Perception studies to determine receiving-stream color objectionability due to effluent discharge

Submitted to

City of Memphis
Public Works Department

By

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Abstract: In the State of Tennessee, the Tennessee Department of Environment and Conservation (TDEC) is the NPDES permitting authority who sets color limits for a recreational water use color narrative under the auspices of EPA review that requires effluent discharge to be free of objectionable color, but the narrative lacks numeric guidance on how to determine an acceptable discharge color. The City of Memphis, Tennessee had concerns about the subjectivity of the narrative and initiated a color study to provide TDEC with recommendations to establish numeric limits for NPDES permit compliance. This color study links human perception of river color contrasts (subjective) with measured apparent color, dissolved and suspended particles, true color, dissolved particles and environmental data (objective) through four psychological experiments that show perception of objectionable river color is primarily a result of cloud cover (sky reflections) and seasonal leaf foliage, not the background color of the river or contributing effluent color. When Experiment 1 participants visited three riverside locations once a month for a year only one person noticed an objectionable color, while the remaining perceived color contrasts related to cloud/sky reflections. Similar results were obtained in Amazon's Mechanical Turk (AMT) Experiments 2-4, where the results show that the significance of environmental factors, cloud cover and seasonal foliage, overshadow any effect the wastewater effluent color may have on perceived objectionable river color differences. Since an individual's perception of objectionable color is the result of environmental factors and not the contribution of discharge from M.C. Stiles' plant into the Mississippi River, this suggests that a numerical limit for the M.C. Stiles' discharge is unnecessary as this will not affect objectionable color perception at this location.

Introduction

The Tennessee Department of Environment and Conservation (TDEC) *General Water Quality Criteria* for recreation, *Ch.* 0400-40-03-.03(4)(d) provides that there shall be no "total suspended solids, turbidity or color in such amounts or character that will result in any objectionable appearance to the water, considering the nature and location of the water" (TDEC 2013). The narrative, however, does not provide a numeric indication as to what level of color discharged is acceptable. Memphis (as well as its industrial users subject to pass through prohibition) has expressed concern that the narrative standard is subjective and as to whether it provides a definitive goal for permit compliance.

The National Pollutant Discharge Elimination System (NPDES) permit program has included a narrative permit condition in the permits issued to industrial and municipal direct dischargers. The NPDES permit for the M.C. Stiles Wastewater Treatment Plant (WWTP) in Memphis, Tennessee states "The wastewater discharge must not cause an objectionable color contrast in the receiving stream" (City of Memphis 2012). These permit conditions have been appealed by Memphis. The appeals are still pending. EPA and TDEC asserted that they observed an objectionable color contrast in the Mississippi River caused by the mixed effluent-river water from the City of Memphis' M.C. Stiles WWTP. Numeric color effluent limits are not defined by the NPDES permit or TDEC's General Water Quality Criteria. As a result, the EPA, TDEC, and City of Memphis agreed to conduct a "Color Study" as part of a Consent Decree (CD) Case 2:10-cv-02083-SHM-dkv (2012) to help TDEC establish numeric limits for the M.C. Stiles WWTP.

Limited published research exists on the perception of water color in the context of effluent discharge to receiving bodies of water. In 1976, the National Council of the Paper Industry for Air and Stream Improvement (NCASI) performed a study to determine the ability of individuals to detect water color changes, but not whether or not those changes were objectionable (NCASI 1975). Eleven observers were selected to determine if they could detect color changes at the study sites. The study identified the following factors that alter one's perception of changes in water color: site lighting and lighting changes (e.g., time of day, cloud cover), observer viewing placement, river depth and width, background color and turbidity, river stage, river bottom characteristics and visibility, turbulence, and the direction of color change. Psychological influences such as memory, confusion, and observer differences also played a role in one's perception of changes in water color.

In 1989, a color study was conducted on the Hiwassee River where the Bowater pulp and paper mill discharges to determine if color changes were detectable and whether or not those changes reduced the perceived attractiveness of the river. Study participants rated colored water samples in jars, artificial streams, numerous images of the river, and made on-site observations from a boat. During on-site observations, water samples were taken and tested for apparent color. All photography and on-site ratings were done in the middle part of the day and under similar lighting with intermittent cloud cover. It was determined that participant's perception of changes in water color was influenced by seasonal changes, background flora, the river's surrounding environment (e.g., industrial vs. wooded site), water

contents, and lighting conditions. The results of the study indicate that observers can discriminate water color differences; as apparent water color increases the perceived attractiveness decreases.

As part of the effort to provide meaningful data from which to establish numeric limits for the M.C Stiles WWTP, the University of Memphis has sought to develop an algorithm that estimates the extent to which a given water color is considered objectionable at the M.C. Stiles WWTP. The University of Memphis Ground Water Institute in the Civil Engineering Department is working in coordination with the Department of Psychology to develop a comprehensive approach to this problem to address both the objective and subjective nature of the study. The proposed study extends the findings from previous studies by investigating to what extent Mississippi River water color is objectionable when a) the color is considered in isolation; b) the color is considered in combination with the Mississippi River scenery; c) the color is considered in combination with weather variables (wind, rain, etc.); and d) participants who are very familiar with the Mississippi River are compared with participants who are not familiar with the river.

Background

The City of Memphis is located in Shelby County, TN. The City owns and operates the M.C. Stiles WWTP which treats 100 million gallons per day (MGD) before discharging to the Mississippi River. Two industrial users, a pulp mill and a baker's yeast producer, discharge dark colored wastewater to the M.C. Stiles WWTP. The pulp mill produces cotton cellulose for 8 continuous days followed by a 6 day non-production period. The pulp mill generates an average of 5.30 MGD of wastewater during pulp processing and an average of 0.73 MGD during non-production cycles. The baker's yeast industry generates an average of 0.93 MGD. The dark colored wastewater flows from both industries directly to the M.C. Stiles WWTP without pretreatment. While Memphis' WWTP provides some treatment, colored wastewater may, nevertheless, be discharged to the Mississippi River.

The Mississippi River drainage basin includes all or parts of 31 states and two Canadian provinces and transports an average of 150 million tons of sediment annually in the lower Mississippi River (Thorne, et al. 2008). The U.S. Army Corps of Engineers (USACE) Memphis District is responsible for keeping the channel open for navigation by retaining a minimum 9-foot-deep and 300-foot-wide waterway (Division Bulletin No. 2 Navigation Conditions for 2011 2011). On average, the Mississippi River at Memphis, TN, is 0.5 miles wide with a flow between 120,000 - 820,000 MGD (US Army Corps of Engineers 2012).

The Wolf River is a tributary to the Mississippi River that traverses east to west across Shelby County, draining approximately 220 miles^2 (28%) of the county. It converges with the Mississippi River approximately 0.4 miles south (downstream) of the M.C. Stiles WWTP outfall and directly north of Harbor Town, a residential area where recreation occurs on the riverbank (e.g., walking, jogging, and minimal fishing), on the Mississippi River (e.g., boating and some canoeing/kayaking), but rarely if ever in the river (e.g., swimming and water contact sports) due to hazardous conditions (e.g., powerful flow of the river, debris, and barge traffic). The only flow gage on the Wolf River is at Germantown Road, approximately 18.6 miles upstream from its confluence with the Mississippi River, but the Wolf is expected to gain in flow as it moves through the City. At the Germantown Road gage, the average flow

over the past six years (2007-2013) is 603 MGD with a minimum and maximum flow of 114 MGD and 18,681 MGD respectively.

Objective Analysis

Environmental, hydraulic and hydrologic data were compiled over a year to capture the factors that impact the perception of objectionable effluent-river mixed color. River and effluent samples were collected once a week for a year for tri-stimulus and platinum-cobalt testing from the following six locations: (1) upstream of the effluent outfall to act as the control color, (2) downstream of the effluent outfall for the immediate wastewater effluent impact, (3) location north of Wolf River eddy effects and south of the first downstream location, (4) Wolf River at Highway 51 to avoid Mississippi River backwater conditions, (5) Harbor Town, a residential area, where there is heavy recreation and is downstream of the Wolf River confluence with the Mississippi River, and (6) effluent from the contact basin (see figure 1). On-site instrumentation collected weather parameters, Mississippi River elevation, and images of the Mississippi River at a location upstream and downstream of the effluent outfall.

Water sampling

Mississippi River, Wolf River, and wastewater effluent grab samples were collected every Wednesday morning from January 2013 - 2014 (n = 54) at the sampling sites shown in Figure 1. Samples were transported to the University of Memphis and analyzed on the same day using two methods: Platinum-Cobalt and tri-stimulus. Hach Method 8025, modified to the NCASI procedure for Platinum-Cobalt which is a common standard for pulp and paper effluent, was used to analyze all samples for true and apparent color on a DR/2500 (Hach Company, Loveland, CO). Prior to this investigation, the City of Memphis wastewater laboratory conducted a study on the effects of pH on color and determined there was minimal impact and thus relaxed the pH requirement of 7.60 specified by Method 8025 to the range of 7.55 – 7.70. Prior to analysis, the collected samples were also adjusted to fall within this range. For tri-stimulus tests, undiluted samples for locations A, B and C (see figure 1) were also prepared using Method 8025-NCASI to analyze for true and apparent color on a Black Comet CXR SR (Stellar Net Inc., Tampa, FL). Tri-stimulus color values represent three-dimensional space by sampling over the light spectrum of 220 – 1100nm, and are provided as L*a*b* (lightness, red/green, and yellow/blue, respectively) (CIE 2004).

Environmental condition

Environmental conditions influence a person's perception of color (Hiwassee River Study 1989; NCASI 1975); therefore, weather conditions, river stage and effluent discharge observations were collected over a one-year period from January 2013-2014. A Vantage Vue Wireless Weather Station (Davis Instruments, Hayward, CA) (Figure 1, location B) recorded precipitation, wind speed and direction, and temperature every 15 minutes, while cloud ceiling data (i.e., overcast, broken, and clear) was provided by the Memphis International Airport (MIA) weather center located 11 miles from the study site. Mississippi River stage was recorded from a stilling well installed along the bank using a Levelogger Gold 3001 F15/M5 (Solinst, Canada) on a 15-minute interval. The pressure transducer was downloaded and redeployed weekly with stage corrections made to mean sea level by performing a survey from a

benchmark set using an R8 survey-grade GPS unit (Trimble, Sunnyvale, CA), and corroborated with river stage recordings from the downstream Weather Bureau Gage (MS126). River stage readings were corrected for barometric pressure with a Barologger Gold 3001 F5/M1.5 (Solinst, Canada).

Trophy Cam 8 MP Trail Cameras (Bushnell Outdoor Products, Kansas City, MO) located upstream and downstream of the effluent outfall (Figure 1, locations A and C) were oriented due west to capture photos of the Mississippi River and the adjacent bank hourly for 12 hours starting at 6 A.M. for one year to capture seasonal and lighting changes. The images had to be filtered to remove photos with blocked views of the river (e.g., barges and birds) and processed for use in the Mechanical Turk experiments (discussed in the subsequent section).

Platinum-Cobalt Results

Partial correlations were performed by SPSS 21 (IBM Software, Armonk, NY) to analyze true and apparent color data, as shown in Table 1, for each sampling location (Figure 1 – A, B, C, E, F, G) controlling for upstream color[1], the natural background color of the river at this location. Effluent apparent color (Figure 1 – B) is significantly related to the first downstream location (C), $r = .336$, $p = .017$, and second downstream location (E), $r = .381$, $p = .006$, but is not significantly related to the third downstream location (F) where the majority of recreation occurs along the river bank. The apparent color at the third downstream location (F) is significantly related to the apparent color of the Wolf River (G), $r = .307$, $p = .030$. Similar relationships exist for true color data. Effluent true color is significantly related to the first and second downstream locations, $r = .570$, $p < .001$, $r = .44$, $p = .001$, respectively, while the Wolf River true color is significantly related to location F, $r = .484$, $p <.001$. These correlations show that the color of the Wolf River has a greater impact on the color of the Mississippi River at Location F where recreation is prevalent than the wastewater effluent.

Subjective Analysis

To understand the factors that contribute to an individual's perception of environmental conditions *in-situ* and of color change *ex-situ* without other visual and physical stimuli interference, the University of Memphis' Psychology Department developed an on-site environmental condition questionnaire (Experiment 1) and a series of three of Amazon's Mechanical Turk (AMT) experiments (Experiments 2-4). AMT surveys are a well-accepted method for conducting psychological cognitive studies that provide a large random pool of respondents for minimal cost in a short period of time (Mason and Suri 2011) Statistical analyses were performed by SPSS 21.

Experiment 1

Experiment 1 was developed to determine which factors contribute to an individual's decision to recreate on or near a body of water – in this case the Mississippi River – and how individuals perceive river color/ river color contrasts.

[1] The minimum background color of the Mississippi River is 140 Color Units (CU) – this compared to the background colors of the two aforementioned studies: the Hiwassee River (40 CU) and the NCASI study (2-15 CU).

Participants

Announcement flyers seeking participation were posted throughout the University of Memphis campus, an urban, commuter campus with a significant number of non-traditional students; thereby, randomizing the sample pool in age, race, and discipline. Up to 15 students from various departments, with three repeat participants, were recruited monthly for a year (*n*=90).

Methods and Procedures

Participants were told they would visit three locations to record their assessment of the environment, and questionnaires were provided on-site to avoid priming participants about the location or purpose of the study. On-site surveys were conducted monthly from April 2013 - 2014. Each month, volunteers visited sites (Figure 1 – D, F and G) and answered questions pertaining to their observed surroundings as well as their interest in recreating there. To avoid priming the participant, water color objectionability questions were avoided and general questions about the color of the trees, sky and water were asked instead. The survey was designed to incorporate open-ended responses and a rating scale. Participants rated the likelihood of recreation for various activities (e.g., kayaking, running, picnicking, swimming, and others) and commented on whether they would participate in that activity. Responses pertaining to river water color were categorized by whether a participant could detect a color change (multiple color response) or not (single color response).

Results

Across the three survey sites, Table 2 shows that 206 (76.3%) of participants only detected a single river color, while 64 (23.7%) detected multiple colors which were primarily due to sky reflections with one individual who detected an 'orange-brown' color at the WWTP (Figure 1 - D). As indicated in Table 2, white, grey, and blue color combinations were deemed products of sky reflection as they are colors frequently detected due to sky reflections in turbid waters that are sediment-rich (Bruan and Smirnov 1993; Lynch and Livingston 2001). When participants were asked if the color of the water was uniform/consistent, 11 people noted different 'brown' patches at the Wolf River (Figure 1 - G) and 1 person noted patches of 'dark brown' at the WWTP (Figure 1 - D). In a few instances (n=6), participants made recreational decisions based on a single 'brown' river color; only one of the decisions was made at the WWTP.

Overall, individuals did not notice a water color contrast or consider water color a major factor in their recreational decision criteria. The majority of recreational decisions were based on other environmental conditions (e.g., insects, weather, personal safety (i.e., crime), and river current).

Experiment 2

Experiment 2 was developed to determine the color deviation necessary for color contrast perception.

Participants

Eligibility criteria for participation in each AMT experiment mandated that respondents reside in the United States, be validated members of AMT, and not be color-blind. Response times (RTs), demographics, and computer monitor specifications were recorded for each of the 694 participants.

Methods and Procedures

Participants were provided a brief overview of the survey format and instructed to rate the color of each stimuli pair as 'similar' or 'dissimilar' – recorded as binary '0's and '1's, respectively - as quickly as they could. Before starting the survey, participants were asked to type the instructions in their own words for quality control. Then, two color swatches (a stimuli pair) were presented in tandem for the participant to rate with a 0.65 s lag between stimuli until all pairs were rated. The color swatches were derived in Adobe Photoshop CS6 by taking RGB values for primary colors and then taking color steps of 30 R/G/or B units to compose the remaining colors in-between green and blue, as show in Figure 2, for a total of 44 swatches. Each color swatch was matched uniquely with another color swatch for a total of 932 color pairs with an additional 60 randomly selected stimuli duplicates shown on a white background (1020 pixels tall by 700 pixels wide). To reduce the total survey time for participants, the survey was divided into four trials, each with 248 color pairs. Participant response choices (RCs) and RTs were averaged and graphed with respect to the color step distance between color swatches in the stimuli pair.

Results

RT data and the corresponding RC data were filtered to exclude short RTs (<0.2s) and long RTs (>5s) before removing outliers with standard deviations greater than 2.5 times the mean (Whelan 2008; Baayen and Milin 2010). Five participants who either lived outside the United States or failed to complete RCs were excluded from all analyses. 574 stimuli pairs were analyzed[2]. Of the 77,468 remaining responses, outliers were removed affecting 6.5%of the data.

Figure 3 (a) shows a non-linear relationship between the average RC in relation to the color deviation of the stimuli pair being rated. By color step 4, 50% of participant responses were split showing that participants distinguished between 'similar' and 'dissimilar' colors. As colors became more dissimilar (i.e., higher color step), the curve becomes asymptotic at a mean dissimilar response of one. Participants agreed on 'similar' colors up to 4 color steps and 'dissimilar' colors after 6 to 8 color steps. Figure 3 (b) shows that 'similar' decisions up to 4 color steps become more difficult for participants to rate as the color deviation increases slightly. After 4 color steps, decisions become easier as the stimuli become increasingly 'dissimilar'. The color steps between 4 and 6 to 8 are a difficult range for individuals to distinguish color differences.

[2] Some stimuli did not conform to the R/G/ or B step distance and thus were excluded from the analysis.

Experiment 3

Experiment 3 was developed to determine which environmental variables had an impact on river water color contrast perception.

Participants

Experiment 2 eligibility criteria applied to Experiment 3, with a total of 240 participants. RTs, demographics, and computer monitor specifications were recorded for each survey participant.

Methods and Procedures

Three primary environmental conditions that impact water color perception were identified and assigned with two 'extreme' categories for a 2 x 2 x 2 design where each '2' represents two conditions in each category, thus: (1) time of day (6:00-12:00 and 12:00-18:00); (2) cloud cover (clear and overcast); and (3) seasonal flora changes (leaves on and leaves off) [3]. Of the 8 bins (i.e., 2 x 2 x 2) generated from the environmental conditions, three downstream photos (Figure 1, location C) were selected for each bin. Each of the environmental conditions related to the stimuli pair were coded '0' if the conditions were the same in both photos shown (e.g., overcast/overcast or clear/clear) or '1' if the conditions were different (e.g., overcast/clear or clear/overcast). Each of the 24 downstream photos was matched with every other photo for a total of 276 stimuli pairs. The survey was split into two trials, each with 138 stimuli. Experiment instructions and stimuli presentation were identical to those in Experiment 2.

Results

One participant took the survey outside the United States and was excluded from all analyses. The remaining outliers were removed as they were in Experiment 2. Of the 34,506 responses, 11.6% of the data required removal due extremely high, sporadic RTs which was likely due to server malfunctions that occurred, nevertheless leaving an extremely large survey set of approximately 30,503 responses.

The trials were analyzed using a mixed-effect regression analysis with time of day, cloud cover, and foliage as fixed factors and subjects fitted as random factors to account for the variance between subjects (Baayen, Davidson and Bates 2008). The model was fitted using restricted maximum likelihood estimation (REML) for RC. The final model shows both cloud cover, $F(1, 29447.88) = 3356.67$, $p < .001$, and leaf foliage, $F(1, 29452.37) = 175.32$, $p < .001$, significantly predicted RC[4]. Cloud cover, $t(29447.88) = -57.937$, $p < .001$, and leaf foliage, $t(29452.37) = -13.241$ $p < .001$, results show that participants are more likely to rate those stimuli pairs with the same environmental properties (e.g., overcast vs. overcast) as similar as compared to those with different properties (e.g., overcast vs. clear). Another

[3] The remaining two environmental conditions collected during this study, rain and wind, were excluded as primary variables. There were not enough rainy days to be statistically valid. The impact of wind on river color perception was captured with cloud cover and seasonal foliage changes.

[4] The same model was analyzed with a logistic regression mixed-effect model in SAS 93 (SAS, Cary, NC) . The results show that cloud cover, $F(1, 29318) = 2729.09$, $p < .001$, and leaf foliage, $F(1, 29318) = 173.06$, $p < .001$, are significant predictors of RC. Individuals are more likely to see 'dissimilar' water colors when cloud cover, $t(29318) = -52.24$, $p < .001$, and leaf foliage, $t(29318) = -13.16$, $p < .001$, for each photo are identical.

mixed-effect regression analysis was run to relate RT to the factors in the prior model. Cloud cover, $F(1, 29440.63) = 119.81$, $p < .001$, and leaf foliage, $F(1, 29442.28) = 16.49$, $p < .001$, were significant predictors of RT. Cloud cover, $t(29440.63) = 10.946$, $p < .001$, and leaf foliage, $t(29442.28) = 4.061$, $p < .001$, results show that it took participants longer to rate those stimuli pairs with the same environmental properties as compared to those with different properties, which is consistent with the RT results from Experiment 2. Individual environmental parameters for each photo in the stimuli show that color change detection, or 'dissimilar' RCs, increases on overcast days and those months when leaf foliage is visible in the background of the photos as shown in Table 3.

Experiment 4

Experiment 4 was developed to link perceived river water color contrast with laboratory color analysis data, while excluding background flora from the stimuli as this condition was addressed with Experiment 3.

Participants

Experiment 2 eligibility criteria applied to Experiment 4, with a total of 240 participants. RTs, demographics, and computer monitor specifications were recorded for each survey participant.

Methods and Procedures

To link perception of color change to laboratory measured color values, one morning (6:00 – 12:00) and one afternoon (12:00 – 18:00) downstream photo along with the corresponding upstream photos were randomly selected on days that water samples were taken and analyzed for a total of 79 photo pairs. The 24 photos from Experiment 3 were also added. Images were pre-processed in two ways: upstream images were color balanced to downstream images and downstream images were color balanced to upstream images using Adobe Photoshop CS6's color match tool. Stimuli were color match coded to represent how the stimuli were color matched. Color matching was performed to reduce the effects of glare and intrinsic differences between cameras. Reversing the color balancing order helped to remove order bias. Each photo was then cropped to limit the participant's field of view to focus solely on the water surface. In total, 103 photo pairs generated 206 stimuli that were split evenly into two trials. An additional photo ID was assigned to each of the four stimuli (2 photos in a day times the 2 image pre-processes) for each day to assist in removing variance caused by laboratory measured color value duplication across the four stimuli (photos). Experiment instructions and stimuli presentation were identical to those in Experiment 2.

Results

After 28 errant photo pairs (56 stimuli) were removed, there were 150 stimuli available for analysis. From the remaining data, the outliers were removed as they were in Experiment 2. Of the 22,748 responses, outliers were removed affecting 6.2% of the data.

The trials were analyzed using a mixed-effect regression analysis with cloud cover (i.e., clear, cloudy, and overcast), time of day (i.e., 6:00-12:00 and 12:00-18:00), river elevation, and upstream, downstream and

effluent apparent color (Figure 1 – A, B, and C) as fixed factors[5] with subjects and the photo ID fitted as random factors to account for the variance between subjects and the variance between duplicated photos taken on the same day (Baayen, Davidson and Bates 2008). The model was fitted using REML for RC. The final model shows that cloud cover, $F(2, 9640.36) = 70.77$, $p < .001$ is the only significant predictor of RC[6]. Clear vs. overcast cloud coverage, $t(7978.86) = 9.79$, $p < .001$, and cloudy vs. overcast cloud coverage, $t(11465.90) = 9.47$, $p < .001$, results show that individuals perceive clear days more dissimilar than cloudy or overcast days. Of note, Experiment 4 was developed to examine the effect of apparent water color, not cloud cover, on RC; therefore, the significance of clouds (not the t-direction) as a predictor of RC is important only to show that cloud cover overshadows any effect apparent water color may have on an individual's perception of water color contrast.

To determine if color matching impacted upstream, downstream, and effluent apparent color for RC, the data was split on the color match code and the same mixed-effect regression analysis was performed. There was no significance for either color match group suggesting that the color match did not impact how individual's perceived apparent color in the stimuli.

Conclusions

A color study was conducted to help establish when mixed effluent-river color may be perceived as objectionable. This study links human perception of river color contrasts (subjective) with measured true and apparent color and environmental data (objective) through four psychological Experiments. Experiment 1 involved participants (n = 90) visiting three riverside locations once a month to determine which factors impact recreational decisions as well as identify any objectionable water color contrasts. Only one person noticed an objectionable river color, while none of the participants made a recreational decision related to objectionable river color. Experiments 2-4 were conducted using Amazon's Mechanical Turk (AMT). Experiment 2 found color to be similar up to 4 color steps from the control and dissimilar, thus objectionable, after 6 to 8 color steps, following a non-linear response. Experiments 2 and 3 investigated the influence of environmental conditions and color (true and apparent) on perceived color differences through participant responses (similar versus dissimilar). Statistical analyses for Experiments 3 and 4 reveal that color objectionability, or dissimilar responses, was attributed to cloud cover and seasonal leaf foliage, and not related with the color values of analyzed water samples. Since perceived objectionable color is the result of sky reflectivity (cloud cover) and surrounding flora (seasonal leaf changes) and not the contribution of discharge from M.C. Stiles' plant into the Mississippi River, this suggests that a numerical limit for the M.C. Stiles' discharge is unnecessary as this will not affect objectionable color perception at this location.

[5] Whereas results from Experiment 3 show leaf foliage as a significant factor in objectionable river color perception, leaf foliage was not included in Experiment 4 because the photos were cropped to focus solely on the color of the water to reduce the effects of environmental variables on the perception of river color contrast.
[6] The same model was analyzed with a logistic regression mixed-effect model in SAS 93. The results show that cloud cover, $F(2, 18085) = 8.89$, $p < .001$, is the only significant predictor of RC.

Acknowledgements

This work was funded by the City of Memphis' Division of Public Works. We thank George Relyea, Eric Goddard, and the Ground Water Institute's staff and students for their contributions.

Table 1. Apparent and True Color Unit Data for Each Sampling Location

	Sampling Location	Maximum (CU)	Minimum (CU)	Mean (CU)	Standard Deviation (CU)
Apparent Color	Upstream (A)	2698	142	717	523
	Effluent (B)	2910	261	1127	644
	Downstream (C)	2445	137	724	479
	Downstream 2 (E)	2487	128	683	468
	Wolf River (G)	3383	88	476	503
	Downstream 3 (F)	2458	108	699	504
True Color	Upstream (A)	108	7	30	21
	Effluent (B)	1005	58	443	308
	Downstream (C)	140	14	58	33
	Downstream 2 (E)	159	8	47	29
	Wolf River (G)	473	23	88	76
	Downstream 3 (F)	193	9	41	32

Table 2. Combined On-Site Participant Responses to River Color at Every Survey Location

Single Colors	Count	Multiple Colors	Count
Brown	150	Blue-brown[b]	31
Blue	27	Grey-brown[b]	11
Grey	25	White-brown[b]	4
Green	3	Orange-brown[a]	1
Tan	1	Other combinations[b]	17
Total	206	**Total**	64

[a] Color combination not related to sky reflection
[b] Color combination related to sky reflection

Table 3. Crosstabs of Response Choice Predictors and Response Choice

Category	Parameters	Similar RC	Dissimilar RC	Total
Cloud Cover	Clear vs. Clear	4194	2855	7049
	Overcast vs. Overcast	2889	4231	7120
	Clear vs. Overcast	2927	12587	15514
Leaf Foliage	None vs. None	2790	4290	7080
	Foliage vs. Foliage	2373	4722	7095
	None vs. Foliage	4847	10661	15508
Total Per Category		10010	19673	29683

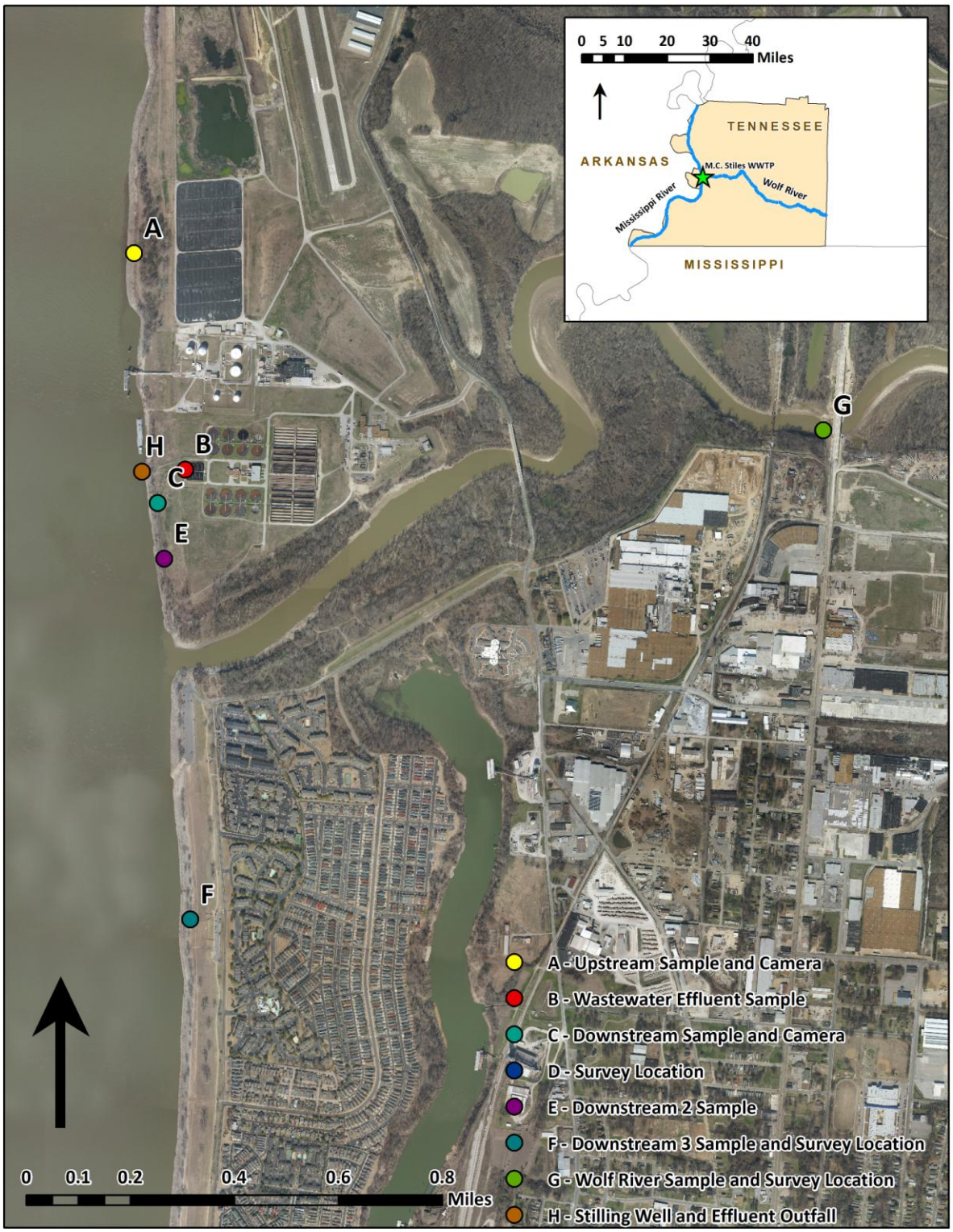

Figure 1. Study site locations for objective and subjective analyses.

Figure 2. Colors used in Experiment 2 to generate stimuli to determine color change perception.

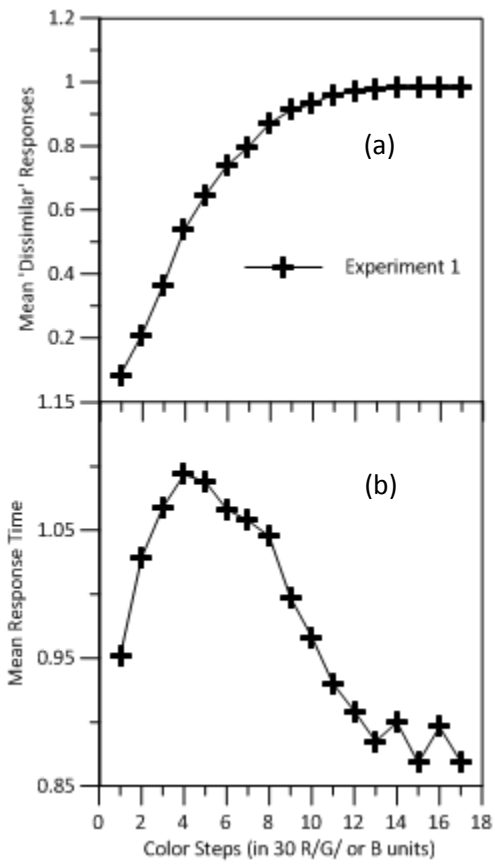

Figure 3. Results from Experiment 1 showing non-linear curves: a) the average dissimilar responses in relation to the color steps between color swatches in the stimuli has a slight sinusoidal curve showing that responses are not made arbitrarily and b) the average response time in relation to color steps shows that it takes individuals longer to make 'similar' decisions and gradually becomes faster as obvious 'dissimilar' stimuli are shown.

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