# Flood Mud: Improving Flood Sediment Management for Vermont Towns


*Photo by Bryan Pfeiffer via, The Associated Press.*

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## I. Abstract & Purpose

Vermont experienced catastrophic flooding in July 2023. Given that these floods are expected to become more frequent and severe with climate change, effective response and recovery measures are becoming increasingly important. Sediment deposition was an overlooked impact of the floods, despite the fact that many areas in Vermont were left covered in feet of mud after flood waters receded. Our work investigated how sediments were handled in developed areas in July 2023's flood response. Based on our research, we identified gaps in this response and made recommendations for improvement in future flood events in Vermont. In the first half of the report, we demonstrate that flood response did not adequately protect human and environmental health from flood sediment hazards and that guidance and clean-up protocols were lacking. In the second half of the report, we present our research on flood sediment management practices and make ten recommendations for better flood sediment management. This research and these recommendations can be used to advocate for policy changes in Vermont that address the current gaps in flood preparedness and response.

## II. Summary of Recommendations

1. Certify more categorical disposal facilities for local disposal and handling of sediments
2. Distribute "Flood Mud" fliers before, during, and after flood events
3. Designate and train a group of people in each municipality to be in charge of flood clean-up, including proper sediment management
4. Set up a clean-up station(s) in each town immediately following a flood to distribute personal protective equipment (PPE), provide clean water for hand-washing, provide guidance and contacts, distribute fliers
5. Leave sediments in place when they cannot be removed or do not pose an obstacle or health problem
6. Minimize dust pollution with wet street sweeping techniques
7. Sort sediment at its disposal site based on potential for contamination and particle size
8. Expand state flood relief funding to cover municipal and residential sediment testing
9. Investigate and initiate remediation of contaminated sediments
10. Consider reuse options for clean sediment

## III. Background

### a. Summer 2023 Vermont Flood Context

This summer, the state of Vermont experienced catastrophic flooding that destroyed homes, infrastructure, farms, and natural ecosystems and shut down communities, business, and roads. In June, consistent rain saturated the soil, preventing it from absorbing much more water in July's extreme rain events. Flooding began on July 9th. In just 48 hours, more than 2 months worth of rain (6-9 inches) fell in areas of Vermont (Banacos, 2023; McDaniel & Slater, 2023). Montpelier, one of the hardest hit places in Vermont, received 5.3 inches of rain in one day, the most rainfall per day since recording began in 1948 (Banacos, 2023). Both the amount of rain, river levels, and the flooding damage matched or exceeded that of Tropical Storm Irene (Banacos, 2023; Sadoff & Barton, 2023). The extent of July's flooding impacts were second only to the Great Flood of November 1927, which occurred prior to modern day flood control measures (Banacos, 2023). Between July 18th and 21st, a second round of extreme rain and flooding hit the state, exacerbating impacts from the initial flooding (Hirschfeld, 2023). Water surpassed the Federal Emergency Management Agency's (FEMA) designated flood zones, catching homeowners off-guard, and impacted many Vermonters who lack flood insurance (Berlin, 2023; Root, 2023). Floods claimed two lives, displaced people from their homes, set off landslides, overflowed wastewater treatment facilities, washed out bridges and roads, picked up debris, spilled hazardous materials, and deposited sediments that interfered with human land use (Giles & Dockser, 2023; McDaniel & Slater, 2023; Sadoff & Barton, 2023). Vermont flood response has cost over $100 million and recovery is still ongoing as of October (Banacos, 2023; Jacoby, 2023; Kinzel, 2023).

Despite the extensive local and national news coverage of the flooding in Vermont, news articles rarely mention the issue of sediment deposition, let alone its cleanup. The Connecticut River Conservancy speculated that sediment deposition was an unaddressed issue and the few articles that covered the topic corroborated this. In residential areas of Chester, VT, "mounds of river sediment sunk like beach sand underfoot" and filled people's backyards (Mearhoff, 2023). In Weston, Vermont, the fire chief discussed plowing four inches of sediment out of the firehouse (McDaniel & Slater, 2023). Farmers who were interviewed also described how their fields and crops were covered in a layer or coatings of silty mud or dust (Engisch, 2023; Sadoff & Barton, 2023). The images taken post-flood show the thick mud that was left behind in inundated houses when floodwaters receded (Fig. 1 and 2). While images and articles suggested that deposited sediment was a problem, the sparse discussion of its impacts and clean-up indicated that it was an overlooked aspect of flood response, with likely consequences for human and environmental health.

**What is sediment?**

**Sediment** refers to weathered and eroded material of all grain sizes that is **transported** by wind, ice, or water – such as a river. When sediment is wet, it may be referred to colloquially as **mud**.

**Figure 1.**

*Mud-covered bridge on July 13, 2023 in Montpelier, Vermont*


*Note.* Photo by Charles Krupa, The Associated Press (Rathke, 2023).

**Figure 2.**

*Flood deposited sediments by Okemo Resort in Ludlow, VT.*


*Note.* Photo by Sammy Blanchette, NECN (Fortier, 2023).

## b. Sediment Deposition in Floods

When streams and rivers flow at higher-than-normal velocities and flow outside of their channels, they erode their banks and pick up sediments that are carried until floodwaters recede and slow down enough for particles to settle out (Crawford et al., 2022; Weber et al., 2023). During this summer's floods, turbidity – a measure of suspended matter – in rivers was much higher than under normal flow conditions, indicating high sediment loads (Fig. 3). For instance, the turbidity in the Lamoille River was over 1000 times higher than normal, increasing from 3 FNU to 4099 FNU (FNU units measure the amount of light scattered by a water sample) (Giles & Dockser, 2023). This sediment was either carried to Lake Champlain or was deposited in inundated areas when the water slowed (Ashley et al., 2008; Giles & Dockser, 2023). Sediments may not seem like a big deal compared to other obvious flood impacts such as inundation of homes and water-damaged property. In fact, floodplains (flat, low-lying areas by rivers and streams) are considered some of the best land for agriculture because rivers contribute sediment deposits that make for productive soils in the long-term, as is the case for much of the Champlain Valley (Sadoff & Barton, 2023). However, sediment has the potential to be contaminated, and it can end up in places where it disrupts human health, infrastructure, and the environment.

**Figure 3.**

*Flooding rivers carry sediment down the Ottauquechee River in Quechee, VT, on July 10, 2023.*

*Note.* Photo by Jessica Rinaldi, The Boston Globe (Fortier, 2023).

## c. Human and Environmental Health Effects of Sediments

In addition to damaging property and creating challenges for clean-up, sediments can also contain chemical and biological contaminants that make them dangerous to human health. As a result of the floods, there were over 200 reported spills of hazardous materials and 24 wastewater treatment facilities overflowed or compromised, sending untreated or partially treated sewage into the rivers (Giles & Dockser, 2023). From flooded farm fields, livestock waste, fertilizers, and pesticides washed into the river. In urban areas, industry and road chemicals (e.g., heavy metals from brake and tire wear), oils, gas, and larger debris ended up in the floodwaters (Giles & Dockser, 2023; Pintair, 2023). Bacteria (e.g., *E.coli*) metals (e.g.,lead, arsenic), nutrients (e.g.,phosphorus), and organic molecules (e.g., pesticides) can be adsorbed to the sediment particles suspended in floodwater and subsequently are deposited along with them, introducing contaminants with well-documented health consequences to flood-affected areas (Crawford et al., 2022). Contaminants that have recently spilled are not the only problem: older sediments along rivers have often accumulated contaminants, such as heavy metals and persistent organic pollutants (POPs) from historical sources, including industry (e.g., polychlorinated biphenyls) and agriculture (e.g., DDT and other pesticides), which can be released when these sediments are eroded and disturbed in floods (Crawford et al., 2022). In addition to having health effects for people who are exposed, these contaminants can have effects on other organisms and leach from piled sediments into water sources.

> **Hazardous materials:**
> Hazardous materials are defined under Vermont Hazardous Waste Management Regulations (VHWMR) and broadly include all **petroleum products; toxic, corrosive chemicals;** any compounds listed under the federal Comprehensive Environmental Response, Compensation, and Liability Act (**CERCLA**), and any other "chemical or substance that, when released, **poses a risk to human health or other living organisms** and that is listed by the Secretary by rule" (VT DEC, 2022).

The extent of contaminant adsorption to sediment particles is highly dependent on sediment particle size: smaller particles such (silts and clays) have high surface-area-to-mass ratios and thus can adsorb comparatively more contaminant molecules than larger particles (sand and gravel) (Ashley et al., 2008). Smaller sediment particles require slower water velocities before settling out and deposition. Homes and other buildings act as a filter: water must significantly slow before entering building cracks, allowing small particles to deposit inside while larger particles settle outside on roads, lawns, and fields. Concerningly, studies have found higher concentrations of contaminants in inundated homes than in areas outside homes or in the original river sediments (Ashley et al., 2008). These fine sediments are also harder to clean up and can stick to skin when people handle sediment-coated materials, resulting in the potential for exposure via ingestion.

Sediments themselves can pose risks for human health, even when they are not contaminated with other compounds. When sediments dry, they form a dust that, when disturbed by wind or people cleaning, becomes airborne. This creates a form of particulate matter air pollution that has similar respiratory health effects as wildfire smoke and urban smog. Particulate matter, especially the smallest particles, irritates the respiratory system and has been shown to exacerbate asthma and other breathing problems and put one at higher risk for heart and lung disease (US EPA, 2016; Weber et al., 2023). If these dust particles also carry bound contaminants, inhalation of dust results in inhalation exposure to compounds with their own toxic effects (Weber et al., 2023). Once airborne, sediments deposited in outside areas can be carried by wind into homes and to other areas that had not been flooded or affected initially (Ashley et al., 2008). Therefore, regardless of contamination, flood sediments may have impacts on human and environmental health, and it is important to properly handle them to mitigate these risks.

## IV. Understanding Community Flood Sediment Response

### a. Methods

This work sought to better understand how flood sediments were managed post-flood, specifically in developed areas built in natural floodplains. We asked: Who cleaned up the sediments? With what precautions? Under what guidance, and from who? Was sediment tested, and, if so, was it contaminated? Where were the sediments brought? Based on these findings, as presented below, further research was conducted on how flood sediment response could be improved, leading to ten recommendations for future flood sediment response in Vermont.

*Community Outreach*

To be able to make a set of recommendations for the future, we needed to understand how sediment deposition affected Vermont communities, how it was cleaned-up and managed post-flood, and what guidance or protocols already exist in Vermont to address sediment clean-up. We selected five towns heavily impacted by flooding (Montpelier, Johnson, Londonderry, Jamaica, and Ludlow) as case studies (Fig. 4). Research primarily relied on interviews with municipal employees and residents.


**Figure 4.** *Map of the 5 heavily-impacted towns investigated in this research.*

Additionally, we developed an anonymous survey to assess who conducted sediment clean-up, whether sediment removal guidance was provided, the guidance clarity and modes of communication if it was, and respondents' satisfaction with the guidance and overall flood sediment response. To distribute the survey, we contacted environmental non-profits, regional planning commissions,  and municipality departments across Vermont and requested that they include a link to the survey in their online updates (for example, newsletters or social media posts). We also also posted on the Middlebury and Springfield, VT Front Porch Forum sites.

*Understanding Existing Policies & Protocols*

We also researched existing policies and flood resources within each town and statewide. We combed through town webpages, especially flood resources pages, and Hazard Mitigation Plans. For statewide information, Vermont's Flood Ready page was used as a starting point and we followed links from there. VT Department of Environmental Conservation (DEC) pages which were especially useful for finding potentially relevant information, including their "Waste Management and Prevention" and "Watershed Management" pages. Additionally, we had phone and email conversations with VT DEC employees from the Spills Division, Solid Waste Management Program, and Communications departments. We reached out to various environmental consulting groups that recommended reading the state rules for disposal of development soils and dam sediments. We reviewed these policies, and spoke with a member of the Vermont Natural Resource Council (VNRC) regarding dam sediment removal. Finally, to understand what happened with sediments on agricultural land, we talked to USDA Farm Service Agency (FSA) and Natural Resource Defense Council (NRDC) employees.

### b. Town Case Studies

In the following sections, we present our findings on how flood sediments were cleaned-up and managed after the summer 2023 flooding in these five heavily-impacted towns.

*Montpelier*

Town Overview: Montpelier is the capital city of Vermont and has a population of about 8,000 people. It is located in the north-central part of the state along the Winooski River and its North Branch tributary, making it within the Lake Champlain watershed.

Sediment Impacts: In Montpelier, 2-10 inches of flood sediments covered downtown streets and were described as "penetrative" (personal communication, 10/12/2023). Sediments washed into everything, including homes where they permanently ruined anything that was not a hard surface (couches and carpets, for instance) (personal communication, 10/12/2023).

**Montpelier residents reflect on sediment clean-up:**

*"Cowboy-like"*

*"Breathed in some bad stuff"*

*"Dust cloud in Montpelier for weeks"*

Sediment Clean-Up: Clean-up began the day after the flood and was "cowboy like," primarily conducted by residents and volunteers (personal communication, 10/26/2023). Mud was shoveled into garbage bags along with debris and piled on street curbs in 10-foot high piles. One resident explained that many of them were totally covered in mud and recognized that they likely breathed in "some bad stuff" but were not considering how toxic it may be (personal communication, 10/12/2023). A few days after the disaster, an emergency hub for volunteers was set up and they were distributing masks and gloves, but most people were still not wearing them, and these measures came too late (Fig. 5 and 6). A few days later, the city used a street sweeper to clean up the remaining coating of drying sediment, which suspended sediment particles in the air. As one resident put it, "it was just a dust cloud in Montpelier for weeks" (personal communication, 10/26/2023).

Sediment Clean-Up Guidance: No guidelines on flood sediment clean-up were in place prior to the flooding, according to the Montpelier Public Works Department (Kurt Motyka, personal communication, 10/18/2023). At some point, the city said electronics needed to be separated out (electronics commonly contain toxic heavy metals and must be disposed of separately), but it was too late as things were already in mixed up garbage piles and the city gave up trying to enforce separation.

Sediment Disposal: The city collected trash into garbage bins, which eventually ended up in Vermont's singular landfill in Coventry, Vermont. Two out-of-state companies assisted with debris hauling via a state contingency contract for disasters: Ceres assisted with the actual hauling and Tetra Tech was contracted for 3rd party monitoring and quantifying (City of Montpelier Public Works, 2023). Any sediment that was mixed up with this debris also ended up in the landfill. The city also used front loaders and dump trucks to shovel sediments (free of household solid debris) off of streets, and these were brought to the Montpelier Public Works Department's stump dump (off of Finch Road, just north of the downtown). The stump dump is a depression where soils, stones, brush, concrete, leaves, and sediments from the town are stockpiled: materials dry as water drains into the soil. While the stump dump was not used to dealing with such high volume, it had sufficient space for disposal of these flood sediments. Sediments were stockpiled but were not tested for contamination, nor were reused for other purposes (personal communication, Kurt Motyka, 10/18/2023). Residents also did not report any knowledge of screening or testing of sediments.

Existing Protocols: Montpelier has a Local Hazard Mitigation Plan from 2021, but it doesn't include guidance for sediments other than recognizing that hazardous materials and debris in floods can be a risk. Either way, this doesn't constitute a longer-term plan or policy that applied to flood sediments this summer. Montpelier's "Flood Guide" also does not offer tips for handling sediments post-flood.

**Figures 5 and 6**.

*Volunteers and residents do not wear PPE while shoveling flood sediments in Montpelier, VT.*

*Note.* Photos by Charles Krupa, The Associated Press (Rathke, 2023).

*Johnson*

Town Overview: Johnson is home to less than 1,400 people and is located in northern Vermont. The town is located where the smaller Gihon River intersects with the larger Lamoille River, which eventually drains into Lake Champlain.

Flood & Sediment Impacts: Flooding of both rivers had acute and long-term impacts for Johnson. The wastewater treatment plant, library, post office, fire department, town office, health clinic, and the town's only grocery store were wiped out and/or flooded (The Vermont Community Foundation, 2023). The mobile home community, providing low-income housing, was also wiped out, and many homes and businesses were inundated, with floodwaters leaving mud in their wake. Two gravel roads were wiped out, washing an estimated 3.6 million pounds of gravel or more into the Lamoille River, to be deposited downstream (Jason Whitehill, personal communication, 10/3/2023). Additionally, there was a spike in pet owner visits to the veterinarian due to illnesses that could be associated with elevated exposure to contaminated flood waste in yards (Greg Stefankski, personal communication, 11/5/2023).

Sediment Clean-Up & Guidelines: Sediment was not at the forefront of people's minds during clean-up despite its potential for health consequences (personal communication, 11/5/2023). In response to the floods, Johnson revitalized its COVID response team and shifted those involved to a flood response role (personal communication, 11/5/2023). There were no formal guidelines for what to do with sediments, and sediment still sits unmoved on many Johnson properties (Dean Locke, personal communication, 10/3/2023). Clean-up and road repair was conducted by five municipal employees including the town's Road Foreman and took about a day.

Sediment Disposal: Sediment deposited on roads was taken to the local dump site, the Johnson Transfer Station, run by Lamoille River Solid Waste Management District (LRSWMD) (Jason Whitehill, personal communication, 10/3/2023). In total, there were four loads of 50-60 yards of sediment brought to the dump. The dumped sediment was hydroseeded as a means for erosion control and as of October 2023, grass was growing on it.

*Londonderry*

Town Overview: The town of Londonderry is in southern Vermont with a population of slightly over 1,600 people. Its downtown is situated on the West River, a tributary of the Connecticut River.

Sediment Impacts & Response: Floods inundated streets, parking areas, businesses, homes, and yards leaving the Londonderry “pretty darn muddy,” and as of October, sediments still dirtied many areas. Residents and town employees conducted clean-up with support from FEMA, the Red Cross, and Neighborhoods Connections, a local non-profit. Despite this aid, there was no official state or local communication for dealing with flood sediments specifically. Other debris, including ruined household and business items, was collected by the town and brought to the Londonderry Transfer Station, where it was cataloged for possible FEMA replacement funding. State contractors assisted with handling this waste under the same arrangement as in Montpelier because the transfer station was not certified to handle such materials (Esther Fishman, personal communication, 10/18/2023).

*Jamaica*

Town Overview: The town of Jamaica is located just downstream of Londonderry on the West River and has a population of about 1,000.

Sediment Impacts & Response: Immediately downstream of Londonderry on the West River, the town of Jamaica received large amounts of sediments of varying grain size. Unlike in Londonderry, where outside support came quickly, Jamaica received no assistance with or assessment of flood damage. It was not until the town submitted a Vermont Emergency Management questionnaire in early October that assistance finally arrived from FEMA, Vermont Emergency Management (VEM), and the National Resources Conservation Service (NRCS) (survey response). Digital communication was described by one survey respondent as “cursory.”

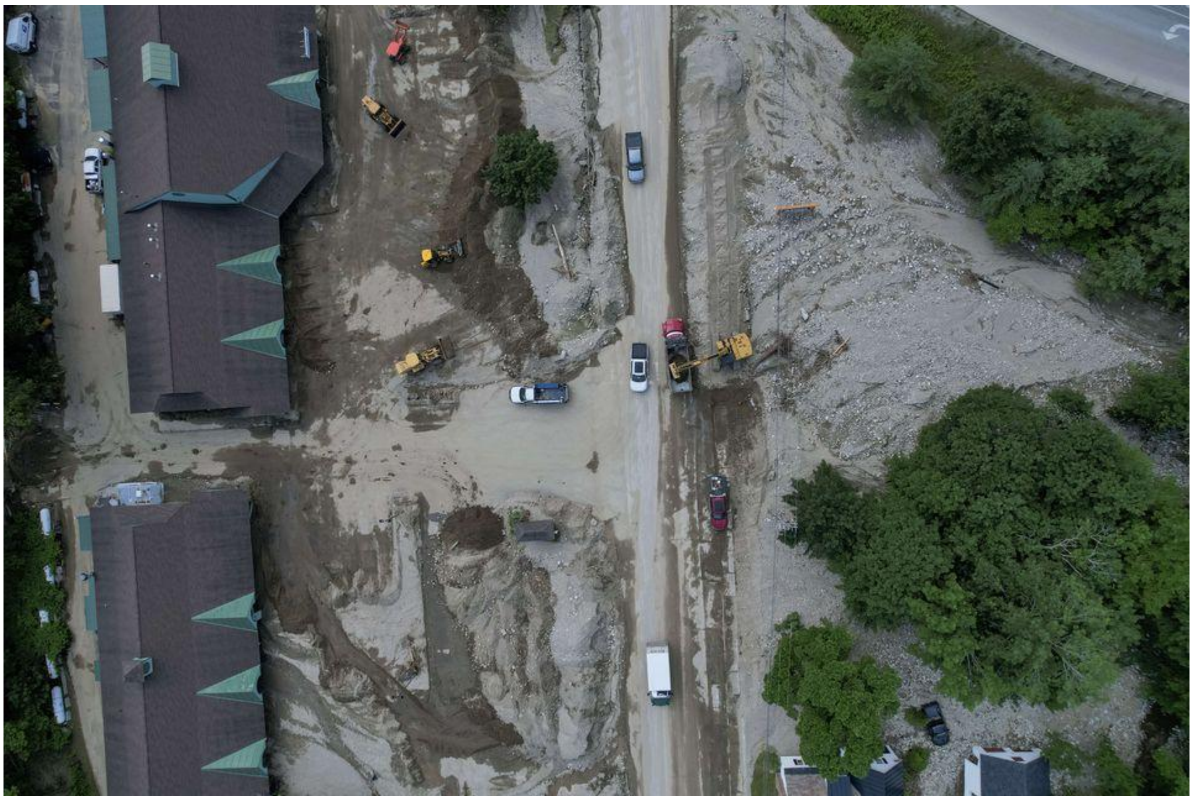
*Ludlow*

Town Overview: Ludlow is located in southern Vermont and is home to less than 1,000 people. The Black River, a tributary of the Connecticut River, flows through the town. Jewell Brook drains into the Black River in downtown Ludlow.

Sediment Impacts & Response: The flooding of Black River and Jewell Brook left much of the town covered with deep silty sediments (Fig. 7). Black River Action Team volunteer organizers led a spontaneous cleanup effort of the downtown area in the days following the floods. Resources provided by the organizers included printed safety sheets for volunteers, handwashing stations, and PPE, including face masks, latex gloves and eyewear. Flood cleanup coordinators required volunteers to work in teams. Sediments were removed using shovels and buckets. The town requested that the sediment be piled next to but not obstructing the roadway. Town employees collected and disposed of the sediments (personal communication, 10/13/23).

**Figure 7.**

*Overhead photograph of sediments deposited in downtown Ludlow*



*Note.* Photo by Vincent Alban, The Boston Globe (Damiano, 2023).

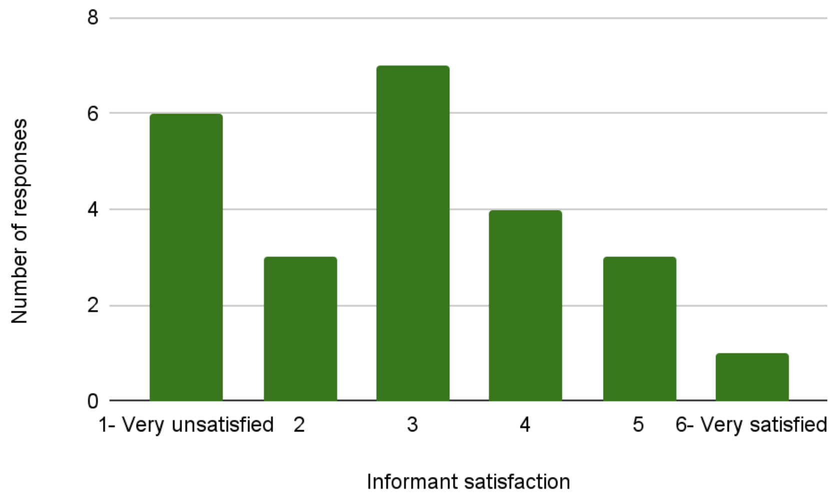
### c. Survey Results

Our anonymous survey received 24 responses. Overall satisfaction with flood response related to sediment management and disposal was low, averaging 2.9 out of 6 (1-6 scale with 1 being the least satisfied) (Fig. 8). Of the ten respondents who answered that they knew who performed flood cleanup, seven reported it was themselves, residents, or volunteers who did the work. Two people indicated that local road crews were responsible for removing sediments. People either did not know if sediments were tested for contaminants (40%) or answered that they were not (60%).

Only a fifth of respondents reported receiving any guidance regarding flood sediment cleanup (Fig. 9). When those who did receive guidance were asked how helpful they found it to be, the average satisfaction score was 4.2 (on a 1-6 scale, 1 being the least satisfied). However, their satisfaction with communication and clarity of this guidance was low, with an average satisfaction rating of 2.7 (Fig. 10). Additionally, when asked to expand on what was included in this guidance, answers were vague, people didn't remember, or guidance seemed more debris-related (ie, separating paint cans/pesticides/oil/unknown substances from other garbage).

**Figure 8.**

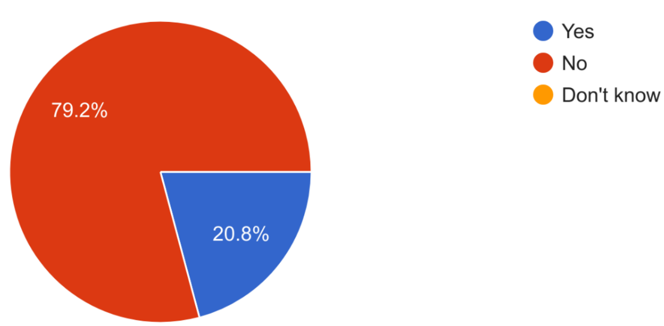
*Respondent satisfaction with flood response*




*Note.* Responses to the question "How satisfied were you with overall flood response related to sediment management and disposal?" (n = 24).

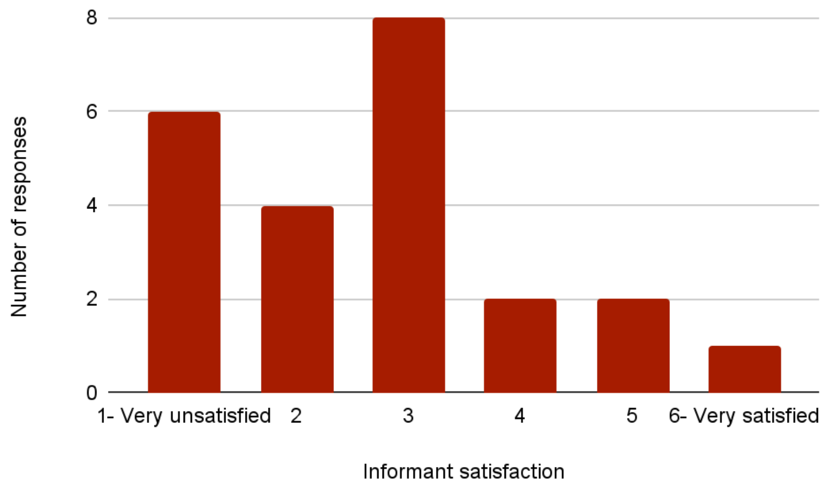
**xfure 9.**

*Percentage of respondents who received flood sediment clean-up guidance*




*Note.* Responses to the question "Following the summer 2023 floods, did you receive any guidance about how to clean up and/or dispose of sediment deposited on your property or nearby surroundings?" (n = 24).

**Figure 10.**
*Respondent satisfaction with communication and clarity of guidance*




*Note.* Responses to the question "How satisfied were you with the communication and clarity of guidance about sediment management and disposal?" (n =24).

## d. Existing Statewide Policies and Protocols

Analyzing local and statewide guidelines and policies (Table 1) revealed that sediments deposited in developed areas during flood emergencies are scarcely considered. Although Vermont's Flood Ready page provides numerous resources for flood response, these rarely discuss how to deal with sediments specifically and are focused more on dealing with water (including water contamination and preventing mold growth) and solid debris management post-flood. The Agency of Natural Resources (ANR) page of Flood Recovery Resources briefly recommends using PPE when cleaning up mud and silt and calling the HAZMAT Hotline to report sediments that are contaminated. However, it gives vague instructions for how to tell if sediment is contaminated and does not deal with the fact that it may be hard to know if something is contaminated if there was not a known spill within the property or obvious an fuel smell (other types of contaminants may not smell or may be from unknown sources). Vermont Emergency Management's general Debris Disposal Guide does not mention sediments. The Department of Environmental Conservation (DEC) Spills Program worked with contractors and helped assess properties impacted by fuel oil spills – sediments that were reported to smell of petroleum were tested for contamination and brought to the landfill if they were found to be contaminated. However, again, this does not deal with other types of potential contamination (i.e., toxic metals, pesticides, sewage waste).

Given the lack of flood sediment policies and protocols for developed areas, we decided to investigate how sediments may be handled in natural floodplain areas, such as on farmland, and assess how those rural procedures could be adapted for urban use. The USDA Farm Service

Agency (FSA) has the Emergency Conservation Program (ECP) that provides cost-share funding and technical assistance for farmers dealing with damage from natural disasters (USDA Farm Service Agency). Their practice of 'Obstruction Removal' deals with moving cobble, gravel, sand, and silt deposits over 12 inches deep, and these can be used to fill in gullies and depressions scoured out or eroded by flooding. For less than 12 inches of deposits, the practice 'Grading, Shaping, and Releveling' incorporates sediments back into the land with tillage. Testing of sediments is not required or funded by the program. These supported practices could apply to this summer's flooding damages on agricultural land, but Vermont's FSA did not begin site assessments and taking applications until October (Eileen Powers, personal communication 10/25/2023). Additionally, the UVM Extension's Agricultural and Environmental Testing Lab made soil testing free for flood-affected farms until August 15 (Outcropn, 2023). There were also several pieces of guidance related to managing flooded produce, corn silage, and forages that came from the UVM Extension. Generally, flooded and sediment-covered crops were considered ruined given the high risk of contamination. This guidance also recommends testing for heavy metals and organic contaminants prior to replanting. Soil and sediment quality is commonly thought about in the agricultural world, which may explain why guidance for farms seems to have been more robust than for developed areas.

Additionally, we found that Vermont does have protocols for managing sediments in developed areas from sources other than floods. For instance, IRule outlines a process for investigating risk and managing contaminated development soils (VT DEC). Urban flooding can result in similar contaminants in flood sediments. Vermont also has a Dam Safety Program that requires testing of sediments impounded by dams as part of dam removal permitting – contaminated sediments cannot be released downstream and require an approved management plan (Karina Dailey, personal communication, 10/24/2023). Therefore, Vermont is not entirely new to dealing with contaminated or potentially-contaminated sediments, and it seems possible that these protocols and policies could be adapted or expanded upon to apply to flood sediments. Many of the same options for disposing of, remediating, and reusing development soils or dam-impounded sediments may be relevant for flood deposited sediments.

**What are development soils?**

**Development soils** are soils contaminated with polycyclic aromatic hydrocarbons (**PAHs**), **arsenic (As)**, or **lead (Pb)**, common compounds in Vermont's urban areas (VT DEC).

In light of the recent floods, many communities and governments are working to improve flood preparation and response. For instance, Montpelier created the Commission for Recovery and Resilience to advance and support community initiatives to build resilience to future flood events. The Vermont Legislature allocated an additional $14.75 million to the Flood Resilient Communities Fund, which assists with reducing future floods impacts, particularly for low-income and marginalized communities. These discussions can serve as an opportunity to bring flood sediment management and education into the picture, and involved groups may be able to assist in communicating about flood sediment clean-up and distributing resources.

**Table 1:** Existing Vermont resources for flood cleanup and preparedness.

| Organization/Agency | Resource | Intended Audience |
|---|---|---|
| VT ANR | Flood Ready webpage | Residents impacted by flooding |
| VT ANR | Flood Recovery Resources | Residents impacted by flooding |
| VT Emergency Management | Debris Disposal Guide | Homeowners |
| VT DEC | Spills Program website | Residents/workers handling fuel/chemical spills |
| VT DEC | IRule | Property owners and developers dealing with contaminated soils |
| VT DEC | Dam Safety Program | Dam owners, those living close to dams |
| USDA Farm Service Agency | Emergency Conservation Program | Farmers |
| UVM Extension | Agricultural and Environmental Testing Lab (soil testing) | Farmers and landowners impacted by flooding |
| VT ANR | HAZMAT Hotline | Residents and workers looking to report contamination |
| VT Emergency Management | Flood Resilient Communities Fund | Communities working to improve flood resilience |

## V. Improving Flood Sediment Response in Vermont

### a. Recommendation Development

Based on our research into how flood sediments were managed and Vermont's existing, related policies, we have developed a set of recommendations for improved flood response. These recommendations were formulated to address the shortcomings identified by residents and municipal employees. Solutions were sourced in large part from interviews with representatives from the Department of Environmental Conservation, Vermont Natural Resources Council, and various environmental consulting groups, who all had suggestions for improvement. Online research was conducted to find case studies on how other states have managed to flood sediments. Finally, further research on reuse and remediation options was conducted using literature reviews and U.S. Environmental Protection Agency resources. Information from these many sources was combined to generate a set of recommendations.

## b. Case Studies

Although information on how other states have handled flood sediments was scarce, we found two case studies which employed creative reuse techniques.

*Case study 1: Nebraska River Flood Sand Deposit Removal Plan*

The Nebraska Department of Environmental Quality (NDEQ) developed a sediment removal plan in response to extreme floods experienced during March of 2019 within the state. This plan included options for where sand and sediment should be moved from farmlands and property depending on its level/type of contamination. If contaminated with fecal matter, oil, or hazardous chemicals, the plan recommends sediment to be taken to a solid waste management site. However, if testing shows that the sediment is sufficiently clean, there are reuse suggestions that provide an opportunity for sustainability in natural disaster response. While sediment grain size in Nebraska is larger (they were dealing with more sand and less clay than in Vermont), these practices can still be valuable. It was suggested that sediments can be used for:

- Daily cover at municipal solid waste landfills (contact the nearest municipal solid waste landfill to determine if they will accept the sand for use as daily cover)
- Erosion repair
- Landscaping
- Bedding at dairy operations
- Repairing and constructing roads
- Fracking projects
- Deicing roads in the winter
- Other land improvements and developing opportunities

Dairy operations are prominent in the state of Vermont and – if sediment is determined to be clean – then using it as bedding may be a great reuse option, although the finer clay particles of sediments in Vermont are likely less ideal for this. Similarly, although sand can be used for deicing in the winter, clays are not generally used for this. But, generally, knowing if the sediment is clean can allow for its sustainable reuse. Even once sediment is determined uncontaminated, however, the NDEQ does note that it should not be reused for direct human contact like in children's play areas or personal gardens.

*Case study 2: Rhode Island Department of Health Yard and Public Space Cleanup After Floods*

The Rhode Island Department of Health (RIDOH) established suggestions for how residents should clean yards and public spaces after flooding events to minimize health risks. Many of their suggestions could be applicable to Vermont as they focus mostly on addressing flood risks that are common anywhere, including how to recognize the potential for contaminants in sediment and debris. The RIDOH's recommendations include:

- Follow guidance from FEMA for making sure yards and fields are safe for cleanup activities and play.

    - Yards that have been contaminated by flooded sewage systems should be sanitized by a liberal application of hydrated lime, available at lawn and garden stores and lumber yards. Ask specifically for hydrated lime, which differs from limestone, or "ag lime", which is more commonly used for garden applications.
    - Keep children and animals away from limed areas until the lime is no longer visible.
- Wear appropriate clothing when cleaning, including long pants, long-sleeved shirts, gloves, and rubber boots, to avoid contact with contaminated materials.
- Avoid dry sweeping to limit your exposure to dust particles. Mist down areas to contain the dust and collect the dust with a wet/dry shop vac.
- Consider wearing an N-95 mask and eye protection when working in dusty areas.
- Bring a change of clothes and shoes with you to avoid tracking any possible contaminants from the flooded areas into your home or car.
- Always wash your hands thoroughly with soap and warm water or an alcohol-based hand sanitizer when you are done cleaning.

These health and safety precautions are important in a flood response for protecting cleanup participants from the hazards associated with flood sediments. Additionally, RIDOH suggests that sediments can be disposed of at solid waste sites and reuse options include for road reconstruction and as landfill cover. Using lime could be a good option for remediating sediments in place, rather than having to remove them, and can also make the soil better for gardening.

## VI. Recommendations

### a. Mitigating Flood Damage

The best way to prevent future impacts is to address the root causes of flood devastation, including climate and flood mitigation and resilience efforts that are already well underway in Vermont. Reducing greenhouse gas emissions to slow climate change will prevent increasing extreme precipitation events that cause catastrophic flooding. Restoring and protecting river corridors and natural floodplains allows sediments to deposit away from settled areas. This includes the removal of small and derelict dams, and stopping development within floodplains (McCallum & Brouwer, 2023). Additionally, taking steps to prevent hazardous materials spills during floods to prevent the contamination of sediments in the first place (i.e., ensuring propane tanks are tied down, storing electronics above ground-level) (Baxter et al., 2013). While these mitigation steps are important, it is inevitable that future floods will affect developed areas. Therefore, our recommendations address post-flood sediment response, which is currently overlooked in Vermont policy and protocols.

### b. Ten Recommendations for Improved Community Flood Sediment Management

In small Vermont communities, flood cleanup is conducted in an "all-hands-on-deck" fashion primarily by community volunteers without proper training and often without any support or supervision. In these emergency scenarios, clear guidance from state and local leaders is necessary to ensure a safe and efficient response. We have compiled recommendations for actions at the state and local level which provide better support, protection, and guidance for community-led flood sediment cleanup. These recommendations, summarized in Table 2 and described in more detail below, below, follow a general chronological order outlining steps to take before, during, and after floods.

**Table 2.** Summary of recommendations for improving flood sediment management in Vermont communities.

| **Summary of Recommendations** |
|---|
| 1. Certify more categorical disposal facilities for local disposal of sediments |
| 2. Distribute "Flood Mud" fliers before, during, and after flooding |
| 3. Designate and train leader(s) in each municipality to guide flood clean-up, including proper sediment management |
| 4. Set up a clean-up station(s) in each town immediately following a flood to distribute personal protective equipment (PPE), provide clean water for hand-washing, provide guidance and contacts, distribute fliers |
| 5. Leave sediments in place when they cannot be removed or do not pose an obstacle or health problem |
| 6. Minimize dust pollution with wet street sweeping techniques |
| 7. Sort sediment at its disposal site based on potential for contamination and particle size |
| 8. Expand state flood relief funding to cover municipal and residential sediment testing |
| 9. Investigate and initiate remediation of contaminated sediments |
| 10. Consider reuse options for clean sediment |

1. *Certify more categorical disposal facilities*

> **What are CDFS?**
>
> **Categorical Disposal Facilities** (CDFs) are **approved** by the VT Agency of Natural Resources to receive and store inert wastes such as **construction debris, wood and brush, road grit,** and **development soils.**

Prior to 2017, all contaminated soils and sediments had to be brought to Vermont's only landfill in Coventry or to out-of-state landfills, where they could be used as daily cover (a layer of soil on top of the daily deposition of waste to improve stability and retain odors), or disposed of within the landfill, depending on the contamination level. This changed in 2017 when Act 52 was passed, allowing development soils to be disposed of at categorical disposal facilities (CDFs) approved by VT ANR. Contaminated flood sediments pose a similar challenge as development soils as they can contain contaminants from anthropogenic land uses. Certifying more CDFs across Vermont will permit the storage and disposal of sediments closer to their origin, preventing the need for costly and emissions-producing transport. Additionally, designating local disposal sites for flood sediments may help towns obtain FEMA reimbursements as it demonstrates cradle-to-grave tracking of debris (Steven Young, personal communication 11/3/2023). Permitting CDFs does not require the creation of new sites: existing stump dumps, gravel pits, and other local solid waste management locations can apply to be certified. Certification would ensure that these facilities are compliant with already-established human and environmental standards of operation.
However, many of these existing viable facilities have not applied for permits as certification is voluntary and may require changes to operations (personal communication, 10/26/2023). Therefore, the state should incentivize and support this process so that more municipalities and private companies want to and are able to certify their facilities, allowing flood sediments to be managed locally.

2. *Distribute educational "Flood Mud" fliers before, during, after the flood*

In summer 2023, communication about debris, sediment, and other flood impacts came too late, and residents and volunteers were not aware of the risks of sediment exposure nor did they have ways of protecting themselves. Informing the people conducting clean-up about the health risks from exposure (see section on III.c.) and recommending precautionary measures (e.g., wearing PPE, not allowing kids or pets to play in yards/contaminated areas) is of the highest priority for protecting human health. The distribution of Flood Mud fliers in English and Spanish (see section VIII.a.) will provide this information so that adequate and safe sediment and debris clean-up can happen as soon as flood water recedes. The flier has been made available in English and Spanish to support a larger community in understanding the necessary precautions to take.

The Flood Mud flier can be customized to include town-specific contact information. When there is advance warning, municipalities should work to distribute the flier prior to the flood. Municipalities and community organizations can distribute the flier in-paper by delivering it to resident doors or mailboxes and by having it passed out by businesses. It can also be shared publicly online via email newsletters and announcements, social media pages, and online web resources for flood preparation. After the flood, it can be passed out by volunteers and at the clean-up station set up (see Recommendation 3).

3. *Designate and train a group of people to be in charge of flood clean-up, including proper sediment management.*

Each town should designate one or more people to be in charge of coordinating flood clean-up and to run the clean-up station (see Recommendation 2). The clean-up coordinator(s) will encourage clean-up participants to follow the sediment safety and disposal protocol outlined in this document, as well as other relevant protocols provided by the state and town. The clean-up coordinator(s) will gather contact information from participants and make their own contact information available, allowing for improved communication about flood sediment risks and proper management.

4. *Set up a clean-up station(s) in each town immediately following a flood*

Many of the unforeseen health risks of sediment exposure can be mitigated by improving community organizational measures. Towns should designate a site and provide materials (i.e., tents, tables, water source) for setting up a centrally-located clean-up station after a flood. This station can provide clean-up information and serve as a safety hub for clean-up participants. The station will be run by the trained clean-up coordinators (see Recommendation 3). The station's role will be to:

   a. Distribute personal protective equipment (PPE): Steps should be taken to prevent direct contact with – and subsequent ingestion and inhalation of – sediments. State funding for the distribution of PPE including HAZMAT suits, KN-95 masks, rubber gloves, and safety glasses should be provided. Long sleeves and rubber boots are also useful protective measures. The removal of contaminated clothing when entering uncontaminated homes and buildings should also be encouraged so as to not drag the harmful dirt and particles indoors.
   b. Provide clean water for hand-washing: The clean-up station will have a hand-washing place for people to quickly wash themselves of potentially contaminated sediments. The setup of the hand-washing station may vary by town, it could be a few 5-gallon buckets with soapy water, garden hoses, or a portable sink setup; the only requirement is that clean water and soap is available. Clean-up coordinators should encourage frequent and thorough hand washing.

c. Educate & provide contacts: Clean-up coordinators at the stations can help guide consistent flood response. This job includes explaining where to put and how to separate debris and sediments, recommending safety precautions, and providing contacts for aid and relief funding.
d. Distribute fliers: Flood Mud fliers should be available at clean up stations in addition to other flood response materials.

5. *Leaving deposited sediments in place when necessary or beneficial to do so*

Sediments may be deposited in an amount or location in which they would be difficult to remove and transport, or where they may have benefits for land uses. For instance, it may not be feasible or necessary to remove deep sediments from large fields, yards, and farms, or other areas with topography that makes operating machinery a challenge. Sediments are rich in nutrients vital to the productivity of the land, and landowners may wish to leave the sediments and their benefits in place. However, prior to using sediment-covered areas, sediments should be tested to determine the type and level of possible contamination. With this knowledge, people can avoid exposure. If sediments are contaminated, sediments may be worth removing for remediation or in-situ remediation options should be explored (see section VIII.b.).

While in-situ remediation can be less expensive, a few concerns with leaving sediment in place need to be taken into account. One is the potential for groundwater contamination: with in-situ remediation techniques, there is usually no liner or protection between the sediment or soil and the groundwater as there would be at a landfill or certified disposal or remediation site (Azubuike et al., 2016). Therefore, it is also important to know about water sources under or around the area and ensure leaching is not occurring while remediation is ongoing. Additionally, deposited sediments should not be built up along the river channel as this could further alter the natural floodplain, contributing to the channeling of floodwaters that creates high water velocity and problems downstream in flood events (personal communication, 10/19/2023). Finally, given their potential for contamination, sediments should not be returned to the river.

6. *Street sweeping to minimize dust pollution*

Sweeping streets after sediments have dried can suspend dust in the air, which poses a risk of respiratory irritation and infection. Rather than dry brushing, street sweeping can happen prior to sediments drying or by using a water spray to control dust. Regenerative air sweepers could also be used, as these do not use water but prevent dust suspension by immediately vacuuming air to capture sediments (U.S. Department of Transportation).

7. *Sort sediment at its disposal site based on contamination and particle size*

Flood sediments vary in the extent and type of contamination regionally and locally. Given that remediation and reuse of sediments may be possible, it is important to separate sediments based on their location of origin and their potential for contamination. This can prevent contamination of clean sediments with dirty ones, improving the amount of sediment available for sustainable reuse. During community clean-up, sediments should be held in separate piles if they are thought to be contaminated (determined by smell, look, or environmental context). Sorting can help determine where the sediment should be transported, since different types of contamination require different disposal and remediation protocols (e.g., lead soils are eligible for storage in CDFs, sewage-contaminated soils may need to go to a landfill). Sediments should also be sorted at disposal facilities based on particle size, since particle size can determine options for reuse (see Recommendation 10) as well as contamination level. Gravel and sand is less likely to be heavily contaminated given their smaller surface-area-to-mass ratios. To an extent, sorting of particle sizes can occur naturally during a flood since larger particles settle out from faster moving waters and smaller particles are more likely to be found at the slower edges of flooded areas. Therefore, keeping sediment sorted during transport and reception at a disposal facility when possible can be helpful.

8. *Sediment testing*

Testing sediments for contamination as soon as possible after the flood plays a crucial role is deciding how to handle them moving forward. However, lab test turn-around times can be days or even weeks. Most situations will require sediments to be moved before test results can be acquired. Roads and residences, for one, need to be cleaned of mud as soon as possible after floods in order to restore emergency access and protect the health of residents. In these cases it is important to assume sediments are contaminated during their immediate clean-up and removal and follow sorting protocols detailed in Recommendation 7 – to store sediment piles sorted by location of origin and perceived contamination (assessed by smell or sight). Since sediments are removed from direct human exposure, testing can occur at the disposal sites once more urgent clean-up has been completed. If sediments are going to be left in place in fields, yards, gardens, or farms, these should be tested for as soon as possible, and precautions should be taken until they are determined to be clean.

Sorting by suspected contamination, as described in Recommendation 7, can assist in prioritizing the type of tests to conduct. Tests for heavy metals, arsenic, and lead can be conducted through the UVM Extension Agricultural and Environmental Testing Lab, as well as UMass or UNH labs. Suspected petroleum contaminated soils can be tested at Endyne Labs in Williston, VT or other commercial laboratories. Sewage, biotic contaminants, herbicides, and pesticides are all potential flood mud contaminants which are not addressed by most soil tests. Fortunately these can be assessed by the VT Department of Health Water Testing Service through phone-order water testing kits. Users must simply strain water out of a sample of mud to send in for testing. More information and lab contact can be found in our Resources for Flood Soil Testing document, which is also linked on the example Flood Mud flier.

We recommend that the state provide funding to cover the cost of soil and water tests. After the summer 2023 flooding, free well water tests kits were made available by phone order to Vermont residents, serving as a precedent in the state: a similar service could be done for sediment testing on private properties to help inform residents' decision making and caution levels.

9. *If sediment is contaminated: investigate and initiate remediation options*

Soil tests should reveal the type and extent of contamination, which will determine if and how sediments can be remediated. The length of the remediation process will vary depending on the type of contaminant and the severity of the contamination, and follow-up testing is generally necessary to determine when sediments can be considered safe for reuse. There are many remediation options each with many variations, and the best option will be dependent on many factors, including site, cost and resource restrictions, contamination level, and amount of sediment. Due to this complexity, we do not recommend one remediation practice, but we have compiled brief information on some of the most relevant ones in the section"Helpful Resources" (VIII.b.). Some contaminants cannot be removed or remediated, in which case proper storage to prevent human exposure and further environmental pollution is necessary. For instance, they can be safely stored long-term in CDFs or at landfills which have methods of encapsulating sediments and preventing leaching and exposure.

10. *If sediment is clean (or once its clean), investigate and implement reuse options*

There are several options when it comes to reusing clean sediments. All require a degree of collaboration between disposal facilities and farmers or road and other construction companies. Solid waste management facilities use soils to cover their landfills on a daily basis – lightly contaminated flood sediments can fill this role as well. Clean sediment can be used to fill sandbags which can be placed to divert water away from buildings, helping to mitigate future flood damage. Larger gravel and cobbles can be reused to rebuild roads, either for roads lost in the floods or future road construction projects (personal communication, 10/24/2023). Other types of construction projects may also be able to use sediment. Clean sediments can be spread on farm fields as nutrient-rich topsoils (Eileen Powers, personal communication 10/25/2023). Finally, clean sediments have the potential to be used as bedding at dairy farms which is a major industry here in Vermont.

**Clean Sediment Reuse Options**

- Daily landfill cover
- Sandbags
- Road rebuilding
- Construction projects
- Nutrient-rich farm soil
- Dairy farm bedding

### c. Options For Implementing Recommendations

Many of these recommendations are well suited for inclusion in Vermont's State Hazard Mitigation Plan (VSHMP) or Local Hazard Mitigation Plans (LHMP) that exist for many communities. These plans are necessary for qualifying for FEMA Hazard Mitigation Grants. Both the local and state Hazard Mitigation Plans are reviewed by Vermont Emergency Management and then must be approved by FEMA. These recommendations could be incorporated into the VSHMP or LHMPs, as they share the goals of reducing vulnerability and increasing resiliency in Vermont. LHMPs are not required, however, and thus do not exist for all towns. Municipal Plans, on the other hand, are required by Vermont statute for all towns and are prepared by Regional Planning Commissions every eight years. As of 2014, these plans are required to include a flood resilience element. Therefore, the state could require or encourage the incorporation of these flood sediment recommendations into these plans, providing another avenue for their statewide implementation. Finally, most of these recommendations, especially related to immediate clean-up safety precautions (Recommendations 2-4) can be advocated for by local groups, including community organizations or regional planning commissions. For instance, these groups could assist with distributing the Flood Mud flier and acting as flood clean-up coordinators.

## VII. Conclusion and Next Steps

As flood events continue to increase in frequency and severity, effective flood response is becoming increasingly important. Flood deposited sediments can carry chemical and biological contaminants and create particulate matter air pollution, posing risks for human and environmental health. Yet, to date, flood deposited sediments have been largely overlooked in Vermont's flood response measures, as demonstrated in this investigation. Residents should be better informed of the risks of sediment exposure and how to reduce risk, which can be achieved by distributing information and personal protective equipment, establishing clean-up stations, and designating local flood clean-up coordinators. Municipalities should have established protocols for the removal and disposal of sediments. Certifying more categorical disposal facilities in the state can help facilitate local sediment management. Expanded testing availability can help municipalities determine how and when sediments can be left in place, reused, or remediated. These recommendations can be incorporated into future statewide flood response plans and protocols with the goal of improving Vermont resiliency. This document can be used by organizers, including the Connecticut River Conservancy, to advocate for the incorporation of improved flood sediment education and management into long-term statewide policy.

## VIII. Helpful Resources

### a. Flood Mud Example Flier

Printable English and Spanish versions and Testing Resources (QR Code)

# FLOOD MUD
## Safe cleanup protocol

### Know the hazards

**Submerged hazards**

Mud and water may be concealing sharp debris. Exercise caution when navigating flooded or muddy areas.

**If you smell something, say something**

Foul-smelling mud may be contaminated with sewage or petroleum. Both can be harmful to human and environmental health. If you suspect sediments are contaminated, call your local Flood Cleanup Coordinator(s).

**Airborne sediment**

Sediments with a small particle size (silt) become airborne when dry and disturbed. These particles are irritating to our respiratory systems. **Try to remove sediments before they get a chance to dry.** Re-hydrate silty sediments before attempting their removal to avoid disturbance.

### Testing

For information on mail-in soil testing services, scan the QR code.

### Stay safe

**Hygiene / PPE**

Face mask, gloves and eye protection, long sleeved clothing and sturdy shoes should always be worn while handling flood mud. Wash your hands frequently to prevent illness or infection.

**Work in groups**

For your safety, never clean up a flooded site alone.

**Call for help**

If you encounter any areas you believe to contain chemical or physical hazards, do not hesitate to call your local Flood Cleanup Coordinator(s).

### Disposal

**Pile flood mud** next to the roadway. Do not obstruct the roadway, storm drains lamposts, hydrants or other structures. The town will come collect and dispose of sediments later.

**NEVER put mud back into a river**

Once flood mud has contacted roadways and homes, they may carry contaminants which could harm river ecosystems.

### **Contact information** (site-specific):

**Local Emergency Services** ______________________________

**Flood Cleanup Coordinator(s)** ______________________________

**Waste Management Coordinator(s)** ______________________________

## b. Remediation Options

There are many remediation options; this section describes a few that may be relevant to the scale of flood sediments, but it is important to remember that this is not an exhaustive list.

*Monitored Natural Attenuation*

The most "hands-off" option for remediation, both in-situ and ex-situ, is Monitored Natural Attenuation (MNA), which can work for lightly contaminated soils (US EPA, 2021e). MNA allows for remediation to occur over time through natural processes, primarily degradation by bacteria already present in the soil. Volatile contaminants are also allowed to evaporate and can be destroyed by sunlight, and other pollutants remain sorbed into the soil to prevent their release. Dilution of contaminants by mixing with clean water or other soils may also reduce contamination levels, and in some cases chemical reactions with natural substances in the environment can reduce toxicity (US EPA, 2021e). However, it is important to note that this process takes time, and continuous monitoring of sediment and groundwater contamination is necessary to determine effectiveness and safety level.

*Bioremediation*

Bioremediation uses microorganisms to break down organic contaminants, such as pesticides and petroleum, in sediments and soils (Azubuike et al., 2016; US EPA, 2021a). There are several forms of bioremediation, including using bacteria, fungi (mycoremediation), and plants (phytoremediation). Depending on the pollutant, degradation may occur in aerobic or anaerobic conditions (US EPA, 2021a). These organisms consume and digest contaminants in their metabolisms, degrading them to less toxic forms (Azubuike et al., 2016). Bioremediation is an appealing option because it is environmentally friendly, low-cost, and can be done in-situ or ex-situ (Azubuike et al., 2016).

In most cases, bioremediation relies on taking steps to increase microbial activity and growth in the soil, such as providing nutrients and aerating or mixing the soil (biostimulation) (Azubuike et al., 2016; US EPA, 2021a). Adding compost to soil is one way to stimulate bacterial activity, which is a promising opportunity given that Vermont requires household composting as of 2020. When effective microbial communities are not present, microbes may be injected or soil piles are seeded with plants known to have remediation benefits (bioaugmentation). Ex-situ (once sediment has been removed) bioremediation via biopiles (piles of sediment are amended with nutrients and often aerated) and windrows (involves periodic turning of piles) are likely the most effective ways of carrying out ex-situ bioremediation at categorical disposal facilities or other places where flood sediments are dumped (Azubuike et al., 2016). Bioreactors likely would not be a time- or cost-effective option for the quantity of sediments sites may be dealing with (Azubuike et al., 2016).

In-situ bioremediation options for organic contaminants are also possible, but it is important to prevent exposure until testing reveals that levels are sufficiently lowered. Natural attenuation would likely take longer than desired for heavily-contaminated soils, but adding nutrients to sediments could accelerate breakdown. Several in-situ techniques rely on adding nutrients along with aerating soils, but aeration may be skill- and labor-intensive option for fields and backyards filled with sediments (Azubuike et al., 2016). Phytoremediation is an option, although it has its drawbacks. Plants are less effective at degrading organic contaminants than microbes, although they can stimulate fungal growth in soils (Azubuike et al., 2016). Plants may be able to take up heavy metals, but these never truly leave the system: metals may move up the food chain when plants are consumed, and when plants die and degrade these metals are released again (Azubuike et al., 2016). However, plants do have benefits for preventing leaching and erosion of contaminated soils to protect water sources. Therefore, these options for sediments that cannot be feasibly removed may be beneficial, depending on location, human interaction with the area, and contamination type and level.

Under the right conditions and with enough time, bioremediation can remove >99% of organic contaminants (Azubuike et al., 2016). However, it is important to note that it may not completely finish the job off and testing would be beneficial for determining levels prior to reusing sediments. Additionally, while organisms may be able to take up heavy metals, these just get incorporated into biomass that will later break down, meaning they are not entirely removed from the system (personal communication, 10/26/2023). Thus, the benefits of bioremediation are generally limited to organic-contaminated soils, and site conditions and soil testing are necessary for determining the best remediation option.

*Activated Carbon*

Activated carbon is a porous graphite material with high surface area for adsorbing contaminants. It can be added (injected) in-situ or ex-situ to adsorb organic contaminants such as petroleum and chlorinated solvents, preventing them from leaching. Since activated carbon does not remove or degrade molecules, it is often used along with biostimulation or bioaugmentation (US EPA, 2018).

*Electrokinetics*

In in-situ or ex-situ electrokinetics, an electrical current is run through the soil by installing a cathode and anode (US EPA, 2021b). Positively charged ions, including heavy metals, move toward the anode, while negatively charged ions move to the cathode. Once at their respective electrodes, contaminant ions can be removed by precipitation, electroplating, or pumping water. To make contaminants more soluble and mobile, complexing agents can be added to the soil. While most commonly used for cationic metals, electrokinetics can also work for organics. Electrokinetic applications work best in high moisture soils, as contaminants move through water-filled pores making it applicable for wet flood sediments (US EPA, 2021b)

*Chemical Oxidation and Reduction*

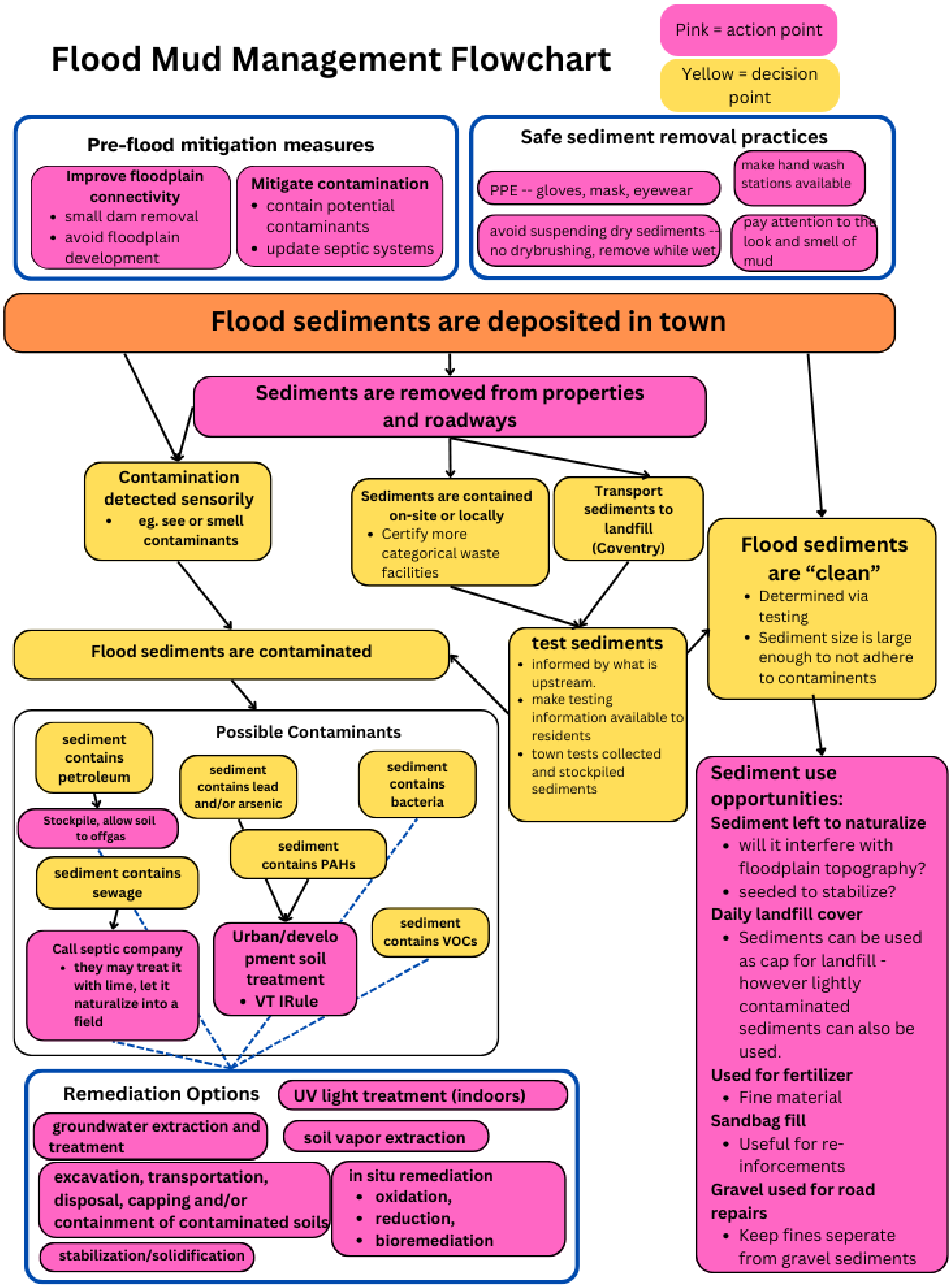
Chemical oxidizing or reducing agents can be added to sediments both in-situ or ex-situ to transform contaminants into less toxic or less mobile forms via chemical redox reactions – the transfer of electrons. Some common oxidizing agents include permanganate, persulfate, and hydrogen peroxide, which can degrade organic contaminants (US EPA, 2021c). The most commonly used reductant is zerovalent iron (ZVI), which can be especially helpful for remediating halogenated compounds and metals (including arsenic and chromium) (US EPA, 2021d).

*Solidification and Stabilization*

In solidification, the contaminants are encapsulated as an impermeable solid, such as by adding cement. In stabilization, contaminants are stabilized via chemical reactions. For instance, lime is commonly added to soils, which alters soil structure to stabilize it and also reacts to make metals less soluble, preventing leaching (National Lime Association, 2006). Solidification and stabilization cannot degrade or remove contaminants, but it transforms waste into a form that limits leaching and human exposure and can be faster and more cost-effective than other remediation options (US EPA, 2021f). Barriers such as liners at disposal sites can also prevent leaching and exposure to contaminants in sediments.

### c. Flood Mud Management Flow Chart

This is a flow-chart visualizer which helped us create recommendations for flood sediment cleanup. There is a web of complex decision making, which is dependent on the circumstances of the flood and its sediments. The flow chart can help connect pathways from deposition to disposal, reuse, or remediation for a wide variety of situations and contaminants.


Flood Mud Management Flowchart
Pink = action point
Yellow = decision point
Pre-flood mitigation measures
Improve floodplain connectivity
• small dam removal
• avoid floodplain development
Mitigate contamination
• contain potential contaminants
• update septic systems
Safe sediment removal practices
PPE -- gloves, mask, eyewear
make hand wash stations available
avoid suspending dry sediments -- no drybrushing, remove while wet
pay attention to the look and smell of mud
Flood sediments are deposited in town
Sediments are removed from properties and roadways
Contamination detected sensorily
• eg. see or smell contaminants
Sediments are contained on-site or locally
• Certify more categorical waste facilities
Transport sediments to landfill (Coventry)
Flood sediments are "clean"
• Determined via testing
• Sediment size is large enough to not adhere to contaminents
test sediments
• informed by what is upstream.
• make testing information available to residents
• town tests collected and stockpiled sediments
Flood sediments are contaminated
Possible Contaminants
sediment contains petroleum
Stockpile, allow soil to offgas
sediment contains lead and/or arsenic
sediment contains bacteria
sediment contains sewage
sediment contains PAHs
Call septic company
• they may treat it with lime, let it naturalize into a field
Urban/development soil treatment
• VT IRule
sediment contains VOCs
Sediment use opportunities:
Sediment left to naturalize
• will it interfere with floodplain topography?
• seeded to stabilize?
Daily landfill cover
• Sediments can be used as cap for landfill - however lightly contaminated sediments can also be used.
Used for fertilizer
• Fine material
Sandbag fill
• Useful for re-inforcements
Gravel used for road repairs
• Keep fines seperate from gravel sediments
Remediation Options
UV light treatment (indoors)
groundwater extraction and treatment
soil vapor extraction
excavation, transportation, disposal, capping and/or containment of contaminated soils
in situ remediation
• oxidation,
• reduction,
• bioremediation
stabilization/solidification

## IX. Acknowledgements

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