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Extraction of Zinc from Airport Stormwater Runoff using Oyster Shells

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Zinc (Zn) in stormwater runoff have been found to be highly toxic to aquatic ecosystems. A pilot program was evaluated for the removal of Zn levels from stormwater runoff at a west coast airport facility showing high levels of Zn runoff in the stormwater drainage. The objective of this research was to evaluate the effectiveness of the pilot program by reviewing three aspects of the stormwater runoff: 1) water sampling from influent and effluent roof runoff; 2) whether Zn particles were absorbed into the oyster shell fragments; and 3) whether Zn particles were attached to fragmented oyster shells and/or compost materials. The use of fragmented oyster shells mixed into compost and sand served as a medium for the remediation of Zn from stormwater runoff from unpainted galvanized hangar roofing. Influent and effluent water samples determined the effectiveness of an oyster medium in the removal of Zn levels. Data obtained from the influent water samples showed excessive amounts of Zn particles in stormwater, whereas the effluent levels showed a capture rate of > 99% of Zn from the stormwater system. No signs of Zn particles were found inside the fragmented oyster shells, nor were there an abundant amount of Zn particles found in the other medium.

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The objective of this study was to evaluate the effectiveness of a pilot program being done at the Snohomish County Airport (herein referred to as "the Airport" or "Airport") with their consultant, Landau Associates Inc., Edmonds, Washington, to lower Zn effluent to a level below the Washington State Department of Ecology benchmark of 117 µg/L. This study evaluates the effectiveness of the filtering system that Landau Associates Inc. designed to capture or extract Zn from stormwater before it can enter the watershed. To do this, there were three elements of the pilot program that were evaluated: 1) whether tests from influent and effluent showed a decrease in Zn levels to an acceptable level; 2) if the Zn penetrated the fragmented oyster shells; and 3) if Zn was captured within all the medium or the fragmented oyster shells alone.

The Airport is situated on 1,315 acres of land and is located 30 miles north of downtown Seattle, six miles southwest of Everett, Washington. The Airport is less than one mile from the Puget Sound. According to the airport master record, the Airport currently has approximately 524 based aircraft and 108,087 operations over a 12-month period ending January 1, 2018. This airport is classified as a reliever airport under the National Plan of Integrated Airport Systems (NPIAS). Runway 16R/34L is the primary runway with an orientation to the north/south. The runway is 9,010 feet long by 150 feet wide and has a Cat I ILS approach. The secondary runway is 16L/34R and is 3,004 feet long by 75 feet wide. The airport does have a third runway 11/29 with an orientation to the east/west. Runway is 4,504 feet long by 75 feet wide; however, the runway has been closed indefinitely. The airport is a certified FAR Part 139 airport and is home to The Boeing Company B747, 767, 777, and 787 aircraft manufacturing plants. Aviation Technical Services (ATS) is a Maintenance Repair Operation (MRO) located at the south end of the airport. The MRO performs maintenance and inspections on airlines. The Airport has a total of 326 general aviation hangars of all sizes located in the central and east sides of the airport, as well as six privately owned condominium T-hangars on the southeast side of the airport.

Literature Review

"A common use for zinc is to coat steel and iron as well as other metals to prevent rust and corrosion; this process is called galvanization" (Roney, Smith, Williams, Osier, & Paikoff, 2005, pp. 1-2). Airport facilities commonly have unpainted, galvanized corrugated metal hangar roofing, and over time, weathering and rain remove fine Zn particles from the galvanized metal, entering storm drains and flowing into streams and rivers. Good’s (1993) study of roof runoff of metals and aquatic toxicity in stormwater found extremely high Zn concentrations in stormwater runoff from unpainted, galvanized roofing. The high levels of Zn discovered in the stormwater runoff were found to be very toxic to rainbow trout (Good, 1993). Irwin, VanMouwerik, Stevens, Seese, and Basham (1997) looked at Zn environmental hazards and found “in western watersheds that are affected by metals, particularly copper and zinc, that fish kills were associated with runoff and rainstorm events” (p. 7). The Seattle-Tacoma International Airport has tested a radial-flow filtration container to reduce stormwater Zn from airport buildings, resulting in a 60-90% reduction of dissolved Zn from leaf compost medium filters (Noling, 2004). Elevated Zn levels also have been discovered at other airports that have unpainted, galvanized hangar roofing such as the Snohomish County Airport in Everett, WA. (A. Rardin, personal communication, December 19, 2016).

Köhler, Cubillas, Rodríguez-Blanco, Bauer, and Prieto (2007) documented the effect of the size of fragments of calcium carbonate shells on their capacity to uptake, or absorb, dissolved metals. Their study found a progressive increase in the removal rate of cadmium, as well as Zn, as the shell size fraction decreased. From the Köhler et al. (2007) study, we expected to see high levels of Zn in the influent to the treatment tanks reduced by the incorporation of fragmented oyster shells in the treatment medium. The research team did not know if there would be any removal of Zn using the medium materials without the fragmented oyster shells.

Analyses of samples collected in accordance with the National Pollutant Discharge Elimination System (NPDES) permit for this site indicated elevated Zn levels greater than 14,000 µg/L in storm runoff from the east condominium hangars. The Washington State Department of Ecology - Industrial Stormwater General Permit (ISGP) Zn benchmark value is 117 µg/L (Bartlett, 2015).

Materials and Methods

Two of the six condominium hangars (C-17SE and C18-NE) at the Airport were used in the pilot program. Both hangars have unpainted, galvanized roofing panels. The partial treatment area for C17-SE is ~2,850 square feet (one-fourth the area of the total hangar roof surface), and for C18-NE ~1,476 square feet (one-fourth the area of the total hangar roof surface). Rainwater and weathering remove Zn particles from the roofing panels, which are then captured within the medium (Polka & Ninteman, 2015). Two types of tanks, cylindrical and rectangular, were used in the pilot program. For this research, only the medium from the cylindrical tanks were sampled. Figure 1 displays the location of the east condominium hangars in relationship to the surrounding area.

Existing rain gutters and modified downspouts were used on the hangars being evaluated in the pilot program. Large plastic tanks were then placed under the drain spouts and a French drain was inserted at the bottom of each tank. A treatment medium (consisting of 25% fragmented oyster shells, 15% compost, and 60% sand) fills the tank to within 17 inches from the top. This gap provided enough space in each tank to prevent water from overflowing as the water seeped through the underlying medium. Water samples were collected from the tanks three times in 2016 and twice in 2017 to determine the Zn levels in the influent and effluent from the tanks.

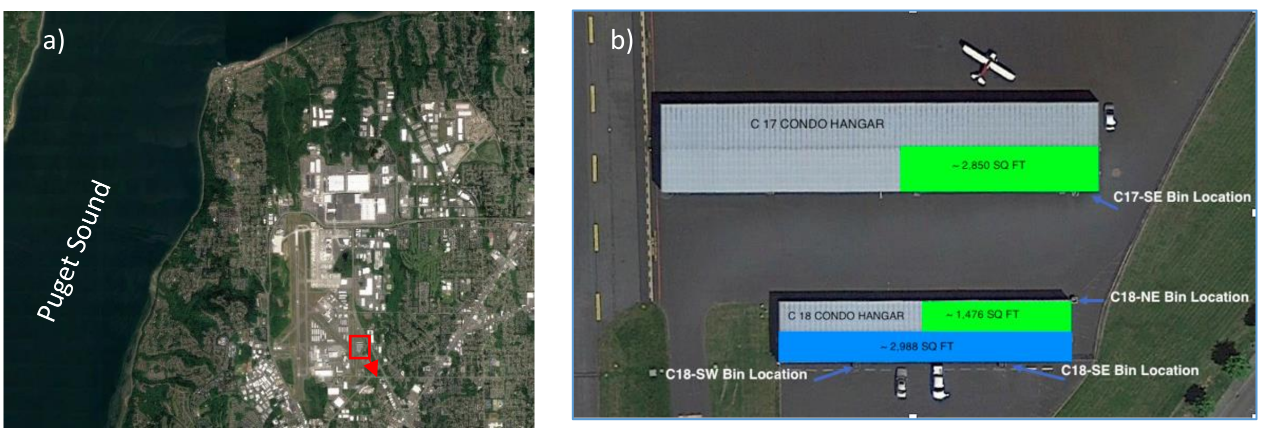


Figure 1. (a) Photo from Google Earth showing the location of Paine Field east condo hangars including watershed direction, (b) east condo hangars C-17 and C-18.

Treatment Tanks

Two cylindrical tanks are inside the Airport Operations Area; each have a capacity of 210 gallons. These tanks receive roof runoff from the southeast section of hangar C17 (known hereinafter as C17-SE) and the northeast section of hangar C18 (known hereinafter as C18-NE), respectively. Samples were collected from these tanks for evaluation in the University laboratory.

Two rectangular tanks outside the Airport Operations Area have a capacity of 276 gallons each. These tanks receive roof runoff from hangars C18-SE and C18-SW. Only water samples were collected from these tanks.

After the rainwater seeps through the medium in each tank, it then drains out of the French drain directly into storm drains. Stormwater from the east condominium hangars flows off airport property into the Swamp Creek drainage basin, which in turn feeds Lake Washington.

Figure 2(a) shows the cylindrical tank located at hangar C18-NE. Figure 2(b) is a typical view peering into the tank from the top, displaying the two areas (inside and outside sections) from which medium samples were collected, and later analyzed in the laboratory. A sample of fragmented oyster shells was provided to the researchers to be used to establish the starting level of Zn on the shells before they were used as part of the medium in the tanks.

Figure 2. (a) The cylindrical tank for C18-NE being tested. (b) Locations where samples were collected.

The Airport will replace the treatment medium when Zn levels in the effluent samples start to rise above the levels in previous quarterly samples. The medium used in this pilot study is expected to last up to three years (A. Rardin, personal communication, December 19, 2016).

Results and Discussion

Analysis of samples of stormwater runoff both before (the influent) and after (the effluent) water had filtered through the treatment medium indicated the effectiveness of the medium to remove total Zn from the water. The fate of the Zn removed from the inflowing stormwater was explored by analyzing samples of the treatment medium as well as subsamples of its various components - the oyster shells, the compost, and the sand.

Analysis of Water Samples

Water samples were collected from the cylindrical treatment tanks at hangars C-17 SE and C-18 NE by Landau Associates Inc. on January 12, May 19, and October 13, 2016, and on April 7, and October 23, 2017. The samples were placed in an ice chest, packed in ice, and delivered to an ALS Environmental Group Laboratory at a temperature of ~3.9°C. ALS Environmental used EPA Method 200.8 to test for Zn levels. This method provides for the determination of trace elements in waters and wastes by inductively coupled plasma-mass spectrometry testing method (Long, Martin, & Martin, 1990).

The Certificate of Analysis from ALS Environmental shows the results of the analyses of the influent (untreated runoff) and effluent (water that has passed through the treatment medium) samples for Zn in the stormwater for the period of January 2016 through October 2017 (Bagan, 2016), and (Tables 1 and 2).

The large increase in total Zn levels in samples collected on April 7, 2017, at C18-SW and C17-SE could not be explained. Record rainfall occurred between October and April, but there were no large increases in Zn levels in samples from either of the other two remaining tanks to indicate that the increased rainfall was the cause. Inspections of the roof drainage systems to the ground tanks and of the roofing itself indicated nothing out of the ordinary that would explain the higher Zn levels, although roof degradation in those areas may have been a contributing factor (A. Rardin, personal communication, May 9, 2017).

The NPDES permit for Snohomish County Airport specifies only total levels of Zn; therefore, only the total Zn was evaluated in this study. Results of the water analyses show a >99% reduction in total Zn to a level well below the Washington State EPA (WSEPA) benchmark value for Zn of 117 ug/L (micrograms per liter).

Table 1

Results of Analyses for Zn in Samples of Stormwater Runoff at Hangar C-17 SE

Date	C17-SE (Total Influent Zn) *(µg/L)*	Washington State EPA Benchmark for Zn *(µg/L)*	C17-SE (Total Effluent Zn) *(µg/L)*	Percentage Zn Removed
01/12/16	8,000	117	17.0	99.7875%
05/19/16	7,000	117	7.3	99.8957%
10/13/16	7,100	117	2.8	99.9605%
04/07/17	18,000	117	18.0	99.9000%
10/18/17	9,600	117	7.2	99.9250%

Influent samples are of untreated water as it runs off the hangar roof. Effluent samples are of the water after it has seeped through the treatment medium, but prior to entering the stormwater drainage system.

Table 2

Results of Analyses for Zn in Samples of Stormwater Runoff at Hangar C18-NE

Date	C18-NE (Total Influent Zn) *(µg/L)*	Washington State EPA Benchmark for Zn *(µg/L)*	C18-NE (Total Effluent Zn) *(µg/L)*	Percentage Zn Removed
01/12/16	10,000	117	19.0	99.8100%
05/19/16	6,200	117	8.3	99.8661%
10/13/16	6,200	117	6.2	99.9000%
04/07/17	11000	117	25.0	99.7727%
10/18/17	12,000	117	12.0	99.9000%

Analyses of effluent samples collected from two rectangular tanks at hangars outside the airport operations area, C-18 SW and C-18 SE, also showed a >99% efficiency in removal of Zn from the hangar roof runoff (Tables 3 and 4).

Table 3

Results of Analyses for Zn in Samples of Stormwater Runoff at Hangar C18-SW

Date	C18-SW (Total Influent Zn) *(μg/L)*	Washington State EPA Benchmark for Zn *(μg/L)*	C18-SW (Total Effluent Zn) *(μg/L)*	Percentage Zn Removed
01/12/16	14,000	117	13.0	99.9071%
05/19/16	7,300	117	3.5	99.9520%
10/13/16	8,200	117	1.25	99.9847%
04/07/17	52,000	117	5.3	99.9898%
10/18/17	14,000	117	9.0	99.9357%

Even though the analyses of influent samples collected at hangars C17-SE and C18SW on April 7, 2017, showed extremely high concentrations of Zn (Tables 1 and 3), the analyses of the effluent samples indicated the efficiency of the filtering medium (≥99%) in removing the Zn from stormwater runoff.

Table 4

Results of Analyses for Zn in Samples of Stormwater Runoff at Hangar C18-SE

Date	C18-SE (Total Influent Zn) *(μg/L)*	Washington State EPA Benchmark for Zn *(μg/L)*	C18-SE (Total Effluent Zn) *(μg/L)*	Percentage Zn Removed
01/12/16	2,700	117	8.8	99.6740%
05/19/16	7,300	117	1.25	99.9828%
10/13/16	8,700	117	1.25	99.9856%
04/07/17	6,000	117	3.6	99.9400%
10/18/17	12,000	117	11.0	99.9083%

Analyses of Treatment Medium Samples

To determine the fate of the Zn removed from the stormwater runoff, samples of the treatment medium were collected for analysis. The samples were collected (by the senior author) from the treatment tanks at hangars C17-SE and C18-NE with a plastic spoon (to avoid metal contaminating the samples) and placed in plastic laboratory-provided sample bags. The samples were frozen and remained frozen until analysis at the University laboratory. At the laboratory, subsamples of the various components of the treatment medium were then prepared for analysis using the Optima 8000 Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and (or) Hitachi S-2600N Scanning Electron Microscopy with an Energy Dispersive X-Ray (SEM & EDX) technique.

ICP-OES is an analytical tool that can identify and quantify the elements present in a sample at concentrations down to parts-per-billion levels. A more qualitative method, SEM & EDX, allows the evaluation of the distribution and binding of metal ions on the surface of a sample. The scanning electron microscopy focuses a narrow beam of electrons on the sample to produce an image of the surface structure at the nanoscale. The EDX coupled with SEM characterizes the chemical composition within the SEM image and provides more quantitative elemental mapping of the sample surface.

Three test runs were made of 1-gram subsamples of each of the treatment medium samples collected from the two treatment tanks. Thus, six analyses were made on samples from each tank, three on the sample from the inside section of each tank, and three on the sample from the outside section of each tank (Figure 1(b)). The ICP-OES analyses were based on the Standard Reference Material 2781 for Domestic Sludge specified by the National Institute of Standards and Technology (NIST) (2015). The results of those analyses are shown in Tables 5 and 6.

A fresh specimen of the oyster shell fragments that were used in the treatment medium was obtained from the airport maintenance department. A sample of the fragments, which ranged in size from 1 mm to 20 mm, were then prepared for analyses in triplicate by ICP-OES methods. The results of those analyses – the concentrations of Zn in the shells alone (the control specimen) – represented the base level of Zn in the shells. These initial Zn levels in the shells could then be subtracted from those in the treatment medium samples to determine the "true" amount of Zn that was removed from the influent stormwater by filtration through the medium (Tables 5 and 6).

The results of the ICP-OES analyses of the samples of the medium from the two tanks indicate that the outside sections of the tanks "outperformed" the inside sections in terms of the extraction of Zn from the stormwater. Figure 2(b) shows the arrangement of the perforated pipes that allows the inflowing stormwater to be distributed across the top of the tank, which results in more water entering and filtering through the outside section of the tank. The sample from the inside section of the tank at hangar C18-NW contained an average (for three "runs") concentration of Zn of 10,158 ug/g dw (micrograms per gram in dry weight); in the sample from the outside section of this tank, the analyses showed a concentration of Zn of 13,616 ug/g dw. Results were comparable for the samples from the tank at hangar C17-SE – concentrations of Zn were greater in samples from the outside section of the tank (Tables 5 and 6).

Table 5

Results of Analyses for Zn in Samples of Medium in Stormwater Treatment Tank at Hangar C17-SE

C17-SE	Run 1 µg/g dw	Run 2 µg/g dw	Run 3 µg/g dw	Average µg/g dw
Inside Sample	10,024	10,428	8,908	9,787
Controlled Specimen	(3.333)	(3.333)	(3.333)	3.333
Total Inside Sample	10,021	10,424	8,905	9,783.33
Outside Section	7,883	12,416	12,836	11,045
Controlled Specimen	(3.333)	(3.333)	(3.333)	3.333
Total Outside Sample	7,880	12,412	12,833	11,041.67

Note. The Controlled Specimen is the fresh oyster shells before being used in the treatment medium.

Table 6

Results of Analyses for Zn in Samples of Medium in Stormwater Treatment Tank at Hangar C18-NE

C18-NE	Run 1 µg/g dw	Run 2 µg/g dw	Run 3 µg/g dw	Average µg/g dw
Inside Section	11,524	10,037	8,914	10,158
Controlled Specimen	(3.333)	(3.333)	(3.333)	3.333
Total Inside Sample	11,521	10,033	8,911	10,155
Outside Section	16,297	10,245	14,301	13,614
Controlled Specimen	(3.333)	(3.333))	(3.333)	3.333
Total Outside Sample	16,294	10,241	14,298	13,611

Note. The Controlled Specimen is the fresh oyster shells before being used in the treatment medium.

Scanning Electron Microscope (SEM) deploys an electron beam on conductive or semi-conductive sample surface to obtain the surface imaging information at the nanoscale. Energy Dispersive

X-Ray (EDX or EDS) spectrometer coupled with SEM could characterize each element on the surface and provides more quantitative elemental mapping.

Fragmented oyster shells were collected from the medium and washed with tap water. One cleaned shell was cracked manually into two pieces for the measurements on the outer surface, the inner surface, and the cross-section. The samples were first coated with a thin gold (Au) layer to increase its conductivity in a Hummer VI Sputter Coating Machine (Hummer VI, Anatech Ltd., Hayward, CA). The scanning electron microscope (SEM) observations were carried out in a Hitachi S-2600 SEM. The "Quartz XOne" Energy-Dispersive X-ray (EDX) system (Quartz Imaging Corporation, Canada) equipped on the Hitachi SEM was used to collect the EDX spectra and analyze the element fittings.

The structure and the elemental components are found to be consistent at various sites on the outer surface. As shown in Figure 3(a), irregular-shaped clusters, in tens of microns, adhere to the top of a fine porous layer. The pore size is about 300nm and less. The EDX spectrum (Figure 3(b)) indicates three major components on the outer surface: zinc, calcium, and iodine. Among them, Zn is dominant, with a weight percentage of 80% ~ 90%.

Analyses of Oyster Shells within the Medium

Fragments of oyster shells were collected from the medium and thoroughly washed with tap water. The cleaned fragment was then cracked manually into two pieces to enable measurements and analyses of the outer surface, the inner surface, and the broken surface, or cross section of the shell. The samples were first coated with a thin layer of gold to increase their conductivity in a Hummer VI Sputter Coating Machine (Hummer VI, Anatech Ltd., Hayward CA). Scanning electron microscope images of the shell surfaces were made in a Hitachi S-2600 SEM. The "Quartz XOne" Energy-Dispersive X-ray (EDX) system (Quartz Imaging Corporation, Canada) on the scanning electron microscope was used to collect the EDX spectra and analyze the chemical character of the sample.

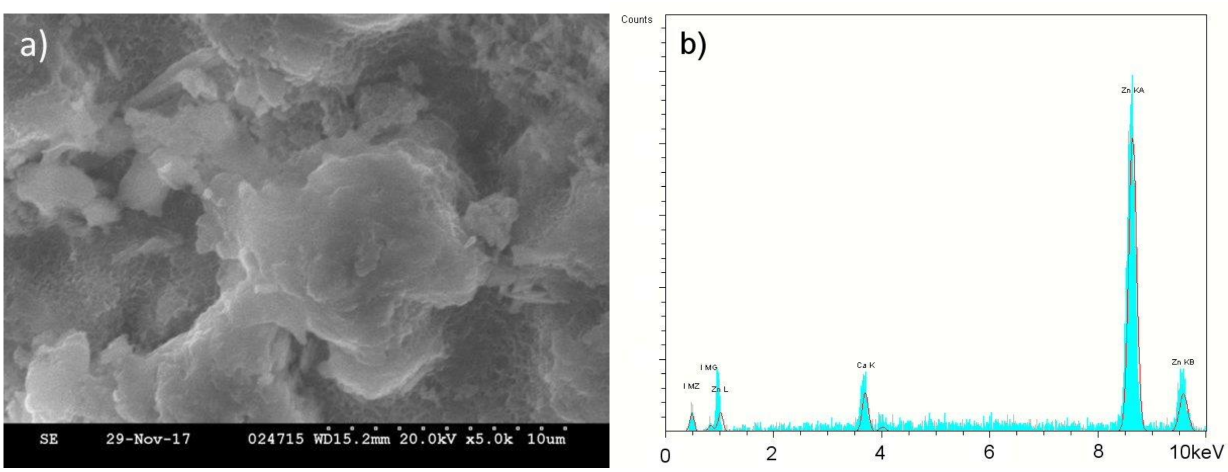


Figure 3. (a) The SEM image. (b) EDX spectrum on the outer surface of the oyster shell.

The inner surface of the shell shows a different morphology than the outer surface. Three typical morphological features were observed on the shell's inner surface, examples of which are designated by numbered arrows in Figure 4(a). EDX spectra indicate the presence of calcium and iodine in the features labeled 1 and 2; the spectrum for feature 1 and 2 is shown in Figure 4(b). Zinc was indicated only in the spectrum for feature 3 (Figure 4(c)). The proportion of each element on feature 3 was similar, within the error limits of the method, to that on the outer surface of the shell. Additionally, the feature labeled 3 shows a micro-structure (clusters and fine pores) similar to that on the outer surface. Therefore, we deduce that the elements contained in feature 3 could have come from the "crumbles" on the outer surface when the shell was cracked for sample preparation.

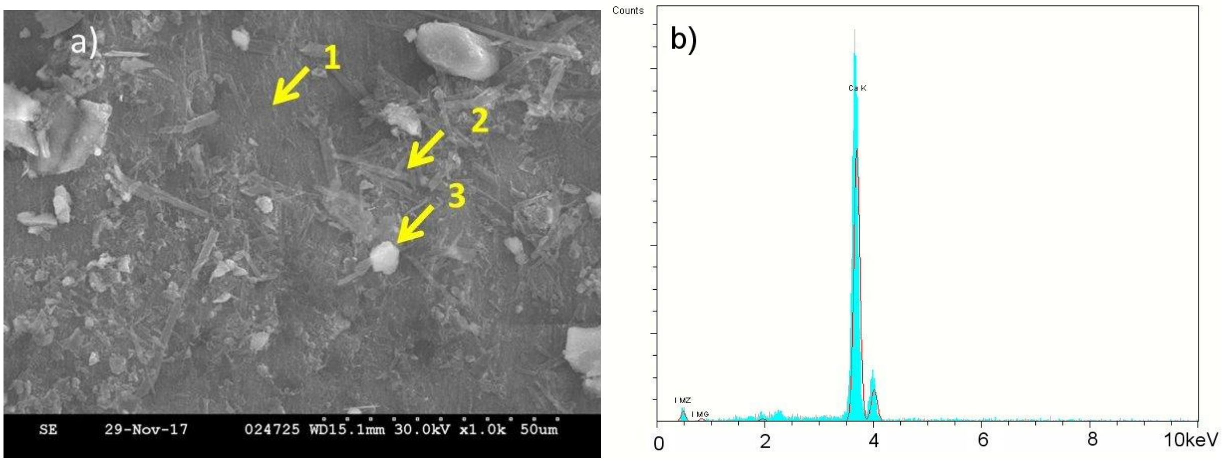
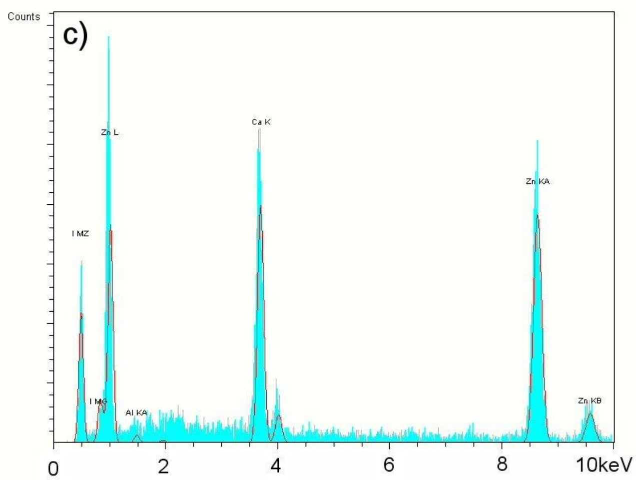


Figure 4. (a) The SEM image on the inner surface of the oyster shell. (b) EDX spectrum on Feature 1 and 2.



(c) EDX spectrum on Feature 3.

The SEM image of the shell cross section (Figure 5(a)) shows that most of the shell body is composed of stacked layers, except for a thin veneer at the outer surface. Three EDX scans were made of the shell cross section, from the inner surface to the outer surface (Figures 5(b), (c), and (d)). Zinc was present only in the veneer at the outer surface of the shell (Figure 5(d)). The exact thickness of this veneer could not be measured directly because of the limit of the EDX resolution. From the difference in the morphological structures on the SEM image, however, the thickness is estimated to be about 20 µm or less, which is <5% of the total shell thickness.

The absence of Zn inside the shell body (Figure 5(c)) supports our earlier conclusion that the Zn in the small clusters in the area labeled 3 on the inner surface of the shell (Figure 4(a)) is from the outer surface rather than being present within the internal structure of the shell itself. Additionally, the iron and chromium indicated by the EDX spectra near both the inner and outer surfaces of the shell (Figures 5(b) and (c)) is thought to represent contamination from the EDX sample holder, which is made of magnetic steel.

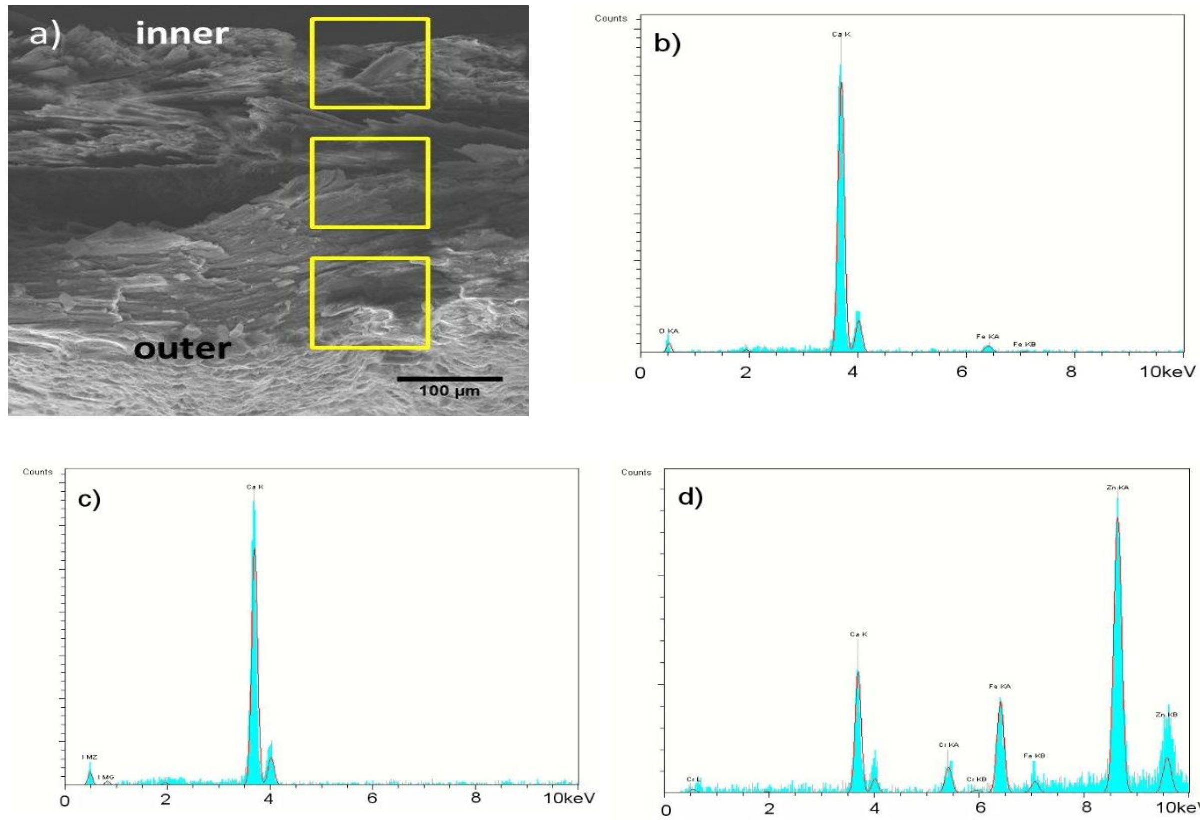


Figure 5. The SEM image of the shell cross section and the EDX spectra collected on three different regions. The three yellow squares in (a) the SEM image mark the scanning regions for the EDX spectra. (b), (c), and (d) from the inner surface (top) to the outer surface (bottom) correspondingly.

Analyses of Compost Mixture

A final set of analyses were made to determine if Zn was captured within the compost mixture or on the fragmented oyster shells alone. From the treatment samples of wet compost collected from the cylindrical tanks, 3-gram subsamples were prepared for analyses by SEM and EDX methods. The subsamples were air dried in a vacuum hood for one week. The dried powder was fixed on an SEM sample holder (stub) with conductive tape and a layer of gold was applied to the sample surface.

A typical view of the dried compost powder under SEM is shown in Figure 6. Six areas of interest were labeled, and the elements within these areas were analyzed with EDX. For the areas with a smooth surface, such as that labeled 1 in Figure 6 and shown in an enlarged view in Figure 7(a), the major component is silicon dioxide (SiO_2) (b).

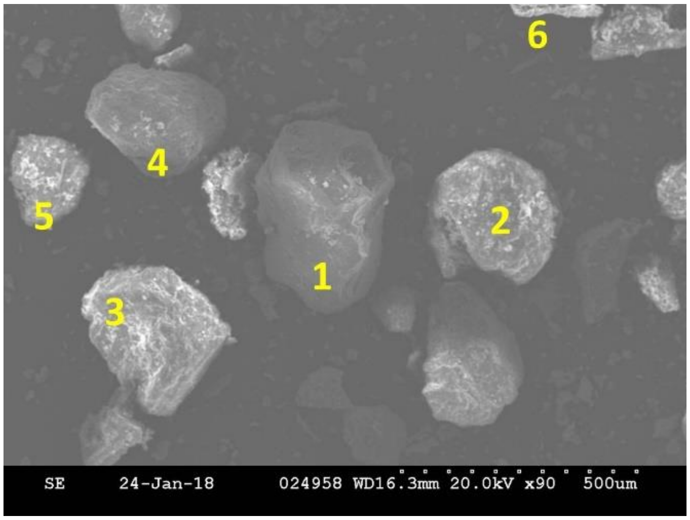


Figure 6. The SEM image of the dried compost at the magnification of ×90. Six areas of interest were marked with numbers for further EDX analysis.

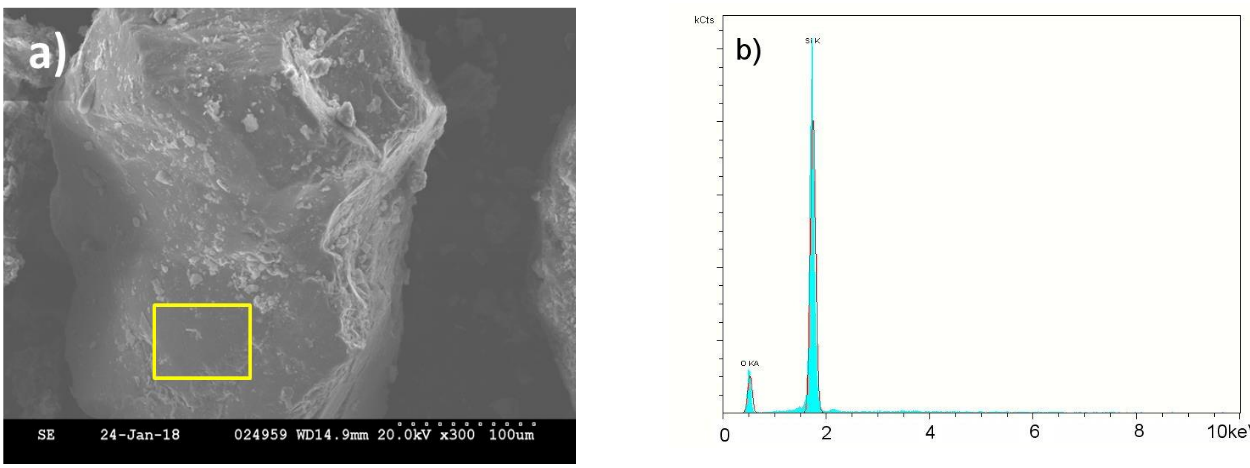


Figure 7. (a) The SEM image of Area No. 1. (b) The EDX spectrum of the smooth area marked with the yellow rectangle

Numerous fine crumbles on the surfaces of the bigger compost particles were identified on the SEM image in areas numbered 2 through 5 on Figure 6, and such a crumbled surface is shown in Figure 8(a). Examination of the EDX spectra of this area (b) indicates the presence of high concentrations of SiO_2 along with several other elements, such as calcium, magnesium, aluminum, iron, zinc, manganese, and barium. Among these constituents, Zn was present at a weight percentage of approximately 1.5 to 3.

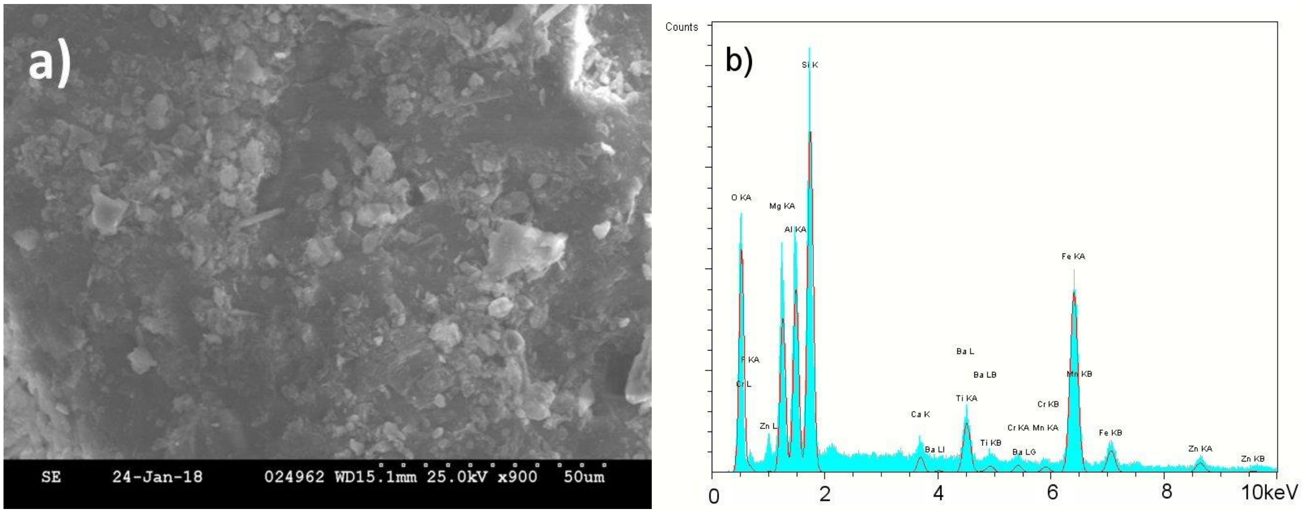


Figure 8. (a) The SEM image of the crumbles in Area No. 3. (b) The corresponding EDX spectrum.

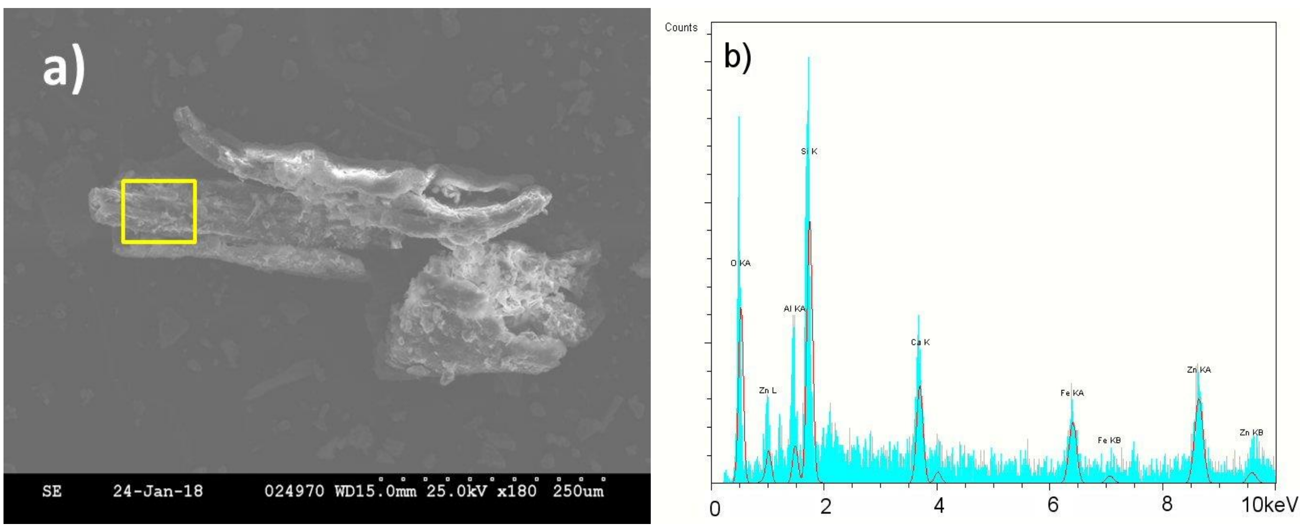


Figure 9. (a) The SEM image of the shell flakes mixed in the compost in Area No. 6. (b) The EDX spectrum corresponding to the area marked with the yellow rectangle.

Besides the smooth and crumbled surfaces of the particles in the powdered compost samples, oyster shell flakes were also observed, infrequently though not surprisingly. In the area outlined in the yellow rectangle in Figure 9(a), Zn was also identified along with the dominant SiO_2 and the other elements noted above (b). Even though the percentage of Zn in this specific area was as high as 20% by weight, the total proportion of Zn in the overall compost mixture is considered to be very low because similar structure was detected in far less than 1% of the area of the entire observed compost sample.

Conclusions

The presence of zinc (Zn) in runoff from unpainted, galvanized hangar roofing into airport stormwater drainage systems can be detrimental to wildlife and the environment. Airports across the northwest are noticing elevated levels of Zn in required quarterly water samples of their stormwater runoff. The Snohomish County Airport in the State of Washington, along with Landau Associates Inc. have installed a pilot treatment system that has been shown to remove excessive Zn from the runoff, which then can flow to adjacent creeks and lakes without adversely affecting the environment. The inclusion of oyster shell fragments in the treatment medium – a compost and sand mixture – has resulted in the extraction of virtually all (>99%) of the Zn in the runoff from the hangar roofing.

Analyses of samples of the runoff entering the treatment tanks (influent) and of the water flowing out of the tanks (effluent) documented the removal, or extraction, of Zn by the treatment medium. Determining the fate of the Zn removed from the runoff, however, required an analysis of the treatment medium itself.

Separate samples of the treatment medium, the oyster shell fragments, and the compost mixture with the shell fragments removed were analyzed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and (or) Scanning Electronic Microscopy with Energy Dispersive X-Ray (SEM & EDX) techniques. Those analyses indicated that Zn had been sorbed onto the outer surfaces of the oyster shell fragments, but only in a veneer that was less than 5% of the entire shell thickness, and was not present within the interior structure of the shell. Further analyses of samples of the compost mixture indicated their composition to be primarily SiO_2 (silica = sand), with very little or no Zn present. It is concluded that virtually all of the Zn was absorbed by the oyster shells incorporated in the treatment medium.

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