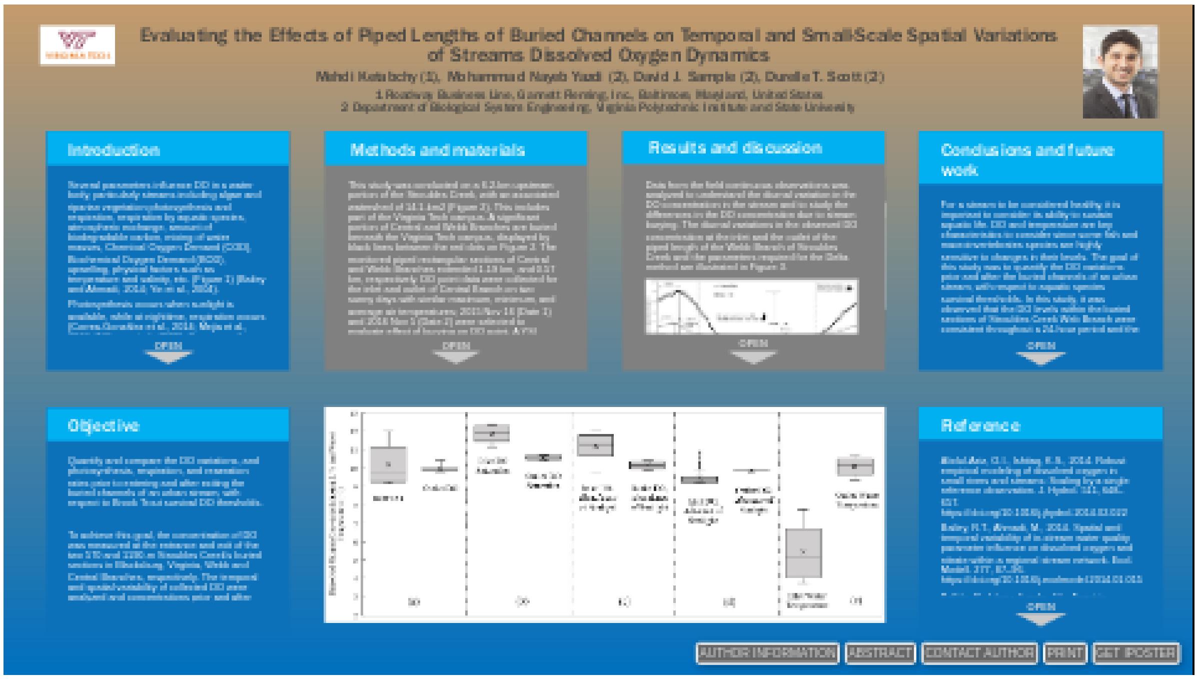
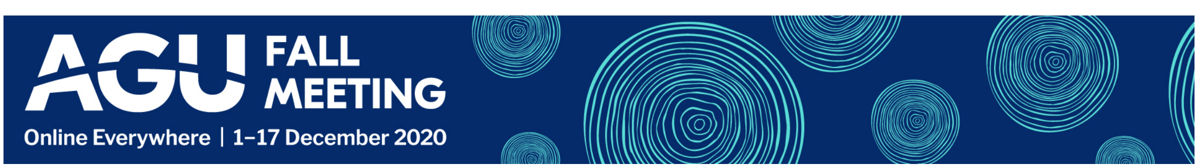
Evaluating the Effects of Piped Lengths of Buried Channels on Temporal and Small-Scale Spatial Variations of Streams Dissolved Oxygen Dynamics



Mehdi Ketabchy (1), Mohammad Nayeb Yazdi (2), David J. Sample (2), Durelle T. Scott (2)

1 Roadway Business Line, Gannett Fleming, Inc., Baltimore, Maryland, United States
2 Department of Biological System Engineering, Virginia Polytechnic Institute and State University

PRESENTED AT:



INTRODUCTION

Several parameters influence DO in a water body, particularly streams including algae and riparian vegetation photosynthesis and respiration, respiration by aquatic species, atmospheric exchange, amount of biodegradable carbon, mixing of water masses, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), upwelling, physical factors such as temperature and salinity, etc. (Figure 1) (Bailey and Ahmadi, 2014; Yin et al., 2004).

Photosynthesis occurs when sunlight is available, while at nighttime, respiration occurs (Correa-González et al., 2014; Mejia et al., 2019; Williams et al., 2000); Consequently, these two processers strongly influence DO concentrations, as evidenced by the commonly observed diurnal variation in oxygen levels. A study was conducted in a suburban shallow stream in central-western Mexico measured DO concentrations and temperature over five days (Correa-González et al., 2014); Results showed that high reaeration coefficient and high temperature cause a minimum DO during early night hours.

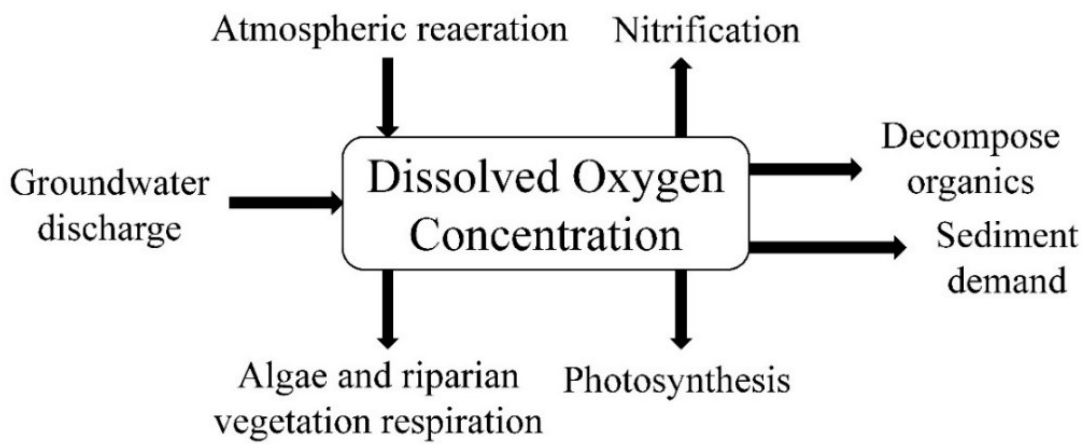


Fig. 1. The major in-stream processes affecting DO level

The DO mass balance-based approaches are proposed to determine the photosynthesis, respiration, and reaeration rates (Correa-González et al., 2014). There are several mass balance-based approaches including the Delta Method (Chapra and Toro, 1991), the Temperature Correction Method (TCM) (Butcher and Covington, 1995), and the Extreme Value Method (EVM) (Wang et al., 2003).

Urban headwater streams have been commonly buried and used as to convey waste out of urban areas. As a result of stream burial - a process in which streams are converted into culverts, pipes, concrete-lined ditches, or simply paved over - urban and suburban areas lose the benefit of highly ecosystem services provided by streams such as habitat for a variety of aquatic species and plants (Bernhardt and Palmer, 2007). The buried sections might face significant reductions in the level of DO when compared to the day-lighted sections upstream and downstream (Trice, 2016). The levels of DO can be a determining factor for the survival of a number of sensitive species – such as Brook and Brown Trout – and thus make a significant impact on aquatic habitats.

Despite the adverse effects of burying streams into culverts or pipes on streams DO, no study has evaluated these impacts on DO behavior and dynamics, photosynthesis, respiration, and reaeration processes of streams.

The current study focused on small-scale of buried channels in a medium-sized urban watershed (Ketabchy et al., 2018). However, the outcome of this study can be used as a basis for DO variations of long-length of buried sections of urban streams and rivers beneath the larger urbanized watersheds, informing the restoration design projects to improve the aquatic habitats survival and diversity conditions.

METHODS AND MATERIALS

This study was conducted on a 6.2-km upstream portion of the Stroubles Creek, with an associated watershed of 14.1-km2 (Figure 2). This includes part of the Virginia Tech campus. A significant portion of Central and Webb Branches are buried beneath the Virginia Tech campus, displayed by black lines between the red dots on Figure 2. The monitored piped rectangular sections of Central and Webb Branches extended 1.19 km, and 0.57 km, respectively. DO point data were collected for the inlet and outlet of Central Branch on two sunny days with similar maximum, minimum, and average air temperatures; 2015 Nov 16 (Date 1) and 2016 Nov 5 (Date 2) were selected to evaluate effect of burying on DO point. A YSI ProODO (YSI Incorporated, Yellow Springs, OH, USA, ±1.00% DO) probe was used to collect measurements of DO (in both concentration, mg/L and percent saturation), water temperature, and ambient air pressure at each site.

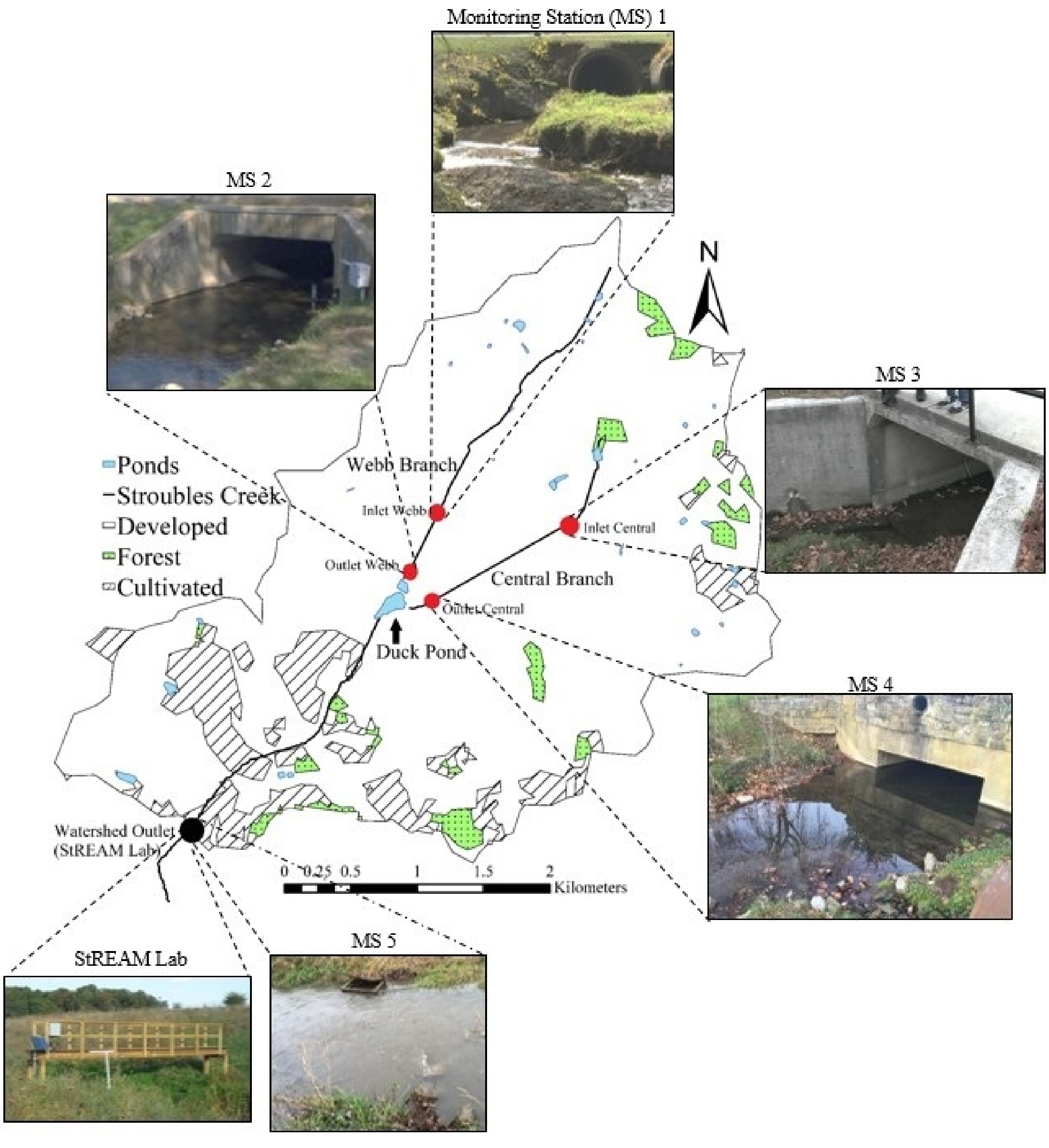


Fig. 2. Land cover map of the Stroubles Creek watershed, located in Virginia, with location of monitoring stations (MS) of DO measurements on the Central Branch and Webb Branch of Stroubles Creek.

Photosynthesis, respiration and reaeration rate calculations

The DO mass balance equations for systems named as Delta Method is shown in Eq. (1) (Chapra and Toro, 1991; Williams et al., 2000). Values of the reaeration coefficient (ka), average daily photosynthesis rate (Pav) and daily average respiration rate (R) can be calculated from a series of diurnal curves using a piecewise solution of the mass balance. Temperature variation and location of stream were also found to influence DO saturation concentration, the metabolic rates, and the reaeration rate coefficient.

RESULTS AND DISCUSSION

Data from the field continuous observations was analyzed to understand the diurnal variation in the DO concentration in the stream and to study the differences in the DO concentration due to stream burying. The diurnal variations in the observed DO concentration at the inlet and the outlet of the piped length of the Webb Branch of Stroubles Creek and the parameters required for the Delta method are illustrated in Figure 3.

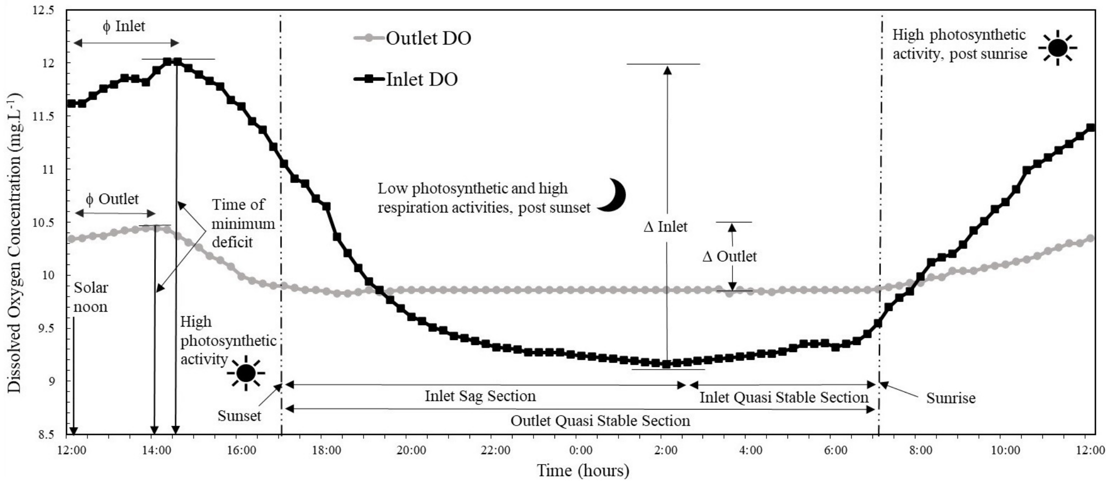


Figure 3. Variations in DO concentration for the buried channel of Webb Branch between 2016 Nov 25 at 12:00 and Nov 25 at 12:00; Note the effect of availability of sunlight on the DO concentration for both inlet and outlet.

Mean DO at the inlet and outlet during a full diurnal cycle was 10.2 and 10.0 mg·L-1, respectively, while the standard deviation (STD) DO for inlet and outlet was 1.0 and 0.2 (statistically significant, $P < 0.05$), respectively, indicating a smaller extent of outlet DO variations compared to the inlet (Figure 4). The extent of DO variations of the inlet for both the abundance and absence of sunlight was greater than outlet (Figure 4); the reason for this was the reduced exposure of piped lengths to sunlight and reduced magnitude of aquatic plants respiration during night hours for the piped section. The study demonstrated that the levels of DO in water during the sunlight through the buried section of Webb Branch decreased by approximately 11% as water flowed through the piped section.

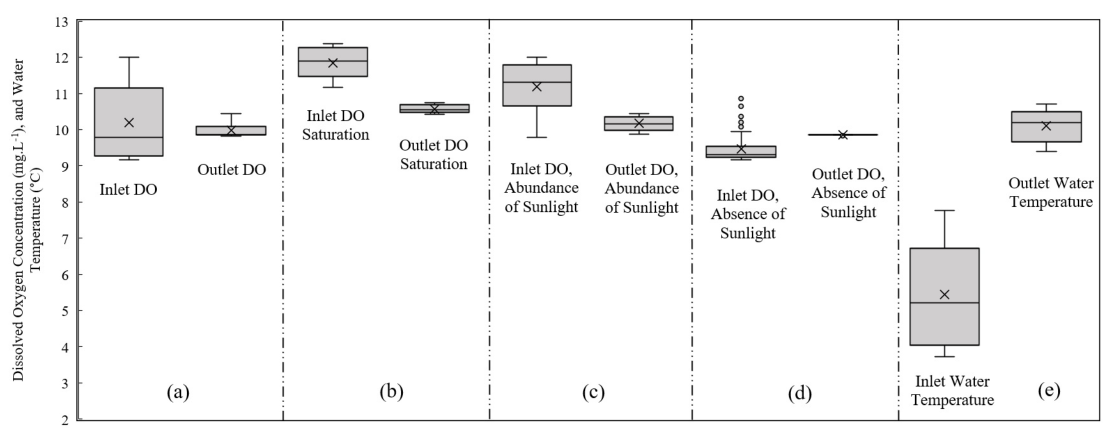


Figure 4. Webb Branch inlet and outlet variations during the diurnal continuous measurement at 2016 Nov 24, for (a) observed dissolved oxygen, (b) saturated dissolved oxygen, (c) dissolved oxygen in the abundance of sunlight, (d) dissolved oxygen in the absence of sunlight, and (e) water temperature.

The comparative variations of DO, DO saturation, and water temperature for the inlet and outlet is also displayed in Figure 5.

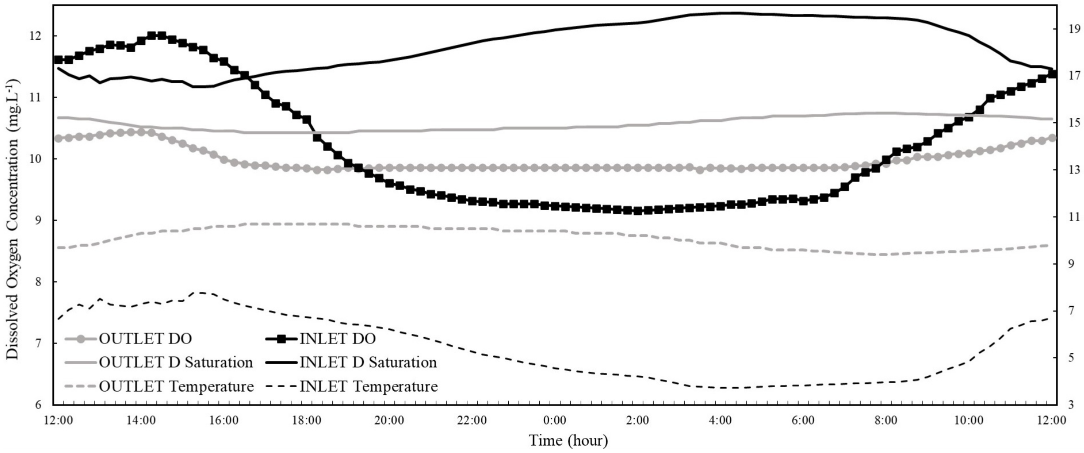


Figure 5. Comparative variations of DO, DO saturation and water temperature for Webb Branch inlet and outlet

Photosynthesis, respiration and reaeration rates

The predicted and estimated values of reaeration, photosynthesis and respiration rates were calculated through the Delta, EVM, PLM methods and predictive equations using the Webb Branch continuous measurement. The schematic comparison of the calculated values for inlet and outlet are displayed in Figure 6.

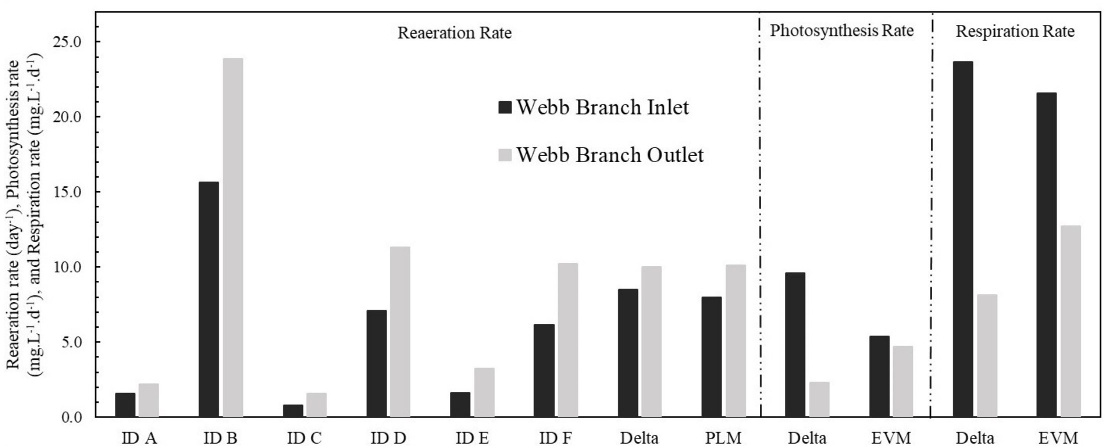


Figure 6. Comparison of the average reaeration, photosynthesis, and respiration rate values for the Webb Branch inlet and outlet using the empirical and modeling approaches, during a full diurnal cycle at 12:00 on 2016 Nov 24 and at 12:00 on 2016 Nov 25.

CONCLUSIONS AND FUTURE WORK

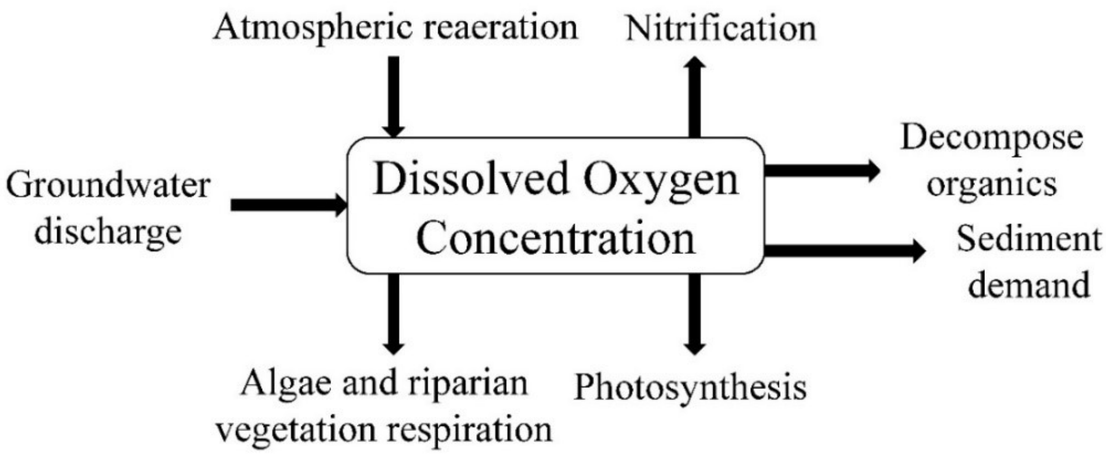
For a stream to be considered healthy, it is important to consider its ability to sustain aquatic life. DO and temperature are key characteristics to consider since some fish and macroinvertebrates species are highly sensitive to changes in their levels. The goal of this study was to quantify the DO variations prior and after the buried channels of an urban stream, with respect to aquatic species survival thresholds. In this study, it was observed that the DO levels within the buried sections of Stroubles Creek Web Branch were consistent throughout a 24-hour period and the DO levels on the open stream sections fluctuated in a sinusoidal manner during the same period of time. In addition, DO levels decreased at the outlet pipe of Web Branch and Central Branch by 11% and 6%, respectively, during daytime compared to the inlet DO levels. Also, it was observed that the temperature conditions varied as the water flowed through the piped section. The average photosynthesis, respiration, and reaeration rates were computed at the Webb Branch on a DO diurnal cycle using a series of mathematical and empirical approaches. Unlike reaeration rate that was increased at the outlet compared to inlet, the photosynthesis and respiration rates were reduced, primarily due to less solar radiation and riparian vegetation oxygen uptake.

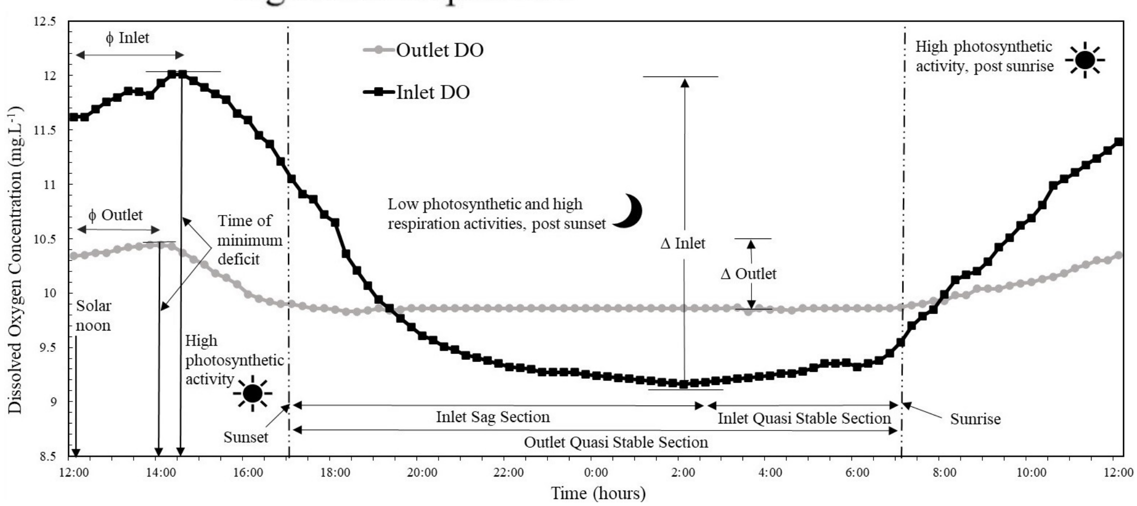
To further extend this study, it is suggested that a study of the macroinvertebrate diversity and quantity be performed before and after the piped sections to have a better understanding of the impact of the buried streams on stream ecology. Further analysis is also required to evaluate the effect of buried channels on DO across seasons. It is to be noted that since no observations for the DO concentrations were available for several spots through the buried stream length, an in-depth analysis in the effect of buried channel length on the DO concentration remains to be analyzed. Our findings can be used as a basis for large-scale burial of streams and rivers and its effects on the dissolved oxygen thresholds required for native aquatic habitats survival. The results and hence, the conclusions derived in this study are highly sensitive to the in-situ conditions including natural (climate, vegetation, soil etc.) and anthropogenic factors (instrumentation, artificial or modified runoff etc.). A diverse set of case studies with longer period of observation in consideration of diverse climatic factors, and several streams with a variety in the buried channel length will assist strengthen the conclusions derived in this study.

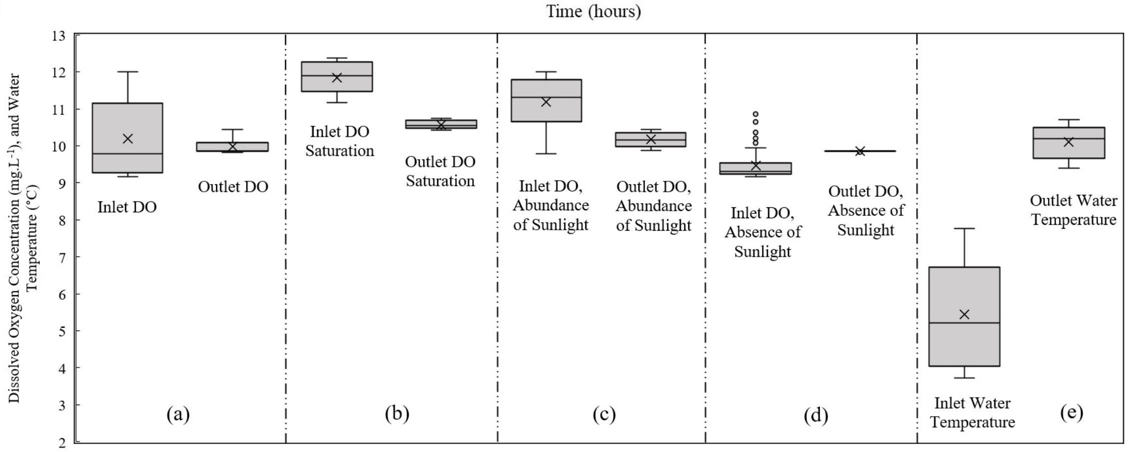
OBJECTIVE

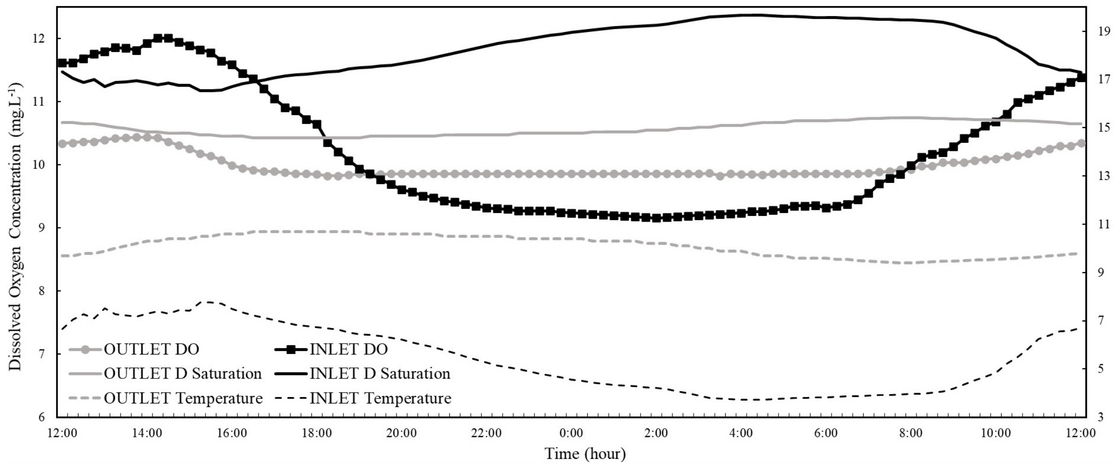
Quantify and compare the DO variations, and photosynthesis, respiration, and reaeration rates prior to entering and after exiting the buried channels of an urban stream, with respect to Brook Trout survival DO thresholds.

To achieve this goal, the concentration of DO was measured at the entrance and exit of the two 570 and 1190-m Stroubles Creek's buried sections in Blacksburg, Virginia, Webb and Central Branches, respectively. The temporal and spatial variability of collected DO were analyzed and concentrations prior and after the buried sections were compared.

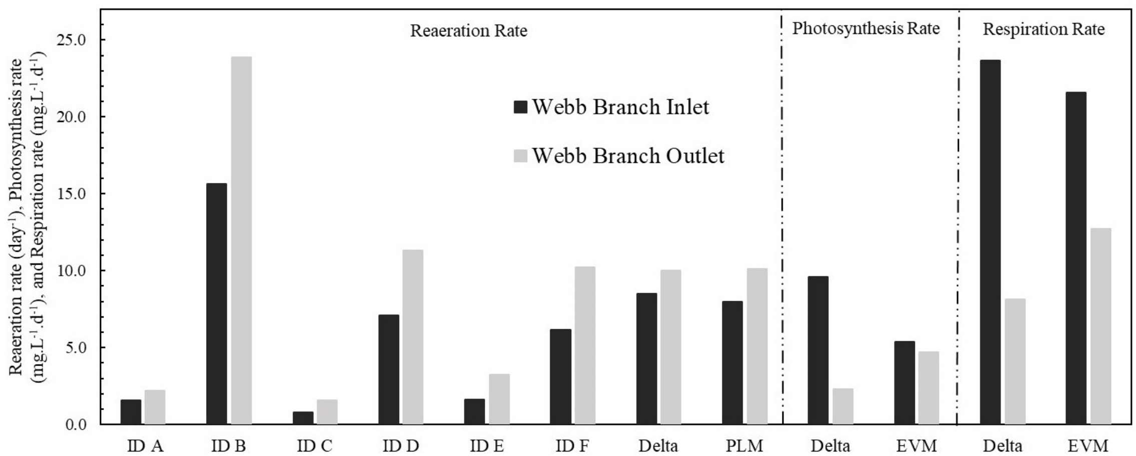








Dissolved Oxygen Concentration (mg.L-1)
Water Temperature (°C)
OUTLET DO
INLET DO
OUTLET D Saturation
INLET D Saturation
OUTLET Temperature
INLET Temperature
Time (hour)
12:00
14:00
16:00
18:00
20:00
22:00
0:00
2:00
4:00
6:00
8:00
10:00
12:00



Reaeration rate (day-1), Photosynthesis rate (mg.L-1.d-1), and Respiration rate (mg.L-1.d-1)
Reaeration Rate
Photosynthesis Rate
Respiration Rate
Webb Branch Inlet
Webb Branch Outlet
ID A
ID B
ID C
ID D
ID E
ID F
Delta
PLM
Delta
EVM
Delta
EVM

REFERENCE

Abdul-Aziz, O.I., Ishtiaq, K.S., 2014. Robust empirical modeling of dissolved oxygen in small rivers and streams: Scaling by a single reference observation. J. Hydrol. 511, 648–657. https://doi.org/10.1016/j.jhydrol.2014.02.022

Bailey, R.T., Ahmadi, M., 2014. Spatial and temporal variability of in-stream water quality parameter influence on dissolved oxygen and nitrate within a regional stream network. Ecol. Modell. 277, 87–96. https://doi.org/10.1016/j.ecolmodel.2014.01.015

Balbín, R., López-Jurado, J.L., Aparicio-González, A., Serra, M., 2014. Seasonal and interannual variability of dissolved oxygen around the Balearic Islands from hydrographic data. J. Mar. Syst. 138, 51–62. https://doi.org/10.1016/j.jmarsys.2013.12.007

Du, X., Shrestha, N.K., Wang, J., 2019. Assessing climate change impacts on stream temperature in the Athabasca River Basin using SWAT equilibrium temperature model and its potential impacts on stream ecosystem. Sci. Total Environ. 650, 1872–1881. https://doi.org/10.1016/j.scitotenv.2018.09.344

Espinasse, B., Picolet, G., Chouraqui, E., 1997. Negotiation support systems: A multi-criteria and multi-agent approach. Eur. J. Oper. Res. 103, 389–409. https://doi.org/10.1016/S0377-2217(97)00127-6

Luo, K., Hu, X., He, Q., Wu, Z., Cheng, H., Hu, Z., Mazumder, A., 2018. Impacts of rapid urbanization on the water quality and macroinvertebrate communities of streams: A case study in Liangjiang New Area, China. Sci. Total Environ. 621, 1601–1614. https://doi.org/10.1016/J.SCITOTENV.2017.10.068

Mcbride, G.B., Chapra, S.C., 2005. Rapid Calculation of Oxygen in Streams: Approximate Delta Method. J. Environ. Eng. 131, 336–342. https://doi.org/10.1061/(ASCE)0733-9372(2005)131

Yin, K., Lin, Z., Ke, Z., 2004. Temporal and spatial distribution of dissolved oxygen in the Pearl River Estuary and adjacent coastal waters. Cont. Shelf Res. 24, 1935–1948. https://doi.org/10.1016/j.csr.2004.06.017

Yoshikawa, T., Murata, O., Furuya, K., Eguchi, M., 2007. Short-term covariation of dissolved oxygen and phytoplankton photosynthesis in a coastal fish aquaculture site. Estuar. Coast. Shelf Sci. 74, 515–527. https://doi.org/10.1016/j.ecss.2007.05.004

AUTHOR INFORMATION

Mehdi Ketabchy is a water resources engineer at Gannett Fleming, Inc. based in Baltimore, MD and a former graduate student at Virginia Tech. He is passionate about water resources and environmental engineering areas, as he has conducted several research and practical projects in various areas of environmental and water resources engineering fields. He also serves as an editor on the editorial board of the Journal of Water Management Modeling (JWMM).

If you have any questions or comments, you can reach out to him through mketabchy@gfnet.com or kmehdi87@vt.edu.

ABSTRACT

Sunlight plays an important role in regulating the nutrient cycle in streams. Throughout the years, more streams are buried to accommodate for residential or commercial facilities. This results in severe impacts on the health of streams due to altered exposure to sunlight, air, and soil; it subsequently affects the growth of aquatic and riparian vegetation, thus impairing the water quality of streams. Although urbanization effects on urban surface streams are well understood, the adverse effects of burying streams on dissolved oxygen (DO), reaeration, photosynthesis and respiration processes have been mainly remained theoretical. This study evaluated the effect of stream piping on DO for two sections of Stroubles Creek in Blacksburg, VA through comparing the water quality prior to entering, and post exiting the buried sections of the Creek. Monitoring DO was conducted through manual readings and continuous measurement for a number of days in Fall 2015 and 2016. The results indicated that the water DO level decreased by approximately 11% as water flowed through the buried sections. The covered section of the stream also caused variability of the water temperature, resulting a possible disturbance to the downstream ecosystem. The buried channels-induced DO variations effects on the Brook Trout (*Salvelinus sp.*), a sensitive species present at the Stroubles Creek headwaters was also assessed. Further, the photosynthesis rate, reaeration coefficient, and daily respiration rate were computed prior and after one of buried channels through a series of mathematical and empirical approaches to assess the buried channels effect on the aforementioned parameters. The photosynthesis and respiration rates were reduced at the inlet compared to outlet, primarily due to less solar radiation and aquatic vegetation oxygen uptake, however, reaeration rate was increased at the outlet compared to inlet. This study can assist the decision makers and resource planners in taking the appropriate decisions regarding daylighting stream channels to improve water quality or/and accommodate increasing demand for urbanization.