INTERVENTION STRATEGIES TO IMPROVE WATER QUALITY ON COUNTRY CLUB BAYOU

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INTRODUCTION

Country Club Bayou, formerly Slaughterhouse Ditch, is located in southeast Houston. The bayou drains from east to west connecting to Brays Bayou. The upper portion of the bayou is conveyed in a concrete channel that was initially placed in the early 1900's. The lower portion of the bayou from the Hughes Street railroad bridge to the confluence with Braes Bayou is open, unlined channel.

Figure 1 is a portion of a USGS map of the area based on field survey data from 1915. The map shows the bayou branching upstream of Evergreen Cemetery, with both branches depicted as open ditch. The upper branch runs west towards downtown, stopping near the present day US 59. In 1915 most of the bayou was open ditch. Sometime between 1922 and the late 1930's the bayou west of Evergreen Cemetery was covered over as part of a WPA project. In 1948 the open portion from Evergreen Cemetery to Hughes Street (the Hughes Tool Complex) was covered.

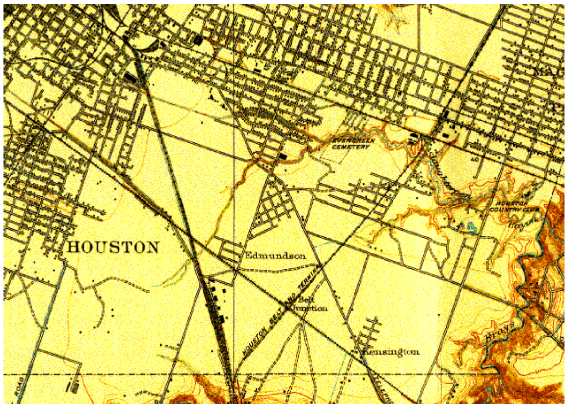

Figure 1. Country Club Bayou in 1915; Mostly open ditch

Figure 2. Hughes Street Outfall

Pollution of the bayou has been problematic for at least a dozen years. Suspected high nutrient loading somewhere in the covered portion of the bayou contributes to observed low dissolved oxygen values, a septic odor, and septic (black) color.

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Figure 2 is a photograph of the transition from the covered portion of the bayou to the open portion. The location is just upstream of the Hughes Street Bridge.

PROBLEM STATEMENT

At times the water at just upstream of the Hughes Street Bridge (Figure 2) does not meet state water quality standards for unclassified waters. Unclassified waters are waters which are not specifically listed in Appendices A or D of §307.10 of Title:30, Part 1, Chapter 307 of the Texas Administrative Code. Table 1 lists some of the relevant standards. While symptomatic treatment is technologically feasible, the purpose of this project was to document an investigation to locate sources of pollution and evaluate intervention strategies to mitigate the effects of pollution.

Table 1 Selected Water Quality Standards for Unclassified Waters

Parameter	Value	Remarks
Dissolved Oxygen	2.0 mg/L - 24 hr. average 1.5 mg/L - absolute minimum 3.0 mg/L - proposed[1]	
Sulfate	65 mg/L - proposed[1]	
pH	6.5-9.0 - proposed[1]	
Fecal Coliform	200 cfu/100mL 2000 cfu/100mL	Contact recreation Non-contact recreation
Temperature	4°F above ambient 1.5°F above ambient	Fall, Winter, Spring Summer

[1] These values are proposed for Segment 1014 (Buffalo Bayou above tidal) for contact recreation and limited aquatic life use.
See: (http://www.tnrcc.state.tx.us/ water/quality/standards/revisions.html)

GENERAL APPROACH

The general approach to this research was based on the EPA user's guide for addressing pollutant inputs into storm water systems guide (USEPA 1993) and on a protocol developed for detection of rainfall induced infiltration into a sanitary sewer system (Cleveland et. al. ,1993). Country Club Bayou is unique in that a large portion of the drainage is covered with areas of limited subsurface access so that many of the techniques in the EPA guide can only identify approximate pollutant locations. The approach used field monitoring, tracer studies, and computer modeling to test several possible intervention strategies for Country Club Bayou.

FIELD MONITORING

Water samples from Country Club Bayou were jointly collected at locations plotted on Figure 3 by the City of Houston and University of Houston. The samples were jointly analyzed for the characteristics shown on the data entry form of Figure 4. The data were entered into a MS ACCESS database and grouped in different ways to determine if meaningful relationships between the measurable parameters were present. For example, at each sample collection site the arithmetic mean value of selected parameters were compared during odor and no-odor conditions.

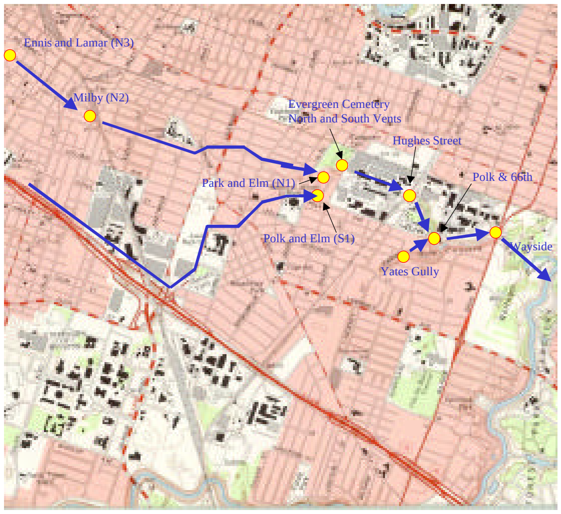
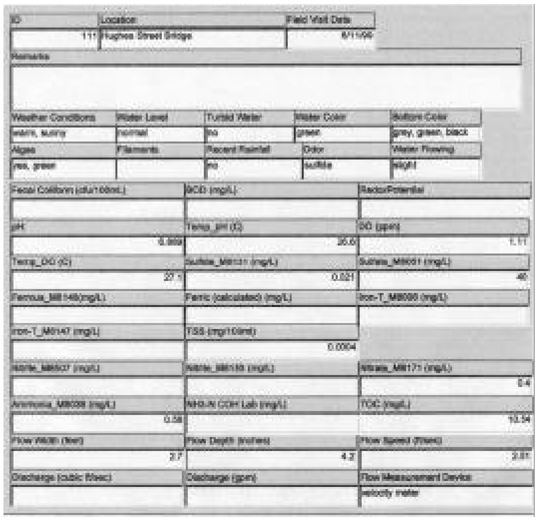


Figure 3. Sampling Locations



ID: 111
Location: Hughes Street Bridge
Field Visit Date: 8/11/99
Remarks:
Weather Conditions: warm, sunny
Water Level: normal
Turbid Water: no
Water Color: green
Bottom Color: grey, green, black
Algae: yes, green
Filaments:
Recent Rainfall: no
Odor: sulfide
Water Flowing: slight
Fecal Coliform (cfu/100mL):
BOD (mg/L):
RedoxPotential:
pH: 6.969
Temp_pH (C): 26.6
DO (ppm): 1.11
Temp_DO (C): 27.1
Sulfide_M8131 (mg/L): 0.021
Sulfate_M8051 (mg/L): 46
Ferrous_M8146(mg/L):
Ferric (calculated) (mg/L):
Iron-T_M8008 (mg/L):
Iron-T_M8147 (mg/L):
TSS (mg/100ml): 0.0004
Nitrite_M8507 (mg/L):
Nitrite_M8153 (mg/L):
Nitrate_M8171 (mg/L): 0.4
Ammonia_M8038 (mg/L): 0.58
NH3-N COH Lab (mg/L):
TOC (mg/L): 10.54
Flow Width (feet): 2.7
Flow Depth (inches): 4.2
Flow Speed (ft/sec): 2.01
Discharge (cubic ft/sec):
Discharge (gpm):
Flow Measurement Device: velocity meter

Figure 4. Data Entry Form

A two-sample t-test assuming unequal variances was selected to compare the mean values of the sample groups being tested (Dixon and Massey, 1983). A level of significance of 5% was used. This level of significance represents the chance that one will falsely reject the null hypothesis.

Table 1 is a listing of the results for the analysis for odor versus no-odor conditions. When odor conditions are observed at Hughes Street, the DO at Hughes Street is 1 mg/L lower, on average, than when odor is not observed. The DO at Polk and 66th exhibits a similar pattern. Upstream of Hughes, and downstream of Polk and 66th, the DO values are the same, regardless of whether odor is observed at Hughes or not. The BOD at all locations where data were collected was always greater during odor episodes than during no-odor episodes.

Table 2 is a listing of the results for the analysis for upstream-downstream analysis. Data in this analysis were grouped into one upstream group and one downstream group. Park and Elm N1, Polk and Elm S1 and Evergreen Cemetery were taken as a single group. Hughes Street, and Polk and 66th were taken as the downstream group.

The DO values decrease moving downstream as expected. The bayou's oxygen demand and low re-aeration capabilities in the covered portion are one explanation of this decline. The BOD values also decrease moving downstream, except in 1998. These results suggest that the bayou has some assimilative capacity for organic materials entering from runoff.

Table 2 Mean values for Odor-No Odor analysis

		DO	Ammonia	Sulfate	Fecal Coliform	BOD
Ennis and Lamar (N3)	Odor	4.59	**2.44**	57.14	114,470	
	No Odor	5.33	**1.73**	48.86	31,883	
Park and Elm (N1)	Odor	5.34	1.05	52.78	107,477	*100.00*
	No Odor	5.81	0.72	48.87	164,806	*12.00*
Polk and Elm (S1)	Odor	4.95	0.55	62.59	17,043	**39.25**
	No Odor	5.34	0.66	55.57	15,462	**9.62**
Evergreen,North and South Vents	Odor	4.73	**0.98**	53.57	59,944	**64.06**
	No Odor	4.73	**0.72**	46.77	182,356	**10.49**
Hughes Street	Odor	**2.29**	0.88	**52.68**	**285,550**	**23.25**
	No Odor	**3.64**	0.71	**39.68**	**149,721**	**6.87**
Polk and 66th	Odor	**3.65**	**0.93**	**52.49**	20,244	**74.10**
	No Odor	**4.79**	**0.73**	**43.38**	171,827	**8.98**
Yates Gully	Odor	4.15	0.88	**55.55**		
	No Odor	4.77	0.67	**45.44**		
Wayside Drive	Odor	4.82	0.80	**51.37**		
	No Odor	4.40	0.79	**42.35**		

Differences in **Bold** values are statistically significant at p=0.05
Differences in *Italic* are statistically significant at p=0.10

Table 3 Mean values for Upstream-Downstream analysis

		DO	Ammonia	Sulfate	Fecal Coliform	BOD
All Data	Upstream	**5.20**	**0.70**	**55.50**	**68,122**	**48.16**
	Downstream	**3.28**	**1.13**	**46.89**	**257,015**	**12.77**
Mean_98	Upstream	**5.56**	**0.56**	**53.70**	**47,431**	12.66
	Downstream	**3.35**	**1.34**	**47.02**	**293,456**	12.88
Mean_99	Upstream	**4.86**	0.85	**57.19**	80,608	**72.30**
	Downstream	**3.21**	0.81	**46.78**	83,918	**12.38**
No Odor	Upstream	**5.16**	**0.68**	**52.12**	106,725	**57.81**
	Downstream	**3.97**	**1.29**	**40.66**	149,721	**6.87**
Odor	Upstream	**5.31**	0.77	58.39	**60,458**	**65.00**
	Downstream	**2.69**	0.99	53.22	**355,502**	**22.64**

Differences in **Bold** values are significant at p=0.05
Underline pairs represent values that are not different at p=0.05

All the upstream FC values regardless of grouping are within one standard deviation of the mean value for all upstream data except for the No Odor condition when the upstream value is nearly two standard deviations higher. The downstream FC values are always greater than the upstream value except for the Mean_99 grouping and the No Odor grouping where the values are the same (downstream is same as upstream). These results can be interpreted to suggest that during No Odor conditions the FC values are unchanged as one moves downstream, but during odor conditions the FC increases moving downstream.

Further study shows that the upstream DO, FC, and BOD are all about the same value, but downstream during odor conditions, the FC triples. This result suggests that the odor conditions are either caused by some input between Evergreen and Hughes or by some process difference between Evergreen and Hughes. The 1999 FC difference is negligible suggesting that the input or process involved has changed. Because a natural process change is unlikely, one can conclude that the input character into this section of the bayou has changed since 1998.

The data sets were also grouped into quarterly time blocks for a summary analysis of selected water quality parameters. Figure 5 is a bar chart relating the mean DO value when odor was reported in the field notes and when no odor was reported, grouped quarterly, at the downstream location group. Figure 6 is a bar chart relating the mean BOD value when odor was reported in the field notes and when no odor was reported, grouped quarterly, at the downstream location group.

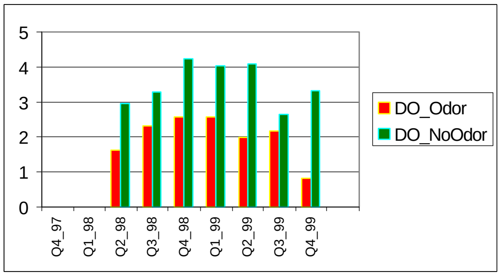


Figure 5. Quarterly DO Mean Values

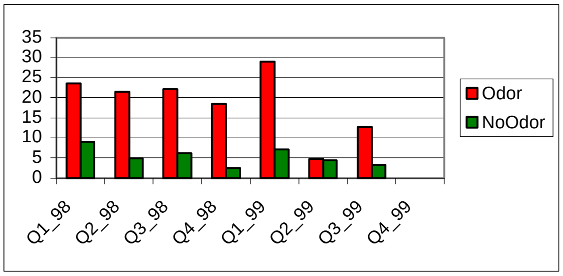


Figure 6. Quarterly BOD Mean Values

The mean values of DO during the first five quarters of the research are remarkably consistent, with the odor conditions being producing a 1mg/L reduction in DO at Hughes Street Bridge. The mean values of BOD are much higher when odor is reported indicating that one cause of the odor is an organic load that elevates the BOD values. BOD appears to be a good predictor of odor conditions.

TRACER TEST

The purpose of the tracer test is to determine connectivity and average time-of-travel (residence time) in different sections of Country Club Bayou and to estimate the degree of mixing. The tracer tests were conducted in response to a series of tests reported by the City of Houston team. The COH tests were conducted in February 1999. Table 4 lists the results reported by the COH team in a project meeting at HDHHS on March 23, 1999.

Table 4 Time of Travel COH Tests

Deployment Location	Distance to Hughes	Time-of-travel
North Vent	2250 feet	1 day
South Vent	2250 feet	3 days
Polk and Elm (S1)	3000 ft	2 days, North tunnel
Park and Elm (N1)	2800 ft	2 days, North tunnel

The University of Houston experiments were conducted as independent confirmation of the visual tracer tests performed by the city team. A fluorescein dye tracer is released at upstream access locations and concentration is monitored at the outfall near Hughes Street Bridge. The flow-line distance from the release points were estimated using the storm sewer maps of the area (Sheet 209B; 12-1-1980). Table 5 lists the results of the UH tests/

Table 5 Time of Travel UH Tests

Release	Recovery	Distance	Travel time	Discharge[1]	Discharge[2]	Mixing Length
North Vent	Hughes	2250 feet	1.1 day	520 gpm	342 gpm	2 feet
Evergreen	Hughes	2750 feet	0.7 days	1694 gpm	660 gpm	11 feet
Polk and Elm	Hughes	3750 feet	0.9 days	2500 gpm	630 gpm	13 feet
Ennis	Milby	2400 feet	0.3 days	N/A		N/A
Hughes	Polk and 66th	1450 feet	0.2 days	600 gpm	598 gpm	N/A
Ennis	Ennis	1 feet	N/A	N/A	2.5 gpm[3]	N/A

[1] Discharge measured at Hughes Street using method in Appendix I

[2] Discharge calculated from travel time

[3] Discharge estimated by dilution

COMPUTER MODELING

A hydraulic model was used to develop flow-depth-velocity data for the water quality model. In developing these data a range of discharges was chosen and the hydraulic model used to compute the depth with matching conditions forced at the downstream portion of the model. The average depth for each section in the hydraulic model was saved and a linear regression model was used to develop a discharge-depth power-law relationship for use in the water quality model. The tracer test results were used to calibrate the hydraulic model.

Figure 7 is a map of the QUAL2E model used in evaluating water quality impacts on Country Club Bayou from the five alternative intervention measures. The blocks represent the approximate location of the element centroids in the QUAL2E computer program and the numbers are the element numbers used in the program.

The conceptual model for the basin assumes that the upstream portion of the bayou can be approximated as a water source (headwater) element in the program and the entire south branch is simulated in the same fashion. The input, if any, at Yates Gully is simulated as a point source of water with associated water quality constituents.

The model simulates dissolved oxygen (DO) and BOD using flow values independently computed using a hydraulics model. This separation is necessary because the hydraulic component included in QUAL2E could not produce the backwater-type flow regime observed in Country Club bayou.

Figure 7. QUAL2E Conceptual Model

Calibration was accomplished by trial-and-error. Various parameters in the QUALE input files were changed and the simulation output compared to the mean values observed in the field monitoring study. The goal was to force the predicted DO and BOD to fall within a prescribed calibration range based on the field data analysis. Odor conditions are simulated by adding point loads near the suspected locations in the study area (Near 3100 Lamar upstream of Altic).

The selection of the input location was based on a theme-map constructed from the HDHHS and Field reports. Once the model was calibrated several intervention strategies were simulated to predict the effectiveness in a qualitative sense. The strategies simulated were a channel modification, flow augmentation, source control, and forced aeration.

The channel modification simulation assumed that the section underneath the Hughes Facility is reduced to a width of 3 feet. The hydraulic model was used with this modification to produce a set of depth-velocity values for use in the QUAL2E model. At the lowest flow the model predicts that a narrower channel actually makes the DO situation worse. Even at high flow the model predicts negligible improvement using the narrower channel, thus based on this model this strategy is not expected to be effective.

The scheduled flow augmentation strategy assumed that the flows were increased by 64 gpm at selected locations by release of water from a fire hydrant. Two locations were studied with the model. The first location is upstream of the Altic street junction box, but downstream of the point load used to simulate the effect up upstream BOD loading in the drainage area. The second location is upstream of the point source. The two different locations were selected to determine if augmentation in the upper end of the drainage area produces a more improved water quality than augmentation in the lower (downstream) end of the watershed.

Figure 8 is a typical plot comparing the odor baseline case with the augmented case at different system flow rates. Because the flow augmentation rate is constant the greatest impact occurs at the lowest system flow rate. In all cases the model predicts that the addition of a small volume (4-20% of the total flow) of high quality (DO =5.5 mg/L) water improves the water quality at the Hughes Street outfall.

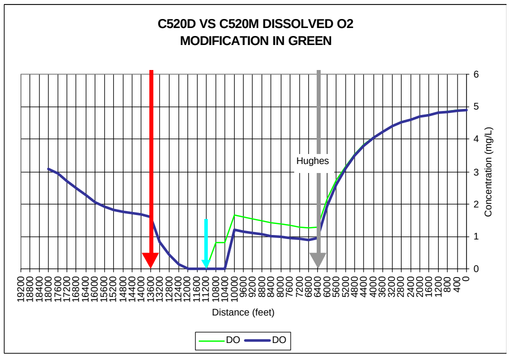
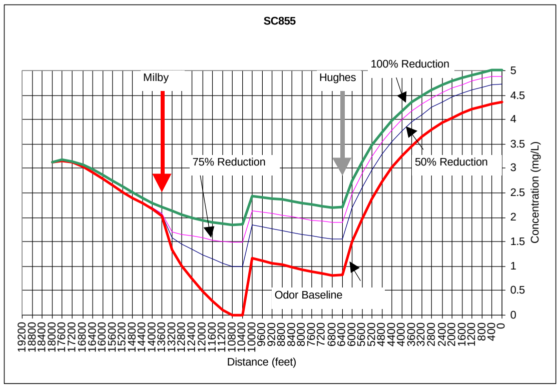


Figure 8. Typical Flow-Augmentation Profile

Similar results are produced when the location of the flow augmentation is moved upstream of the point source. The amount of water quality improvement is slightly less than the previous set of cases, but the results imply that the location of the flow augmentation is unimportant. This insensitivity to input location is useful because multiple hydrants upstream of the outfall could be used as augmentation sources.

Source control was simulated as fractional reductions in BOD loads at the point source without changing any other input in the computer model. The simulations used the odor baseline and the no-odor baseline as the two extremes. The no-odor case represents complete source control (100% reduction in input load). Figure 9 is a plot of these two extremes with two intermediate cases (50% and 75% reduction).

The forced aeration strategy is modeled assuming that some efforts to improve mixing in the covered portion between the Altic St. junction box and the outfall, increases the re-aeration in this reach. The increased re-aeration is modeled by assuming that 10% and 50% increases the re-aeration coefficient, respectively. Figure 10 is a plot comparing the baseline case and the increased re-aeration case. A 10% increase in the Hughes Facility section improves the water quality at the outfall while the 50% increase produces a dramatic increase. In both cases although the DO in the water is higher, the BOD loading is unchanged and the sediment oxygen demand is the same so that downstream of the outfall the conditions approach the baseline conditions.



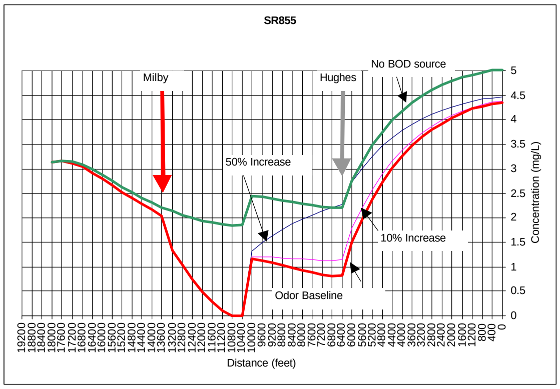


Figure 9. Source Reduction Simulations

Figure 10. Forced Aeration Simulations

Based on the computer predictions the channel modification option only marginally improves water quality (measured as DO at Hughes), and would be costly to implement. Flow augmentation at either location provides a good improvement in water quality at all flows simulated. Source control is predicted to have the most improvement, however it is not possible to predict how much source control can be achieved by vigorous monitoring and enforcement. A combination of a lower degree of source control and flow augmentation can produce results similar to a more rigorous source control alone. Forced aeration is also promising, but actual prediction of improvement is beyond the computational tools in this research.

RECOMENDATIONS

Table 5 is a list of the six strategies considered with notations on the perceived complexity, estimated cost, and reliability. Routine monitoring continued enforcement (source control), flow augmentations, and cleaning of portions of the bayou are recommended for long-term management of water quality on Country Club Bayou.

Table 6. Potential Intervention Measures

Strategy	**Complexity**	**Cost**[1]	**Reliability**	**Modeled**
Channel modification	Complex	\$500,000[a]	Low	Yes
Mechanical/chemical aeration	Complex	High	Unknown	Yes
Constructed wetland	Complex	Unknown	Unknown	No
Flow augmentation	Simple	\$185,000[b]	High	Yes
Divert low flow to treatment	Simple	\$350,000[c]	High	No
Source control	Moderate	\$250,000[d]	Moderate	Indirectly

[1] Cost estimate basis: Costs are totals for five years of service.

a) Channel modification: 0.5 miles of underground construction. Assume cost is 1 million dollars/mile. Cost of channel modification is estimated to be at least \$500,000, excluding maintenance.
b) Flow augmentation: Assume water for augmentation costs \$2.00/1000 gallons. Then the estimated cost for five years of continuous augmentation is about \$185,000.
c) Diversion to treatment: Assume installation of a lift station to pump 1000 gpm into the sanitary system is \$100,000. Assume diversion operating costs are \$0.10/1000 gallons. Estimated cost for five years is \$350,000.
d) Source control: Assume that the University expenditures represent one-half the costs that would be incurred by the City of Houston (monitoring, enforcement, follow-up) The estimated annual cost to maintain the level of effort at that of September 1999 is \$50,000/year.

The water should be analyzed in the field for temperature, pH, dissolved oxygen, ammonia and sulfide. Water samples should be collected and analyzed for CBOD and Fecal Coliform. Depressed DO or elevated sulfide or elevated ammonia should be investigated immediately to identify possible sources.

Table 7. Alert Values for Country Club Bayou

Measurement	Value	Recommended action
Dissolved Oxygen[1]	<1.0 mg/L	search for pollutant source; consider flow augmentation
Ammonia[1]	>1.5 mg/L	search for pollutant source
Sulfide[1]	>0.15 mg/L	search for pollutant source; rotten egg odor should be present; bottom sediment should be black; consider flow augmentation.
Spheratolis (filaments)[1]	visible	search for pollutant (sanitary) source
Fecal Coliform	>200[2] >10,000[3]	begin search for sanitary source; industrial source possible.
CBOD	>15 mg/L[3]	begin search of pollutant source

[1] Field measurement; assumes instrument(s) available
[2] State value
[3] Practical value based on data collected in this project

Table 7 lists the water quality measures and alert values based on data collected in this research. The alert values represent the mean values from data collected during odor episodes, or estimates of values indicative of odor conditions. If alert values are exceeded, flow augmentation and source control procedures should be implemented as outlined in Cleveland et. al. (2000).

Flow augmentation supplements monitoring and enforcement by providing a tool to address low water quality by a short-term intervention. When a contaminant source is identified that has degraded the water quality, an augmentation release can be used to temporarily improve the water quality while the source is being eliminated.

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