



TECHNICAL REPORT 2077
June 2014

Modeling Tool to Quantify Metal Sources in Stormwater Discharges at Naval Facilities (NESDI Project 455)

Final Report and Guidance

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ADMINISTRATIVE INFORMATION

The work described in this report was performed for the Navy's Environmental Sustainability Development to Integration (NESDI) Program by the Energy and Environmental Sciences Group at Space and Naval Warfare Systems Center Pacific in collaboration with Dr. Robert Pitt of the University of Alabama, the originator of the WinSlamm model.

Released by
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Under authority of
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EXECUTIVE SUMMARY

This report describes results of a demonstration/validation project to assess the use of the urban stormwater model Windows Source Loading and Management Model (WinSLAMM) to characterize sources of copper and zinc in storm runoff at Navy facilities, a common compliance problem for Navy bases across the nation. The Navy's Environmental Sustainability Development to Integration (NESDI) Program funded this project (Project 455) and the work described in this report was performed by the Energy and Environmental Sciences Group at Space and Naval Warfare Systems Center Pacific in collaboration with Dr. Robert Pitt of the University of Alabama, the originator of the WinSlamm model.

The technical approach taken was to optimize and calibrate the WinSlamm model specifically for Navy facilities using Navy-specific drainage characteristics and stormwater datasets from multiple drainages. The model calibration was based on a comparison of over 300 stormwater datasets and detailed site characterizations from 19 drainages on 11 Navy Bases in the Southwest, Northwest, and Mid-Atlantic regions of the U.S. ranging in size from 1 to 1400 acres. The model generated reasonable results though with a relatively high degree of variability that was primarily a result of first-flush (first hour of runoff) stormwater data, the most common data collected across the country and because it was possible only to compare current operations and land uses against historic storm data.

A spreadsheet tool based on the WinSLAMM calibration was developed to perform the modeling in a simplified format for use by Navy facility managers. A spreadsheet was generated for each of the three Navy Regions where the calibration was performed to account for differences in model outcomes primarily a result of variations in regional rainfall effects. The report provides guidance on the use of the spreadsheet tool, with a particular focus on how to collect and enter key site characterization data from an onsite review of facility drainages. This includes identifying and measuring areas within 53 different source area categories within land use areas that can be characterized as mostly residential, commercial, or industrial. Using the tool in other Navy Regions should be based on how similar rainfall is in the area to the type of rainfall used in calibrating the tool for the three regions.

The project has created a simple and potentially useful tool that facility managers can use to identify where and relatively how much copper and zinc are generated throughout their drainages. The tool can therefore be used when developing strategies to implement control practices to meet compliance. The model was used to generate a table of the top 14 industrial source land uses for both copper and zinc across all three regions to provide a general overview of relative sources. The report appendices provide information on measured source strengths of many common materials found on Navy facilities, specific guidance with an example for conducting a site characterization, and the model calibration reports that also contain candidate stormwater control practices with a measure of their potential effectiveness in each of the three Navy Regions.

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INTRODUCTION

The following report describes results of a demonstration/validation project to assess the urban stormwater model Windows Source Loading and Management Model (WinSlamm) to characterize sources of copper and zinc in storm runoff at Navy facilities. The Navy's Environmental Sustainability Development to Integration (NESDI) Program funded this project (Project 455) and the Energy and Environmental Sciences Group at Space and Naval Warfare Systems Center (SSC) Pacific, in collaboration with Dr. Robert Pitt of the University of Alabama, the originator of the WinSLAMM model, performed the work described in this report.

The project was designed to develop a method to assess sources copper and zinc as requested in NESDI Need N-0713-10 submitted by Navy Region Southwest:

“To reduce/eliminate copper and zinc in stormwater discharges we need to accurately identify and quantify sources of copper and zinc in drainage areas that are not meeting the acute toxicity standard and benchmark values and then develop Best Management Practices to reduce/ eliminate the sources. Visual inspections of the drainage areas have been insufficient in identifying and quantifying sources of copper and zinc so we have been unable to develop and implement effective BMPs to meet our permit requirements.”

The project deliverable includes this report describing the project goals, methods, and modeling results, as well as guidance on conducting a site characterization and use of the modeling tool. Appendix A provides a second independent report previously delivered that describes the relative magnitude of various source materials generating copper and zinc. Appendix B contains detailed guidance for completing the site characterization process. The final deliverable also includes the Microsoft Excel® spreadsheet modeling tool as a separate set of files. Appendices C and D provide two detailed reports describing the complete calibration procedures conducted by Dr. Pitt, along with descriptions of candidate storm- water control practices, particle size distributions for source areas, and soil compaction effects on infiltration rates.

BACKGROUND

Copper and zinc are ubiquitous contaminants found in stormwater discharges in urban and industrialized areas. These contaminants originate from a variety of sources and input pathways that flow into stormwater conveyance systems, eventually affecting receiving water bodies. Navy environmental managers have identified copper and zinc concentrations as commonly exceeding National Pollutant Discharge Elimination System (NPDES) permit benchmarks (Katz, Rosen, and Arias, 2006). Toxicity identification evaluations also identified these metals as the principal toxicants in stormwater. Exceedance of NPDES benchmark levels and toxicity standards pose a potential for notices of violation as well as civil lawsuits. In addition, numerical limits of copper and zinc waste load allocations instituted through the Total Maximum Daily Load (TMDL) are creating an even more stringent compliance landscape such as those starting to be implemented into Navy Regions Southwest permits.

Navy facility environmental managers are facing a daunting challenge to meet their more stringent stormwater discharge requirements. Even with existing Best Management Practices (BMPs), a lack of accurate assessment tools and framework for prioritizing contaminant sources leaves facility managers at risk. To meet current and future permit and TMDL requirements, an appropriate stormwater management tool to optimize the selection of the most effective BMPs for reducing end-of-pipe contaminant concentrations and mass loads. A key element to implementing effective BMPs is to first identify and quantify the relative contributions of metals to stormwater runoff from the

various sources present on the facility. This project was designed to provide this information as a calibrated and verified modeling tool that identifies and quantifies these sources and thereby provide the key information needed to optimize management decisions on implementing BMPs to mitigate them.

PROJECT GOAL

The project goal was to demonstrate and validate a tool for stormwater management that Navy facility environmental managers could use to identify and quantify relative sources of copper and zinc found in stormwater runoff. SSC Pacific scientists expect facility managers to use the tool to better assess their drainages and thereby identify where control practices would create the highest potential for mitigating contaminant loads.

TECHNICAL APPROACH

The technical approach was to optimize the off-the-shelf Windows Source Loading and Management Model (WinSlamm) developed by PV & Associates for use at Navy facilities across the country. WinSlamm is a small-scale watershed hydrology and water quality modeling tool previously applied to various industrial and municipal sites around the country. While widely used, the model requires the input of specific land use data to optimize its predictive accuracy in quantifying stormwater contaminant loading and effects of implementing control practices. The project effort therefore focused on gathering Navy facility-specific source and storm-water parameter data to calibrate, validate, and optimize the model for Navy use.

The WinSLAMM model uses three basic model parameter datasets to generate an estimate of the relative magnitude and contribution of site pollutant sources to storm pollutant discharges. These include:

1. Site land use and source characteristics (e.g., roofs, parking lots, laydown), storm water management practices (e.g., infiltration, treatment system), and structure of the storm discharge/conveyance system (e.g., perviousness, slope, soil type)
2. A pollutant source loading dataset that describes the amount of pollutant derived from various site land uses and site materials based on historical regional datasets
3. A detailed regional historical rainfall dataset describing frequency, magnitude, and intensity over relatively long periods of time (years)

In this project, the approach was to take WinSLAMM's built-in regional residential, commercial, and industrial pollutant source datasets as a starting point and modify them to account for site characteristics and stormwater datasets specific to Navy facilities.

METHODS

MODEL CALIBRATION

The calibration method focused on using a highly detailed characterization of land uses/ infrastructure and site materials at a number of U.S. Navy base drainages to generate model predictions of storm-water volume, particulates, copper, and zinc masses and concentrations, and comparing them to actual storm-water datasets. The standard model pollutant source loading data were then modified iteratively (storm by storm, outfall by outfall, and region by region) to generate predictions that best fit the observed stormwater contaminant data. The following paragraphs

describe the basics of this effort. Appendices C and D include two separate annual calibration reports by Dr. Pitt and provide a complete description.

SSC Pacific scientists generated a model calibration by conducting detailed site characterizations at 19 drainages on 11 Navy bases in the Southwest, Mid-Atlantic, and Northwest regions of the U.S. The sites evaluated, shown in Table 1, ranged from 1 to 1400 acres in size and represented the wide range of land use diversity found at Navy bases around the country. The characterizations used aerial photos, geographic information system (GIS) and facility maps, and most importantly, a site visit to quantify/validate categories and sizes of land uses, materials, and infrastructure within each drainage. The characterization method detailed later in this report is the most critical piece of information facility managers will need to run the modeling tool for their sites.

The characterizations, along with local rainfall data and standard model input parameter files, were used to compare the model output against a historical storm-water contaminant dataset collected for each drainage. This dataset was composed almost entirely of concentrations of total solids, copper, and zinc measured in grab samples collected during the first hour of storm flow (first-flush). Very few full-storm composite samples, flow data, or total and dissolved metal data were available. PV & Associates originally designed the model to utilize full-storm composite datasets with a breakout of particulate (as total suspended solids (TSS) and dissolved metals, so where possible, the calibration process considered the few available composite and metal speciation data available. The limited availability of full-storm datasets clearly influenced the calibration outcomes and contributed to model uncertainty.

Initially, the project team made comparisons iteratively storm by storm at one drainage site by modifying the pollutant source loading data associated with each land use to produce a best fit between model result and storm data. Once a best fit was found for a single drainage, the iterative process was repeated at each successive drainage until completed for the entire region. After generating each regional pollutant source loading file, SSC Pacific scientists made additional model-observation comparisons of land use, wash-off rates, and mass loading adjustments to obtain results with the least error (sum of squares of the residuals). These later adjustments were made when calibrating the last few sites. Overall, the calibration process evaluated more than 300 storm event datasets from the 19 Navy sites.

MODEL RESULTS

The calibration procedure produced a series of model predictions that SSC Pacific scientists compared to the original historical stormwater dataset. Various regression, probability plots, and statistical evaluations were generated to assess how well the model compared to the historical datasets. Figure 1 shows an example of the regression plots for total copper and zinc loads and Figure 2 shows data distribution probability plots. The regressions show a generally reasonable regression relationship between model and observed data (r -square values ~ 0.7), given the high variability of the input data. Similarly, the model and observed data distributions also generally overlaid one another reasonably well, given their large variation and range. Note that the log-log scales on the plots minimize the visual scatter inherent in these stormwater datasets.

The high degree of variation of first-flush stormwater data observed at even at a single site was magnified when evaluating it at multiple sites. This was clearly a large source of variation and uncertainty when evaluating model results as was only being able to compare current operations and land uses against historic storm data. An evaluation conducted to assess these variations found that the first-flush data did not have any relationship to storm size, duration, intensity, or an antecedent dry period. SSC Pacific scientists evaluated the uncertainty and made some adjustments using the

limited concurrent first-flush and full-event monitoring data. Therefore, the model calibration really only provides a reasonable prediction of an average load condition over many storm events. Examples of the final observed versus calculated loads for the last 10 validation sites are shown in Figure 3.

During the model calibration phase it was determined that the off-the-shelf WinSlamm model could be improved with the addition of tracking particulates and contaminants in sub-drainages. This became particularly important when attempting to include laydown areas that are common throughout Navy bases. The off-the-shelf version of the model was therefore modified to allow independent tracking of these relatively important source areas, adding sophistication as well as complexity in using the full model.

The calibration/validation process led to the development of a pollutant source loading file specific to regional Navy land uses/materials, providing the best overall predictions to the observed storm-water copper and zinc loading data. Given the calibration uncertainties, complexity, and the likely inability to use the WinSLAMM software on Navy networks, SSC Pacific scientists determined that a spreadsheet would be the best method for implementing the tool by facility managers, who are already time-limited. A spreadsheet tool was therefore developed from WinSLAMM that has all of the underlying pollutant source calibrations and rain file algorithms built in for three Navy regions. Facility managers can simply implement the tool by entering the areal extent and category of source areas/materials for a drainage area to obtain a reasonable estimate of relative source area pollutant contributions.

Table 1. Regions, bases, and outfall drainage areas used in calibrating the commercial off-the-shelf WinSlamm stormwater quality model for Navy-specific use.

Region	Base	Outfall	Drainage Area (acres)	Comment
Southwest	Naval Base San Diego	1	1.4	Pier
		13	3.2	Pier
		14	50	
		51	19	
		70	78	
		72	45	
		73	17	
	Naval Base Coronado	9	5	
		26	73	
	Naval Base Point Loma	26	6.4	Pier
Northwest	Naval Base Kitsap Bangor	2	1442	
		3A	9	Pier
	Naval Station Everett	A	15	Pier
		B	12	
	Naval Air Station Whidbey Island	3D	13	
	Naval Base Kitsap Bremerton	15	104	
	Naval Magazine Indian Island	120	3	
Mid Atlantic	St. Julien's Creek Annex	40/41	26	
	Joint Expeditionary Base Little Creek-Fort Story	7	3	

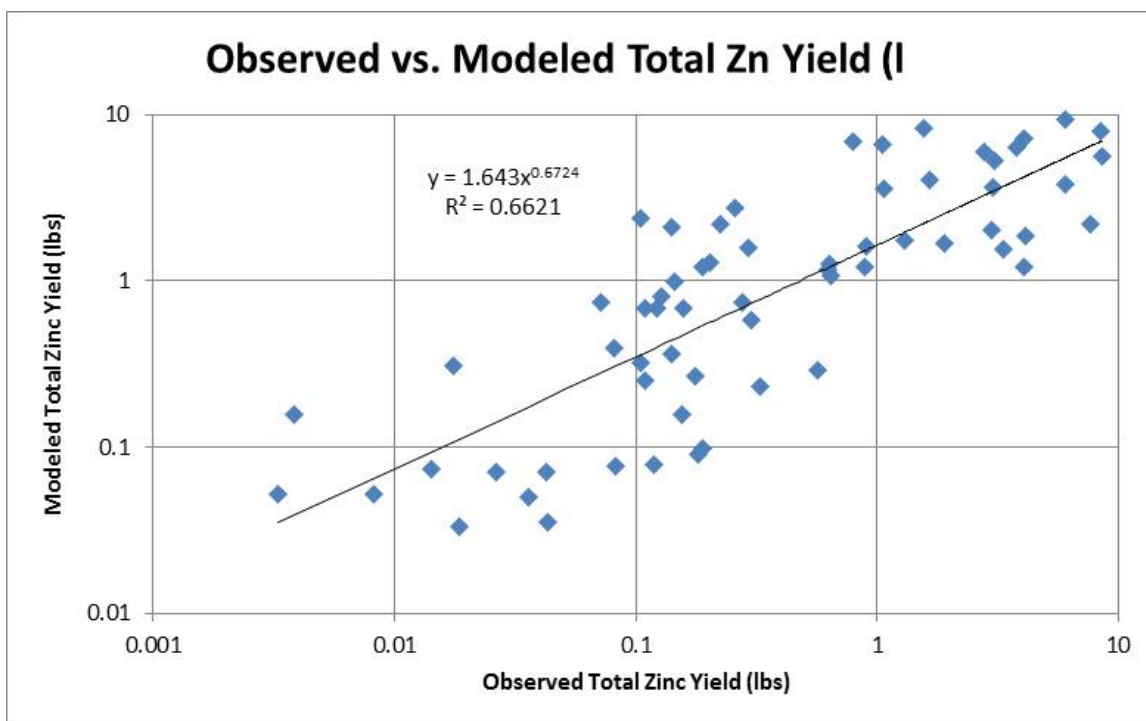
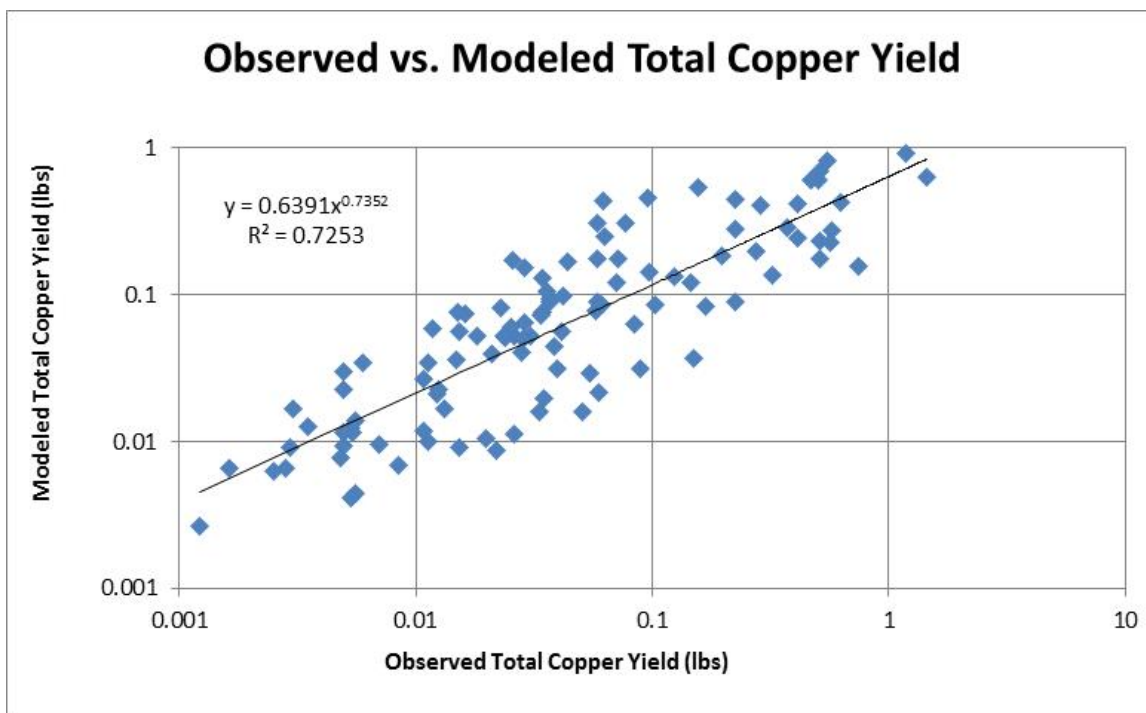


Figure 1. Model predictions vs. observed stormwater copper (top) and zinc (bottom) for multiple Navy Southwest Region outfalls. Results are shown on a log-log plot.

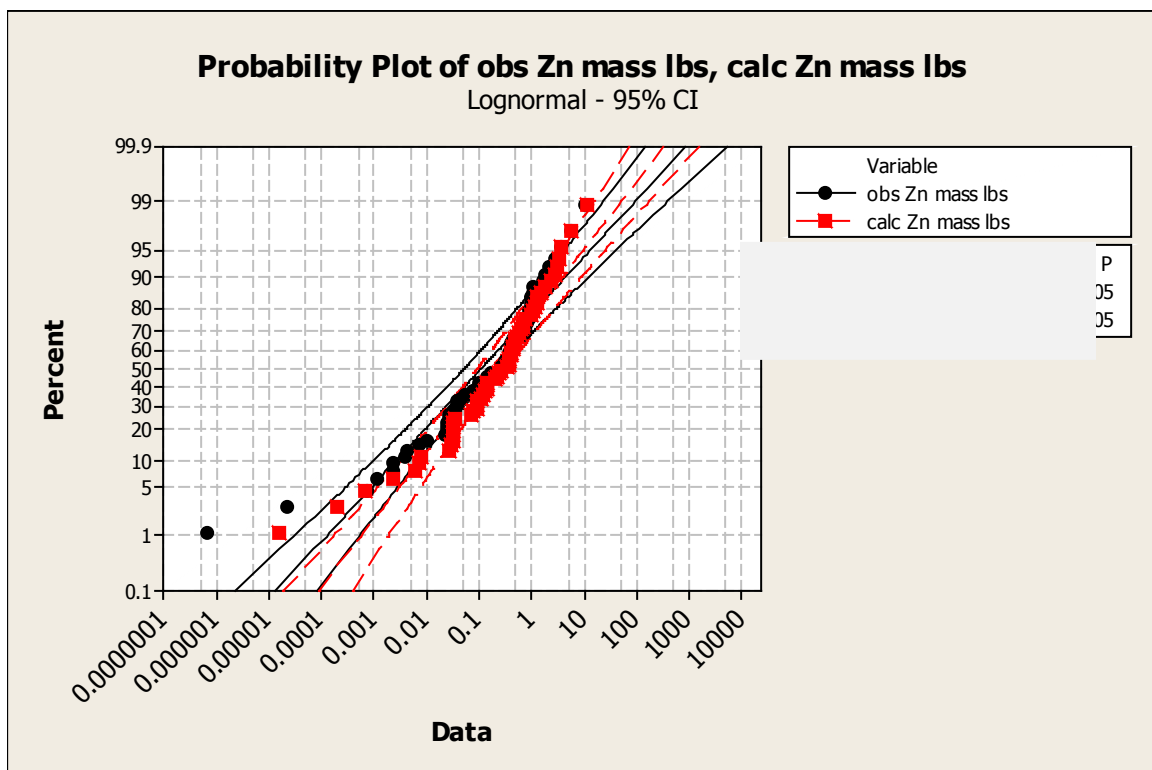
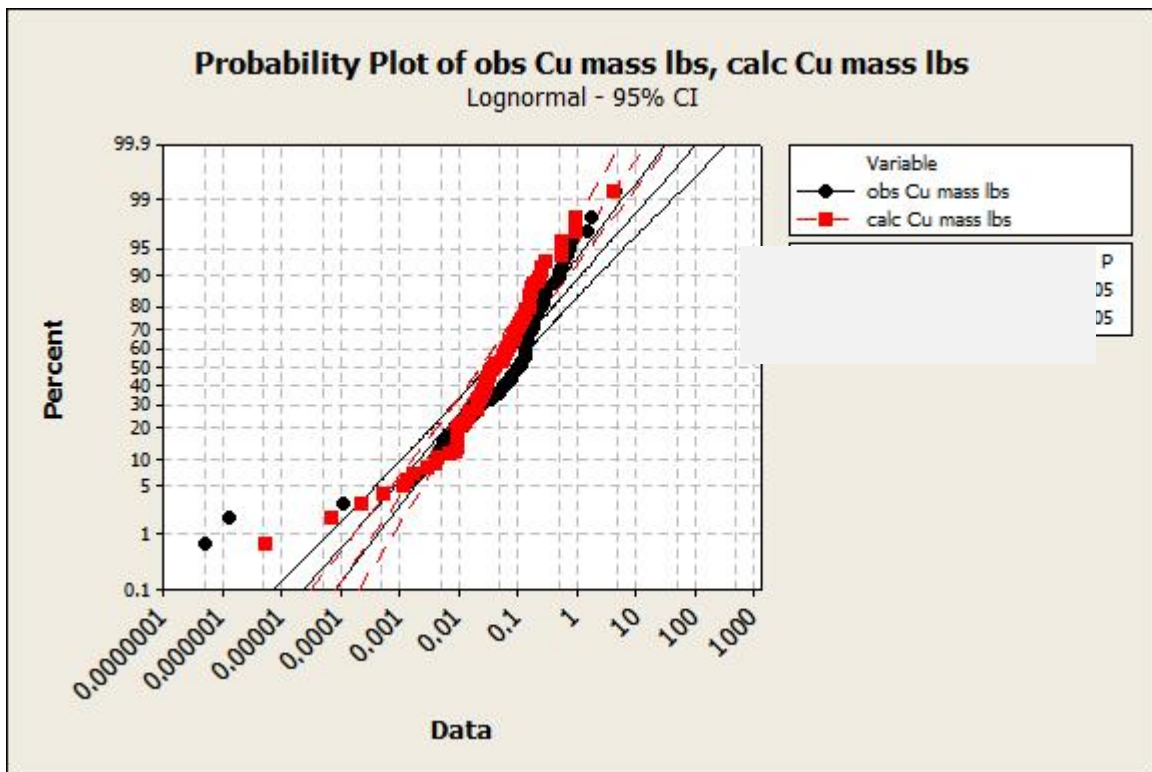


Figure 2. Probability distribution plots showing observed (●) and modeled (■) copper (top) and zinc (bottom) mass data. The closer the overlap in the two distributions, the closer the model matches the observed data. Results are shown on a log-log plot with 95% confidence intervals shown with line.

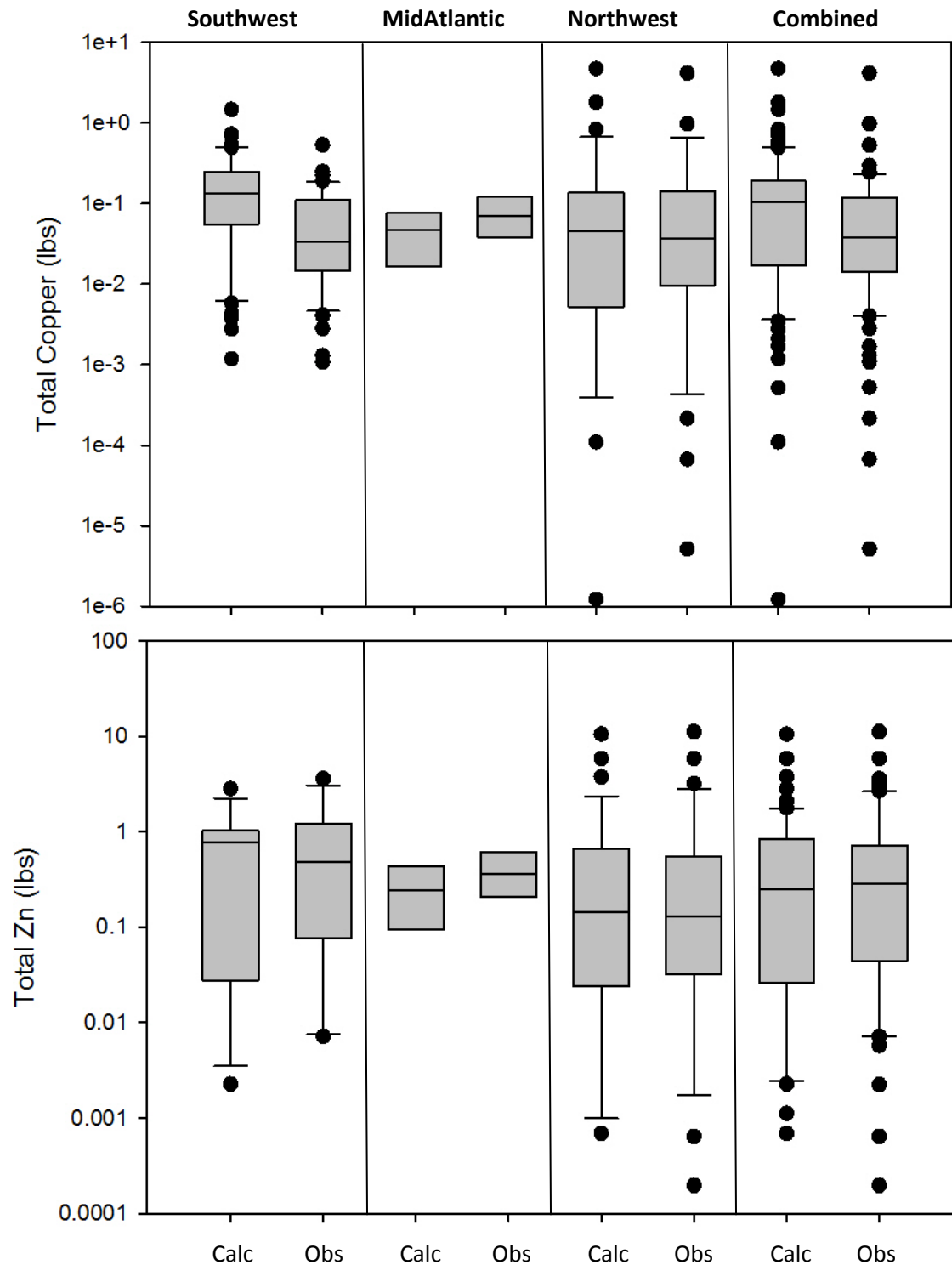


Figure 3. Box and whisker plots comparing pairs of observed and calculated copper (top) and zinc (bottom) mass loads for the three Navy Region datasets and all three combined. The box shows the median as the internal horizontal line in the boxes while the upper and lower ends of the boxes indicate the 75th and 25th percentile values respectively. The ends of the whiskers indicate the 5 and 95th percentile values, while the individual dots indicate observations outside of the 5th to 95th percentile range.

GUIDANCE ON USING THE SPREADSHEET TOOL

As described above, the spreadsheet tool provides a good screening tool for identifying relative source strengths of various land uses/source areas/materials found on Navy facilities. The spreadsheet tool is provided for three Navy regions: Southwest, Northwest, and Mid-Atlantic, in a standard Microsoft Excel® workbook. The main difference among the three regions appears to be related to differences in the interaction of rainfall and sources. The team based the Region Southwest calibration on San Diego area bases. The rainfall in this area is generally characterized by intense, short duration, limited overall totals, and long dry periods. Rains in the San Diego area are heavily seasonal, with most of the rain occurring from the late fall to spring, and with a long dry period during the summer. Total annual rain depths are typically low, but can vary greatly from year to year.

SSC Pacific scientists based the Navy Region Northwest calibration on western Washington bases adjacent to Puget Sound. Rainfall in this area is characterized by moderate long duration, high overall totals, and short dry periods. The annual rains in this region are about 30 to 50 inches/year and can vary greatly over short distances. The rains are generally distributed evenly throughout the year, although the driest fall months have about half the rain totals as the wettest spring and winter months.

The Navy Region Mid-Atlantic calibration was based on bases in the Norfolk, Virginia area. Rainfall in this area is characterized by intense, long duration, high overall totals, and short dry periods. The total annual rains in this area range from about 45 to 50 inches/year and are generally distributed evenly throughout the year, but some snow may occur in the winter, and the area is periodically subjected to severe hurricane-driven weather.

Facilities outside the specific calibration areas can use the spreadsheets as a screening tool, though the results will have a higher level of uncertainty. It is best to use the spreadsheet that is based on rainfall characteristics that are most similar to the area of interest.

Follow these two main steps after choosing a specific regional spreadsheet:

1. Perform a site characterization (input data)
 - a. Site overview
 - b. Characterization components
 - c. Site survey
 - d. Post survey processing
2. Run the spreadsheet tool
 - a. Enter individual area input data
 - b. Run and evaluate tool output

SITE CHARACTERIZATION

Site characterization is by far the most critical and time-consuming step because once the data are entered into the tool, the model automatically and quickly calculates and generates output. The facility manager must evaluate the location and spatial extent of specific pre-defined land uses and materials present on his or her sites. A combination of GIS, aerial photos, or computer-assisted design (CAD) drawings for the facility can accomplish this task. However, a thorough evaluation really requires walking the site and reviewing what and how much is there and how it is connected to the storm conveyance system. The facility manager will also gain important insight about the nature of the onsite materials. The type of structural materials is a very important factor, given that the amount of copper and zinc potentially leaching from them can be very different (see the Leachate Report in Appendix A). We provide an outline of steps below to perform the site characterization process, though Appendix B provides a detailed step-by-step account.

The site visit can be a time consuming effort, especially the first time. The manager will need to apply some subjectivity and judgment. We therefore provide some tips and examples below to help you through the process. While having highly detailed information is best, one must weigh it against the time it takes to collect it. We recommend a happy medium of getting the big things off the list using GIS or aerial photo information and getting the smaller but important site elements by walking the site.

We recommend that you start with the end in mind. Review the spreadsheet tool input tab. There are 53 different categories of potential source areas/materials inputs (Table 2). Each of these land uses is further divided into its primary character as residential, commercial, or institutional land use areas. Your drainage might only have a few of these characteristics, depending on the size and complexity of the site. It is best to first identify the boundary of the drainage, that is, the contiguous area that is connected through a conveyance system that eventually reaches a single outfall discharge location. Knowledge of or surface elevation data, and the location of the conveyance system are usually used to divide bases into specific drainages, which is commonly, though not consistently available within Base stormwater GIS (Geographic Information Systems). Though we have observed some errors in boundary delineations during site walk-through, the departures from the drainage maps were relatively small.

SITE OVERVIEW

Figure 4 through Figure 6 show Examples of common starting points for developing a drainage site overview. The first example is a storm-water GIS map showing the outline (thicker purple line) of the drainage area for outfall 73 at Naval Base San Diego. Two adjacent drainage areas are outlined with cyan lines. The second example is an aerial photo of the same area taken from Google Earth™, where the drainage boundary was overlain using polygon tools within the application (this can be facilitated using the “image overlay” capability in Google Earth™). If available, both drainage area overviews should be printed for use when conducting the site visit because each overview has useful information that allows users to quickly identify where they are located on the site. In particular, the GIS provides information such as building numbers and drain inlets, while the aerial images provide information such as building shapes, colors, and street/parking area delineations. We recommend that the large overview area be divided up into smaller “like” areas with easily recognizable elements such as large buildings, streets, or green space to provide more manageable survey areas with higher resolution and detail. These overviews should be printed for use during the site visit for taking notes. Facility managers can use the overview maps to create a locator grid to locate sub-area descriptors.

Other helpful ancillary information to gather before the survey is where the conveyance systems are located and where management practices such as infiltration areas or treatment systems may be present. Mark them on the overview sheets ahead of time. The spreadsheet tool does not fully implement the BMP portion of the WinSlamm model, but facility managers can account for this by adjusting the relative size of a source area by the percentage of the expected contaminant reduction of the BMP (e.g., a 1-acre area with an expected/measured 50% treatment reduction in copper and zinc would be entered into the model as a 0.5-acre area).

Table 2. WinSLAMM model source area input categories. Each category is also characterized into primarily residential, commercial, or institutional type areas. The goal of the site characterization is to locate and measure out the areal extent of each of the source areas present in the drainage and enter it in to the spreadsheet tool input tab.

Roofs		26	Heavy laydown paved areas- connected
1	Roofs Flat - connected	27	Heavy laydown paved areas-disconnected
2	Roofs Flat - disconnected	28	Light laydown unpaved - connected
3	Roofs Pitched - connected	29	Light laydown unpaved - disconnected
4	Roofs Pitched - disconnected	30	Moderate laydown unpaved - connected
5	Galvanized metal roofs and/or a lot of galvanized material- connected	31	Moderate laydown unpaved - disconnected
6	Galvanized metal roofs and/or a lot of galvanized material-disconnected	32	Heavy laydown unpaved - connected
7	Copper metal roofs and/or a lot of copper material-connected	33	Heavy laydown unpaved - disconnected
8	Copper metal roofs and/or a lot of copper material-disconnected	Special Areas	
Parking/Streets/Sidewalks/Driveways		34	Aircraft operations-connected
9	Paved parking-connected	35	Aircraft operations-disconnected
10	Paved parking-disconnected	36	Other metals paved-connected
11	Unpaved parking-connected	37	Other metals paved-disconnected
12	Unpaved parking-disconnected	38	Other metals unpaved-connected
13	Driveways/loading dock -connected	39	Other metals unpaved-connected
14	Driveways/loading dock -disconnected	40	Other galvanized materials paved- connected
15	Sidewalks - connected	41	Other galvanized materials paved- disconnected
16	Sidewalks - disconnected	42	Other galvanized materials unpaved - connected
17	Streets - with curb and gutters	43	Other galvanized materials unpaved - disconnected
18	Streets - no established drainage alongside road	44	Treated Wood Paved-connected
Pervious Areas		45	Treated Wood Paved-disconnected
19	Landscaping areas /undeveloped areas	46	Treated Wood Unpaved-connected
20	Landscape/undeveloped areas next to buildings and/or parking lots	47	Treated Wood unpaved-disconnected
21	Other pervious infiltration areas	48	Other copper materials paved- connected
Storage/Laydown Areas		49	Other copper materials paved- disconnected
22	Light laydown paved areas- connected	50	Other copper materials unpaved - connected
23	Light laydown paved areas- disconnected	51	Other copper materials unpaved - disconnected
24	Moderate laydown paved areas - connected	52	Artificial turf-connected
25	Moderate laydown paved areas - disconnected	53	Artificial turf-disconnected

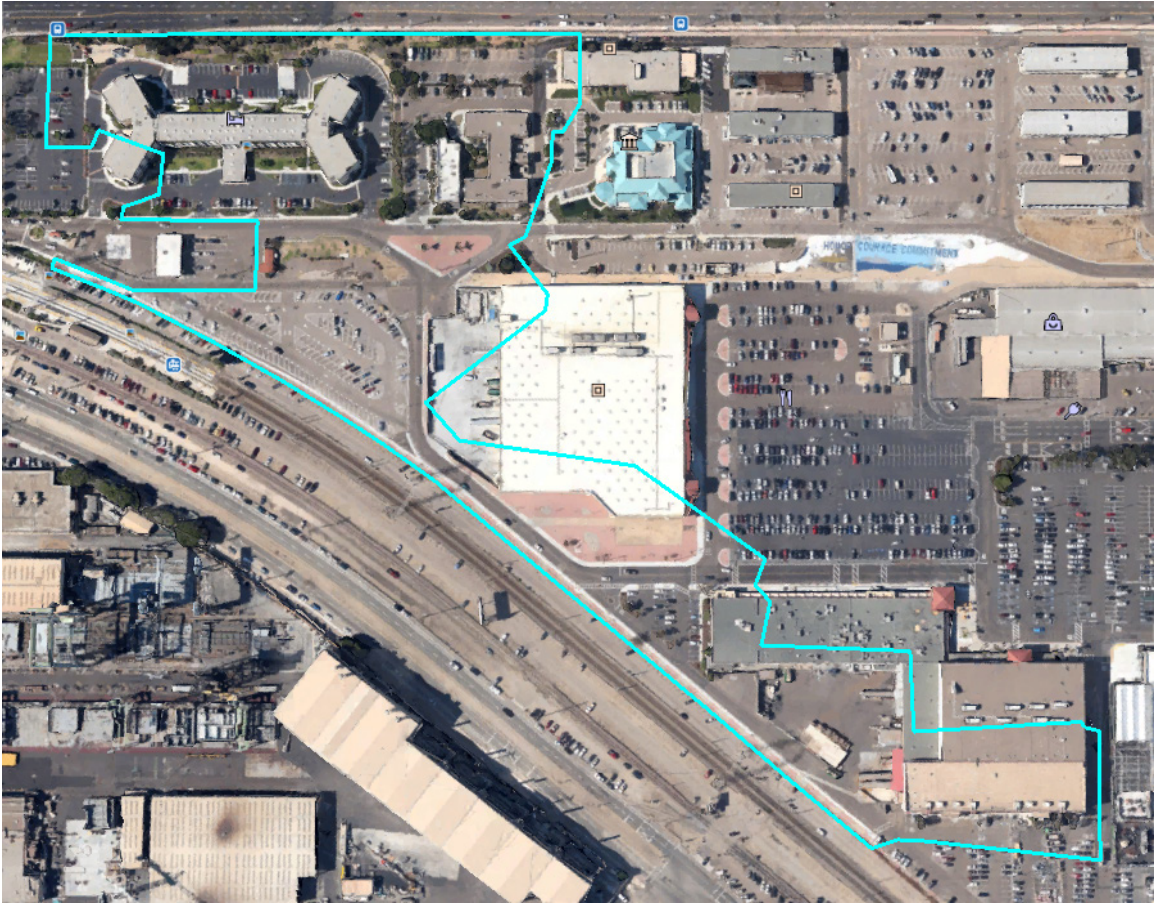


Figure 5. Example outline of Naval Base San Diego storm-water drainage area for outfall 73 using Google Earth™ aerial image as the starting point. The overlay can be facilitated using Google Earth's™ image overlay capability. This complete overview should be printed for use during the site survey, if available.

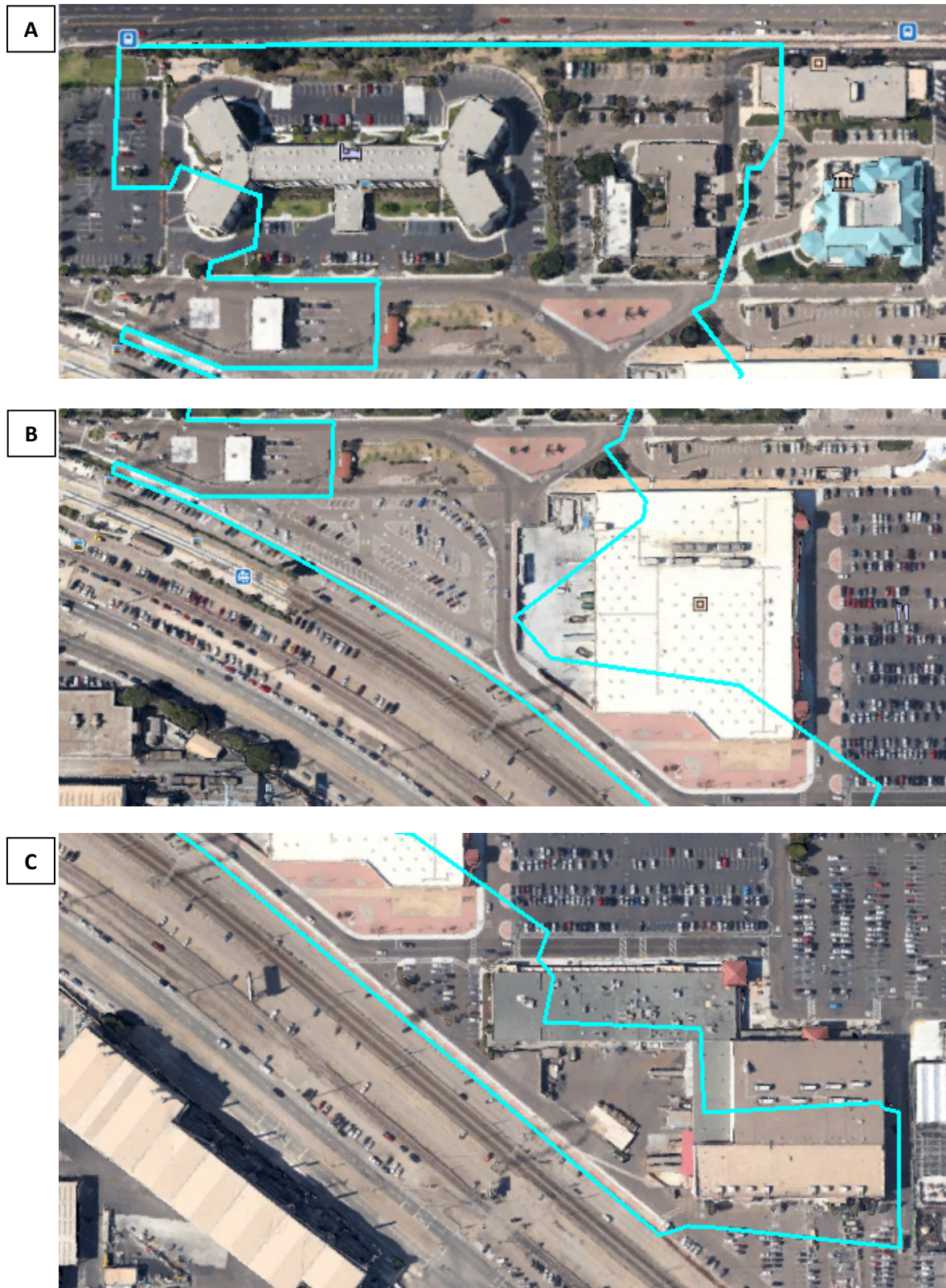


Figure 6. Drainage area overview broken down into three (A, B, C) overlapping regions to facilitate higher detail and for taking notes during the site survey.

CHARACTERIZATION COMPONENTS

As previously mentioned, facility managers can use the site characterization to identify the location, type, and spatial extent of each of the 53 categorized source areas/materials within a drainage, as shown in Table 2. For example, these characterizations can include roofs, parking/streets/sidewalks, pervious or undeveloped lands, or laydown/storage areas containing mixed materials such as metals or treated wood. Many of the main categories are observable on the overview images and their irregular polygon areas can be measured using online tools such as Free Map Tools[®] area-calculator (<http://www.freemaptools.com/area-calculator.htm>) or with standard GIS measurement tools. While facility managers can do this before the site survey, changes in site characteristics can and do occur at frequencies greater than updates to imagery and GIS, so we encourage managers to do their measurements after validating site components. Once on site, one can use highly accurate GPS receivers, a surveyor's wheel, or even one's own stride to obtain lengths, areas, or perimeters. All three methods, performed in combination or alone, should provide a reasonably accurate measure when conducted consistently.

Three key elements to the characterization usually not evident on the overview images are the type of materials present, its connectedness to the storm-water conveyance system, and the presence and extent of pervious and impervious surfaces. Our efforts at assessing the relative amount of copper and zinc that leach off of many common materials show that the actual material making up the structures can have an impact on quantifying their magnitude as a copper or zinc source to the overall drainage (see Appendix A). It is therefore particularly important to note the presence and extent (surface area) of metal materials such as galvanized steel, uncoated fencing, railings, light poles, containers/dumpsters, gangplanks, scaffolding, gutters, piping, and even the metal grates covering stormwater catchments. Facility managers can find these materials as parts of structural components, and as dense groupings within laydown or storage areas (Figure 7). In either case, these materials can be uniquely identified in the spreadsheet tool when observed in measurable quantities.

This last statement describes the somewhat subjective and arbitrary aspect of the site assessment. Facility managers must judge the relative magnitude in terms of surface area of the materials they observe and put them into context of the entire drainage. A galvanized gutter system on a small building may be measurable but potentially not worth quantifying as a separate item when large areas of laydown containing a high percentage of galvanized and mixed metal materials also exist. While controlling any of these sources can be helpful to mitigating contaminants in storm runoff, quantifying the larger congregation of source materials is more important from a potential future management control action than ensuring that every single source is identified. The fact that there can be hundreds of these potential sources speaks to the problem facing our bases, but also the opportunity for future mitigation using material substitutions or treatment measures.

Another key element in the characterization is how sub-drainage areas physically connect to the discharge pipe/outfall, an element not easily observed without conducting the site survey. In particular, the facility manager should evaluate each land use for how it connects directly to the conveyance system or if it first intersects a pervious area, which has the effect of mitigating the volume and amount of contaminant, discharged. Examples of roofing that directly connects through a downspout to the conveyance system and roofs disconnected by first draining to vegetation, soil, or an infiltration area are shown in Figure 8. The model also accounts for the connectedness of large surface areas such as streets or parking areas that drain directly to the conveyance system through curb/street drains or indirectly to swales/pervious areas (Figure 9).

The third important element of information in the calculations that is not always evident from the overview images is the perviousness of the land surfaces. Large green spaces are generally observable from the overviews, but small landscaped or infiltration areas, for instance those around buildings, are not always observable. For example, facility managers may not be able to differentiate artificial turf from actual turf in aerial images, and turfs' contaminant source strengths are considerably different. Even large soil sites may not be differentiated from concrete on overview maps (Figure 10). The site survey allows the facility manager to clearly identify these potential differences and enter this information as a separate entry in the spreadsheet tool. The spreadsheet also considers the amount of compaction that may exist for a non-paved area (areas around buildings or as storage or parking areas are assumed as compacted, for example, resulting in significantly greater storm-water flows than from non-compacted areas). Field notes should therefore indicate the degree of compaction expected for the non-paved source areas.

SITE SURVEY

The basic method for the site survey is to walk the site making notations directly on the hardcopy images. Bring a copy of Table 2 to remind yourself of the categories. Create and use a simple set of abbreviations and/or Table 2 line numbers for taking notes. Roughly draw in those items that are not present in the imagery. It is probably easiest to start out in a corner of the drainage and work methodically across the site. Note types of ground surfaces, how land use elements are connected or not to the conveyance system, which sometimes requires assessing where the runoff will likely flow based on site elevation. Identify where significant architectural or standalone materials comprised of galvanized, copper, or other metal surfaces exist. When mixtures of surfaces such as intermittent hardscape are located within a vegetated area, it is probably best to measure the whole area and then estimate the percentage area for each element within it. You should also use the same method to assess the areal extent of mixed materials such as when there is a substantial amount of galvanized machinery or walkways on rooftops, or when a storage area or laydown area is partially filled with specific metal materials of note. You should enter these separate amounts into the spreadsheet tool under the special areas category.

During the site survey, it is particularly important to locate, assess, and measure out the areas of laydown and storage that are common throughout Navy facilities. Some of these areas are permanently designated for this purpose, while others are more ephemeral and may not show up in the aerial imagery or GIS maps. The facility manager enters these areas into the spreadsheet tool based on their relative intensity/density of materials. Examples of light, moderate, and heavy are shown in Figure 11 through Figure 13. This is clearly a subjective evaluation that you should do as consistently as possible across the facility and drainages. These areas frequently contain sizeable groupings of metal and other materials that are relatively large sources of leachable copper and zinc, including the galvanized fencing that usually surrounds them. As described previously for mixed material areas, the surface area of copper, galvanized, or treated wood materials can be estimated as a percentage of the total area and entered in to the spreadsheet under the special areas category, while the remainder percentage is entered in to the spreadsheet under laydown/storage.



Figure 7. Examples of metal materials making up architectural components as well as grouped within laydown storage areas.



Figure 8. Examples of roofs directly connected to the storm-water conveyance system (top) and those disconnected that drain to vegetation, soil, or stone-filled infiltration areas like those shown in the bottom photos.



Figure 9. Examples of street and parking areas directly connected to the conveyance system (left) and indirectly connected through a vegetated swale.



Figure 10. Examples of large surface areas that may not be discernable as non-paved or paved from an aerial image.



Figure 11. Example of heavy laydown area containing a high percentage of galvanized materials. The roughly 1000 ft² area visible consists of ~ 75% galvanized materials. Therefore, the entry to the spreadsheet would be 750 ft² under “Other galvanized materials paved- connected” and 250ft² under “Heavy laydown paved areas- connected”.



Figure 12. Example of moderate laydown area.



Figure 13. Example of light storage area. The area of fencing (height x length) and the few galvanized materials should be entered separately into the spreadsheet tool under “Other galvanized materials paved- connected”.

POST SURVEY PROCESSING

Once the site is evaluated, the total area for each category of land use source area must be calculated for entry into the spreadsheet tool. As described previously, multiple methods exist for deriving the individual areas, including using a GPS receiver, a surveyor's wheel, stride length, or a GIS measurement tool. We found that using the Free Map Tools area-calculator tool (freemaptools.com) in concert with GoogleEarth™ polygons provide an effective way to organize, measure, and visualize the data (Figure 14). The outline of steps for this method is described below. A more detailed step-by-step description is shown in Appendix B. Regardless of the method, to derive total areas, we recommend maintaining a record of the location as well as areas of the individual land use elements to allow you to target them later for management control practices. For your convenience, we have provided a tab in the spreadsheet tool labeled "Individual Areas Input" that allows you to enter in the individual areas that will automatically populate the spreadsheet tool's main input tab ("Input").

Steps for using Google Earth™ with Free Map Tools© area-calculator tool:

1. Open GoogleEarth™
2. Use the "Add Polygon" tool to outline the perimeter of an area (use "Add a Path" for the special case of measuring the length of linear features such as galvanized fencing)
3. Choose a color and opacity of 50% to outline each broad category of land use
4. Name the polygon (or path) with an ID using your own shorthand designations that details the specific category information (e.g., "Bldg-310r PR-D" refers to residential (r) building 310 with pitched roof (PR) disconnected (D) from the drainage system) and/or grid locator
5. Outline the land use by clicking along the perimeter of the land use (or length of a linear feature)
6. Save the polygon or path as a KML file (right click on the polygon or path)
7. Follow steps 2 through 6 for all individual areas (see Figure 14 for an example of polygon overlays)
8. Open Free Map Tools© (<http://www.freemaptools.com/area-calculator.htm>)
9. Browse for and open your KML file under "Read KML"
10. Uploading the file will automatically calculate the polygon areas (areas of fencing need to be calculated separately by multiplying the path length by average fence height)
11. Save/store the individual area data directly in the Individual Areas Input worksheet of the spreadsheet tool or save separately for later entry into the tool
12. Repeat steps 9 through 11 for each polygon KML file you previously generated.

The remaining six worksheets provide the results of the model calculations. The Area, Runoff, TSS, Cu, and Zn parameter worksheets show individual tabular results and graphs. A tabular summary of all the results are in the last worksheet labeled Source Values. Facility managers must update each of the individual parameter sheets by clicking on the update button at the top of each page, though the source values worksheet updates automatically without an update button. Once you click the button, you will see the table and graph results generated by the embedded model macros. You can review the results only after the macros complete the calculations. We recommend that you run the update on all sheets before reviewing any of the results. All cells in the results worksheets are protected, though the data can be copied and pasted into other worksheets or applications for further evaluation or report preparation.

The tabular and graphical results on each of the individual parameter worksheets are similar and divided into residential, commercial, and industrial land use types. Values are calculated for the source amount of a parameter as a percentage of the total land use type and as a percentage of the total drainage area. The values are sorted from largest to smallest based on the relative source contribution of a land use category to the total area. The top 10 source categories are shown in the pie charts (the sum of the remaining areas is shown as the eleventh pie piece). The relative source strength of Runoff, TSS, Cu, and Zn for each area is also shown as a ratio (e.g., a value of 2.0 indicates that the area contributes twice the source of a parameter relative to its size). The top 10 source areas for the entire area are shown in the table and horizontal bar chart on the far right side of each worksheet.

The Source Values worksheet contains the summary table of calculated results for all parameters as a function of the land use category. The table shows the magnitude of the sources in each category as percentages (repeating the individual worksheet values) and by runoff volume in cubic feet per year, and total suspended particulates, copper and zinc in units of pounds per year. These data provide the relative source contributions calculated by the model for each land use category measured in the drainage. Facility managers can compare the relative source contributions of each parameter by reading across the row.

USING THE SPREADSHEET TOOL RESULTS

SSC Pacific scientists developed the spreadsheet tool to identify and quantify relative sources of copper and zinc found in facility storm-water runoff so facility managers can use the information to better develop mitigation strategies for instituting control practices. The tool results provide the manager with relative source strength data for each land use area in the drainage. Managers can evaluate these data in terms of the overall contribution magnitude or as a relative source contribution percentage. While a particular source area may be the overall largest contributor to the runoff, it may be composed of many individual elements and/or spread out throughout a drainage (e.g., from many roofs) and may not necessarily lend itself to a cost-effective management control practice. Thus, managers must also consider the relative source contribution results, as this information may identify more concentrated sources that may be easier or less costly to control.

To evaluate relative source strengths, we tested the model for all three regions by entering in 1-acre values for all source area categories for industrial land use and sorted the results by both copper and zinc in lbs/y. The following two tables show the top 14 sources within the industrial land use categories for each of the three regions generated by the model. The categories in these top 14 sources are relatively consistent across the regions, though there are some differences in their exact order. Facility managers can use these results as a broad generalization for evaluating relative site sources. For example, exposed copper materials and treated wood are clearly large copper sources, as artificial turf and exposed galvanized materials are for zinc. Also, there is little difference in unit area

A final note on the results in Table 3 and Table 4 is that very little crossover exists in the land use source area categories that are relatively large sources of copper, and those that are sources of zinc. This suggests that in many cases, mitigating a relatively high source area for copper may not have as much effect on zinc reduction, and vice versa, though most mitigation steps affect both metals.

As mentioned previously, the calibration reports generated by Dr. Pitt for this project also contain information on control practices for candidate stormwater, particle size distributions for source areas, and soil compaction effects on infiltration rates. Appendices C and D describe the effectiveness of various mitigation strategies when applied to any one of the three Navy regions, including pavement and roof disconnections, roof runoff rain gardens, biofilters, porous pavement, grass filters, grass swales, green roofs, street cleaning, catchbasins and hydrodynamic separators, Multi-Chambered Treatment Train (MCTT), and selection of media for treatment devices. While the detail is based on full implementation of the WinSlamm modeling software, the results are shown in terms of their estimated potential effectiveness for each of the three Navy regions.

Table 3. Comparison of industrial area land use categories for copper source strengths by region. The values represent the top 14 modeled copper sources.

SW Industrial	Cu (lbs/yr)
Copper metal roofs and/or a lot of copper material-connected	7.5
Copper metal roofs and/or a lot of copper material-disconnected	7.2
Other copper materials paved- connected	7.0
Other copper materials paved- disconnected	6.9
Other copper materials unpaved - connected	5.7
Other copper materials unpaved - disconnected	5.5
Heavy laydown paved areas- connected	4.2
Heavy laydown paved areas-disconnected	4.2
Moderate laydown paved areas - connected	4.1
Moderate laydown paved areas - disconnected	4.0
Treated Wood Paved-connected	3.5
Treated Wood Paved-disconnected	3.4
Treated Wood Unpaved-connected	2.8
Treated Wood unpaved-disconnected	2.8
NW Industrial	Cu (lbs/yr)
Copper metal roofs and/or a lot of copper material-connected	10.2
Copper metal roofs and/or a lot of copper material-disconnected	10.0
Other copper materials paved- connected	9.6
Other copper materials paved- disconnected	9.5
Other copper materials unpaved - connected	6.2
Other copper materials unpaved - disconnected	6.1
Treated Wood Paved-connected	4.8
Treated Wood Paved-disconnected	4.8
Heavy laydown paved areas- connected	3.8
Heavy laydown paved areas-disconnected	3.8
Treated Wood Unpaved-connected	3.1
Treated Wood unpaved-disconnected	3.1
Moderate laydown paved areas - connected	2.7
Moderate laydown paved areas - disconnected	2.7
MidLant Industrial	Cu (lbs/yr)
Copper metal roofs and/or a lot of copper material-connected	11.2
Copper metal roofs and/or a lot of copper material-disconnected	10.6
Other copper materials paved- connected	10.6
Other copper materials paved- disconnected	10.2
Other copper materials unpaved - connected	9.4
Other copper materials unpaved - disconnected	9.0
Treated Wood Paved-connected	5.3
Treated Wood Paved-disconnected	5.1
Treated Wood Unpaved-connected	4.7
Treated Wood unpaved-disconnected	4.5
Heavy laydown paved areas- connected	2.1
Heavy laydown paved areas-disconnected	2.0
Moderate laydown paved areas - connected	1.6
Moderate laydown paved areas - disconnected	1.5

Table 4. Comparison of industrial area land use categories for zinc source strengths by region. The values represent the top 14 modeled zinc sources.

SW Industrial	Zn (lbs/yr)
Artificial turf-connected	7.8
Artificial turf-disconnected	7.7
Heavy laydown paved areas- connected	4.6
Heavy laydown paved areas-disconnected	4.5
Other galvanized materials paved- connected	3.1
Other galvanized materials paved- disconnected	3.0
Galvanized metal roofs and/or a lot of galvanized material- connected	2.9
Galvanized metal roofs and/or a lot of galvanized material-disconnected	2.8
Moderate laydown paved areas - connected	2.3
Moderate laydown paved areas - disconnected	2.3
Other galvanized materials unpaved - connected	2.3
Other galvanized materials unpaved - disconnected	2.2
Light laydown paved areas- connected	1.3
Light laydown paved areas- disconnected	1.2
NW Industrial	Zn (lbs/yr)
Artificial turf-connected	20.6
Artificial turf-disconnected	20.5
Heavy laydown paved areas- connected	1.6
Heavy laydown paved areas-disconnected	1.6
Galvanized metal roofs and/or a lot of galvanized material- connected	1.5
Galvanized metal roofs and/or a lot of galvanized material-disconnected	1.5
Moderate laydown paved areas - connected	0.8
Moderate laydown paved areas - disconnected	0.8
Light laydown paved areas- connected	0.7
Light laydown paved areas- disconnected	0.7
Paved parking-connected	0.4
Paved parking-disconnected	0.4
Roofs Pitched - connected	0.2
Streets - with curb and gutters	0.2
MidLant Industrial	Zn (lbs/yr)
Artificial turf-connected	40.4
Artificial turf-disconnected	38.8
Galvanized metal roofs and/or a lot of galvanized material- connected	6.6
Other galvanized materials paved- connected	6.3
Galvanized metal roofs and/or a lot of galvanized material-disconnected	6.3
Other galvanized materials paved- disconnected	6.0
Other galvanized materials unpaved - connected	5.6
Other galvanized materials unpaved - disconnected	5.4
Heavy laydown paved areas- connected	2.8
Heavy laydown paved areas-disconnected	2.7
Moderate laydown paved areas - connected	2.3
Moderate laydown paved areas - disconnected	2.2
Light laydown paved areas- connected	1.3
Light laydown paved areas- disconnected	1.3

SUMMARY

In summary, this report describes the development and use of a spreadsheet modeling tool to provide a quantitative method for identifying sources of copper and zinc to stormwater runoff on Navy facilities. The goal was to provide facility managers with a tool to help them choose where to most effectively apply runoff controls. The WinSlamm tool was calibrated using site characteristics and stormwater data from Navy facilities for three separate Navy regions. The calibration was based on a comparison of over 300 stormwater datasets and detailed site characterizations from 19 drainages on 11 Navy bases in the Southwest, Mid-Atlantic, and Northwest regions of the U.S., ranging in size from 1 to 1400 acres. The model generated reasonable results, though with a relatively high degree of variability was primarily related to the high degree of variability that is associated with first-flush (first hour of runoff) data along with, and because it was possible only to compare current operations and land uses against historic storm data.

SSC Pacific and the University of Alabama developed a spreadsheet tool based on the calibration to perform the modeling in a simplified format for use by Navy facility managers. A spreadsheet was generated for each of the three Navy regions where the calibration was performed to account for differences in model outcomes primarily a result of variations in regional rainfall effects. The report provides guidance on the use of the spreadsheet tool, with a particular focus on how to collect and enter key site characterization data from an onsite review of facility drainages. This includes identifying and measuring areas within 53 different source area categories for land use within areas that can be characterized as mostly residential, commercial, or industrial. Using the tool in other Navy regions should be based on how similar rainfall is in the area to the type of rainfall used in calibrating the tool for the three regions

The project has created a simple and potentially useful tool that facility managers can use to identify where and relatively how much copper and zinc are generated throughout their drainages. Facility managers can therefore use the tool when developing strategies to implement control practices to meet compliance. The report appendices provide information on measured source strengths of many common materials found on Navy facilities, specific guidance with an example for conducting a site characterization, and the model calibration reports that also contain control practices for candidate stormwater with a measure of their potential effectiveness in each of the three Navy regions.

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Katz, C.N., G. Rosen, and E. Arias. 2006. "Stormwater Toxicity Evaluation at Naval Station San Diego, Naval Submarine Base San Diego, Naval Amphibious Base Coronado, and Naval Air Station North Island. SPAWAR Systems Center San Diego Technical Report 1938 (May), San Diego, CA.

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