (1961-1990)
BUFFALO SHIP CANAL
RIVER
Hanna Furn Corp
Republic Steel Corp
Great Lakes Power
Fibers, Inc
Pillsbury Mills Inc
Cargill Inc
Electric Clev
Hughes Mohawk
Brewer Corp
Michigan Limestone Div
U S Steel Corp
Allied Chemical Corp
Allied Chemical
Kelly
Holland Co
Dow Chemical
Midland Co
Hanna Furn
Fuhrmann
Blvd
W Shore R R Lines
Conrail Railroad
Great Lakes
Dairy Co
Ohio
South
Park
Blvd
Lake Erie
Bridge
Tunnel
Pier
Lighthouse
Pumping Station
Water Intake
Pipeline
Tank
Stack
Tank
Co
Water Treatment Plant
Hydro Electric Power Authority
Niagara Frontier Port Authority
Buffalo Harbor Lighthouse
Buffalo Harbor Lighthouse
Buffalo Harbor Lighthouse

A diurnal fluctuation in dissolved oxygen was observed at Hydrolab Sites 2 and 7 (e.g. Figure 5.19), particularly during dry periods early in the sample season (June and early July). Algae and rooted aquatic plants can deliver oxygen to the water through photosynthesis (Mitchell and Stapp, 1995) so that dissolved oxygen levels rise from the morning and peak in late afternoon/early evening. At night, aquatic organisms continue to respire, consuming oxygen, and therefore the dissolved oxygen levels begin to decline through to the next morning. A diurnal fluctuation typically was not observed at Hydrolab Site 4.

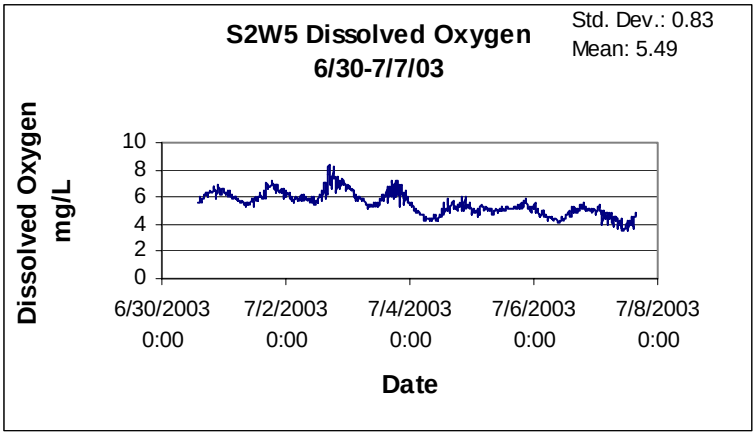


Figure 5.19 Example of diurnal pattern in dissolved oxygen, Site 2

5.4.4 Turbidity-TSS Relationships

Numerous studies have examined the relationship between turbidity and total suspended solids (TSS) in an effort to improve our ability to evaluate watershed-scale erosion and sediment transport dynamics (e.g. Lewis, 1996; Sun et al., 2001; Davies-Colley and Smith, 2001; Irvine et al., 2003). There can be several advantages to using automated turbidity measurements as a surrogate for TSS sampling in the examination of sediment erosion and transport. These advantages include the capability of providing fine time resolution measurements for extended periods, without having to rely on sampling teams to catch transient storm events with minimal notice (i.e. keeping teams "on call" to chase storms), and reduction of laboratory costs for the analysis of TSS. Ultimately, the success of using turbidity measurements in place of TSS sampling relies on the accuracy of the TSS-turbidity rating curve. Pfannkuche and Schmidt (2003) reported an r^2 of 60% between suspended sediment and turbidity, while others (e.g. Lewis, 1996; Davies-Colley and Smith, 2001; Tomlinson and De Carlo, 2003) have produced rating curves with higher r^2 values. Variability in the relationship may be related to a variety of factors, including changes in particle size, shape and composition, as well as the presence of humic acids.

Perrelli et al. (2005) used the rating curves developed by Irvine et al. (2003) to transform the 2000 turbidity time series into a TSS time series. Subsequently, the TSS time series was used to calibrate the erosion and sediment transport component of the HSP-F model for the watershed (e.g. Figure 5.20).

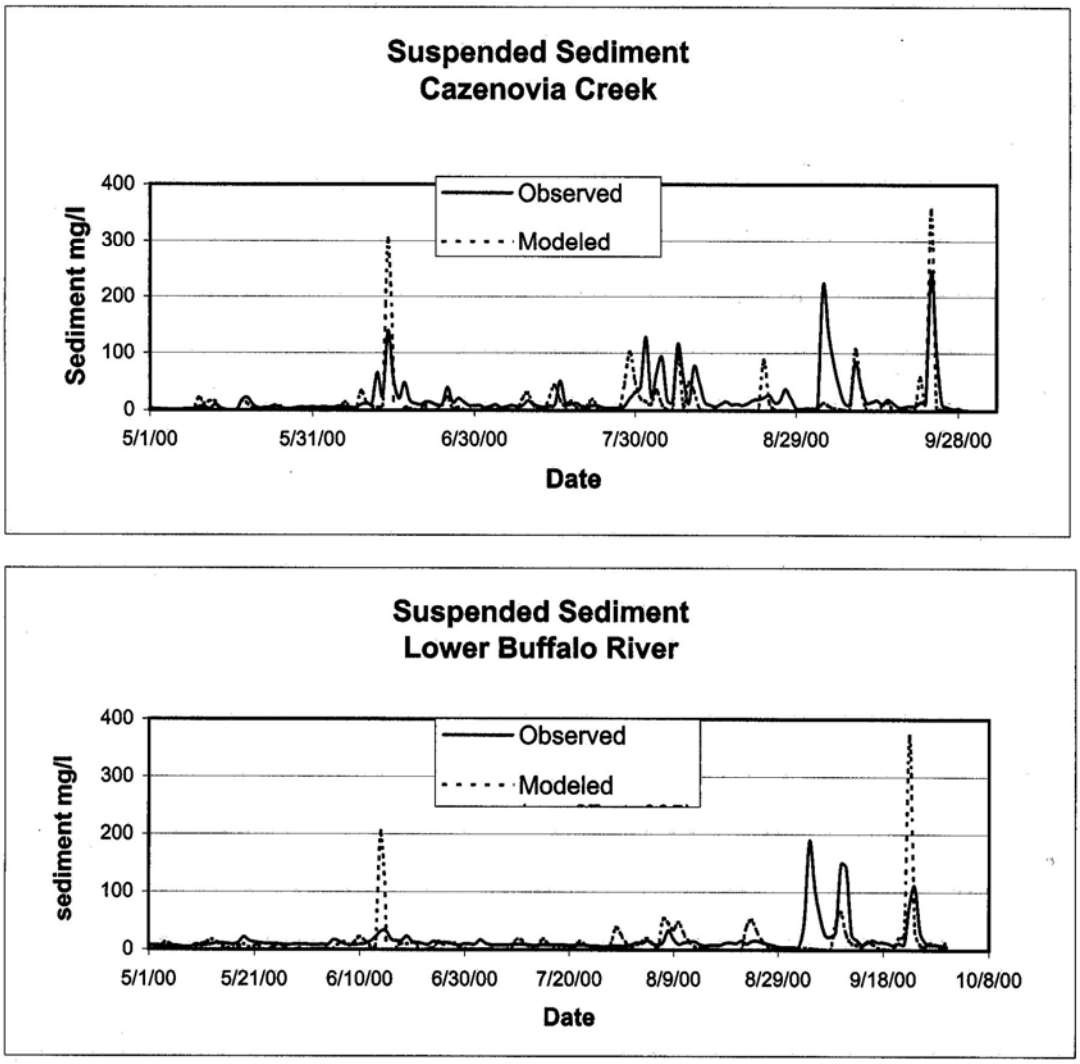


Figure 5.20 Model calibration results for suspended sediment estimates at Site 7 (top) and near Site 4 (bottom)(from Perrelli et al., 2005)

In the current study, the TSS concentrations were compared to turbidity measurements to develop a TSS-turbidity rating curve. To filter possible extraneous turbidity readings, the rating curve was developed using an average of the four turbidity measurements taken during the hour that the sample for TSS analysis was collected. Initial scattergrams and subsequent residual analysis indicated that a logarithmic transformation of the raw data was appropriate for the final form of each rating curve. The rating curves were developed using the combined 2003 and 2004 data for each site and the results are shown in Figure 5.21. The slopes of the regressions were significantly

different from 0 (α=0.05) and the r^2 values are comparable to those reported in other studies. Irvine et al. (2003), working with a smaller data set from the 2000 sampling effort, found it was not necessary to logarithmically transform the data for Hydrolab Sites 4 and 7 and reported r^2 values of 74% and 72%, respectively. Sun et al. (2001) concluded that turbidity-TSS relationships may be both site and time-specific, so that a relationship is normally unique for a particular catchment and within a particular period of time. Certainly, Figure 5.21 indicates there is some spatial variability of the turbidity-TSS relationship (based on differences in the regression slopes and intercepts).

5.4.5 Habitat Site Water Column Profiling with Hydrolab Datasonde

The raw water column profiling data for all sample sites in 2003 and 2004 are included on the attached CD. Probably of greatest interest for this project are the dissolved oxygen and turbidity levels. The mean values of dissolved oxygen and turbidity at each sample depth for 2003 and 2004 are shown in Tables 5.5 and 5.6.

Table 5.5 Mean Dissolved Oxygen (mg L^{-1}) and Turbidity (NTU) Based on Weekly Samples, 6/11-9/24/03

Site	D.O., 0.5 m depth	D.O. 1.0 m depth	D.O., near bottom	Turbidity, 0.5 m depth	Turbidity, 1.0 m depth	Turbidity, near bottom
1	7.05	6.98	6.68	16.21	16.81	24.4
2	6.38	6.13	4.32	19.63	22.97	92.18
3	5.94	5.75	3.69	21.23	22.54	110.09
4	5.87	5.66	3.14	15.63	15.49	40.49
5	5.70	5.40	3.25	15.45	14.85	29.45
6	5.82	5.53	5.46	13.69	13.79	92.71
7	5.81	5.63	3.60	12.08	17.04	39.11
8	6.00	5.67	3.87	15.39	13.21	25.95
9	5.95	5.67	4.20	11.58	12.77	38.63
10	5.72	5.39	4.38	9.59	10.24	17.55

Table 5.6 Mean Dissolved Oxygen (mg L^{-1}) and Turbidity (NTU) Based on Weekly Samples, 6/25-9/24/04

Site	D.O., 0.5 m depth	D.O. 1.0 m depth	D.O., near bottom	Turbidity, 0.5 m depth	Turbidity, 1.0 m depth	Turbidity, near bottom
1	7.11	7.01	6.68	16.11	17.05	24.40
2	6.31	6.09	4.32	20.09	23.61	92.18
3	5.73	5.54	3.41	20.91	22.64	115.61
4	5.60	5.38	3.14	14.18	14.02	40.49
5	5.43	5.13	2.93	13.76	12.91	29.76
6	5.55	5.23	5.23	11.35	11.60	98.58
7	5.58	5.36	3.30	9.94	10.80	39.92
8	5.79	5.49	3.58	10.84	11.02	24.0
9	5.78	5.49	3.94	9.86	11.30	39.94
10	5.41	5.08	4.10	8.76	9.66	17.51

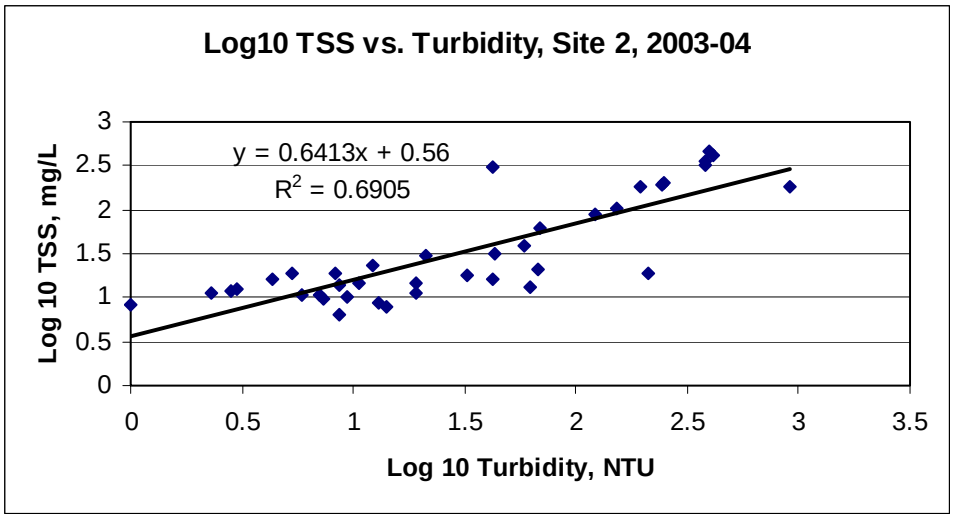


Figure 5.21

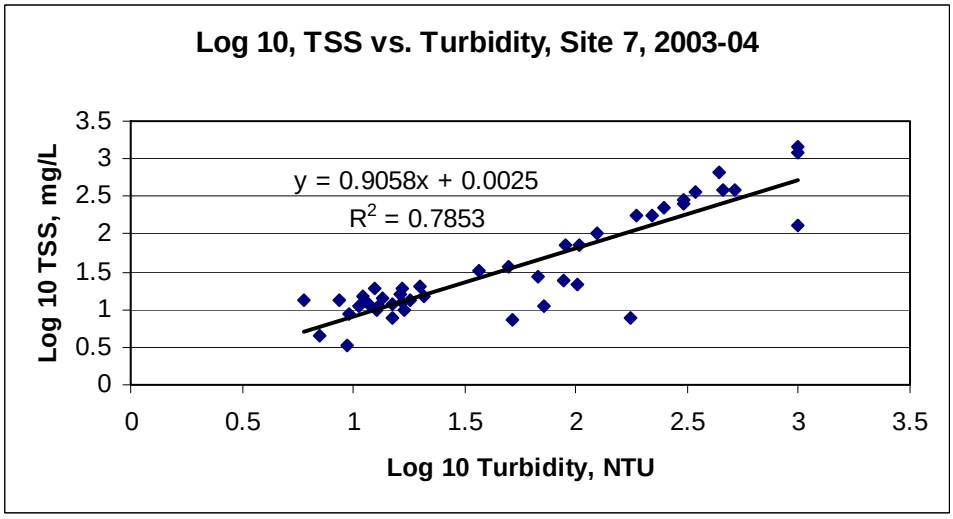
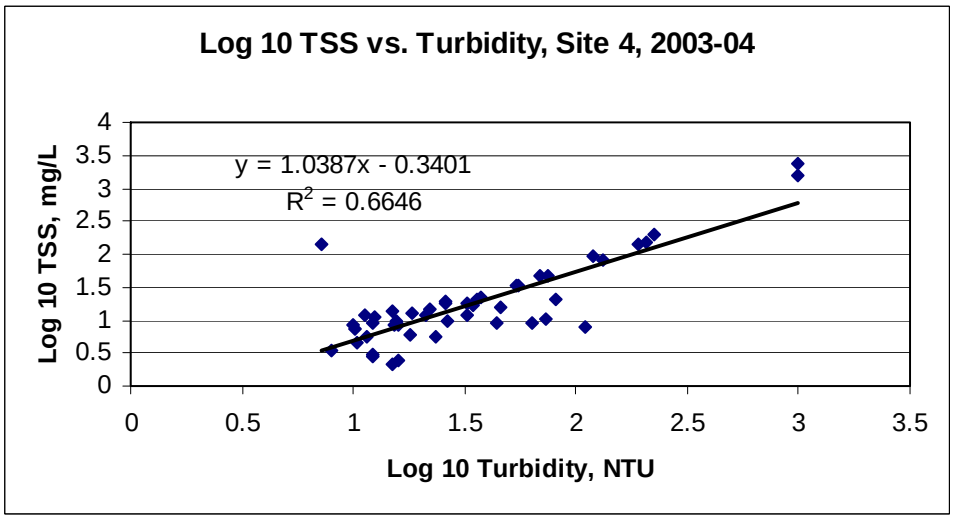


Figure 5.21



The data for each site are consistent between the two years, 2003 and 2004 (Tables 5.5 and 5.6). There is a general trend of decreasing dissolved oxygen and increasing turbidity with depth. The decrease in dissolved oxygen levels is consistent with the forcing factors described in Figure 5.7. In particular, the low dissolved oxygen near the bottom may be impacted by sediment oxygen demand (Jaligama et al., 2004). Suspended solids concentrations generally are higher near a river's bed, as a result of the combination of material settling and some near-bed saltation (temporary uplift and transport). Therefore, it is not surprising that turbidity readings were the highest near the bed. When considering the analysis of the data logged at fixed depths (Hydrolab Sites 2, 4, and, 7), it is important to keep in mind the potential for vertical variation. For example, the frequency of dissolved oxygen non-compliance (Tables 5.3 and 5.4) reflect a depth of 1-2 m; a greater frequency of non-compliance probably would occur in waters closer to the river bed.

Tables 5.5 and 5.6 show that, on average, Site 1 had the highest dissolved oxygen levels within the water column, as compared to the other habitat sites. Site 1 is upstream of the dredged navigable channel. Site 2, located in the upper portion of the dredged navigable channel, also had higher mean dissolved oxygen levels for the upper 1 m. However, dissolved oxygen levels decreased an average of 1.8-2.0 mg L^{-1} towards the riverbed at Site 2, a situation that seems to be well-explained by Figure 5.7. It is interesting that Site 6 did not exhibit the strong vertical trend in dissolved oxygen levels that were recorded at the other sites (Tables 5.5 and 5.6) and, on average for both years, the near-bed dissolved oxygen levels at this site were higher than the surrounding sites. A review of the data did not indicate that the higher levels of dissolved oxygen at this site were related to cooler water temperatures (e.g. due to shading from tree along the riverbank), but aquatic plant growth is apparent in this section of the river, which may contribute to the higher levels.

Mean turbidity typically was 20 NTU or less in the upper 1 m for all sites and there was a weak trend towards lower turbidity at Site 1, increasing turbidity at Sites 2 and 3, and then a general decrease in turbidity in the downstream direction from Site 3. The near bottom turbidity measurements exhibited a similar spatial trend, although as noted previously, the turbidity readings at this depth generally were higher, in the 20-100 NTU range, on average.

5.4.6 Profile vs. Continuous Logging Results

As noted in Section 5.2.1., Hydrolab continuous logging Sites 2 and 7 were selected to represent the upstream boundary conditions of the AOC, while Site 4 (Ohio St. Bridge) was selected to represent the longitudinal mid-point of the federal navigable channel. It was not intended that the logging sites necessarily would reflect the water quality conditions of the specific habitat sites. In fact, it was expected that there would be some spatial variation (e.g. Irvine et al., 2005). However, it is worth investigating whether the continuously logged data could be used to reflect conditions at the individual habitat sites. It was shown in Section 5.4.5 that variation was observed in the sample

verticals at the habitat sites. Therefore, the habitat locations with greatest probability of being similar to the logging sites were those in close proximity, at a 1 m depth.

Figure 5.22 shows the relationship between the different water quality parameters at Hydrolab logging Site 4 (Ohio St. Bridge) and Habitat Site 9 (see Figure 5.1) and Figure 5.23 shows the relationship between the different water quality parameters at Hydrolab logging Site 7 (mouth of Cazenovia Creek) and Habitat Site 1 (see Figure 5.1). The relationships were developed by averaging the logged Hydrolab data within the three hour period that the water column profiling was done. Temperature, conductivity, and dissolved oxygen showed strong, positive trends between Hydrolab logging Site 4 and Habitat Site 9. The turbidity and pH unexpectedly showed negative, although weaker, relationships. It would be possible to consider the continuous data from logging Site 4 as reflecting the general conditions of Habitat Site 9 (1 m depth) for temperature, conductivity, and dissolved oxygen. The turbidity and pH values are in the same general range for logging Site 4 and Habitat Site 9, but the temporal trend is not consistent.

Weak positive trends were observed in Figure 5.23 for all parameters. Profiling was done at the downstream location of Habitat Site 1 (Figure 5.1), and the site, in fact, would represent a mix of conditions between Cazenovia Creek and the upper Buffalo River. It is not surprising that the relationship between Hydrolab logging Site 7 (mouth of Cazenovia Creek) and Habitat Site 1 are relative weak, because of the mixing at Habitat Site 1.

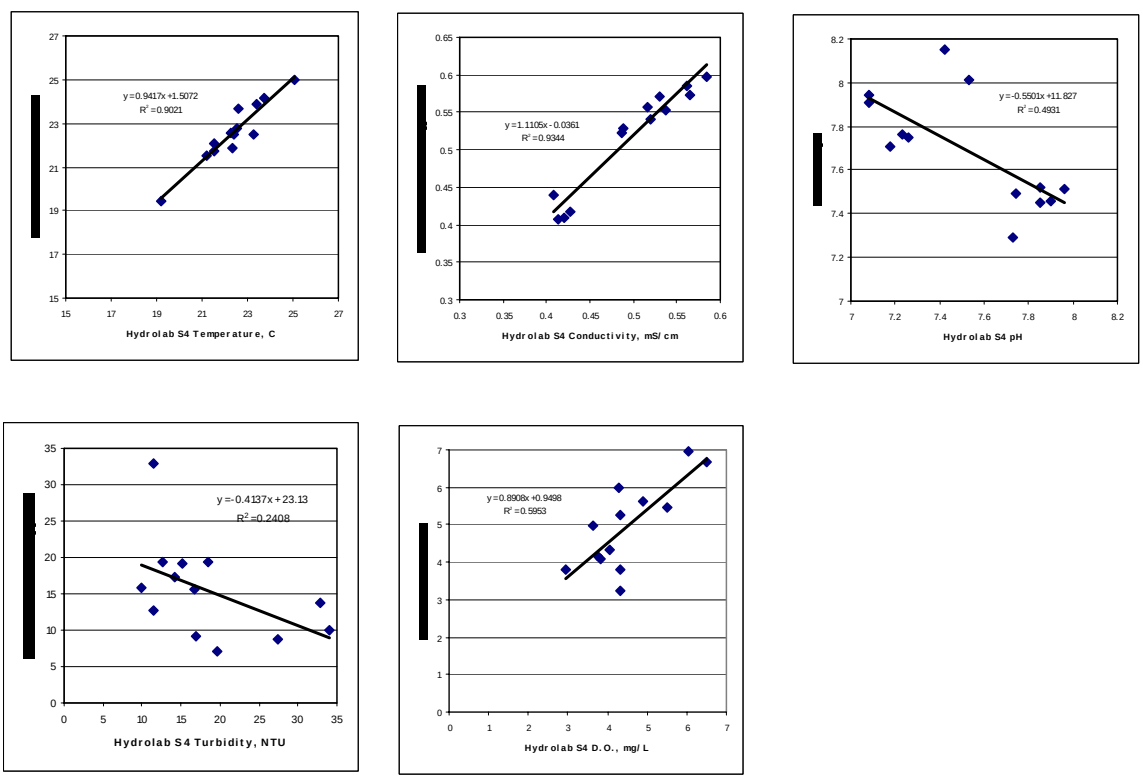


Figure 5.22 Hydrolab continuously logged data (Hydrolab Site 4) vs. water column profile results (1 m depth) at Habitat Site 9

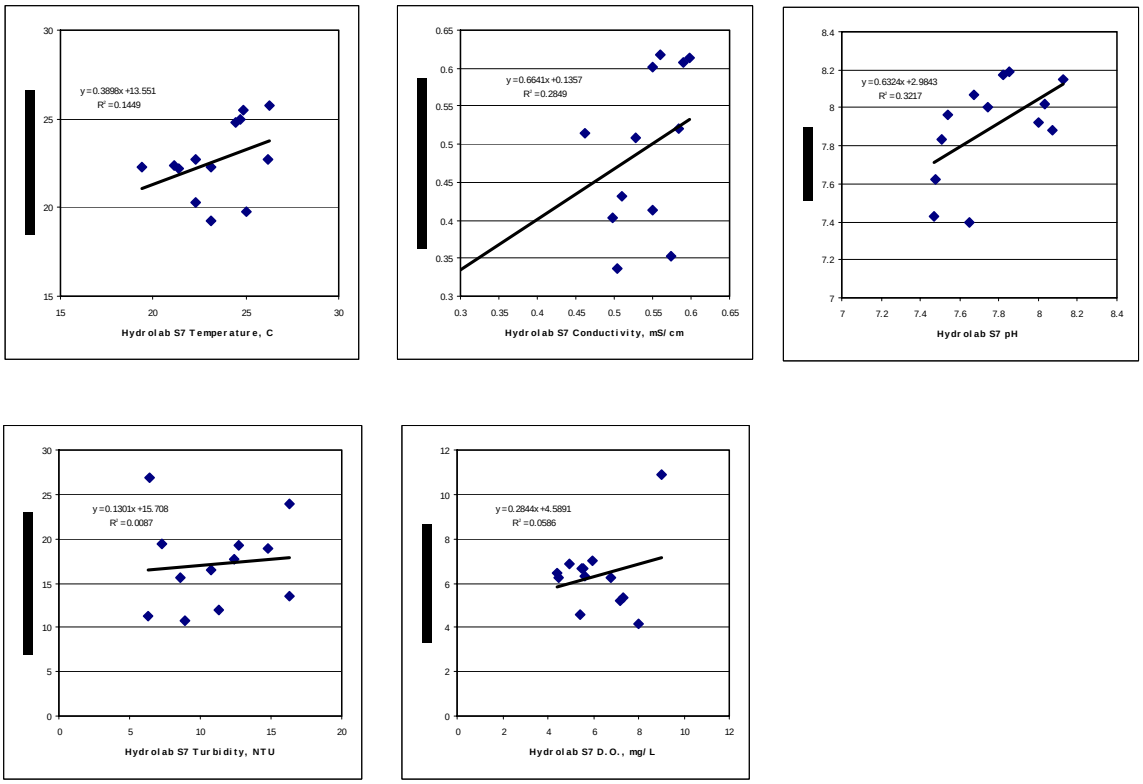


Figure 5.23 Hydrolab continuously logged data (Hydrolab Site 7) vs. water column profile results (1 m depth) at Habitat Site 1.

5.4.7 *E. coli* Levels

The results of the *E. coli* testing at Hydrolab Sites 2, 4, and 7 are shown in Table 5.7. The high levels associated with the storm event of 9/9/04 are consistent with the fecal coliform results reported by past studies (e.g. Irvine and Pettibone, 1996; Wills and Irvine, 1996; Irvine et al., 2005b). The *E. coli* levels on two dry weather dates were relatively low (50-500 m.o./100 mL), but the levels at all sites for the 9/22/04 sample date were elevated. A review the USGS gauge data for Cazenovia, Cayuga, and Buffalo Creeks indicated that flows on 9/22/04 were relatively low (34-88 cfs)(0.96-2.5 m^3s^{-1}) and it had been at least four days since a storm event had occurred.

Table 5.7 *E. coli* Levels per 100 mL, 2004

Date	Time	Site 2	Date	Time	Site 7	Date	Time	Site 4	Event/Dry
9/9/2004	11:10	36,100	9/9/2004	11:20	25,700	9/9/2004	10:55	32,800	E
9/9/2004	12:17	32,100	9/9/2004	12:30	25,200	9/9/2004	11:55	38,700	E
9/9/2004	14:15	24,700	9/9/2004	14:05	27,400	9/9/2004	13:50	30,200	E
9/10/2004	10:05	18,300	9/10/2004	10:10	12,400	9/10/2004	9:45	15,700	E
9/15/2004	11:55	500	9/15/2004	12:00	600	9/15/2004	11:00	50	D
9/22/2004	10:20	2,160	9/22/2004	10:25	1,820	9/22/2004	9:55	1,580	D
9/29/2004	11:00	100	9/29/2004	11:05	200	9/29/2004	11:50	50	D

Winkler (2005) sampled for *E. coli* on a daily basis at Hydrolab Sites 2, 4, and 7 between 3/24 and 4/10/04. Analysis was done using the Coliscan Easygel test, per the procedures outlined in Section 5.3. Water temperature ranged between 1.5-8.8 ^{o}C, 2.8-11.5 ^{o}C, and 1.8-8.7 ^{o}C at Sites 2, 7, and 4, respectively. River discharge conditions (to the top of the AOC) ranged between baseflow and approximately 6,500 cfs (184 m^3s^{-1}) (representing a combined rain and snowmelt event). The geometric mean *E. coli* levels were 31 m.o./100 mL, 9 m.o./100 mL and 112 m.o./100 mL at Sites 2, 7, and 4 respectively. Temperature and seasonal conditions may be limiting factors governing *E. coli* levels in the river. Although the higher end flow conditions would have been sufficient to move the bacteria to the river via overland runoff and also erode bed material (re-introducing bacteria to the water column), it seems that the bacteria had not yet become established (e.g. through re-inoculation of bed sediment) or multiplied under the protection of the sediment. Irvine and Pettibone (1996) found a similar seasonal trend for fecal coliform in the watershed. It seems likely that there is a critical time (and associated temperature range) at which the bacteria levels may be expected to increase.

5.5 Conclusion

Dissolved oxygen levels frequently were below state guidelines within the dredged portion of the AOC (representing all habitat sites except Site 1). Dissolved oxygen levels upstream of the dredged channel more frequently were above state guidelines, particularly in 2004. It appears that the low dissolved oxygen levels are related to a combination of stratification in the river at low flows that can reduce aeration, high sediment oxygen demand, together with long residence times due to system hydraulics (in particular, dredging increases channel cross-sectional area and residence time), and background biochemical oxygen demand (see Figure 5.7). Vertical variation in dissolved oxygen was observed at most sites, with lower levels being recorded near the bed of the river. This vertical trend was less apparent at Site 6, possibly due to the impact of aquatic vegetation.

During dry periods turbidity in the upper 1 m at all sites typically was <20 NTU (5-15 mg L^{-1}). Turbidity increased near the bed (ranging between approximately 20-100 NTU), generally as the combined result of sedimentation from above and near bed saltation. Turbidity during storm events was much greater, reaching 1,000 NTU (~300-600 mg L^{-1}). Unless the event was of extreme magnitude, such as the storm of 9/9/04, there was a trend of decreasing turbidity in the downstream direction as the result of sediment deposition.

Levels of pH on average ranged between 7 and 8. These pH levels are related to the buffering capacity of the limestone and dolomite bedrock of the area and are not unusual for watersheds in this region. Conductivity varied in the range of about 0.3-0.7 mS/cm, but frequently showed a characteristic decrease during runoff events as the groundwater solute concentrations were diluted by stormwater.

The levels of *E. coli* were high during storm events (up to 38,700 m.o./100 mL) at upstream sites, as well as at the Ohio Street Bridge. This is consistent with past studies

(e.g. Irvine and Pettibone, 1996; Irvine et al., 2005b) and again documents the importance of the upper watershed as a bacteria source. The *E. coli* levels were lower during dry periods, in the range of 50-2,200 m.o./100 mL. The upper end of this range still is high, but again, these results are consistent with past studies.

The Coliscan Easygel system was easy to use and provided results that were consistent with past studies of the river. Other citizen's groups throughout the U.S. successfully have used the Coliscan Easygel system in monitoring programs (e.g. Alabama Water Watch (1999); Virginia Citizen Water Quality Monitoring Program (2003); Texas Watch (http://www.texaswatch.geo.txstate.edu/Newsletters/98-04.pdf); Hoosier Riverwatch (http://www.in.gov/dnr//riverwatch/pdf/manual/Chap4.pdf); Alliance for the Cheasapeake Bay Citizens Monitor (http://www.acb-online.org/pubs/projects/deliverables-87-1-2003.pdf); University of Vermont (2003)). The Virginia Department of Environmental Quality approved the Coliscan Easygel method for screening purposes and independent testing (e.g. Alabama Water Watch, 1999; Deutsch and Busby, 2000) has shown that Coliscan Easygel results are comparable to standard methods.

5.6 References

Alabama Water Watch, 1999. *Quality Assurance Plan for Bacteriological Monitoring*, Prepared for U.S. EPA Region 4.

APHA (American Public Health Association), 1985. *Standard Methods for the Examination of Water and Wastewater, 16th ed.,* APHA, Washington, D.C.

Atkinson, J.F., Bajak, T., Morgante, M., Marshall, S., and DePinto, J.V. 1994. *Model Data Requirements and Mass Loading Estimates for the Buffalo River Mass Balance Study*, U.S. EPA Report, EPA 905-R94-005.

Blair, S.M. 1992. Dissolved Oxygen Model for the Buffalo River. Unpub. M.S. Thesis, Department of Civil Engineering, University at Buffalo.

Davies-Colley, R.J. and Smith, D.G. 2001. Turbidity, suspended sediment, and water clarity: A review. *Journal of the American Water Resources Association,* 37(5): 1085-1101.

Deutsch, W.G. and Busby, A.L. 2000. *A Field and Laboratory Manual for a Community-based Water Quality Monitoring Program in the Philippines,* International Center for Aquaculture and Aquatic Environments.

Diggens, T.P. and Snyder, R.J. 2003. Three decades of change in the benthic macroinvertebrate community and water quality in the Buffalo River Area of Concern, 1964-1993. *Journal of Great Lakes Research,* 29(4):652-663.

Hall, J.S. 1997. Examination of a Numerical Model for Dissolved Oxygen in the Buffalo River. Master of Engineering Project, Department of Civil Engineering, University at Buffalo.

Irvine, 2003. Continuous Measurement of Conventional Parameters in the Allegheny River and Oil Creek, PA, in Support of the Oil City CSO Long Term Control Plan, Report for the City of Oil City, PA and Malcolm Pirnie, Inc., Pittsburgh, PA.

Irvine, K.N. and Pettibone, G.W. 1996. Planning level evaluation of densities and sources of indicator bacteria in a mixed land use watershed. *Environmental Technology*, 17: 1-12.

Irvine, K.N., Somogye, E.L., and Pettibone, G.W. 2003. Turbidity, suspended solids, and bacteria relationships in the Buffalo River watershed. *Middle States Geographer,* 35: 42-51.

Irvine, K.N., McCorkhill, G., and Caruso, J. 2005. Continuous monitoring of conventional parameters to assess receiving water quality in support of combined sewer overflow abatement plans. *Water Environment Research,* 77(3):

Irvine, K.N., Perrelli, M.F., McCorkhill, G., and Caruso, J. 2005b. Sampling and modeling approaches to assess water quality impacts of combined sewer overflows – The importance of a watershed approach. *Journal of Great Lakes Research,* 31:105-115.

Jaligama, G.K., Atkinson, J.F., and Irvine, K.N. 2004. Impact of combined sewer overflows on dissolved oxygen in the Buffalo River. International Association for Great Lakes Research, Annual Conference, Waterloo, Ontario.

Lewis, J. 1996. Turbidity-controlled suspended sediment sampling for runoff-event load estimation. *Water Resources Research,* 32(7): 2299-2310.

Marsh, W.M. 1987. *Earthscape A Physical Geography*, John Wiley and Sons, New York, 510p.

Meredith, D.D. and Rumer, R.R. 1987. Sediment Dynamics in the Buffalo River. Report, Department of Civil Engineering, State University of New York at Buffalo, 171p.

Mitchell, M.K. and Stapp, W.B. 1995. *Field Manual for Water Quality Monitoring, 9th ed.,* Thomson-Shore, Inc., MI.

Morisawa, M. 1968. *Streams Their Dynamics and Morphology*, McGraw-Hill Book Company, New York, 175p.

New York State Department of Environmental Conservation (NYSDEC), 1989. Buffalo River Remedial Action Plan. Report to the International Joint Commission.

Perrelli, M.F., Irvine, K.N., and Lee, T.S. 2005. Calibration of BASINS HSP-F in support of a watershed approach to CSO Long Term Control planning. In *Effective Modeling of Urban Water Systems, Monograph 13,* W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt, eds. CHI, Guelph, ch. 20.

Pfannkuche, J. and Schmidt, A. 2003. Determination of suspended particulate matter concentration from turbidity measurements: Particle size effects and calibration procedures. *Hydrological Processes,* 17: 1951-1963.

Sun, H., Cornish, P.S., and Daniell, T.M. 2001. Turbidity-based erosion estimation in a catchment in South Australia. *Journal of Hydrology,* 253: 227-238.

Tomlinson, M.S. and De Carlo, E.H. 2003. The need for high resolution time series data to characterize Hawaiian streams. *Journal of the American Water Resources Association,* 39(1): 113-123.

University of Vermont, 2003. *Watershed Alliance, Watershed Educator's Handbook.*

Virginia Citizen Water Quality Monitoring Program, 2003. *Methods Manual,* Report for Virginia Department of Environmental Quality.

Walling, D.E. and Webb, B.W. 1980. The spatial dimension in the interpretation of stream solute behaviour. *Journal of Hydrology*, 47: 129-149.

Wight, M. 1995. A Numerical Model to Examine Dissolved Oxygen in the Buffalo River. Master of Engineering Project, Department of Civil Engineering, University at Buffalo.

Wills, M. and Irvine, K.N. 1996. Application of the National Sanitation Foundation Water Quality Index to the Cazenovia Creek Pilot Watershed Management Study. *Middle States Geographer,* 29: 95-104,

Winkler, K.A. 2005. The Effect of Temperature and Discharge Rates on the Concentration of *E. coli* present in the Buffalo River Watershed. Unpubl. B.A. Thesis, Department of Geography/Planning, Buffalo State.

APPENDIX 5.1
HYDROLAB SITES DURING DRY WEATHER AND EVENT OF 9/9/04

Hydrolab Site 2, Seneca St. Bridge, dry weather conditions in summer

Hydrolab Site 7, Mouth of Cazenovia Creek, dry weather conditions in summer

Hydrolab Site 4, Ohio St. Bridge, dry weather conditions in summer

Hydrolab Site 2, Seneca St. Bridge, event of 9/9/04

Hydrolab Site 7, Mouth of Cazenovia Creek, event of 9/9/04

Hydrolab Site 4, Ohio St. Bridge, event of 9/9/04