Temperature-dependence in sewer blockage frequency

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Introduction

Sanitary sewer blockages (SSB) cause widespread negative impacts, including aesthetic degradation from odors, and property damage and environmental degradation from sanitary sewage overflow (SSO). In the U.S., where SSOs are tracked by the U.S. Environmental Protection Agency (U.S. EPA Office of Wastewater Management, 2004a), approximately half of SSOs were caused by blockages, with up to 75% of SSOs caused by blockages in the arid Southwest (U.S. EPA Office of Wastewater Management, 2004b). Consequently, prompt remediation of SSB is a high priority for municipalities, and contributes to municipal sewer maintenance costs (maintenance-cost, 2010).

Previous work has attributed SSBs primarily to roots, debris, and fats, oils, and grease (FOG) (U.S. EPA Office of Wastewater Management, 2004b). In the U.S., 60-75% of blockages have fat, oil and grease (FOG) deposits as a contributory factor (Keener et al., 2008), while vegetation intrusion is the chief cause of blockages in Australia (Marlow et al., 2011).

As recognized contributors to SSB, FOG deposits have received considerable attention. FOG deposits form in a saponification reaction between calcium soaps and free fatty acids (He et al., 2011), chiefly from restaurants and industrial sources (Keener et al., 2008). Free fatty acids are insoluble in water, and are transported in greasy effluent. Many municipalities have implemented policies to minimize FOG inputs into sanitary sewers (Bennett and Sukenik, 2006; Hassey and Joyce, 2001; Heckler, 2003; Parnell, 2005; Tupper and Skoda, 2008). Residential outreach is often increased during the holiday season in an effort to minimize FOG inputs due to food preparation (Tupper and Skoda, 2008).

Climate can influence blockage rate by affecting both vegetation and water flow. Marlow et al. (2011), for example, showed a correlation between sewer blockage frequency and the Southern Oscillation Index (SOI) in eastern Australia. The SOI reflects rainfall patterns in the region, with droughts raising blockage risk by decreasing sewer flow volume and increasing sedimentation. Low rainfall also promotes tree root development, which damage pipes by intruding through joins and other weak points (Desilva et al., 2011).

Temperature is one potential driver of SSB that has received little study to date. The viscosity of both water and FOGs decreases with decreasing temperature. For a given pipe network, increased viscosity results in increased frictional head loss (Romeo et al., 2002). In addition, FOG effluent can solidify at lower temperatures, causing overt blockages.

In this study we examine five years of SSB records from the City of Albuquerque municipal sewer system. We explore the relationship between air temperature, sewage temperature, and the frequency of SSB. We find that air temperature is a useful proxy of sewage temperature, and that both air and sewage temperature predict SSB frequency. Specifically, temperature predicts SSB events for which grease was a contributory factor, suggesting that cold weather increases the impact of FOG deposits. SSBs with other causes do not respond to temperature. These relationships shed light on mechanisms of sewer blockage, and can potentially help municipalities anticipate time periods of elevated sewer blockages using readily available atmospheric data.

Methods

Data

Albuquerque Bernalillo County Water Utility Authority (ABCWUA) responds to SSB events after discovery by maintenance workers or reports of blockages from the public. This study used an anonymised dataset of SSB dates, along with engineers' estimates of blockage cause. In total, 913 SSB reports from the period January 06, 2009 - January 31, 2013 (inclusive) were used in this study. The frequency of sanitary sewer blockages is the primary focus of this work.

Sewer grab sample temperature (SGST) measurements were collected by ABCWUA personnel during routine maintenance, using XXX probes XXXX etc. (??mark) SGST measurements were available from 15 manholes, leading to 3 interceptors within Albuquerque. ??(Mark - explain interceptors / structure of this data) In total, 1998 SGST measurements from the period September 28, 2005 - December 19, 2012 (inclusive) were used in this study.

Mean daily air temperature (MDAT) was obtained from the Albuquerque International airport's (KABQ) automated METAR data collection system (available from http://www.wunderground.com/history/airport/KABQ) spanning the years during which either SSB and SGST or measurements were available (January 01, 2005 - January 01, 2014, inclusive).

Since most days had no SSB events, the total number of SSB events per week (W-SSB) was computed and used in subsequent analysis. For comparison with SSB data, MDAT measurements were averaged by week to yield mean weekly MDAT (MW-MDAT). In addition, SGST measurements were averaged by week (all interceptors were combined), yielding mean weekly SGST (MW-SGST). In all analyses that included MW-SGST, weeks without SGST measurements were excluded.

Linear models

First, we used ordinary linear models to estimate the response of MW-SGST to MW-MDAT, interceptor identity, and manhole identity. For final selection of linear model specifications, both Bayes' information criterion (BIC) and parsimony considerations were employed. In favor of parsimony, and due to the small effect sizes and/or statistical non-significance, interceptor and manhole identity were excluded from subsequent models.

Next, we used generalized linear models (GLM) to estimate the response of W-SSB to either MW-SGST or MW-MDAT. We also used a GLM to estimate the response of W-SSB to both MW-MDAT and blockage cause. Due to low sample numbers, the response of W-SSB to both MW-SGST and blockage cause was not estimated.

All analysis was conducted with the R statistical programming environment (R Core Team, 2013).

Results

Air temperature (MW-MDAT) and sewage temperature (MW-SGST)

We found that sewage temperature increased with air temperature (Figure 1). Indeed, the best-ranked model of the response of MW-SGST to MW-MDAT (Table S1) explained the majority of variation in MW-SGST (R^2 = 0.78). However, as air temperature fells below freezing, little further decrease in sewage temperatures was observed (Figure 1).

For reference, all candidate models (ranked by BIC) are shown in Table S2. All high-ranked models (low BIC) show a small but statistically significant effect of interceptors identity on sewage temperature. On the other hand, all models that included manhole identity ranked lower than the null model (which included only MW-MDAT and MW-SGST).

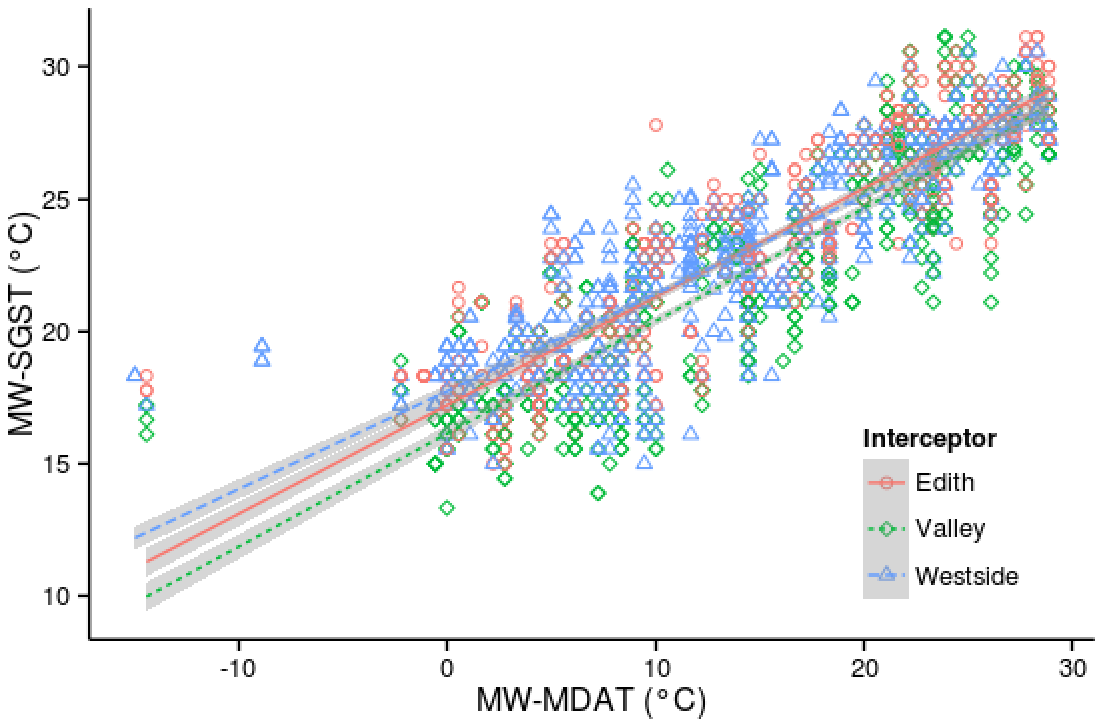

Figure 1: Sewage temperature (MW-SGST) increased with air temperature (MW-MDAT), though interceptors differed slightly in their sewage's temperature responses to air temperature. As air temperature dropped below freezing, no further decrease in sewage temperature was observed.

Sewage temperature (MW-SGST) and sewer blockage frequency (W-SSB)

We find that sewer blockages occurred more frequently during weeks with lower sewage temperatures (Figure 2A). The final linear model specification of the response of W-SSB to MW-MDAT employed a negative binomial GLM with a log link function (Venables and Ripley, 2002). The final relationship was highly statistically significant ($p < 0.001$; Table 1).

The W-SSB data followed an overdispersed Poisson distribution, with forty-one weeks (23.8%) showing one or zero incidents. Consequently, the final negative binomial specification provided a significant improvement over a Poisson GLM (likelihood ratio tests, $p < 0.001$).

R^2 statistics are not available for GLM, though the proportional reduction in deviance (D) provides an analogous measure of the model's explanatory power (Zheng, 2000). For the final negative binomial model, we find that $D = 0.059$, showing that this model explains only a modest amount of variation in observed sewer blockage frequency.

Air temperature (MW-MDAT) and sewer blockage frequency (W-SSB)

We found that sewer blockages were more frequent when air temperature was low. MW-MDAT was a highly significant predictor of W-SSB (Table 2; Figure 2B). However, this model explains very little variation in blockage frequency ($D = 0.018$).

This dataset includes 492 blockages where grease was the estimated blockage cause, representing 53.9% of incidents during the study period. When these grease-caused SSB events were modeled separately, a statistically significant relationship between W-SSB and MW-MDAT was also observed (Table 3; Figure 3A). However, there was no relationship between temperature and non-grease SSB (Table 4; Figure 3B). For the model predicting grease-caused blockages, ($D = 0.040$), compared with ($D = 0.005$) for the model predicting non-grease-caused blockages.

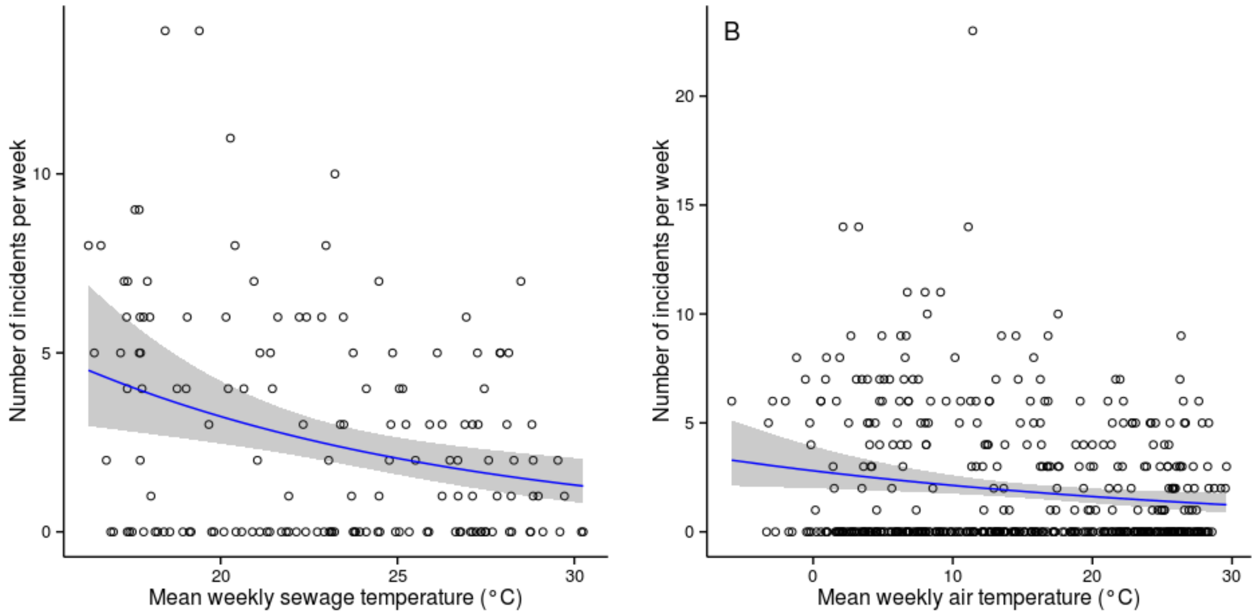

Figure 2: Both sewage temperature (A; n=153 weeks) and air temperature (B; n=471 weeks) can be used to predict sanitary sewer blockages.

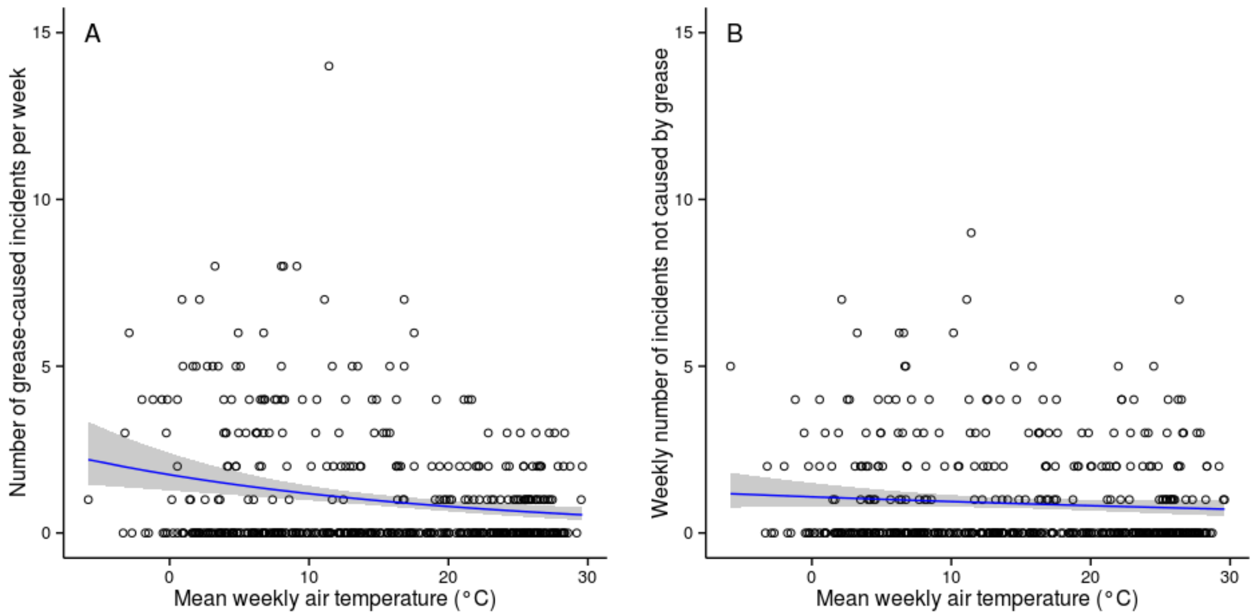

Figure 3: Mean weekly air temperature predicts blockages caused by grease (A; n=471 weeks) but not other blockages (B; n=471 weeks)

Discussion

Notes / todo: ??both sewer temp and air temp are signif predictors, sewer temp is better ??likely that the response of sewer temp to air temp is dependent on local local climate and sewer configuration (mark?), warrants testing in different locales. ABQ diurnal temp, elevation gradient and cold air drainage. ??if municipalities are already collecting SGST, it would be an appropriate addition to system maintenance planning

Temperature data, which are widely and freely available, have modest utility in predicting sewer blockages over weekly timescales. These results suggest that areas experiencing increasing average temperatures may find that this trend alleviates the pressure placed on sewage systems by FOG deposits. Similarly, weather forecasts and real-time weather observations may prove useful for predicting and responding rapidly to blockages, reducing the threat to property and public health.

Data from sewer measurements are a slightly more accurate predictor of blocking frequency. Where these data are regularly collected and rapidly analyzed, they could be used in place of air temperature to anticipate problems in sanitation infrastructure and plan system maintenance.

The relationship between air and sewage temperature is likely to be mediated by ground temperature, and therefore by groundwater levels. The difference in predictive ability between sewage and air temperature may reflect the variable groundwater levels during the seasonal cycle in Albuquerque. Similarly, differences between interceptors and manholes may reflect elevation and land use, via their effects on groundwater temperature. Models including precipitation patterns and/or local physical characteristics (e.g. water table height, land use, sewer configuration, soil type, geology) could test this hypothesis.

With continuing population rise and urbanization, efficient operation of urban waste-water infrastructure is an increasingly important issue for global public health. (Sato et al., 2013) recently highlighted the importance of more research into efficacy of waste-water treatment techniques, particularly in the developing world. The data in this study were not collected specially for research purposes. Rather, this study used data already collected by industry as part of standard operations, married with publicly accessible weather data available online. This demonstrates the potential usefulness of historic industry datasets for addressing future challenges.

Tables

Table 1: Weekly mean sewage temperature (MW-SGST) predicts the number of blocked sewers that week (W-SSB; n=153 weeks)

Variable	Estimate	Standard error	z	p
MW-SGST	-0.09	0.028	-3.18	0.002
Intercept	2.97	0.655	4.54	<0.001

Table 2: Weekly mean air temperature (MW-MDAT) predicts the number of blocked sewers that week (W-SSB; n=471 weeks)

Variable	Estimate	Standard error	z	p
MW-MDAT	-0.03	0.010	-2.68	0.007
Intercept	1.03	0.173	5.97	<0.001

Table 3: Negative binomial GLM predicting response of blockages caused by grease to weekly mean air temperature (MW-MDAT; n=471 weeks)

Variable	Estimate	Standard error	z	p
MW-MDAT	-0.04	0.010	-3.99	<0.001
Intercept	0.56	0.162	3.46	<0.001

Table 4: Negative binomial GLM predicting blockages not caused by grease to weekly mean air temperature (MW-MDAT; n=471 weeks)

Variable	Estimate	Standard error	z	p
MW-MDAT	-0.01	0.010	-1.41	0.157
Intercept	0.08	0.167	0.49	0.628

References

Bennett, W., Sukenik, W., 2006. Atlanta's aggressive grease control program reduces SSOs. Proceedings of the Water Environment Federation 2006, 133–143.

Desilva, D., Marlow, D., Beale, D., Marney, D., 2011. Sewer Blockage Management: Australian Perspective. Journal of Pipeline Systems Engineering and Practice 2, 139–145.

Hassey, P., Joyce, C., 2001. Grease Impact Assessment Rehabilitation Pilot Project. Proceedings of the Water Environment Federation 2001, 698–713.

He, X., Iasmin, M., Dean, L.O., Lappi, S.E., Ducoste, J.J., de los Reyes, F.L., 2011. Evidence for fat, oil, and grease (FOG) deposit formation mechanisms in sewer lines. Environmental Science & Technology 45, 4385–91.

Heckler, P., 2003. Best management practices to reduce pollution from sewers in a large municipality. Proceedings of the Water Environment Federation 2003, 398–410.

Kass, R.E., Raftery, A.E., 1995. Bayes Factors. Journal of the American Statistical Association 90, 773–795.

Keener, K.M., Ducoste, J.J., Holt, L.M., 2008. Properties Influencing Fat, Oil, and Grease Deposit Formation. Water Environment Research 80, 2241–2246.

maintainence-cost, 2010. maintainence-cost. Unknown.

Marlow, D.R., Boulaire, F., Beale, D.J., Grundy, C., Moglia, M., 2011. Sewer Performance Reporting: Factors That Influence Blockages. Journal of Infrastructure Systems 17, 42–51.

Parnell, D., 2005. Innovative Approach to Fats, Oils, and Grease (FOG) Management. Proceedings of the Water Environment Federation 2005, 6737–6747.

R Core Team, 2013. R: A Language and Environment for Statistical Computing.

Romeo, E., Royo, C., Monzón, A., 2002. Improved explicit equations for estimation of the friction factor in rough and smooth pipes. Chemical Engineering Journal 86, 369–374.

Sato, T., Qadir, M., Yamamoto, S., Endo, T., Zahoor, A., 2013. Global, regional, and country level need for data on wastewater generation, treatment, and use. Agricultural Water Management 130, 1–13.

Tupper, G., Skoda, S., 2008. FOG: Collaborating to Keep the Pipes Clear. Proceedings of the Water Environment Federation 2008, 4014–4029.

U.S. EPA Office of Wastewater Management, 2004a. Local Limits Development Guidance.

U.S. EPA Office of Wastewater Management, 2004b. Report to Congress: Impacts and Control of CSOs and SSOs.

Venables, W.N., Ripley, B.D., 2002. Modern Applied Statistics with S, Fourth. ed. Springer, New York.

Zheng, B., 2000. Summarizing the goodness of fit of generalized linear models for longitudinal data. Statistics in Medicine 19, 1265–1275.

Supplemental Information

Table S1: Summary table of the best-ranked model of the response of mean weekly sewage grab sample temperature (MW-SGST) to mean weekly mean daily air temperature (MW-MDAT). Sewer interceptor identity has a significant effect on both model slope and model intercept. $R^2 = 0.78$.

	Estimate	Standard error	t	p
Intercept	17.2	0.163	105.507	<0.001
MW-MDAT	0.41	0.0094	43.655	<0.001
Valley Interceptor	-1.08	0.217	-4.964	<0.001
Westside Interceptor	0.529	0.211	2.507	0.012
MW-MDAT * Valley Interceptor	0.0165	0.0125	1.322	0.186
MW-MDAT * Westside Interceptor	-0.0406	0.0124	-3.267	0.001

Table S2: Candidate models for predicting sewage temperature using mean air temperature, ranked using Bayes Information Criterion. Delta BIC, the difference between each model and its highest-ranked competitor, is a measure of empirical support for that model. A value >10 is considered strong evidence against that model (Kass and Raftery, 1995).

	Model	BIC	ΔBIC
6	MW-MDAT + Interceptor + MW-MDAT * Interceptor	8094.78	-
2	MW-MDAT + Interceptor	8105.16	10.4
4	MW-MDAT * Interceptor	8147.29	52.5
1	MW-MDAT (null model)	8160.33	65.6
3	MW-MDAT + Manhole	8176.95	82.2
5	MW-MDAT * Manhole	8229.28	134.5
7	MW-MDAT + Manhole + MW-MDAT * Manhole	8242.55	147.8