An Assessment of Runoff from Fire Damaged Lands Amended with Biosolids

Authors: Harry Allen, U.S. Environmental Protection Agency [1]
David Crohn, University of California Riverside (retired)
Veronica Hurtado, Las Virgenes Municipal Water District
Susan Chang, Los Angeles City Bureau of Sanitation
Matthew Hutton, Los Angeles County Sanitation District
Greg Kester, California Association of Sanitation Agencies

[1] *Disclaimer: The views expressed by the authors do not necessarily reflect the official views of the U.S. Environmental Protection Agency or the federal government.*

Keywords: Biosolids, Composts, Erosion control, Fires, Metals, Nutrients, Reclamation, Runoff, Water quality

Abstract

Wildfire burn scars may become persistent pollution sources long after fires are contained. Burn scars are subject to increased runoff, leading to erosive loss and impacts to surface water quality such as increased pollution load to surface water from metals and nutrients. Land reclamation with biosolids products offers a solution to these problems. We tested runoff from burn scar plots reclaimed with a one-time application of 3 types of biosolids products and included a control site with no addition. Nutrients, metals, suspended solids, and other constituents were measured in samples collected from collection basins following storm events. The analytical data was weighted for runoff volume. Statistical analysis generated likelihood intervals (Upper Confidence Limits) for mean or median parameters of mass of compounds of interest in runoff or mass exported. Our results demonstrate that reclaiming burn scars with biosolids outperformed the control in 2 of the 3 cases and does not increase pollutant volume. Biosolids have the potential added benefits of encouraging revegetation in burn scar areas and potentially improving soil health. These results provide guidance to land managers and biosolids/compost applicators to understand and monitor these benefits and understand and mitigate potential impacts.

Introduction:

The dangers of wildfires are acute throughout California and much of the western United States, especially when winter vegetation desiccates during dry summer months. In many environments fires denude soils of vegetation – creating burn scars. Burn scars are noted for soil erosion, increased runoff volume, and runoff velocity leading to potential problems in receiving surface waters.

High heat and incomplete combustion of soil litter and organic matter may reduce infiltration potential. Soil litter and organic matter may condense to form hydrophobic soil layers preventing infiltration and increasing runoff.

Increased runoff near burn scars is more likely to result in soil erosion and pollution exports to receiving waters. Exposed soil particles are likely to become dislodged by falling rain. Erosive loss from burn scars is therefore a pollution concern for surface waters as pollutants may be associated with soil particles as well as runoff water. While Nitrogen (N) may be volatilized by fire, nitrate and ammonia are common in runoff from burn scars. Phosphorus (P) can become concentrated in burn ash and be carried by runoff. Runoff containing high N and P can eutrophy surface waters. Heavy metals, associated with soil particles, also may be mobilized by runoff from burn scars. Sediments themselves can damage aquatic habitats and reduce the storage capacities of downstream water bodies such as lakes and reservoirs.

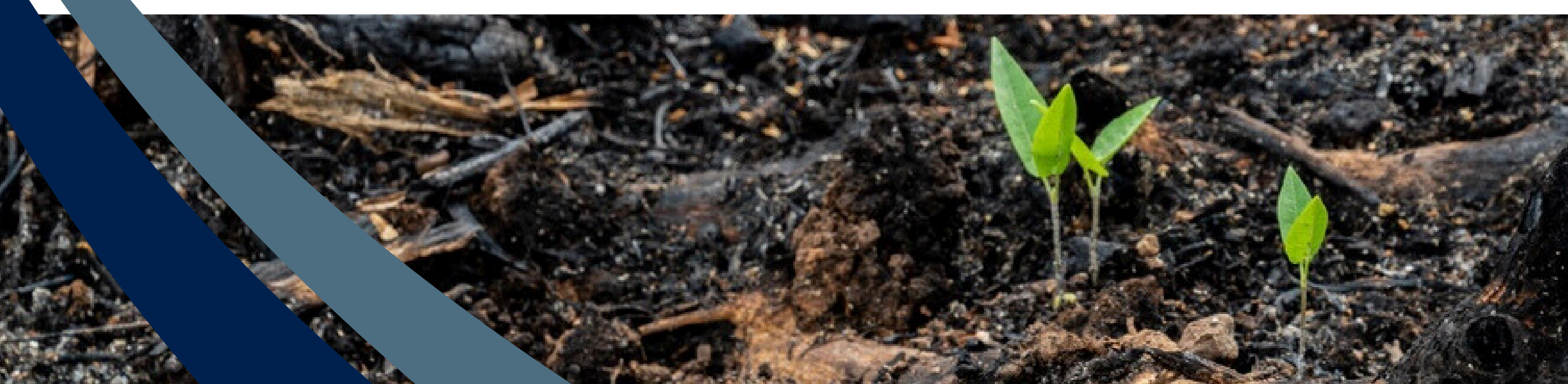
Compost, biosolids, and mulch application have been demonstrated to protect soil, improve infiltration, and reduce erosion from burn scars. Burn scars in California are often treated with wood chips or straw mulches. Compost blankets may perform better than mulches at decreasing runoff volumes and are less likely than mulch to introduce weed seeds and plant disease. One drawback of mulches is that they may pose additional fire hazards.

Composts and biosolids, as compared to options such as straw blankets, enrich soil macro- and micro-nutrients. These nutrients benefit plants but could act as pollutants if exported off-site. Applicators should manage organic loading rates and periodically collect runoff samples, adjusted based on runoff volume, to reflect the mass export per unit treated area. When measured in this fashion pollutant loads may decrease, sometimes dramatically, compared to untreated controls. Biosolids have been shown to be safe and effective for use in Land Reclamation (Crohn 2013, Meyer 2004).

During the Woolsey Fire in Southern California in November 2018, vegetated slopes were affected by fire and high heat in the City of Calabasas and in neighboring communities in Los Angeles and Ventura Counties. Vegetation, mostly coastal sage scrub, was completely burned off.. Subsequent recovery during the following rainy season was spotty. Some areas revegetated promptly while others remained denuded. Land reclamation with biosolids can encourage more consistent vegetative growth, reduce runoff, and restore soil health. Such practices could improve water quality and limit pollution exports.

We compared effects of a single application of three types of biosolids; Class A compost, Class B anaerobically digested cake, and Class A heat dried pellets and compared these to an untreated negative control. Treatment plots were arranged as three replicates of each treatment in a randomized block type configuration. The study objective was to determine if biosolids addition increases plant establishment and leads to a reduction in runoff and pollution exports. In addition, we assessed soil chemical concentrations before and after biosolids amendment application as well as the amendments themselves.

The Las Virgenes Municipal Water District (LVMWD) composting facility (Calabasas, CA) was impacted by the Woolsey Fire which left significant burn scars on the property. The engineered slopes and easy access at the facility were ideal for experimental conditions. It also was a natural choice because biosolids are composted there on-site. Runoff was collected immediately after rain events (during winter-spring months) over two years between 2019 and 2021.

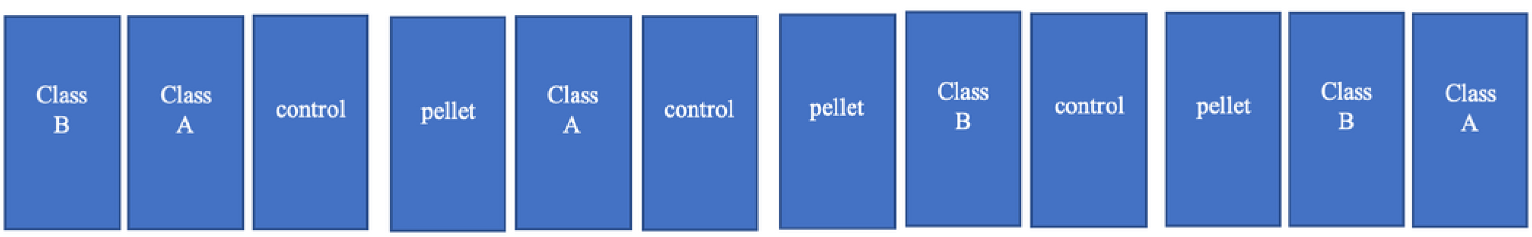


Methods:

The treatment plots were 1 m wide and 3 m in length. Twelve total plots were sited side-by-side on burned slope along a paved road on the property. The plots were contained using a retail garden barrier to ensure that the runoff collected was from the individual treatment plot alone. At the bottom of each plot an open-top PVC pipe was installed to catch water and transmit it to a collection basin (a 30-gallon Rubbermaid trash can). Aluminum flashing was used to ensure runoff was collected in the open-top pipe. A 3-ft deep by 3-ft wide trench was dug at the base of the slope below all 12 plots in order to secure the collection basins.

Three types of biosolids were tested, Class B biosolids (from Tapia Wastewater Treatment Plant (WWTP)), Class A compost (from Triunfo Sanitation District), and Class A heat-dried pellets (from City of Corona WWTP, with hauling provided by Synagro Technologies). The treatment and control plots, were each 3 m2 and were laid out in a randomized block configuration to ensure that replicates did not influence one another.

A single application of biosolids by type was completed in September 2019 (excepting the three control plots). The biosolids were surface applied in a layer <7.5 cm deep. After storm events, water runoff was collected and analyzed for chemical and physical constituents (water quality parameters). Soil and biosolid amendment testing was conducted before and after application for a variety of chemical compounds. The plots were not seeded.



Treatment plot layout: 3 replicates of each treatment and 3 control plots, were constructed and arranged in a Randomized Block design where (plot locations are mixed randomly). Treatments included Class A compost, Class B cake and Class A heat dried pellets. Control plots were prepared with no biosolids added.

Chemical Analyses and Other Performance Measures

Figure 1 Photo of the plots during the experiment.

Unfiltered water samples were collected after each runoff-generating rain event over 2 years (Fall 2019 to Spring 2021) for a total of 6 sampling events. One water sample was collected from each collection basin (1 per treatment plot per rain event).

Runoff volume measurements were also recorded with each water sampling event. This was accomplished by pouring collected runoff into graduated cylinders prior to obtaining the water samples. Runoff volume results were used to determine mass exported as described below.

Chemical analysis included Total Suspended Solids, Volatile Suspended Solids, Nitrate as N, Total P, Ammonia-N, Organic-N, Cyanide, heavy metals, and select organic contaminants. The amount of captured runoff was measured for each rain event. All samples were analyzed by the City of Los Angeles Bureau of Sanitation (LA San) laboratory with the exception of the second soil analysis done in January 2023 by the Sanitation Districts of Los Angeles County. Biosolids samples were also collected at the start of the experimental period in November 2019. Composite soil samples were collected from the entire study area plots at a depth of 0-10 cm below the surface at the beginning of the project. In January 2023, composite soil samples were collected from control and amended plots for qualitative comparison between the initial and post-treatment soil condition. Soil results are shown in Table 1.

Table 1: Soil Concentration (mg/kg) in unamended soil and in all plots at the conclusion of the experiment.

	November 2019 (unamended/ control)	**January 2023 (post-treatment)**			
		A – compost plots	**B – cake amended plots**	**Pellet amended plots**	**Control (unamended)**
Organic N	678	1,090	150	200	439
NH_4-N	53	<153	<156	<163	<161
Kjeldahl N	731	1100	313	429	889
Cyanide	<0.2	0.119	0.175	1.10	0.154
Ni	17	15.1	16.4	17.9	16.1
Se	<0.44	<4.95	<4.85	<4.94	<4.98
Sb	<0.99	<2.97	<2.91	<2.96	<2.99
Cr	16.5	14.7	15.4	16.7	16.8
Cu	19.3	25.1	25.4	31.8	27.0
As	<0.39	5.89	6.05	6.53	6.73
Be	<0.98	0.50	0.51	0.55	0.59
Ag	<0.2	<0.99	<0.97	<0.99	<1.0
Cd	3.38	1.47	1.75	2.04	1.61
Zn	67.9	70.9	75.1	92.7	78.3
Th	<0.2	<1.98	<1.94	<1.98	<1.99
Pb	7.71	8.17	8.06	9.23	8.80
Hg	<0.19	<0.02	<0.02	<0.02	<0.02
Total Phosphate as P (S4500PE)	1,210	2,400	2,550	2,590	2,430
Total Organic C (5310B)	35,300	11,000	14,000	20,000	19,000
pH	7.9	7.3	7.5	7.1	7.6

Note: Non-detect or "censored" results are reported as < the method detection limit.

Results:

Selected soil sampling results from unamended control plots and post-treatment condition soil samples are presented in Table 1. No detectable concentrations of pesticides, PCBs, or semi-volatile compounds (EPA Methods 8081A, 8082, 8260B, 8270C respectively) were found in the initial soil or biosolids samples or post-treatment soil samples (results from biosolids alone (November 2019) are available in Appendix 1). Ammonia as N, Total Kjeldahl N, copper, zinc, and Total Organic C were greater in the biosolids samples than in unamended soil (control). Total Phosphate was greater in Class A compost and Class B cake. Organic N was greater in Class B and Class A heat-dried pellets.

In post-treatment samples, As and Total Phosphate were greater in all plots including the Control. Post-treatment sample results were extremely similar between plots with exception of Organic-N (Class A compost was greatest) and Total Organic C (Pellets and Control were greater). These are single results and not estimates of means or medians and should be viewed qualitatively; however, they show that the amendments were unlikely to increase concentration of these constituents in the treated soil.

Selected runoff water quality results are presented in Table 2. Due to the low number of rain events and small sampling size, results were grouped by amendment plot type resulting in an *n* of 7-9 for each analyte. Figure 2 presents runoff amounts in centimeters. There is a noticeable difference noted in compost amended plots ("A") compared to others.

Organic chemicals, including volatile and semi-volatile organics, pesticides, and PCBs, analyzed by EPA Methods 624.1, 625.1, 608.3, were not detected in any runoff sample with the exception of Isophorone. Several metals had non-detects as well as detections including nickel, selenium, cadmium, chromium, copper, and mercury. All other results were normalized for flow rate to present mass exported (mass of compound lost to runoff) – achieved by multiplying *mass-units/L * volume of runoff captured (L) - per unit area*. Results below the detection limit are included at the detection limit but flagged as censored (e.g., "ncen" or number or censored results).

Table 2. Upper Confidence Limits on mean/median flow-weighted Mass export concentrations by treatment type				
	Class A – compost	**Class B – cake**	**Class A – heat-dried pellets**	**Control**
Organic N (cen)**	131	496	**3,546** (ncen=1)	89.4
NH_4-N*	110	1,201	**4,936**	28.9
Kjeldahl N*	213	1,442	**5,848**	96.4
NO_3-N	49.5	351	**653**	141
Cyanide (cen)	NA	0.159 (ncen=1)	**0.364**	0.032 (ncen=3)
Isophorone (cen)	NA	12.4 (ncen=1)	**14.3** (ncen=3)	NA
Total Phosphate*	14.7	31.0	**257**	35.5
Ni (cen)	0.785 (ncen=2)	0.965 (ncen=1)	1.17	**2.41** (ncen=3)
Se (cen)	0.188 (ncen=5)	0.169 (ncen=7)	**0.232**	NA
Cr (cen)**	0.0103 (ncen=4)	0.0008 (ncen=5)	0.069 (ncen=6)	**8.37** (ncen=6)
Cu (cen)	0.267	1.16	**5.00**	3.54 (ncen=2)
As	0.456	0.088	**0.492**	0.086
Cd (cen)	0.014 (ncen=5)	0.006 (ncen=3)	0.006 (nncen=5)	0.547 (ncen=5)
Hg (cen)**	0.560	0.206 (ncen=2)	0.283	**2.07** (ncen=2)
Pb	NA	NA	NA	NA
Zn	0.543	0.383	**1.13**	0.995
Total Suspended Solids	355	1,344	2,252	**2,725**
Volatile TSS	168 (max)	66.7 (max)	333 (max)	**682** (max)

Notes: For data with censored values the MLE UCL was calculated and censored number reported.
"ncen" represents the number of censored values in the sample
For data with no non-detects, a Bootstrap UCL was calculated. Where results were available for less than n=4, the max value is reported.
Missing data is reported as "NA".
Greatest value UCL per compound is underlined and bolded.
*Indicates a significant difference was detected; **indicates a significant difference using censored data methods.

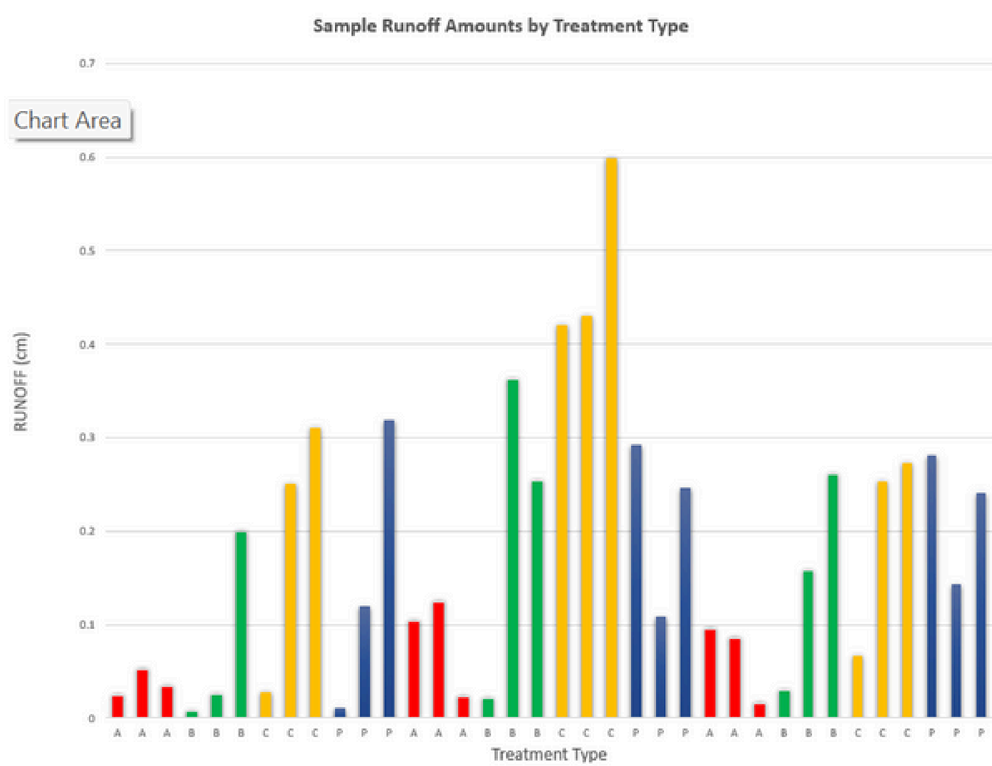


Figure 2 Runoff in cm from plots A - compost, B - cake, C - control, P - pellets. Qualitative results show a dramatic decrease in runoff in A – compost; 12 samples by 4 conditions, collected over 3 sampling events.

Statistical Analysis

Statistics were computed in R-Studio using NADA and NADA2 (for censored data), EnvStats, and other packages after Helsel and others 2020. Bootstrapping is recommended for small sample sizes without censoring. Data with censored results (results that are below detection limits) should be treated with non-parametric methods (Kaplan-Meier Mean Estimates), and quasi-lognormal methods including Regression on Order Statistics (ROS) and Maximum Likelihood Estimation (MLE).

We prepared Upper Confidence Limits (UCLs) on the mean/median of exported mass for selected compounds in run-off. About half of the compounds had one or more censored value. The UCLs were prepared following Helsel (2020) and are an appropriate estimate of data central tendency for each selected compound by treatment type (i. e., A, B, P, and C). Results without censored data use a Bootstrap UCL technique. Results estimated with censored data use a Maximum Likelihood Estimation (MLE) UCL technique. These results are presented in Table 2.

Differences between sampling events were evaluated. In very few cases were significant differences detected (Cyanide: March is greater than January $p=0.0279$, Nitrate as N: March is greater January $p=0.0058$, using censored ANOVA). No other apparent effects were observed due to sampling event/storm event. For this reason, other analytes could be analyzed in aggregate.

We used NADA2 and EnvStats packages to evaluate differences in means for mass export of mercury with censored data. The aggregated mercury mass export data ($n=33$) follow a quasi-lognormal distribution including the percentile of data below detection limits (Shapiro-Francia $W=0.974$). A censored Permutation Test of mean mass export by treatment type shows a significant difference (Test Statistic =10.86 to 10.89, $p = 1e-4$) with higher means for pellets (P, 1.09) and unamended (C, 0.084) compared to compost (A, 0.042) or cake (B, 0.057).

Among compounds with no censored values, Nitrogen as Ammonia, Total Kjeldahl Nitrogen, and Total Phosphate demonstrated a significant difference based on treatment type. This was confirmed with the Kruskal-Wallace Test, One-Factor ANOVA, the Fligner-Killeen test and finally a Permutation One-Factor Test on means.

Discussion:

Denuded burn scars from the Woolsey Fire (November 2018) were treated with 3 types of biosolid amendments. Runoff water samples were collected following storm events to compare effects of a single application of amendments on runoff water quality. Results were evaluated on a flow-weighted basis.

Crohn et al. (2013) found that pollutant losses from burn scars are controlled by composts because runoff is greatly reduced. This is evident in the total runoff measurements in this study (see figure 2). Vegetation further improves the stability of slopes though the revegetation performance of specific treatments was not studied here. Our study goal was to determine if biosolids addition increases revegetation and leads to a reduction in runoff and chemical compound mass exports compared to control plots. The study was carried out for 2 rainy seasons between 2019 and 2021 at the LVMWD composting facility.

Estimated statistical parameters in this study should provide reliable and reproducible estimates of mass export in similar environmental conditions and similar treatment types and application rates. Though the data set is small, UCLs can be generated as likely values for the mean or median of compound concentrations and given appropriate data distribution assumptions. The UCL is the upper end of the data range and sometime called the "margin of safety" for estimates of data central tendency. Therefore, UCLs can be used then to compare regulatory thresholds or other reference value (such as the results from a control group or a subsequent study) (Helsel 2012, Helsel 2020). Our results give a robust estimate of expected compound mass export under similar conditions. Results overall support that the application of biosolids to burn scars decreases runoff quantities and does not increase pollutant loads to surface waters.

Both Class A compost and Class B cake encouraged rapid revegetation in experimental plots as compared to Class A pellets and control plots based on visual observation. Quantifying revegetation was beyond the scope of this study. Impacts to water runoff appeared to be indistinguishable from control plots. No organic chemicals were detected in any of the runoff water samples. Based on UCLs, Class A compost plots outperformed (i.e., had lower concentrations) the other amendments in nutrient mass export and all plots in TSS export (including the control plot).

Biosolids products are effective for reclaiming burn scars as they encourage revegetation, improve soil health, and decrease runoff. Land reclamation using biosolids compost could benefit other impaired sites including mine sites and impaired urban landscapes without negatively impacting receiving water. The study provides needed science on what compounds are important in surface water monitoring after burn scars and what mass export concentrations a practitioner may anticipate. Our results demonstrate that land application of Class A compost and Class B cake does not increase pollutant mass export compared to unamended soils. Class A heat-dried pellets had highly variable results. Presumably, this was simply due to the observation that they would roll off the plots directly into the water catchment. Testing on a gentler slope is advised. Applicators should manage biosolids loading rates and periodically collect runoff samples, adjusted based on run off volume, to reflect the mass export per unit treated area. Further sampling studies are recommended to compare treatments, in particular compost treatments, to address runoff and erosion at burn scar sites.

References

Crohn, D.M., Chaganti, V.N., Reddy, N., 2013, Composts as post-fire erosion control treatment and their effect or runoff water quality, Transactions of the American Society of Agricultural and Biological Engineers, ISSN 2151-0032, Vol. 56(2):423-435.

Meyer, V. F., Redente, E. F., Barbarick, K. A., Brobst, R. B., Paschke, M. W., and Miller, A. L., 2004, Plant and Soil Responses to Biosolids Application following Forest Fire, Ecosystem Restoration, Journal of Environmental Quality, 33:873–881.

Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A., and Gilroy, E.J., 2020, Statistical methods in water resources: U.S. Geological Survey Techniques and Methods, book 4, Chapter A3, 458 p., https://doi.org/10.3133/tm4a3.

Helsel, D.R., 2012, Statistics for censored environmental data using Minitab and R, 2nd ed., John Wiley & Sons, NJ.

APPENDIX 1

	Full results at treatment commencement – November 2019 mg/kg			
	A - compost	**B - cake**	**Pellets**	**Control (unamended soil)**
Organic N	18,900	53,100	52,400	678
NH_4-N	7,670	9,600	3,430	53
Kjeldahl N	26,600	62,700	55,800	731
Cyanide	3.46	<0.2	<0.24	<0.2
Ni	12	26.8	20.1	17
Se	<0.45	<0.43	<0.45	<0.44
Sb	<0.7	<0.67	1.38	<0.99
Cr	11.4	27.4	28.9	16.5
Cu	176	348	250	19.3
As	<0.4	<0.49	2.46	<0.39
Be	<0.02	<0.06	<0.02	<0.98
Ag	1.49	2.86	2.26	<0.2
Cd	2.44	5.78	1.93	3.38
Zn	333	677	623	67.9
Th	<0.2	<0.19	<0.2	<0.2
Pb	4.17	7.28	5.22	7.71
Hg	0.224	1.08	0.5	<0.189
Total Phosphate as P (S4500PE)	4240	14900	161	1,210
Total Organic C (5310B)	414,000	775,000	464,000	35,300
pH	6.6	7.6	6.9	7.9

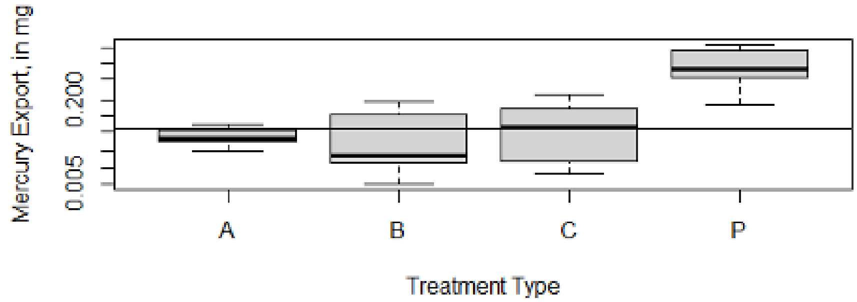


Figure 3 Mercury mass export by treatment type. Data is censored; line represents highest detection limit (significant difference detected).

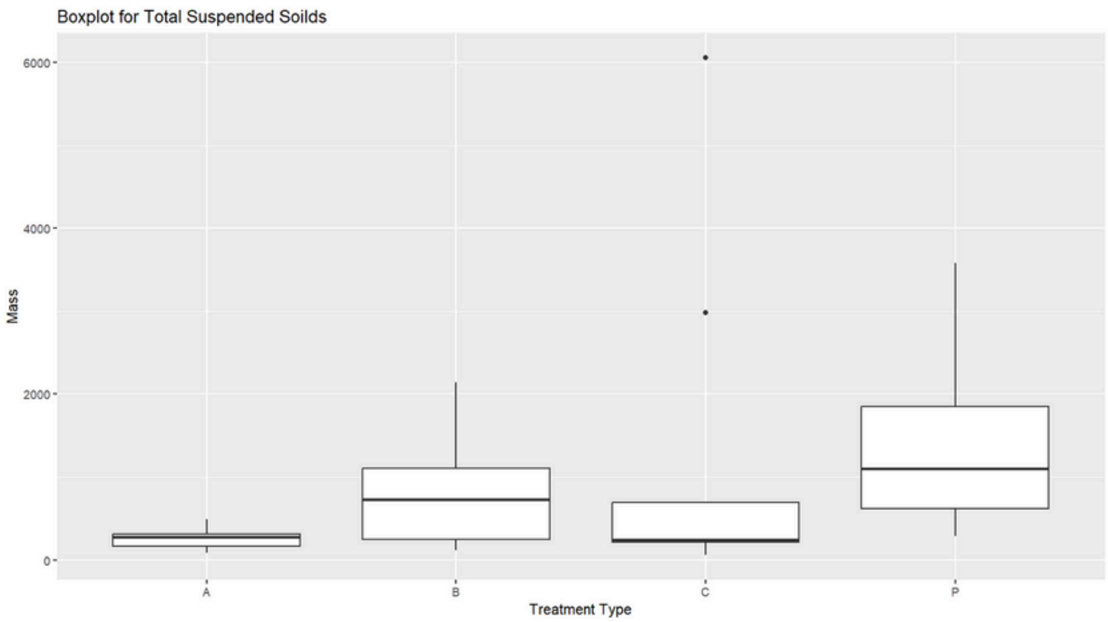


Figure 4 Total Suspended Solids mass export by treatment type.

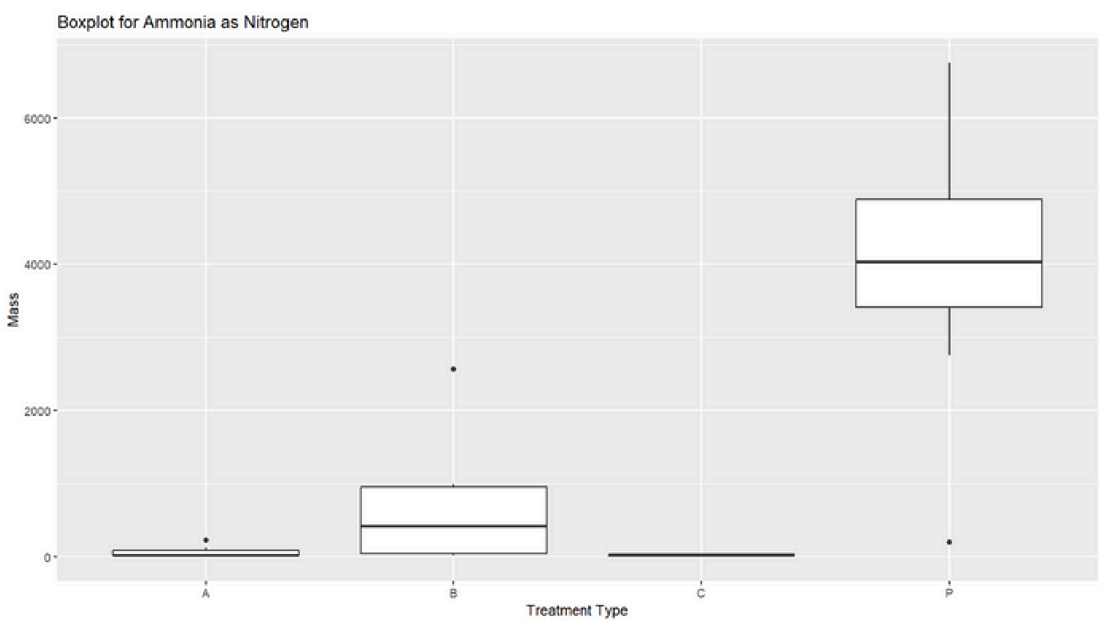


Figure 5 Ammonia as Nitrogen mass export of by treatment type (significant difference detected).