GUIDANCE

Assessment and Management of Stormwater Impacts on Sediment Recontamination

SERDP Project ER-2428

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The research project evaluated tools providing better characterization of the sources (i.e. the low-level intermittent sources associated with events, including how these sources are affected by drainage systems) and the potential chemical and biological effects in the sediment sinks. These methodologies can then be integrated with models to identify impacts on remedies and, specifically, to identify the resilience of proposed and/or implemented remedies.

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Stormwater Sediment Recontamination Assessment Recommendations

SERDP Project ER-2428

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Cleanup at contaminated sediment sites has often been initiated before background sources have been fully identified, quantified and/or controlled. Under such conditions, remediated sites have become recontaminated by continued inputs from off-site sources, including permitted discharges, transport from upstream areas, or from stormwater discharges. Stormwater sources are particularly difficult to understand and manage because of the generally poor characterization of the irregular, event-driven inputs from such sources and the difficulty of managing diffuse sources of large volumes of runoff. DoD policy is that off-site sources must be identified and controlled prior to implementing cleanup, but the tools available to quantify event-driven irregular sources and their characteristics are limited, as is the ability to relate those sources to resulting chemical and biological impacts in sediments. As noted by the SERDP Environmental Restoration statement of need (SERDP ERSON 14-03) “this requires better scientific and technical capabilities to understand releases from these sources and how these source levels relate to potential recontamination of the sediment bed.” SERDP ER-2428 addressed this need and has evaluated a variety of assessment tools for their ability to quantify and evaluate the significance of sediment recontamination by stormwater discharges. The research project evaluated tools providing better characterization of the sources (i.e. the low-level intermittent sources associated with events, including how these sources are affected by drainage systems) and the potential chemical and biological effects in the sediment sinks. These methodologies can then be integrated with models to identify impacts on remedies and, specifically, to identify the resilience of proposed and/or implemented remedies.

The recommended approach to assess and evaluate stormwater discharges and sediment recontamination is based upon the ER-2428 research project but a summary of that project is not included here. The reader is directed to the final report for that project to see how these recommendations were implemented in that particular project. It should also be noted that SERDP has selected a follow-on project to examine the effectiveness of stormwater best management practices (BMPs) relative to the characteristics identified here as contributing to sediment recontamination. The follow-on project (ER18-1371) will examine specific BMPs at use in naval bases for their ability to control contaminant and particulate distributions and the bioavailability of discharging contaminants.

The recommended approach to stormwater characterization for sediment recontamination involves the following steps

1. Watershed characterization
2. Stormwater discharge monitoring
3. Sediment recontamination monitoring
4. Stormwater and receiving water modeling

Watershed characterization is a necessary step to define historical and current land uses, potential stormwater inputs, at-risk receiving waters and potential sampling locations. Stormwater monitoring should involve automated sample collection equipment to allow storm-integrated discharges at appropriate monitoring locations. Receiving water monitoring should identify locations likely to be impacted by stormwater as well as reference locations unlikely to be substantially affected by the stormwater discharges. Modeling is needed to be able to extrapolate from the necessarily finite monitoring program to annual or other long-term average impacts as well as to predict the performance of potential mitigating actions. Each of these will be discussed in more detail below.

1. Watershed characterization

A land development survey of the watershed should be undertaken to determine building along with road and pavement characteristics. Historical information including the identification of potential source areas resulting from past activity should be included in this characterization. Parking conditions and street widths should be noted. Any stormwater management systems should be identified. Photographs and summaries of this survey should be recorded. This information is used to determine expected stormwater loads and to define monitoring locations. Any existing modeling of the stormwater system should be identified. Sediment samples from the stormwater conveyance system and receiving waters should be collected to characterize baseline conditions and identify potential source areas that might be mobilized in a storm event. These data will not directly indicate stormwater recontamination potential but may inform hypotheses about stormwater impacts and help formulate data quality objectives that can be tested in subsequent sampling.

Monitoring locations for subsequent stormwater sampling should be identified as part of the watershed characterizaiton. These locations would normally be used to characterize significant source areas as well as key discharge points to receiving waters. Site selection is also based on sampling crew safety and equipment access. Automatic samplers will likely need to be manually started at the beginning of an event and monitored for successful operation. Photographs and descriptions of each sampling location should be documented.

Potential receiving water impact zones should be identified for each discharge point of interest. Alternative sources and areas subject to potential sediment resuspension and redistribution should be identified as well as quiescent areas that might encourage settling and deposition. Access points for equipment for receiving water characterization must be identified.

2. Stormwater discharge monitoring

Traditional stormwater monitoring is focused on defining the concentration and mass release of contaminants. If the assessment of sediment recontamination is the primary goal, however, this is insufficient. The size and settling characteristics of the stormwater releases is needed as well. The easiest way to do this is to collect sufficient sample to size segregate the solids and associated contaminants in the stormwater. In addition sampling of stormwater from different locations in a watershed may allow separation of the contribution of different land uses such as residential versus naval base contributions.

Stormwater samples should be collected using automatic samplers during storm events so that the cumulative effects of the storm events can be captured. Time dependent sampling to capture a first flush may be useful although the primary concern for sediment recontamination is the average discharges over an event. The sampling should be able separate any flow reversals, e.g. due to tides, from the samples collected. The total stormwater flow as well as large volume water samples should be collected for subsequent analysis. In ER-2428, 10 L water samples were needed to meet the goals of characterizing the stormwater and receiving waters including conducting a variety of chemical analyses and physical characterization and to meet detection and replication requirements. The automated sampling can supplemented as necessary with grab samples of the same volume.

The large volume samples must be split into appropriate fractions and analyzed to determine contaminant loading by size fraction. In ER-2428, composited 10 L samples from each stormwater event were split using a Teflon™ Dekaport splitter and the homogeneous splits subjected to filtration to develop size segregated contaminant and suspended solid concentrations. Rarely is there sufficient solids for direct chemical analysis of the solids filtered out in a given sample. Instead, the contaminant and solid mass in a given size interval is determined by difference between independent analyses of different size fractions. The sample splitting process is illustrated in Figure 1. An aliquot of approximately 100mL was retained from each sample prior to sample splitting for toxicity evaluation.

Briefly, the Dekaport splitter was placed level on the laboratory workbench. The Dekaport was rinsed a minimum of 3 times with Milli-Q DI water. Two analytical blank samples were collected by pouring Milli-Q DI water through the sampler into a HDPE and an Amber glass bottle. Next, 7 Amber glass and 3 HDPE bottles were placed under the Dekaport and 10L of thoroughly mixed stormwater sample was poured into the Dekaport. The amber glass bottles were used for subsequent organic analysis while the HDPE bottles were used for metals analysis. Samples were poured through a 0.5mm sieve to remove debris and were poured at rate that would allow for constant pressure and thus consistent flow through all the tubing of the Dekaport splitter. All 7 Amber glass bottles and one HDPE bottle were capped. The remaining 2 HDPE bottles were then passed through the Dekaport again (approximately 2L of sample) into 5 HDPE bottles; each of which would receive approximately 400mL. These bottles were then capped. For the second stormwater collection event where 20L were collected, these methods were duplicated for the additional 10L of sample volume that was collected. The Dekaport was thoroughly rinsed with Milli-Q DI water between samples. All bottles were shipped on ice to a laboratory (Texas Tech for ER-2428) for further processing and chemical analyses.

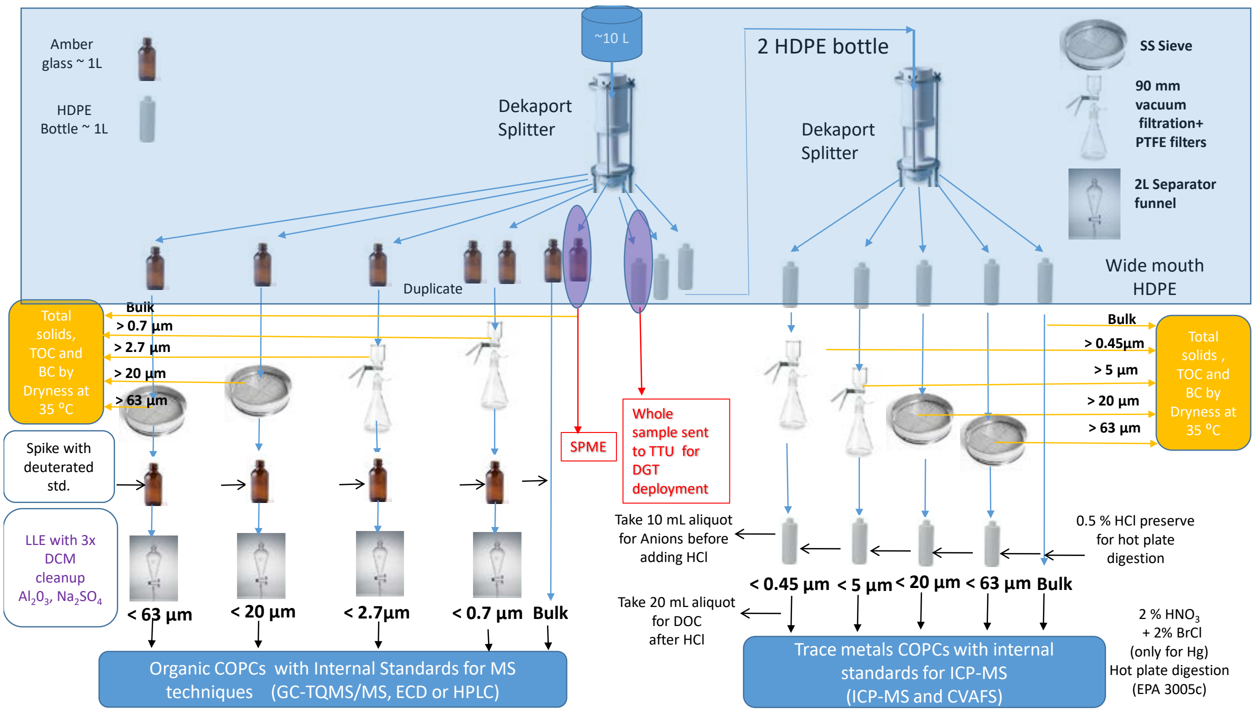

Figure 1 Composite sample splitting schematic for stormwater samples

At the analysis laboratory, the bulk water samples in the amber and HDPE bottles were filtered with 63, 20, 5 (2.7 for organics) and 0.45µm (0.7 for organics) sieves and glass fiber (organics) and PFTE (metals) membrane filters to provide raw samples for chemical analysis by particle size fraction. The different size fractions for organics and metals were based upon commercial availability of appropriate filters for metals and/or organic contaminants to allow efficient filtration and minimal analyte sorption and loss. After passing through the sieves/filters the water filtrate fractions from the amber bottles were subjected to liquid-liquid extraction using a separatory funnel (EPA method 3510). The solvent extracted fractions were then concentrated using a Thermo Scientific Rocket™ Evaporator to low level volumes to obtain desirable detection of persistent organic pollutants (POPs). Deuterated polycyclic aromatic compounds (PAHs) were employed to check the extraction efficiencies. The samples from the HDPE bottles were subjected to metal extraction using hot plate digestion (modified EPA method 3005A).

The solids accumulated on the sieves and filters were used to estimate the mass of solids in individual size fractions by differences. The solids can be further filtered, if necessary, to remove colloidal organic matter retained with the solids and rinsed to remove salts, if from a saline water sample. The solids were dried and the retained solids determined gravimetrically. The difference between filtered solids in two adjacent size filters defines the solids within that size range defined by those filters. For example, the solids and chemical loading in the 20 to 63 µm size range is determined by the difference between the solids mass collected on the 20 µm filter and that on the 63 µm and the contaminant loading by the difference in concentration of the respective filtrates.

A similar approach can be used for chemicals of concern, in this case measuring the contaminant concentration in the filtrate. The calculations for a chemical within a specific size range are illustrated in Figure 2. In short, one of the replicate samples was filtered to remove any contributions from particle sizes larger than that filter and the filtrate was analyzed. The mass of any contaminant or total solids in a particular size fraction was determined by difference (e.g. the total solids or contaminant mass in the >63 µm size fraction was determined by the difference in mass between the bulk samples and the 63 µm filtrate).

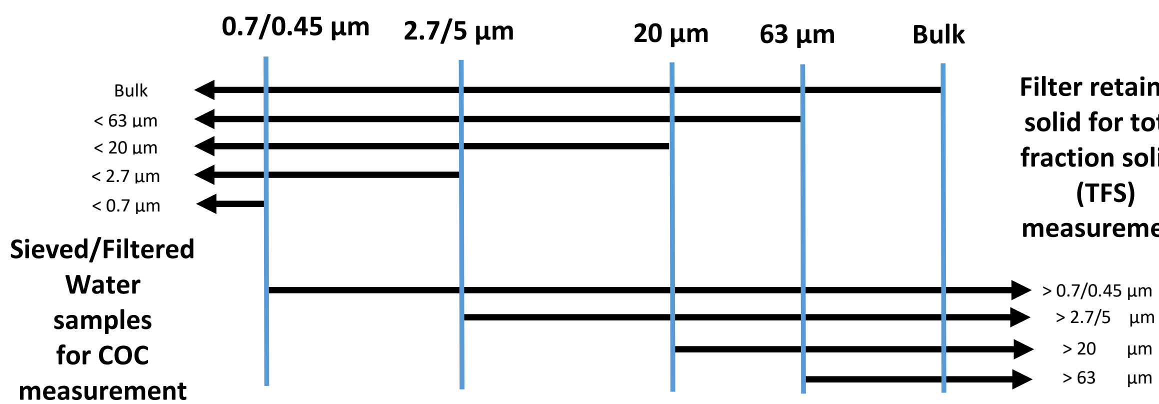

Figure 2 Fractionation of stormwater samples to determine total solids or contaminant mass within a particular size fraction by difference between different filtrate measurements

The concentration in mass/volume of stormwater in a particular filtered size interval is proportional to the mass of contaminant in the stormwater discharge (concentration x volumetric flow= mass of contaminant released). The concentration can also be normalized by the suspended particle concentration in a particular size fraction to provide an equivalent concentration in mass per mass solids on those solids. The latter represents the maximum bulk solid concentration that can be expected due to sediment recontamination. That is, if the sediment in that size fraction were to settle to the bottom of the receiving waters it is not expected to become more concentrated that at the discharge point. Typically, dilution by other sources or receiving water background sediments would likely reduce the average sediment concentration in most systems.

Stormwater discharges that are expected to lead to significant sediment recontamination would have the following characteristics

1. Sufficiently high mass loading in a particular suspended solids fraction leading to settling within the area of concern (e.g. µg/L of contaminant in a >63 µm for rapid settling near the stormwater discharge location)
2. Contaminant concentration on the solids (e.g. mg/kg) that is greater than background or sediment concentrations generated by other sources

The bulk stormwater samples or the samples in a particular size range may also be subjected to toxicity bioassays or measurement of freely available water concentration via passive sampling. The freely available water concentration is increasingly viewed as a surrogate for biological availability. The evaluation of toxicity through passive sampling or bioassays can identify contaminant fractions that may not be significantly contributing to potential sediment or stormwater toxicity or to identify contaminants of primary concern. Chronic toxicity tests with the purple sea urchin (*Strongylocentrotus purpuratus*) embryos were employed in ER-2428 but any water toxicity test relevant to the contaminants of concern might be used.

The methods outlined above were specific to ER-2428 but these can be applied more generally and may be needed to achieve the goal of size segregated contaminant loads and biological effects.

3. Receiving water monitoring

The stormwater discharges need to be linked directly to sediment recontamination. The particle size distribution can provide clues as to where the stormwater contaminants are likely to settle. Water column modeling can provide further clues as to where deposition of the stormwater is likely to occur leading to the potential for sediment contamination.

The most direct way to measure the deposition of stormwater contaminants is through sediment traps placed both near the stormwater discharge and at different locations leading ultimately to a reference location that is unlikely to be directly impacted by the stormwater discharges. Settling chambers provide a direct indication of what is currently depositing as opposed to sediment samples which represent deposition over time as well as subsequent resuspension and reworking events. The settling traps may need to be in-place over a season or multiple storm events in order to collect enough sample to characterize the newly depositing sediments.

The sediment traps employed in ER-2428 were prefilled with hyper-saline brine and topped off with ambient seawater. The high density brine keeps the sediment in the trap from being resuspended after collection. Traps were capped and lowered into the water to divers whom secured the traps to pre-deployed posts on the sediment surface. Once placement was complete, divers carefully removed caps from each sediment trap. Sediment traps were re-capped when any diving related activities occurred on station to avoid potential deposition from those efforts. Potentially, caps could be placed on the traps or automatically triggered if events occur that are not desired to be monitored (such as navigation activities in the vicinity of the traps). At the termination of sediment trap deployment period, divers placed caps back on the traps and recovered and transferred the traps to the surface crew with the assistance of a boat-mounted davit. Traps were transported back to the laboratory and allowed to settle. Once trap material sufficiently settled, overlying water was removed and the remaining material was collected for further processing (i.e. physical, chemical or bioassay analysis).

The sediment within a sediment trap can be subjected to conventional bulk sediment analysis. The total mass collected within a trap (e.g. mg) can be compared to the load of suspended solids from the stormwater (e.g. mg/L). The ratios of particular size fractions may yield a constant ratio for that size particle from the stormwater to the settling trap if there are no other significant sources. This ratio can be compared for different contaminants to try and identify contaminants that are predominantly contributed by stormwater. The concentration in the sediment trap sediments (e.g. mg/kg) can also be compared to the concentration on the stormwater solids. If the sediment traps exhibit concentrations or masses in excess of that which can be linked to the stormwater discharge, alternative sources should be investigated. For strongly solid associated contaminants and for stormwater dominated contributions to the depositing sediment, the ratio of the particle concentration or total mass in the settling trap to that in the stormwater should be a constant. Deviation from a constant can again be a clue to identify the potential for alternative sources.

Sediment traps that can collect ongoing depositing sediment should be the primary goal of identifying potential sampling locations in receiving waters but other sampling approaches for sediments (surficial sediment and cores) as well as physical characterization of the water (salinity, oxygen content, flow) may be useful or required by regulations. Bulk sediment collection, however, has the potential to be influenced by historical sources and may be dominated by other ongoing sources and so the data from these samples are not directly indicative of sediment recontamination.

Sediment trap and collected sediment material should also be subjected to bioassays and passive sampling to try and evaluate bioavailability and effects. In ER-2428, Cd and PAHs in stormwater were primarily found in large (>63 μm) particles. Bioassays showed minimal bioaccumulation or no change in bioaccumulation of the Cd and PAHs and passive sampling showed no change in porewater concentration in sediment pre and post storm events. These data suggest that the PAHs that were leading to rapid bulk sediment recontamination may have little or no biological significance. In this case, it was due to the presence of PAHs in large carbon particles with limited release of these PAHs from these particles. There is no regulatory framework to routinely take bioavailability into account in stormwater discharges but this information could be a moderating factor in decisions made to manage stormwater.

4. Stormwater and receiving water modeling

The data collected from the stormwater conveyance system and the receiving waters are necessarily limited to a small number of events. The complexity of the size fractionation recommended makes it likely that fewer events can be monitored than by conventional stormwater modeling. It is believed, however, that fewer events with the information needed to assess sediment recontamination is much better than more events with more limited monitoring that will lead to ambiguous results relative to sediment recontamination.

In ER-2428, Paleta Creek stormwater monitoring data was used with the WinSLAMM stormwater quality model that was calibrated for the area during previous projects. This project used the flow calculations from the model (calibrated using the detailed land use and development characteristics for the modeled areas in the Paleta Creek watershed, along with long-term regional rain data). The flow data was used in conjunction with the monitored metal and organic contaminant data for several particle size ranges to allow better predictions of the fates of the discharged stormwater particulates after discharge to the receiving waters. The monitoring data and the modeled results were coupled with measurements of receiving sediment impacts and ecological effects. The stormwater modeling enabled calculations of stormwater discharge characteristics as determined by specific drainage area characteristics and activities in the Paleta Creek watershed allowing extrapolation of individual monitored storm events. These stormwater loading predictions, along with information affecting the fate of the discharged suspended and bedload sediments (e.g. particle size distributions and related settling rates), were used to quantify the recontamination potential of the sediments by stormwater discharges.

Receiving water characteristics and sediment deposition and recontamination can also be explicitly modeled. In ER-2428, CH3D was employed to simulate depositional processes. The primary role of the model was to help determine the deposition distribution of particular size particles and to help in linking sources to that deposition as well as examining long-term behavior. As with WinSLAMM, calibration with the characteristics of a particular receiving water environment is typically necessary for quantitative predictions.

WinSLAMM was developed to evaluate stormwater runoff volumes and pollutant loadings in developed areas during a wide range of rain conditions, not just very large storms that are the focus of conventional drainage design models. WinSLAMM determines the runoff based on local rain records and calculates runoff volumes and pollutant loadings from each individual source area within each land use category for each rain. Examples of source areas include: roofs, streets, paved storage areas, loading docks, small landscaped areas, large landscaped areas, sidewalks, and parking lots.

WinSLAMM can use any length of rainfall record as determined by the user, from single rainfall events to several decades of rains. Besides determining the main sources of the stormwater contaminants of concern, the model can calculate the benefits for a series of stormwater control practices, including rain barrels and water tanks for stormwater irrigation, pavement and roof disconnections, roof rain gardens, infiltration/biofiltration in parking lots and as curb-cut biofilters, street cleaning, wet detention ponds, grass swales, porous pavement, catchbasins, media filters, hydrodynamic devices, selected proprietary devices, and combinations of these practices located throughout the watersheds and at the outfalls. The model evaluates the practices through engineering calculations of the unit processes based on the actual designs and sizes of the controls specified and determines how effectively these practices remove runoff volume and pollutants.

WinSLAMM does not use a percent imperviousness or a curve number to generate runoff volume or pollutant loadings. The model applies volumetric runoff coefficients to each “source area” within a land use category depending on site and rainfall characteristics. Each source area has a different runoff coefficient equation based on factors such as: slope, type and condition of surface, soil properties, etc., and calculates the runoff expected for each rain. The runoff coefficients were developed using monitoring data from typical examples of each site type under a broad range of conditions.

Each source area also has a unique pollutant concentration (event mean concentrations - EMCs - and a probability distribution) assigned to it. The EMCs for a specific source area vary depending on the rain intensity. EMCs of many source area types can be estimated based on extensive monitoring conducted in North America by the USGS, Wisconsin DNR, University of Alabama, and other groups. These monitoring efforts isolated source areas (roofs, lawns, streets, etc.) for different land uses and examined long term data on the runoff quality. The pollutant concentrations are also continuously updated as new research data become available, including information collected from source areas at naval facilities. Nationwide regional calibrations based on the National Stormwater Quality Database are available as initial background that can be supported and modified by local monitoring data (as was done for the Navy).

For each rainfall event in a data set, WinSLAMM calculates the runoff volume and pollutant load (randomized EMC x runoff volume) for each source area. The model then sums the loads from the source areas to generate a land use or drainage basin subtotal load. The model continues this process for the entire rain series described in the rain file. It is important to note that WinSLAMM does not apply a "unit load" to a land use. Each rainfall produces a unique load from a modeled area based on the specific source areas in that modeled area.

The model's output is comprehensive and customizable, and typically includes:

1. Runoff volume, pollutant loadings and EMCs for a period of record or each event.
2. The above data pre- and post- for each stormwater management practice.
3. Removal by particle size from stormwater management practices
4. Other results can be selected related to flow-duration relationships for the study area, impervious cover model, biological receiving water conditions, and life-cycle costs of the controls.

A full explanation of the model's capabilities, calibration, functions, and applications can be found at www.winslamm.com. For this project, the parameter files were calibrated using the local San Diego naval facility monitoring data (http://unix.eng.ua.edu/~rpitt/Publications/8_Stormwater_Management_and_Modeling/WinSLAMM_modeling_examples/Site_Descriptions_Calibration_and_Sources_Feb_17_2014.pdf), supplemented by additional information from regional data from the National Stormwater Quality Database (NSQD), available at: http://bmpdatabase.org/nsqd.html as described in the following report describing regional calibrations of WinSLAMM using NSQD information:

http://unix.eng.ua.edu/~rpitt/Publications/8_Stormwater_Management_and_Modeling/WinSLAMM_modeling_examples/Standard_Land_Use_file_descriptions_final_April_18_2011.pdf.

5. Conclusions

The sampling outlined in the preceding steps is believed to provide the stormwater program manager the best opportunity to evaluate the magnitude and significance of stormwater discharges on sediment recontamination. To make the best use of this information it should be one part of a stormwater assessment and management effort that includes modeling to evaluate how these impacts will change with management actions.

Note that it is possible that there are substantial stormwater impacts on bulk sediment recontamination but even then bioavailability evaluation through toxicity and bioaccumulation testing may indicate that this recontamination is not significant compared to other ongoing sources or background sediment resuspension and settling. There remains no routine regulatory paradigm to take this behavior into account but the information collected by the recommendations herein may provide the basis for a determination of no significance of these ongoing discharges.