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Child dermal sediment loads following play in a tide flat

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Dermal contact with sediment is sometimes identified as a pathway of concern in risk assessments. Dermal exposure to sediment is poorly characterized and exposure assessors may rely on default soil adherence values. The purpose of this study was to obtain sediment adherence data for a genuine exposure scenario, child play in a tide flat. This study reports direct measurements of sediment loadings on five body parts (face, forearms, hands, lower legs and feet) after play in a tide flat. Each of nine subjects participated in two timed sessions and pre- and post-activity sediment loading data were collected. Geometric mean (geometric standard deviation) dermal loadings (mg/cm^2) on the face, forearm, hands, lower legs and feet for the combined sessions were 0.04 (2.9), 0.17 (3.1), 0.49 (8.2), 0.70 (3.6) and 21 (1.9), respectively. Participants' parents completed questionnaires regarding their child's typical activity patterns during tide flat play, exposure frequency and duration, clothing choices, bathing practices and clothes laundering. Data presented in this paper supplement very limited prior adherence data for sediment contact scenarios. Results will be useful to risk assessors considering exposure scenarios involving child activities at a coastal shoreline or tide flat.
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Introduction

The US Environmental Protection Agency (EPA) has identified at least one contaminated sediment site in every state in the US (US EPA, 2001). Sediment contamination is widespread for several reasons including: (1) common past and present direct use of water bodies for waste disposal, (2) the roles of major rivers and coastal waters as transportation routes subject to spill impacts, (3) the fact that river mouths represent collection points for point and area source discharges within entire watersheds, and (4) preferential partitioning of some types of contaminants from water to sediments. Sites in which sediments have been identified as contaminated are environmentally varied (e.g., wetlands, rivers, lakes and tidal estuaries). Potential for direct human contact with sediment through recreational and other types of activities exists at some locations. EPA has identified over 60 Superfund sites for which a Record of Decision or Action Memo is in place at which sediment contamination is a concern (US EPA, 2004a). Risk assessments prepared for many of those sites consider potential dermal exposure to sediment. Dermal contact scenarios may involve adults and/or children, residents and/or visitors/trespassers, and variously include beachcombing, boating, construction work, fishing, shellfishing, swimming, and shoreline play or recreation.

Dermal contact with sediment is not well characterized. For marine sediments, only limited measurements obtained from adults are available (Kissel et al., 1996a; Shoaf et al., submitted for publication). For inland water bodies, adherence data are available for a single child activity (Kissel et al., 1996a). Current EPA Guidance (US EPA, 2004b) does not provide exposure factors for sediment scenarios but states that the recommended soil contact protocol could be utilized if appropriate site- and sediment-specific adherence and activity pattern data were available. Adherence of sediment to skin can reasonably be expected to differ from adherence of terrestrial soil to skin. Other factors being equal, increasing moisture content typically increases soil adherence to skin (Kissel et al., 1996b). This effect is most dramatic for large particles since they are relatively heavy and adhere poorly when dry. Therefore, contact with (wet) sediment presents opportunity for relatively high dermal adherence and values specifically applicable to sediment are of interest.

Key variables in the current paradigm for assessment of dermal exposure to chemical contaminants in soil in addition to adherence include surface area exposed, event frequency and event duration, which are site- and scenario-specific, and some measure of absorption efficiency or chemical availability (US EPA, 2001). Currently, default values of these

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exposure factors are defined only for soil contact scenarios. It is likely that all or most of these factors differ between sediment and soil scenarios. The primary purpose of this study was to obtain sediment loading data on multiple body parts for a genuine exposure scenario, child play on a tide flat. Questionnaire data were also collected for each subject on typical activity duration and frequency, clothing worn during activity, bathing patterns and clothes laundering. These responses also supplement very limited prior activity pattern data applicable to a child shoreline recreation scenario. Published examples of risk assessments of coastal contamination that have included child resident or visitor/trespasser scenarios include an evaluation of estuary sediment pollution related to onshore releases (Adams et al., 1994) and of beach fouling related to a tanker wreck (Dor et al., 2003). In the former case, assessment of child dermal exposure is reported but exposure factors specific to children are not. In the latter case, sediment adherence, event duration, and event frequency all appear to be based on theoretical considerations rather than empirical measurements.

Methods

The selected activity was child play on a tide flat. The scenario was identified based on discussions with EPA personnel regarding exposure pathways and receptor groups of concern related to sediment contamination. The field study was conducted on one day in late September 2003 at a tide flat at Jamestown, Rhode Island. Jamestown is located on Conanicut Island at the south end of Narragansett Bay. The Bay receives inputs from multiple watersheds including highly developed urban areas. The tide flat appeared visually to have significant organic content and vegetation was dispersed throughout the site. No maintained swimming beach or park facilities were present. Although field sampling was conducted in late September, the temperature was 75°F and represented a warm weather play scenario. The tide flat was selected because it is frequented by local resident children year round and is not known to be contaminated. A nearby Superfund site, the Newport Naval Education and Training Center, is also located on Narragansett Bay. A risk assessment conducted prior to this study on a portion of that site included child shoreline play scenarios (Tetra Tech NUS, Inc., 1999).

Participants signed written assent forms. Participants' parents signed parental consent forms and filled out questionnaires regarding activity patterns, child bathing, clothing selection and clothes laundering. Human subjects approval was obtained via a University of Washington institutional review board and EPA. The selected activity was a genuine play scenario. Play activity and clothing choices were unscripted. Each subject participated in normal activity for two timed sessions (sessions 1 and 2) ranging from 20 to 60 min. The length of each session was not predetermined and was dependent on the volunteers' desire to continue playing and the availability of the researchers' washing stations.

Nine subjects (three female and six male) ages 7–12 years old participated in the study. There was little variation in the participants' attire. During both sessions 1 and 2, all nine participants were barefoot. During both sessions, male participants wore shorts and no shirts and female participants wore shorts and t-shirts. Common play activities included wading, running and sliding along the shoreline, throwing sediment and digging with bare hands.

The field protocol was similar to previous work and included washing participants before and after unscripted activity (Kissel et al., 1996a; Holmes et al., 1999). Skin surfaces washed included face, forearms, hands, lower legs and feet. Forearm area included skin surface from the wrist to the top of the elbow. Lower legs included the area from the ankle to above the kneecap. Skin surfaces were washed in a specific order (hands, forearms, feet, lower legs and face) using pressurized garden sprayers filled with deionized water. Participants' hands were washed first so that they could be employed to assist removal of sediment if the pressurized spray was inadequate. The wash water from each body part was collected in a large plastic container and transferred to Nalgene® bottles. Pre- and post-activity wash water for session 1 and postactivity wash water for session 2 were transported to the laboratory in Nalgene® bottles. Forearm, hand, lower leg and foot samples were each collected as pooled left and right samples for individual participants (e.g., left and right hand, left and right foot, etc.).

Wash water samples were filtered through pre-weighed 47-mm glass fiber filters with a nominal pore size of 0.5 μm (Gelman Metrigard, Pall Metrigard). Filters were stored in a desiccator (Sanplatec Dry Keeper) before they were pre-weighed. Filters were placed in tared aluminum weigh boats and oven dried (Labline® L-C) at 100°C for 1–2 h. Recovered mass was weighed on an analytical balance readable to 0.1 mg. Validation of the washing technique was conducted in laboratory tests prior to the field study. The validation method was similar to that described in Kissel et al. (1996a). Skin surfaces of five body parts (hands, forearms, lower legs, feet and face) were applied to wet sediment in preweighed pans. Mass recovered from each body part by washing was compared (dry mass basis) to mass loss from the pan. Mean sediment recoveries exceeded 84% for all body parts. Results presented here are not adjusted for recovery.

Total mass recovered (dry basis) was converted to average skin loading for each body part by dividing recovered mass by calculated surface area. Total body surface areas were estimated using the modified Gehan and George equation (Anderson et al., 1985) and height and weight reported for each participant. Surface areas for individual body parts (head, arms, hands, legs and feet) were computed from

regressions (not shown) of percent of total body surface area with age using data from Tables 3–12 in Anderson et al. (1985). The washed surface area of the face, forearms and lower legs were approximated as one-third of the head area, one half of the arm area, and one half of the leg area respectively. One (of 45) preactivity sample produced no detectable residue on the filter. For this case, the limit of detection was used. The limit of detection was calculated by dividing the balance precision (0.1 mg) by the surface area of the specific body part. All 90 postactivity samples had measurable masses greater than the detection limit.

Sediment characterization was conducted at the Analytical Service Center in the College of Forest Resources at the University of Washington. Sediment samples were analyzed for total organic carbon (OC) content by dry combustion. Particle size distribution was assessed by dry sieving. Sediment samples used in analyses were collected at the tide flat during the field study. Sediment characterization presented below is of composited material taken from the field site and may vary from that of material that actually adhered to skin. Statistical results were generated using SPSS (version 9.01 for Windows). Normality tests were conducted on the transformed and nontransformed data using the Lilliefors modification of the Kolmogorov–Smirnov test.

Results

Results of the sediment analysis and characterization are reported in Table 1. Particle size categories are from Wentworth (1922). The tide flat sediment particles fell primarily in the size range associated with sand and only 0.77% of the total sample mass (dry mass basis) was characterized as clay or silt. The organic carbon content decreased in the smallest size fractions with increasing particle size and increased in the three largest fractions with increasing particle size. Increasing organic carbon content in the larger size fractions of marine sediments has been reported in previous studies (Burgess et al., 2001; Wang et al., 2001; Shoaf et al., submitted for publication).

Adherence data were tested for normality using the Lilliefors modification of the Kolmogorov–Smirnov test. Normality was rejected ($P<0.05$) in 29 of 40 tests of nontransformed data, but could not be rejected ($P>0.05$) in 37 of 40 tests of log-transformed data. Sample sizes (typically $n=9$) were too small to definitively characterize the data. However, assumption of log normality is generally more defensible than assumption of normality for skewed data sets in which negative values are impossible. Therefore, results reported in this paper reflect log-transformation of the data. This assumption is consistent with prior reports (Kissel et al., 1996a, 1998; Holmes et al., 1999). Figure 1 shows a typical distribution of sediment loadings.

Pre- and postactivity measurements were collected for each participant for session 1 and postactivity measurements were collected for session 2. No preactivity samples were collected for session 2 because participants started session 2 immediately after session 1 washing. Geometric means and corresponding 95% confidence intervals of pre- and post-activity measurements are reported in Table 2. Post-activity sediment loadings were generally higher than pre-activity sediment loadings for session 1 (Figure 2). Paired samples

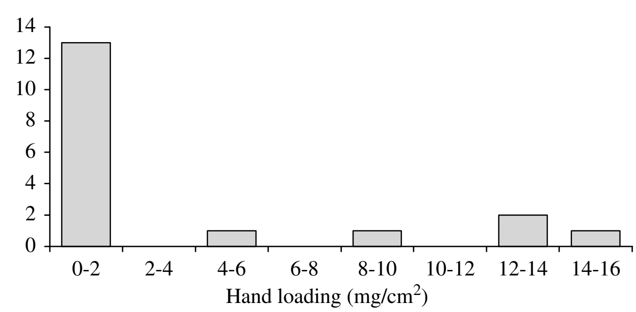

Figure 1. Histogram of combined session 1 and 2 (total $n=18$) post-activity hand loadings.

Table 1. Field site sediment characterization.

Sediment fraction	Size (mm)	Mass[a] (% of total)		OC content (%)	
		Mean[b]	SD	Mean[c]	SD
Clay and silt	<0.0625	0.77	0.072	1.8	0.036
Very fine sand	0.0625–0.124	9.4	0.34	0.92	0.042
Fine sand	0.125–0.249	18	0.37	0.84	0.024
Medium sand	0.25–0.499	34	0.22	0.96	0.069
Coarse sand	0.5–0.999	26	0.27	1.4	0.085
Very coarse sand	1.0–1.999	11	0.016	1.7	0.15

[a]Mass as dry weight.
[b]Mean of two samples. Total does not add to 100% due to rounding.
[c]Mean organic carbon content of two samples.

Table 2. Geometric means (GM) and 95% confidence intervals (CI) of pre- and post-activity sediment loadings (mg/cm^2, dry mass basis).

Body part	GM (CI)			
	Preactivity ($n=9$)	Postactivity, session 1 ($n=9$)	Postactivity, session 2 ($n=9$)	Postactivity, overall ($n=18$)
Face	0.019 (0.008–0.047)	0.036 (0.015–0.089)	0.049 (0.023–0.11)	0.042 (0.025–0.072)
Forearms	0.017 (0.010–0.028)	0.16 (0.060–0.41)	0.19 (0.082–0.43)	0.17 (0.098–0.30)
Hands	0.089 (0.052–0.15)	0.38 (0.070–2.1)	0.62 (0.12–3.1)	0.49 (0.17–1.4)
Lower legs	0.024 (0.003–0.18)	0.68 (0.26–1.8)	0.71 (0.24–2.1)	0.70 (0.37–1.3)
Feet	0.47 (0.18–1.2)	17 (10–28)	26 (17–40)	21(15–29)

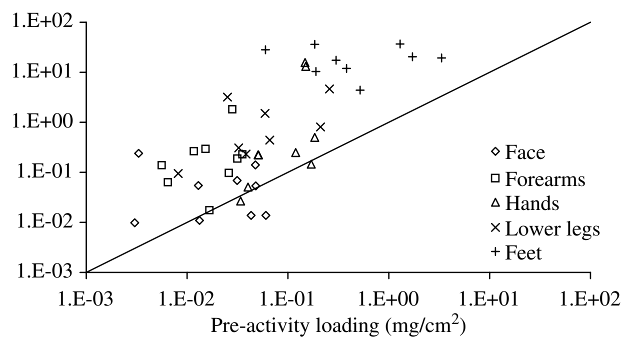

Figure 2. Pre- vs. postactivity sediment loading for session 1. Diagonal line represents perfect correspondence between pre- and postactivity loading.

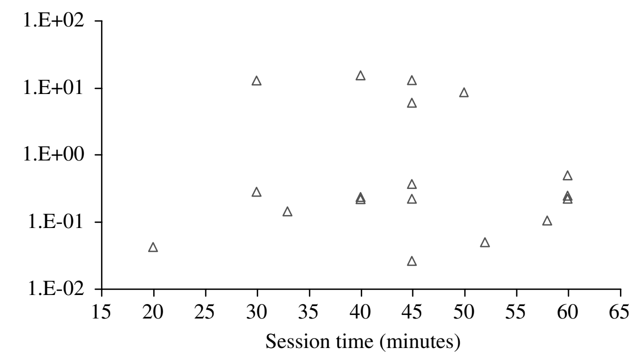

Figure 3. Post-activity sediment loading on hands vs. time spent playing.

t-tests of pre- and postactivity measurements for session 1 showed a significant difference ($P<0.05$) between pre- and postactivity loadings for all body parts except the face. The highest dermal loadings were observed on participants' feet for both sessions 1 and 2 (geometric means of 17 and 26 mg/cm^2, respectively). Postactivity loadings did not differ between sessions. Paired samples t-tests conducted for each body part showed no significant difference ($P>0.05$) in sediment loadings after sessions 1 and 2.

Sediment loading also did not appear to depend upon event duration. Time spent playing during session 1 was 30–60 min and session 2 varied between 20 and 60 min for each participant. Seven of nine subjects had one play episode longer than 40 min and one shorter than 40 min. Paired samples t-tests applied to those seven subjects revealed no significant difference ($P>0.05$) in postactivity sediment loadings on any body part for event durations of less than 40 *versus* greater than 40 min. Postactivity results for hands are plotted against event duration in Figure 3.

Shoreline activity, clothing selection, bathing and clothes laundering information were collected for each subject using questionnaires completed by their parents. Questionnaires asked parents to estimate typical values for warm weather conditions (April to October). Data describing hours per day spent at the tide flat, number of days per week spent at the tide flat, play activities and clothing worn during tide flat play are reported in Table 3. Parents estimated that participants typically spend 2–4 h/day and a median of 3 days/week at the tide flat during warm weather which translates to about 80 warm weather event days per year. Responses to two questions regarding clothes laundering are reported in Table 4. Most parents reported relatively prompt laundering

Table 3. Questionnaire responses (%) regarding typical child warm weather[a] shoreline play activity.

Days per week	*%*	*Clothing worn*	*%*
1	11	Short sleeves	11
3	44	No top	55
4	11	Swim top	11
5	11	Short/long sleeves, no top	11
7	22	Short sleeves, swim top	11
Hrs per day	%	Swim bottom	55
2	33	Shorts	22
3	22	Shorts, swim bottom	11
4	44	Shorts, swim bottom, pants	11
Activity[b]	%	No socks	77
Wade	88	No/low socks	11
Swim	100	No response	11
Lie down	55		
Dig	66	Barefoot	88
Run	77	Barefoot, sandals, shoes	11

[a]Described as April – October in questionnaire.
[b]Respondents could choose more than one activity.

Table 4. Questionnaire responses (% of sample, $n=9$) regarding typical warm weather[a] clothes laundering.

Washed before second wearing	Usually	Sometimes	Never
Shirt/top	88	11	0
Pants/shorts/swim bottom	66	33	0

[a]Described as April – October in questionnaire.

Table 5. Questionnaire responses (% of sample, $n=9$) regarding typical child warm weather[a] bathing behavior.

Length of time after shoreline play before hand washing (h)	%	*Number of showers or baths per week*	%
1–2 hours	33	1	11
2–4 hours	33	2	44
>4 hours	33	4	22
		6	11
		6 or 7	11
Length of time after shoreline play before shower or bath (h)	%	*Number of hand washes per day other than when showering or bathing*	%
1–4 hours	33		
>4 hours	33		
next day or after	33	0	22
		1	44
Change clothes within an hour after shoreline play	%	2	11
		3	11
		4	11
Yes	44		
No	22		
No response	33		

[a]Described as April – October in questionnaire.

of clothing worn for tide flat visitation. Responses to questions regarding bathing are reported in Table 5. Parental answers to those queries suggest potential for significant delay before whole-body bathing.

Discussion

Sediments at the field site were determined to be predominately sand. Because size fractionation was accomplished by dry sieving, some underestimation of fine fractions may have occurred. However, sediment characteristics reported here are similar to those reported by Burgess et al. (2001) for a sampling station (“Beavertail”) located quite near the field site.

Postactivity loadings were significantly higher than preactivity loadings for all body parts except face. Significantly higher postactivity loadings on most body parts are consistent with previous studies (Kissel et al., 1996a; Holmes et al., 1999). In previous field studies, the highest dermal loadings have typically been on hands (Kissel et al., 1996a; Holmes et al., 1999). In this study, the highest postactivity geometric mean loadings were observed on feet (17 and 26 mg/cm^2, for sessions 1 and 2 respectively) rather than hands (0.38 and 0.62 mg/cm^2, respectively) (Table 2). This may reflect site-specific properties of the sediment. Foot loadings observed here were similar to those on the “kids-in-mud” (Kissel et al., 1996a) who played on the shoreline of an inland lake in relatively fine-grained sediments. But participants’ feet remain in contact with shoreline sediment right up to the point of washing. Hand loadings in the former case were much higher. A possible explanation is that sandy sediment is less adhesive and more subject to rapid attrition once active contact stops.

Geometric mean preactivity foot loadings were higher than preactivity loadings on other body parts. This is probably due to the time participants waited to be prewashed. Several of the participants took their shoes off before or immediately upon arriving at the field site. Nevertheless, postactivity foot loadings were substantially higher than corresponding preactivity loadings.

Postactivity loadings were not dependent on activity length when demarcated at 40 min. This is consistent with prior observation that gravimetric loading reaches an apparent saturation level relatively rapidly (Kissel et al., 1998).

Activity pattern, clothes laundering and bathing data were collected from the questionnaires to provide site- and scenario-specific information regarding typical shoreline activity patterns and behaviors. National Human Activity Pattern Survey (NHAPS) data (Tsang and Klepeis, 1996; US EPA, 2002) do not address shoreline or beach sediment contact scenarios. NHAPS data describing time spent at rivers or lakes are aggregated with swimming pool time. The most applicable NHAPS data are limited to time spent playing outdoors and playing outdoors on sand or gravel or on bare dirt. Tsang and Klepeis (1996) reported a median of 1 h/day of outdoor play on “sand, gravel, dirt or grass” for 5–11-year-old doers. Subcategory medians were 3 min/day of play on sand or gravel, 0 min/day on dirt, and 60 min/day on grass. Wong et al. (2000) conducted a Soil Contact Survey (SCS-II) specifically focusing on children’s activity patterns related to dermal contact with soil. Wong et al. (2000) found a median duration of 20 h/week for outdoor play on “bare dirt or mixed grass and dirt” surfaces during warm weather (April–October) for children ≤ 17 who participated in such activity. For children aged 7–12 years, a warm weather median of 21 h/week would be generated (unpublished data). The median time children in the current study (ages 7–12) spend at the tide flat in warm weather was reported to be 12 h/week. Both Wong et al. and Tsang and Klepeis reported data from national studies. Given that the NHAPS results are seasonally balanced rather than limited to warm weather, rough agreement on a median of 10–20 h/week of outdoor recreation on unpaved surfaces among doers can be postulated. Observation of apparent allocation of a relatively large

fraction of that recreational time to shoreline activity in the current study likely reflects ease of access for local children.

Participants' parents reported a variety of activities at the tide flat. All of the participants swam at the tide flat and over half typically lay down, ran and dug in the shoreline sediment during warm weather months (Table 3). These activities present potential for substantial dermal contact with sediment.

Bathing and hand washing information is needed to determine the time interval until sediment is removed from skin from washing to improve estimates of event duration. Tsang and Klepeis (1996) reported a median hand washing of three to five times per day and median child bathing of one time per day. Similarly, Wong et al. (2000) reported median child hand washings of four times per day and median child bathing of seven times per week. Median values reported by parents in this study were one time per day for child hand washing and two times per week for child bathing. The earlier data for washing behavior were obtained via phone script and multiple choice questioning. Subjects were obtained via random digit dialing and may have been inclined to report conservative answers to anonymous interviewers regarding hygiene. The questionnaires in the current study were completed via face-to-face interviews in a relaxed and informal setting. The parents may have felt less threatened. In the absence of definitive explanation, the disparity should be interpreted as an indication of uncertainty in bathing information that bears on duration of exposure.

This study was a pilot study intended to demonstrate the feasibility of obtaining site-specific sediment loading values from unscripted activities. Results reported here supplement limited existing data available for coastal shoreline sediment contact scenarios. The small sample size ($n = 9$) reduces ability to generalize to activity patterns and adherence values for larger populations. Nonetheless, information reported on adherence, activity patterns, bathing patterns and clothing choices may be useful to risk assessors attempting to conceptualize and characterize children's exposures. Deviance from national survey results, especially with respect to event and bathing frequency, is of note.

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