Draft Proposed Methodologies for Estimating the Sanitary Sewer Exfiltration N and P Load in the Chesapeake Bay Watershed

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Background

Wastewater represents the single largest source of N in urbanized watersheds and leaking sanitary sewers have the potential to export N and P to streams and waterbodies (Bernhardt et al., 2008). Sanitary sewers (SS) leak from defects and structural failures, but because most sewers are not designed to flow at high pressure, joints are not always designed to prevent inflow and outflow and sewers can leak without any specific failure (Ellis et al., 2003; Rieckermann et al., 2007; Rueedi et al., Walch et al., 2014; ASTM, 2009). Sanitary sewers often infiltrate (I/I) in wet locations or during wet periods, and exfiltrate during dry periods or in dry locations (Nguyen et al., 2021). System wide exfiltration can range from 1.7%-25% of total flow (Rutsch 2008; Ellis et al., 2004; Blackwood et al., 2005; Selvakumar, 2004; Schiff et al., in prep) and because concentrations of N and P within raw wastewater are two to three orders of magnitude greater than background stream and groundwater concentrations, even small leaks can result in significant loading. Current versions of the CAST model do not explicitly account for this sewer exfiltration load, resulting in it being misappropriated to other sources. We propose three possible frameworks and a hybrid approach for modeling SS exfiltration in Phase 7 of CAST which vary in terms of their requirements for data, expert judgement, and time.

Option A

Option A is developed to be entirely informed by existing literature and data and therefore does not require soliciting additional data from utilities. Exfiltration will be estimated per unit service area or per capita based on existing literature and applied to the SS service area of the Chesapeake Bay watershed (CBW), distributed to the developed LU within the service boundary. Initial literature review indicates 0.15 – 1.76 lb N/acre/year from SS exfiltration (Delesantro et al., 2022; Nguyen and Venohr, 2021; Lerner and Halliday, 1994; Schiff et al., in prep) and additional literature review is advised. Conversion of literature reported values to areal exfiltration estimates or per capita estimates requires assumptions because different methods are used to estimate exfiltration in the literature including modeled or measured to stream, groundwater, or from pipe and values are often reported relative to pipe length or network exfiltration.

Option B

Option B is developed to require minimal data from wastewater utilities and leverages literature agreement on SS exfiltration per unit length of gravity fed pipe averaged over systems or catchments. While reported exfiltration of individual pipe lengths varies widely (9.5-1900 gal/day/km; Hoffman and Lerner, 1992; Ellis et al., 2009; Ellis and Bertrand, 2010; Schiff et al., in prep), reported or estimated exfiltration at larger scales shows better agreement (228-630 gal/day/km; Delesantro et al., 2022; Nguyen and Venohr, 2021; Lerner and Halliday, 1994; Schiff et al., in prep) likely due to pipe level variation averaging out over catchment or system scales. We propose to estimate service area exfiltration within the CBW based on literature of catchment or system level estimates and utility reported length of SS (1).

$$Load\ exfiltrated = \ Exfiltration\ Rate * Length\ SS\ (gravity) * Concentration\ N\&P \quad (1)$$

Where the exfiltration rate is in gal/year/km and estimated from literature review, the length of SS is reported by utilities for their gravity lines, and the concentration of N and P in raw WW is either reported by utilities or estimated from literature review. Exfiltration load can either be even distributed across developed land use within service boundaries, or more finely distributed by population density using the strong statical relationship demonstrated between population and sewer length (Delesantro et al., 2021).

Option C

Option C is a placeholder for a spatially and temporally explicit model of SS exfiltration. Scientific literature has demonstrated that loading to streams and groundwater from SS exfiltration is spatially influenced by sewer hydrogeomorphic position (Delesantro et al., 2022; Hopkins and Bain, 2018) and spatial-temporal modeling of exfiltration has been conducted with data on pipe location and characteristics, groundwater head, and soils (Nguyen and Venohr, 2021). These methods require extensive data and collecting and managing this data is resource intensive. Further development of Option C should be predicated on the potential availability of necessary resources.

Option D

This option is a hybrid approach where utilities or states may opt for Option A, B, or C depending on the data they can provide and the level of detail they want accounted in their exfiltration estimates.

Option E

No action. No estimation of sanitary sewer exfiltrated N and P load will be added to Phase 7 CAST modeling.

Crediting Discharge Elimination

Sanitary sewer pipe exfiltration discharge elimination can be credited as per protocols detailed in the Walch et al., (2014) report to the Watershed Technical Committee and copied below. This approach credits measured reductions from single pipe segment rehabilitation.

"Sewer Pipe Exfiltration discharges can be credited under Protocol 2. It requires before and after flow metering in the pipe to determine the change in sewage exfiltration as a direct function of the sewer repair, based on the decline in flow rate associated with the capital project. While it is allowable to use the sewage concentration default values, the credit is also subject to a discount factor.

Discount factors:
- 50% if project is within 150' of stream or within 10 feet of a lower elevation storm drain pipe,
- 10% if project is greater than 150' away from the stream or greater than 10' feet from a lower elevation storm drain pipe to account for losses during groundwater migration"

The working group may also consider a complimentary system or network scale crediting of management action. However, any new crediting may be subject to additional review. Here we provide a proposed example in which management action of utilities are accounted for as a percent reduction to exfiltration which is a function of the length of rehabilitated pipe (Figure 1). Precent reduction will vary from 0 to Y where Y will be informed by literature review and expert judgement. Initial literature search yielded a percent reduction of I/I and exfiltration after pipe rehabilitation of 36-70% (Staufer et al., 2012; Batman et al., 2011). The percent length of pipes rehabilitated within a service area (X) to achieve a percent reduction in service area exfiltration nearing the potential limit (Y) will again be informed by literature review and expert judgement. It is generally agreed that few pipes are responsible for most of the exfiltration and that pipe inspection and targeted rehabilitation are the most efficient management approach (Walch et al., 2014). The value of X and the characteristics of the curve should reflect and prioritize targeted rehabilitation. Finally, rehabilitation needs to be defined relying on literature search and expert judgement. Old pipes are more likely to have large leaks (Nguyen et al., 2021; Schiff et al., in prep) and pipe constructions have ASTM designated design lives, therefore defining rehabilitation as a management action within the last T years may be appropriate.

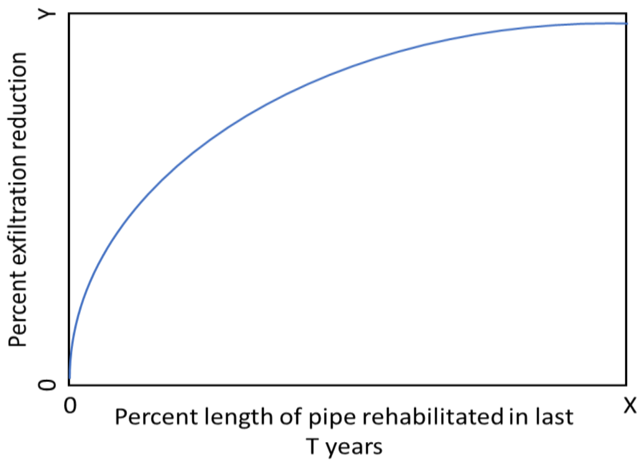

Figure 1: Example method for estimating the reduction to exfiltration from sanitary sewer rehabilitation at system scales where values Y, X, and T will be informed by literature review and expert judgement.

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