

BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL AT CHENNAI (SZ)

ORIGINAL APPLICATION No. 161 OF 2021 (Suo Motu)

Suo Motu

... Applicant

Vs

The Chief Secy & Ors

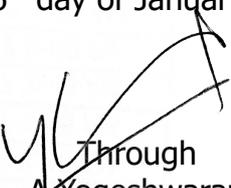
... Respondents

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Dated this the 6th day of January, 2022 at Chennai


Through
A. Yogeshwaran
Counsel for the Applicant

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Memo filed in response to IISWC report

The 9th Respondent respectfully submits as follows:

1. It is submitted that a report by the IISWC along with a covering letter dated 07.10.2019 was submitted to this Hon'ble Tribunal. It is submitted that the issue being considered by the Hon'ble Tribunal was that the clear-felling of trees and undergrowth at the contaminated site would increase the soil run off from the site due to rainfall and other factors and that there was no assessment of this aspect before the clearing was undertaken. It was submitted that the clear-felling of the site changed the entire character of the contaminated area. The IISWC Report is produced as an answer to this issue. It is submitted that the IISWC Report does not address this issue and a reading of the Report would demonstrate the same.
2. It is submitted first and foremost that the Report of IISWC **is about soil erosion control and not about treatment and management of contaminated stormwater run-off**. This difference is crucial to understanding this Applicant's reason for approaching the Hon'ble Tribunal with concern about the release of sediment-bound mercury into the Pambar Shola and Kodaikanal Wildlife Sanctuary from M/s Hindustan Unilever's contaminated site.
3. Soil which is a conglomerate of organic and inorganic material is referred to as sediment when it can be carried away by water, wind or ice. Sediment transport, or sediment load, is the movement of organic and inorganic particles by water – usually rainwater. Transported sediment may include mineral matter, chemicals and pollutants, and organic material. In general, the greater the flow of water, the more sediment that will be conveyed. The storm water flow velocity depends on:
 - the intensity of rainfall (mm/hr)
 - the soil type (cohesive, tightly bound soils are less prone to being mobilised as sediment as opposed to loosely bound soils)
 - the particle size of soils with finer soil particles more likely to be mobilised and flow quickly than coarser or heavier soil particles such as stones, gravel etc.

- the gradient of the surface generating stormwater run-off (steeper the gradient, the faster the flow and the greater the tendency of the water to mobilise sediment.)
4. Soil particles (including silt, clay and sand) are usually classified by size from smallest (clay is less than 0.00195 mm in diameter) to largest (coarse sand can be up to 1.5 mm). Silt falls in between, ranging from 0.0049 to 0.047 mm.
 5. Sediment transport happens through two mechanisms. Water flow can be strong enough to suspend particles in the water column as they move downstream (suspended load), or simply push them along the bottom of a waterway (bedload).
 6. **Bedload** is the portion of sediment transport that rolls, slides or bounces along the bottom of a waterway. This sediment is not truly suspended, as it sustains intermittent contact with the streambed, and the movement is neither uniform nor continuous. Bedload occurs when the force of the water flow is strong enough to overcome the weight and cohesion of the sediment. While the particles are pushed along, they typically do not move as fast as the water around them, as the flow rate is not great enough to fully suspend them. Bedload transport can occur during low flows (smaller particles) or at high flows (for larger particles). Approximately 5-20% of total sediment transport is bedload. In situations where the flow rate is strong enough, some of the smaller bedload particles can be pushed up into the water column and become suspended.
 7. It is submitted that it is also important to appreciate the difference between **suspended sediment** and suspended load. Suspended sediment are any particles found in the water column, whether the water is flowing or not. The **suspended load**, on the other hand, is the amount of sediment carried downstream within the water column by the water flow. Suspended loads require moving water. The size of the particles that can be carried as suspended load is dependent on the flow rate. Larger particles are more likely to fall through the upward currents to the bottom, unless the flow rate increases, increasing the turbulence at the streambed. In addition, suspended sediment – particularly the coarser material -- will not necessarily remain suspended if the flow rate slows.
 8. The **wash load** is a subset of the suspended load. This load is comprised of the finest suspended sediment (typically less than 0.00195 mm in diameter). The wash load is differentiated from the suspended load because it will not settle to the bottom of a waterway during a low or no flow period. Instead, these particles remain in permanent suspension as they are small enough to bounce off water molecules and stay afloat. However, during flow periods, the wash load and suspended load are indistinguishable. Turbidity in lakes and slow moving rivers is typically due the wash load.
 9. Sediment deposition occurs when suspended particles settle down to the bottom of a body of water. This settling often occurs when water flow slows down or stops, and heavy particles can no longer be supported by the bed turbulence.

The suspended particles that fall to the bottom of a water body are called settleable solids. As they are found in riverbeds and streambeds, these settled solids are also known as bedded sediment. The size of settleable solids will vary by water system – in high flow areas, larger, gravel-sized sediment will settle out first. Finer particles, including silt and clay, can be carried all the way out from hills to the plains and estuaries and deltas.

10. It is submitted that understanding sediment is crucial to appreciating the concerns of the Applicant. The measures proposed by IISWC is conventional soil erosion control, whereas what is required is the containment and treatment of contaminated stormwater runoff so that it does not enter the ecologically sensitive Wildlife Sanctuary.
11. It is submitted that the measures suggested are in the form of silt traps, terraces, gabion holding structures and improved ground cover. These are essential soil conservation measures for any site on a gradient and are not specifically designed for contaminated sites. Silt traps are designed to trap silt. It is a fact that only the coarse and heavy component of the suspended water-borne sediment is likely to settle. Silt-traps are inadequate to trap **suspended loads** (temporarily suspended settleable sediment) and **wash loads** (permanently suspended sediment). It is submitted that it is this fine fraction that is likely to contain the highest levels of mercury.
12. It is submitted that it is the finer fraction of soil/sediment that is of particular concern to us in terms of mercury contamination. This is evident from the soil remediation design approved by CPCB and TNPCB. The soil washing-soil sieving process adopted by M/s HUL for separating the finer soil fraction from coarser fractions is based on the tendency of mercury to adhere tightly to the finer soil particles with larger surface area. The coarser fractions of soil, after washing, are found to satisfy soil screening criteria and fit for refilling in excavated areas. The smallest soil particles recovered from this process of washing-filtering are as small as the smallest sieve. The wash water that leaves the filtration system only contains fine particles that are smaller than the mesh size of the smallest sieve. This wash water is a toxic effluent that is required to be contained, directed to a series of holding tanks, settling tanks, lamella clarifiers etc to be treated to acceptable quality standards before being released into the environment or being reused in the process.
13. It is submitted that the action of rain on the contaminated site is exactly the same as the process of washing adopted by M/s HUL. The stormwater run-off from the contaminated site contains mercury-laced sediment of varying particle size. However, unlike the remediation process where this toxic sediment-laden water is generated in a controlled fashion and is subjected to a process of filtration through sieves of smaller and smaller mesh size, the toxic sediment-laden stormwater run-off from the contaminated site is generated uncontrollably – and unmanageably during heavy rain events. Unlike the remediation process where the process water post-filtration through **1 mm** sieve is subjected to an Effluent Treatment Process, the stormwater run-off which is similar to the feedwater in

the remediation process is allowed to run-off into the wildlife sanctuary with only the soil erosion control measures as "treatment." As will be demonstrated below, the soil erosion measures are inadequate to even trap the coarser fraction of the stormwater sediment load greater than **1 mm** in size, leave alone the mercury-contaminated fines.

14. It is submitted that it is absurd to equate soil conservation measures -- which are an essential feature for any sloping surface, and particularly for recently denuded surfaces -- to pollution control measures designed to treat contaminated wastewater. The suspended and wash load sediment are unlikely to be trapped by soil erosion control structures. It is this fraction that is likely to be lost unless the rainwater is treated in a well-designed Effluent Treatment Plant.
15. The IISWC report's recommendations do not address run-off of mercury-contaminated stormwater for the following reasons:
 - a. The efficiency of the soil control measures for trapping even coarse silt will depend on the velocity of the water flow at peak rainfall intensity, the quantum of suspended sediment in the rainwater and adequacy of the residence time in settling basin of the silt trap. The adequacy of residence time depends on the size of the tank in relation to peak rainwater flow and sediment load. Rainwater run-off at peak rainfall intensity of 100 mm/hr from 3 ha site is estimated to be 0.438 cumecs (m³/sec) (page 5 of 17 of report). That translates to 1576.8 cum/hr (0.438*60sec*60min). The consultant has failed to present before deforestation-after deforestation figures for rainwater run-off or sediment run-off.
 - b. To critique the adequacy of Tank 1 Silt Trap 1, let us compare its dimensions to that of ETP1 which is designed to treat 300 KLD of effluent from the soil washing and multistage filtration process. According to the unclear dimensions of Silt Trap 1 given on Page 13 of 17, the total volume of Silt Trap 1's first silt settling tank is 6 m x 1 m x 2.8 m = 16.8 cu.m. The second chamber appears to have a volume of 18.24 cu.m (1.6 m x 1.9 m x 6 m) and the third chamber of 21.09 cu.m (1.9 m x 1.85 m x 6). Taken together, this has a total volume of 56.13 cu.m. This is supposed to handle a peak rainwater flow of 0.438 cum/sec containing an unknown quantum of silt. In other words, at the given rainfall intensity, the three chambers will overflow within 128 seconds (2 minutes and 8 seconds). Contrast this to the design of ETP 1 which is equipped with Grit Chamber, Collection tank, Equalisation tank, lamella clarifier etc to handle a meagre wastewater flow at a rate of 0.0035 cu.m/sec (300 kld/24 hours*60 min*60 sec). The combined volumetric capacity of the Grit Chamber (0.8 cu.m), Collection Tank (40.8 cu.m) and Equalisation Tank (206 cu.m) is 247.6 cu.m. At a flow rate of 0.0035 cu.m/sec, the total volume of this system will be exceeded in 70,457 seconds or 1174 minutes or 19.5 hours. It is noteworthy that even after such a long period for settling of suspended solids, the partially treated wastewater is subjected to further treatment through lamella clarifier, chemical dosing for coagulation and flocculation

(for further settling of solids), a pressure sand filter and activated charcoal filter.

- c. It is submitted that the IISWC report is silent of quantum of soil run-off under different scenarios. Without this estimate, it is impossible to design a silt-trapping system, leave alone a system capable of treating the contaminated rainwater runoff to treated effluent quality standards. Peak rate of Soil run-off as a concentration of suspended sediment in rainwater runoff ought to have been calculated and used as the basis for designing the rainwater treatment structures.
 - d. The location of silt traps along the main stream assumes that the entire quantum of rainwater run-off at a maximum rate of 0.438 cum/sec (cumecs) will run through this drain. If this assumption is incorrect, then an unknown quantum of run-off is bypassing even the grossly inadequate erosion control structures. If this assumption is correct, then the entire quantum is passing through the 5 erosion control structures and overwhelming them as demonstrated above.
16. The estimate of water-borne sediment run-off presented by Chennai Solidarity Group was based on a rainfall intensity of 50 mm/hour for a 1.7 ha site. This amounts to 5.25 kg/ha/yr before felling of trees, and 66 kg/ha/yr after felling of trees.
17. The December 2021 RTI response from TNPCB indicates that TNPCB is unaware of the design modifications recommended by IISWRC and is under the impression that the erosion control structure design is as per earlier Upscaled Remediation plan. It is also clear that the TNPCB has not bothered to verify the adequacy of the proposed design. Under the circumstances, the entire supervision is left to M/s HUL's paid consultants who have provided the faulty remediation process and erosion control design.

Management of storm water run-off from a contaminated site

18. It is submitted that management of stormwater runoff from a contaminated site is different from the management of runoff from an uncontaminated site. In the latter, well-designed erosion control measures are adequate, whereas for the former, erosion control measures need to be complemented with mechanisms to prevent mixing of uncontaminated run-off (say, from clean surfaces such as roof or other uncontaminated surfaces) and contaminated run-off, and infrastructure to store, treat and discharge contaminated stormwater. Keeping the contaminated and uncontaminated stormwater separate, by containing the contaminated area through bunds or temporary roofs, vastly reduces the volume of water that would need to be treated.
19. It is submitted that the entire design does not have any elements geared towards keeping the two stormwater streams separate. This applicant will present first the best practice in terms of erosion control measures and compare that with IISWC's

recommendations, and then comment on the manner in which contaminated water ought to be treated.

20. The Erosion Control Manual of the Oregon Department of Transportation is among the most recent and comprehensive guidance about soil erosion control measures, relevant extracts are annexed herewith.

21. The manual prescribes erosion control measures as follows:

“[1] Retain existing vegetation whenever feasible. Vegetative cover is an effective form of erosion control; very little erosion occurs on a soil covered with undisturbed natural vegetation. If possible, clear only the area where construction will actually occur, street and driveway lines, and cut and fill slopes. Try to integrate existing tree and other natural vegetation into the site improvement plan.

“[2] Vegetate and mulch denuded areas. Newly planted vegetation begins to duplicate the functions of established vegetation. Seed and mulch denuded soils as soon as possible after grading is completed. Mulch helps seedlings to become established and protects the soil from raindrop splash until vegetation takeover. Soils may be seeded with temporary or permanent vegetation. If the soil will be exposed during the winter months, protective measures other than vegetation must be used.

“[3] Divert runoff away from denuded areas. Manage and control runoff in areas that have been denuded. Route runoff into stabilized channels. Divert runoff from off-site around the work areas using temporary piping, diversion dikes or swales. For conveying runoff down steep slopes temporary slope drains or protected flumes should be used with energy dissipaters at the bottom of the slope. The runoff containing sediment should be directed to Baker Tanks, sediment traps or settling basin if turbid flows are anticipated.

“[4] Cover exposed soils. Matting in the form of rolled erosion control products (RECPs), mulch, compost blankets or hydraulically applied matting will protect soils and provide immediate protection that does not rely on seed germination and plant establishment to provide cover.

“[5] Minimize length and steepness of slopes. Slope length and steepness are among the most critical factors in determining erosion risk. Increasing slope length and steepness increase the velocity of runoff, which increases erosive energy. If slope steepness is doubled while other factors are held constant, soil loss potential is increased 2 ½ times. If both slope steepness and length are doubled, soil loss potential is nearly 4 times greater. To prevent erosive velocities from occurring on

long, steep slopes, interrupt the slopes at regular intervals using sediment barriers, terracing or other means.”

“[6] Keep runoff velocities low. The energy of flowing water increases at the square of the velocity. For example, when the velocity doubles; the erosive force quadruples and the water can theoretically move particles 64 times larger by volume. Channel velocities can be kept low by lining drainage ways with rough surfaces such as vegetation and riprap, by designing broad, shallow flow areas, and by constructing check dams at frequent intervals. Concrete channels, although efficient and easy to maintain, convey runoff quickly, often resulting in downstream channel erosion and flooding.

“[7] Prepare drainage ways and outlets to handle concentrated or increased runoff. Construction changes the characteristics of runoff. The creation of impervious surfaces, removal of plant cover, and compaction of soil allows less water to infiltrate into the soil and therefore increases the volume of runoff. Drainage channels should be designed to provide maintenance access for the removal of accumulated sediments. Alternatively, if a project can be designed so that runoff from development areas is allowed to infiltrate into the soil on-site, no off-site channel enlargement or protection should be necessary. To prevent channel erosion from occurring, design drainage ways to withstand the peak flows without erosion, select lining materials appropriate for peak flows, and de-energize concentrated flows at outlets using scour holes and energy dissipaters. If development substantially changes the natural drainage conditions in a watershed, merely protecting the drainage channels on a project site may not be sufficient to prevent erosion.

“[8] Trap sediment on site. Some erosion during construction is unavoidable. The function of a sediment barrier is to prevent sediment from leaving the Project site. Sediment laden runoff should be detained on-site so that the soil particles can settle out before the runoff enters receiving waters. Locate sediment basins and traps at low points below disturbed areas. Use earth dikes or swales to route rainage from disturbed areas into the basins. Sediment barriers and sediment fences can be placed below small-disturbed areas on gentle to moderate slopes. Stormwater temporarily ponds up behind these barriers, allowing sediment to settle out.”

Erosion Control Measure 1: It is submitted that sadly, the first measure of retaining existing vegetation was ignored, and the IISWC did not see it fit to insist on its earlier advice of retaining vegetation and conceded to its client’s demand to denude the site. Prima facie, this vitiates the first principle of erosion control – namely, do not aggravate

erosion.

Erosion Control Measures 2 and 4: These measures of vegetating and mulching denuded areas and covering exposed soils appear to be incorporated into the IISWC report (e.g. on page 8, recommending covering exposed areas with geo-textiles and planting root slip grass).

Erosion Control Measure 3: This measure, relating to diverting runoff away from denuded areas, is not incorporated into the IISWC report. The drainage management measures suggested (e.g. on page 7 of the IISWC report) have more to do with managing runoff from the site rather than preventing run-on into the site, which reduces the volume of stormwater runoff containing eroded soil that needs management.

Erosion Control Measure 5: This measure relates to minimizing length and steepness of slopes. While these seem to be incorporated into the IISWC report by suggesting a system of terrace walls and terraces, as described on pages 4-6 and depicted in the figure on page 10, the adequacy of these structures to deal with the sediment load of stormwater is not demonstrated by any calculations indicating sediment load before and after clear-felling of trees. Also, what is NOT discussed in the IISWC report is how much mercury might be liberated and released into the Pambar Shola during the process of constructing the terraces and terrace walls as this would involve movement of heavy machinery over contaminated soils, and excavation of soils within a hazardous waste contaminated site. The substantial amount of construction needed to put the terraces and terrace walls in place might liberate more mercury in to the Pambar Shola as they might prevent from entering the Pambar Shola after their construction. In the absence of a DPR that delineates such details, it is inevitable that an unquantified amount of mercury may have already been released into the Shola ironically during the construction of the erosion control structures.

Erosion Control Measures 6 and 7: These measures relate to keeping runoff velocities low and preparing drainage ways and outlets to handle concentrated or increased runoff. This has not been incorporated into the IISWC report. Even if the authors of the report claim that the terraces and terrace walls they are proposing obviates the need for keeping runoff velocities low and preparing drainage ways and outlets to handle concentrated or increased runoff, that has not been borne out by data or models.

Erosion Control Measure 8: This measure relates to trapping sediment on site. While this is incorporated in the IISWC report in the discussion on page 5, and the figures of pages 12-17, the capacity and effectiveness of these measures is inadequate as demonstrated above.

22. It is submitted that the present site is not merely an industrial site, but a highly contaminated site. In well-regulated jurisdictions, stormwater management from contaminated sites is subject to stringent guidelines. See for instance, the guidelines published for Stormwater management by the Government of Western Australia. Relevant pages annexed herewith.

What measures are necessary?

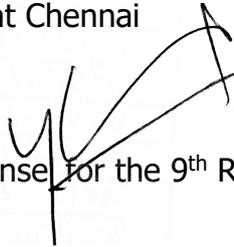
23. The entire process of remediation, including soil washing, filtration, vacuum retorting, effluent treatment, recirculation of treated water, discharge of treated water has been carried out without a mercury balance that can assess the efficiency of the process. A mercury balance would account for the total quantum of mercury brought into the process by accounting for it in various media. Despite repeated representations to the TNPCB, such a mass balance exercise has never been ordered. The certificate that all is well is without any scientific basis. As a first instance, a thorough mass balance exercise should be carried out based on data available by an unbiased party, ideally a relevant subject matter expert from a reputed institute.

24. Silt traps need to be periodically maintained by desiltation and storage of removed silt. TNPCB has admitted that it has no record of maintenance of silt traps or quantum of recovered silt stored on site. Further, till date not a single sample of water and soil from each of the silt traps and from Levange Path have been taken by HUL's consultant NEERI or TNPCB as required under the Environmental Monitoring Framework of the Upscaled Remediation Plan or the Consent to Operate. Such samples, if taken, should be analysed with sufficient sensitivity to ensure that mercury levels at or above levels considered safe for aquatic life (0.026 ug/L -- Canadian) are detected.

25. A detailed stormwater runoff study, sediment load study and capacity of the existing erosion control measures to handle total run-off from the contaminated factory site should be commissioned by engaging independent and unbiased experts paid by TNPCB, with costs recovered from the polluter under the Environment Protection Act, 1986. Liability for Environmental Damages must be assessed as per CPCB guidelines, and the company must be held liable for the same.

It is prayed that this Hon'ble Tribunal be pleased to record the above submissions and pass such order or orders as may be fit, proper and necessary in the facts and circumstances of the case and thus render justice.

Dated this the 6th day of January, 2022 at Chennai


Counsel for the 9th Respondent



EROSION CONTROL MANUAL

GUIDELINES FOR DEVELOPING AND IMPLEMENTING EROSION AND
SEDIMENT CONTROLS

GEO-ENVIRONMENTAL SECTION
OREGON DEPARTMENT OF TRANSPORTATION

CHAPTER 2 EROSION PROCESSES

2.1 CONCEPTS OF EROSION AND SEDIMENTATION

Erosion is a natural process by which soil and rock material is loosened and transported. Erosion by the action of water, wind, and ice has produced some of the earth's most spectacular landscapes. Natural erosion occurs primarily on a geologic time scale, but when human activities alter the landscape, the process of erosion can be greatly accelerated. Erosion is different from but related to sedimentation. Erosion is the removal of soil and sedimentation is the placement of the dislodged soil. Erosion is easier to prevent than it is to control of sediment once it is loosed.

Vegetation protects soil. Leaving vegetation in place is good erosion prevention. Since vegetation on an undisturbed site covers and protects the soil, the removal of that vegetation increases the site's susceptibility to erosion. Disturbed land may have an erosion rate 1,000 times greater than the undisturbed rate. Even though construction requires that soil be left exposed for periods of time, proper planning and use of erosion control measures can reduce the impact of man-induced accelerated erosion.



Figure 2-1 Good Sediment Control

An understanding of the processes of erosion and sedimentation is essential in the development of successful erosion and sediment control plans. The soils, slopes, and drainage patterns of a specific site influence the potential for soil erosion from that area. Drainage from off-site onto the work area can contribute to erosion. Identifying erosion problems at the planning stage and recognizing highly erodible areas, help in selecting effective erosion control practices and estimating storage volumes needed for sediment traps and basins.

Understand the process of water on undisturbed and well vegetated ground: Rain falls on vegetation and the plants absorb the energy of the falling water. Some water is actually absorbed into plant leaves. Decomposing organic matter (thatch and duff) absorb and retain water. Once the water holding capacity of the duff layer is exceeded, the water flows onto the soil. Undisturbed soil has pore space to accept infiltration and plant roots provide conduits along which water can penetrate the soil. When both the duff layer and the soil can hold no more water, it will begin to flow slowly through the duff. This duff mat is anchored in place by living vegetation and it resists being torn apart by moving water. In an undisturbed

condition where vegetation has a developed a duff layer the organic material is being incorporated into the mineral soil by chemical, physical and biological forces so that the opposite of erosion is occurring, soil is being added.

When water volume exceeds the holding capacity of the duff layer and flows on the surface as a shallow sheet, blades of grass, and plant stems still keep water velocity slow and resist erosion. Once waters join into channels in undisturbed conditions the channels are naturally armored by rocks and by thickets of riparian vegetation and the plant roots that armor and bind the soil. In high flow events the tangle of stems slows the velocity of flowing water near the shore, reducing the erosive strength of the water against the banks, even when flows mid-channel may be rapids. When living riparian vegetation is damaged by bank erosion it is self-repairing. Erosion does occur naturally, but usually at a slow pace.

It is instructive to understand how nature addressed erosion and sediment control. Nature provides soft armor to the soil surface. It stores water in an organic layer at the surface and facilitates infiltration of the water into the soil, preventing runoff. Living plants remove water from the soil and once water is flowing nature has built-in erosion prevention in place. Erosion and sediment control measures used on construction sites strive to duplicate the functions provided by natural systems.

2.1.1 TYPES OF EROSION

Erosion results from surface processes (such as [water flow](#) or wind) that remove soil, rock, or dissolved material from one location on the earth's crust, then transport it away to another location.

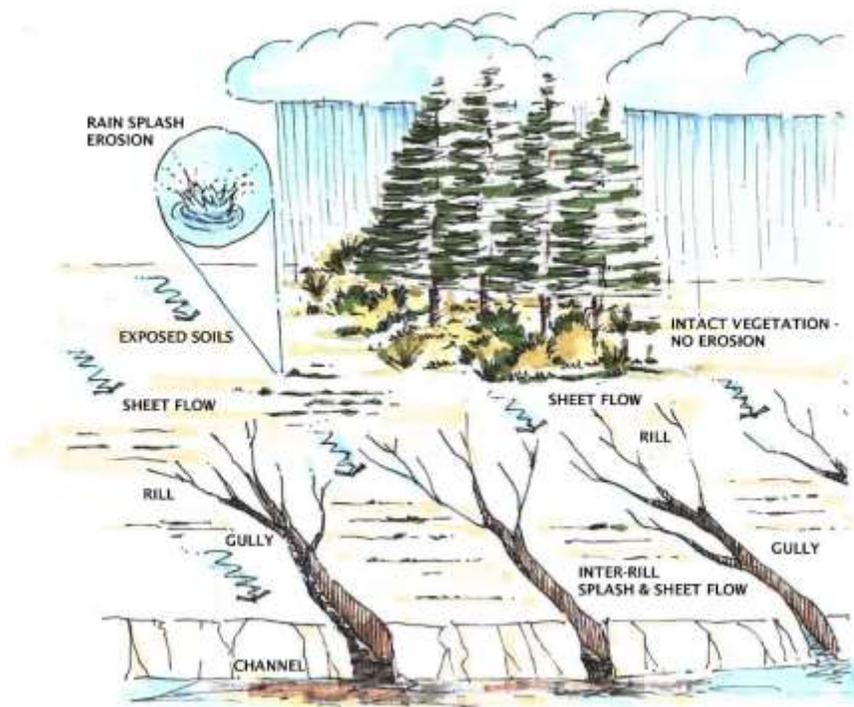


Figure 2-2 Major Types of Soil Erosion

Oxygen demanding materials	Cleared vegetation; human/animal waste; chemical reactions	Reduce oxygen in water, stress/kill salmonid fish and other aquatic life	Biological Oxygen Demand (BOD); Chemical Oxygen Demand (COD); dissolved oxygen
Heavy metals	Paints, flashings, downspouts, tires, preservatives, solvents	Bioaccumulation in food chain; toxic to aquatic life, human health effects	Ar, Cd, Cu, Hg, Ni, Pb, Zn
Petroleum hydrocarbons	Oil, grease, fuels, lubricants	Decreased oxygen levels; aesthetics, human, aquatic and wildlife health effects	Oil & grease; total petroleum hydrocarbons
Synthetic organics	Pesticides, PCBs, combustion products, solvents	Bioaccumulation in food chain; toxic to aquatic life, wildlife and humans	Variety of organics analyses
Concrete	Spills, truck washout, overfull washout basins	Harm to aquatic species, stunted plant growth, ground water pollution	Concrete slurry, Hardened concrete crust surrounding washout

2.3 PRINCIPLES OF EROSION AND SEDIMENT CONTROL

Effective erosion and sedimentation control requires first that the soil surface be protected from the erosive forces to prevent erosion, and second that eroded sediment is captured on-site. Erosion control is the prevention of soil erosion. Sediment control is the trapping of suspended soil particles. Erosion control is easier than controlling sedimentation. Sediment control is necessary because some erosion is unavoidable. The following principles are simple but are effective. They should be integrated into a system of control measures and management techniques to control erosion and prevent off-site sedimentation.

- Fit site construction to the terrain. Review and consider all existing conditions in the initial site selection for the project. When construction is tailored to the natural contours of the land, little grading is necessary and erosion potential is consequently reduced.

- Time grading and construction to minimize soil exposure. Scheduling can be a very effective means of reducing the hazards of erosion. Stage construction activities to minimize the exposed area and the duration of exposure. In scheduling, take into account the season and the weather forecast. Schedule grading to coincide with a dry season. Stabilize disturbed areas as quickly as possible and if possible suspend work during wet season. The 1200-CA Permit and Specifications require that additional measures be employed to during the wet season to prevent erosion and sedimentation.



Figure 2-8 No erosion, stable channel & clear water

- **Retain existing vegetation whenever feasible.** Vegetative cover is an effective form of erosion control; very little erosion occurs on a soil covered with undisturbed natural vegetation. If possible, clear only the area where construction will actually occur, street and driveway lines, and cut and fill slopes. Try to integrate existing trees and other natural vegetation into the site improvement plan.
- **Vegetate and mulch denuded areas.** Newly planted vegetation begins to duplicate the functions of established vegetation. Seed and mulch denuded soils as soon as possible after grading is completed. Mulch helps seedlings to become established and protects the soil from raindrop splash until vegetation takes over. Soils may be seeded with temporary or permanent vegetation. If the soil will be exposed during the winter months, protective measures other than vegetation must be used.
- **Divert runoff away from denuded areas.** Manage and control runoff in areas that have been denuded. Route runoff into stabilized



Figure 2-9 Compost blankets provides erosion prevention

channels. Divert runoff from off-site around the work areas using temporary piping, diversion dikes or swales. For conveying runoff down steep slopes temporary slope drains or protected flumes should be used with energy dissipaters at the bottom of the slope. The runoff containing sediment should be directed to Baker Tanks, sediment traps or settling basin if turbid flows are anticipated.

- **Cover exposed soils.** Matting in the form of rolled erosion control products (RECPs), mulch, compost blankets or hydraulically applied matting will protect soils and provide immediate protection that does not rely on seed germination and plant establishment to provide cover.



Figure 2-10 Seeded perennial rye grass with wattles to shorten slope length

- **Minimize length and steepness of slopes.**

Slope length and steepness are among the most critical factors in determining erosion risk. Increasing slope length and steepness increase the velocity of runoff, which increases erosive energy. If slope steepness is doubled while other factors are held constant, soil loss potential is increased 2 ½ times. If both slope steepness and length are doubled, soil loss potential is nearly 4 times greater. To prevent erosive velocities from occurring on long, steep slopes, interrupt the slopes at regular intervals using sediment barriers, terracing or other means.

- **Keep runoff velocities low.** The energy of flowing water increases at the square of the velocity. For example, when the velocity doubles; the erosive force quadruples and the water can theoretically move particles 64 times larger by volume. Channel velocities can be kept low by lining drainage ways with rough surfaces such as vegetation and riprap, by designing broad, shallow flow areas, and by constructing check dams at frequent intervals. Concrete channels, although efficient and easy to maintain, convey runoff quickly, often resulting in downstream channel erosion and flooding.



Figure 2-11 Check Dams slow runoff velocity

- **Prepare drainage ways and outlets to handle concentrated or increased runoff.**

Construction changes the characteristics of runoff. The creation of impervious surfaces,

removal of plant cover, and compaction of soil allows less water to infiltrate into the soil and therefore increases the volume of runoff. Drainage channels should be designed to provide maintenance access for the removal of accumulated sediments. Alternatively, if a project can be designed so that runoff from development areas is allowed to infiltrate into the soil on-site, no off-site channel enlargement or protection should be necessary. To prevent channel erosion from occurring, design drainage ways to withstand the peak flows without erosion, select lining materials appropriate for peak flows, and de-energize concentrated flows at outlets using scour holes and energy dissipaters. If development substantially changes the natural drainage conditions in a watershed, merely protecting the drainage channels on a project site may not be sufficient to prevent erosion.



Figure 2-12 Stabilized Channel

- **Trap sediment on site.** Some erosion during construction is unavoidable. The function of a sediment barrier is to prevent sediment from leaving the Project site. Sediment laden runoff should be detained on-site so that the soil particles can settle out before the runoff enters receiving waters. Locate sediment basins and traps at low points below disturbed areas. Use earth dikes or swales to route drainage from disturbed areas into the basins. Sediment barriers and sediment fences can be placed below small-disturbed areas on gentle to moderate slopes. Storm water temporarily ponds up behind these barriers, allowing sediment to settle out.



Figure 2-13 Sediment Trap & Energy Dissipater W/ Level Spreader

- **Inspect and maintain control measures.** Inspection and maintenance of control measures are vital to the effective function of an erosion and sediment control facilities and they are required by both the specifications and the permit. Most control measures require regular maintenance. Problems often occur during the first storm of the season. Some problems, like

rills, develop slowly over time and can easily be prevented with inspection and maintenance. Effective functioning of each BMP is required by the permit and the Specifications. The permit requires the contractor inspect active sites weekly and within 24 hours of a storm event of one half inch or more. Correct problems as soon as they develop. Specification Section 00280.30 requires the Contractor assign an individual, knowledgeable in erosion and sediment control, to be responsible for routine inspections of operating erosion and sedimentation control practices. As project permittee, ODOT is ultimately responsible for compliance with permit requirements, including the inspections and monitoring reports.

- **Take Erosion and Sediment Control work seriously.** Erosion and Sediment Control is contracted work for which the Contractor is being paid. The Erosion and Sediment Control work is required in the permit conditions which are enforceable by law and punishable by severe penalties. This work should be conducted and managed with the same level of professionalism and oversight as is provided for other aspects of contracted work.

The principles of erosion and sediment control discussed above generally address issues that operates on the soil's surface. There are engineering practices that work on a larger scale of slope protection. The following practices are the domain of engineers and geotechnical engineers, but their use will improve erosion control results.

- **Slope Rounding and Contour Grading.**

The standard practice of rectilinear grading creates unnatural flat slopes, sharp angles and rapid runoff flow that resists infiltration.

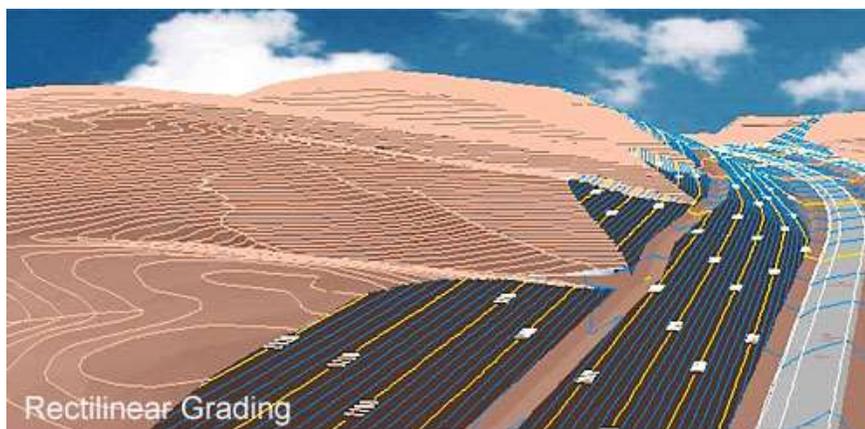


Figure 2-14 Rectilinear Grading



Water quality protection note 52

May 2010

Looking after all our water needs

Stormwater management at industrial sites

Background and purpose

Industrial sites need effective management of stormwater run-off from roofs, pavements, exterior materials storage and process areas to avoid flooding or contamination of sensitive water resources (description in [Appendix A](#)). Contamination risks arise if stored or spilt process chemicals are flushed off-site or into the ground following rainfall.

Substances of concern include acids, alkalis, degradable organic residues, detergents, disinfectants, dyes, engine coolants, fertilisers, fuel, lubricants, metal solutions, pharmaceuticals, salts, poisons and solvents.

Risks can range from minor inconvenience to a major disaster involving harm to people, property and/or ecosystems. A small or repeated chemical discharge over an extended period may lead to contaminant accumulation in an aquifer, sediment or confined surface waters. Chemical spills (if poorly managed) can overwhelm the capacity of receiving water resources to assimilate or break down contaminants and result in degraded water values. Chronic problems also arise where small quantities of persistent contaminants are washed via drains into waterways or wetlands, causing sedimentation, algal blooms, aquatic fauna deaths and/or aesthetic damage. Pollution is an offence and severe penalties apply under the *Environmental Protection Act 1986* ([Appendix B](#)).

The Department of Water is responsible for managing and protecting Western Australian water resources. It is also a lead agency for water conservation and reuse. This note offers:

- our current views on stormwater management at industrial sites
- guidance on acceptable practices used to protect the quality of our water resources
- a basis for the development of a multi-agency environmental code or guidelines that considers the views of industry, government and the community, while sustaining a healthy environment.

This note provides a general guide on issues of environmental concern, and offers potential solutions based on professional judgement and precedent. Recommendations made in this note do not override any statutory obligation or government policy statement. Alternative practical environmental solutions suited to local conditions may be considered. This note shall not be used as this department's policy position on a specific matter, unless confirmed in writing. The note may be amended at our discretion, as new data becomes available.

Regulatory agencies should not use this note's recommendations in place of site-specific conditions based on a project's environmental risks. Any regulatory conditions should consider the values of the surrounding environment, the safeguards in place and take a precautionary approach.

Where a conflict arises between our recommendations and any proposed activity that may affect a sensitive water resource, this note may be used to assist negotiations with stakeholders. The negotiated outcome should not result in a greater risk to water quality than if our recommended protection measures were used.

Scope

This note applies to light, general and heavy industrial sites throughout Western Australia that could harm sensitive water resources ([Appendix A](#)).

It provides a list of recommendations related to stormwater management practices, including proposed environmental impact assessment, which should be addressed.

The note is not intended to cover residential or rural settings.

Advice and recommendations

- 1 Stormwater in industrial estates should be managed in accordance with relevant guidelines published in the *Stormwater management manual for Western Australia* ([reference 3d](#)).

Stormwater system design

- 2 Stormwater volumes may be estimated using the procedures given in *Australian rainfall and run-off* ([reference 4](#)) published by Engineers Australia. Factors to be considered include:
 - a Discharges off-site should be limited to pre-site development peak flows and volumes. If volume control is impractical during major rainfall events (exceeding a one-year average recurrence interval), system designers should assess the hydrological and ecological consequences to the downstream waterways and wetlands, and ensure protective measures are implemented. Appropriate statistical return periods for high intensity rainfall and the duration of storm events should be used when assessing the risk and potential impacts on receiving environments.
 - b Where practical, retention or detention storage systems should be used to manage peak stormwater flows within the on-site stormwater management system.
 - c Controlled release points should be built into any stormwater retention basin to avoid embankment failures or flooding under extreme rainfall conditions.

Stormwater management

- 3 Uncontaminated stormwater runoff from roofs, paths and the landscape should not be allowed to mix with process effluent, stored chemicals or stormwater runoff from areas susceptible to chemical spills. Where practical, processing areas involving the use of chemicals should be weatherproof or covered.
- 4 Areas where stormwater may become contaminated should drain to treatment facilities for removal of solids and chemical residues and testing prior to disposal. Diversion

banks, kerbing, surface grade changes, containment bunds and contained drains should be used to control stormwater runoff from large sites.

- 5 Chemical storage and handling areas should be located within sealed secondary containment areas that allow maximum recovery of any spilt chemicals.
- 6 Paved areas exposed to rainfall where dust, litter or spilt substances accumulate should be regularly cleaned using methods that prevent drainage or leaching of fluid into the surrounding environment. Gross pollutant (litter), oil and sand traps (appropriate to the site) are recommended at drain entry points. These traps require regular inspection and residue removal. First-flush water diversion for dusty outdoor areas should be considered to capture initial stormwater runoff after any extended dry period. These may incorporate flow-diversion valves and stormwater storage for later treatment.
- 7 Turbidity should be controlled by ensuring stormwater run-off is not directed towards or over areas cleared of vegetation, raw material stockpiles or earthworks vulnerable to erosion. Where practical, stormwater should be effectively treated then used preferentially as a process water source, irrigated onto well-vegetated areas or infiltrated to ground via soak pits.
- 8 Chemical solvents and non-degradable detergents used to clean equipment or pavements should not be released into stormwater systems. These chemicals are likely to cause environmental harm if they enter groundwater, wetlands, waterways or marine environments. Where cleaning chemical residues could cause downstream harm, alternative methods such as vacuum cleaning, mechanical scrubbers, high-pressure jetting or steam cleaners may be used to remove soil from machinery and floors.
- 9 Industry is encouraged to adopt the *cleaner production program* initiated by Curtin University in Perth, Western Australia. Additional information is given in Chapter 7 of our *Stormwater management manual for Western Australia* ([reference 3d](#)). Small to medium industries can obtain useful information from the Swan River Trust's *Environmental management and cleaner production directory for small to medium business* ([reference 9](#)).
- 10 Rainwater should not be released from chemical containment areas until tested and found to be uncontaminated. A notice warning of environmental contamination risks should be clearly visible at the compound. Clean rainwater should be released via a manually started pump, rather than via a valved (gravity) discharge. For additional information see our water quality protection note 61 ([reference 3b](#)).
- 11 If stormwater is likely to be contaminated by stored materials or waste dumps, such as sulphide materials yielding corrosive or metal-rich leachate, facilities should be in place to contain or neutralise the contaminants. After adequate settling followed by testing, clean water may be released into the environment.
- 12 Floodways and near-surface groundwater are likely to affect the design and performance of stormwater management systems. Site owners/operators should contact this department for information on the location of flood-prone land.
- 13 Where the groundwater table is within five metres of the surface or soil permeability is poor (less than one metre per day), alternatives to water infiltration may be needed to avoid harmful effects due to watertable mounding.

Stormwater treatment

- 14 Treatment options to limit suspended soil particles and turbidity include:
- a sedimentation basins that provide retention periods of at least two hours
 - b bio-retention systems and constructed wetlands
 - c chemical coagulation, using metal salts or polymers, followed by settling
 - d sand or membrane filters, with periodic backwash into holding basins.
- 15 Fuel, oil and grease removal options include:
- a petrol and oil traps
 - b inclined-plate separators
 - c chemical coagulation and launder systems
 - d dissolved air flotation units.
- 16 Litter reduction options include:
- a employee waste awareness programs
 - b clearly marked recycle bins
 - c floor bucket traps (routinely maintained)
 - d trash racks/bar screens on process water drains
 - e centrifugal litter separators.
- 17 The *Stormwater management manual for Western Australia* ([reference 3d](#)) provides detailed information on the design and operation of most options listed in this section.
- 18 For low levels of non-toxic organic contaminants such as leaves and litter, consider the use of commercial gross pollutant traps or sediment trapping vessels in piped systems before releasing water into offsite drainage or infiltration. Any discharge to offsite waterways or wetlands should only occur during major rainfall events.
- 19 Designated personnel should be assigned to regularly inspect and maintain on-site stormwater systems. Litter, silt and plant matter should be removed, especially prior to the start of the wet season. Nothing should be stored over drain access points. Where necessary, accumulated solids should be removed from treatment systems before a build-up affects system performance or a major storm event flushes the solids downstream.

Stormwater disposal

- 20 Stormwater should be considered as a potential resource. This may have particular appeal in areas where water sources are limited and storage reservoirs can be constructed economically.
- 21 Options for stormwater use include:
- a capture for process use, flushing, cooling water or dust suppression
 - b seasonal storage to supplement irrigation supplies.
- 22 The following options for discharge of excess stormwater, after it has been effectively treated should be considered in preferential order:
- a on-site infiltration/soakage to recharge an underlying groundwater aquifer. The stormwater quality should be compatible with the water quality and environmental

values of the receiving environment. For further information, see our draft water quality protection note 3 *Managed aquifer recharge* ([reference 3b](#)).

- b discharge to a local government or Water Corporation main drainage system, where approved after consideration of flow capacity and water quality characteristics.
 - c release to a local wetland or waterway. For discharge to surface water bodies, stormwater should be uncontaminated and compatible with the seasonal quality of the receiving water resources.
- 23 Erosion controls are likely to be needed for surface drainage systems excavated in steep land (slope greater than one in 15) or through disturbed land. Engineered drop structures or energy dissipation devices should be used where necessary. Gabions, riffles, grouted mattresses, screened rock walls, perennial grasses, cereal crops or surface mats used for erosion control should be an integral component of stormwater management. Where practical, vegetated soakage swales or overland flow waterways are preferred to engineered drains for clean stormwater management in urban and industrial estates.
- 24 Stormwater should not be discharged into sewer systems as it will overwhelm sewer design capacity and disrupt sewage treatment processes.
- 25 Stormwater system entry points should have signs indicating where they discharge and advising that the environment may be harmed by the release of contaminants. This helps to minimise the illicit disposal of contaminating liquids such as parts cleansers and floor wash-down.

Contingency plans

- 26 Site staff and contractors should be made aware of practices designed to minimise contaminant loss to stormwater management systems.
- 27 Site operators and designated staff should be trained to supervise the response to spill incidents and, if necessary, liaise with emergency response personnel such as the Fire and Emergency Services Authority (FESA).
- 28 Equipment such as absorbent litter should be available to clean up minor chemical spills. Hose-down of floor residues into drains should be avoided.
- 29 Drain systems should be designed so that they can be isolated in the event of large fluid spills, until the contaminant is removed. Drain plugs or sandbags should be labelled and located where they can be deployed quickly in an emergency.
- 30 If a chemical spill does escape into the off-site drainage system, the drainage service provider and the Department of Environment and Conservation's pollution response section should be informed immediately. Effective remedial action should be taken to limit any harmful effects downstream. A responsible approach to spills can lessen the risk of adverse publicity, legal action for damages or environmental contamination.
- 31 When chemicals have escaped into drains, water sampling should be arranged using the services of an analytical laboratory accredited by the National Association of Testing Authorities. Results should be compared against guideline criteria for local water values ([reference 1c or 1d](#)) and necessary recovery and remedial action taken without delay.

Appendix A - Key supporting information

Sensitive water resources

Water resources are used for drinking and sustaining ecological systems, industry and aesthetic values. Along with breathable air, uncontaminated water ranks as a most important need for viable communities. Natural water resources must remain within specific quality limits to retain their ecological, social and economic values. They therefore require stringent and conservative protection measures to minimise contamination.

Information on water quality parameters and processes to maintain water values are published in the Australian government's National water quality management strategy papers. These papers are available online at <www.environment.gov.au> select *water > water policy and programs > water quality*.

The Department of Water strives to improve community awareness of catchment protection measures (for both surface water and groundwater), as part of a multi-barrier protection approach to sustain acceptable water resource quality. Human activity and many land uses pose a risk to water quality if contaminants are washed or leached into sensitive water resources in significant quantities. Sensitive waters include estuaries, natural waterways, wetlands and unconfined groundwater.

Sensitive waters support one or more of the environmental values described below:

1 Public drinking water sources

Public drinking water source area (PDWSA) is the collective name given to any area proclaimed to manage and protect a source used for community drinking water supplies. PDWSA include *underground water pollution control areas, water reserves and catchment areas* administered under the provisions of the *Metropolitan Water Supply, Sewerage and Drainage Act (WA) 1909* or the *Country Areas Water Supply Act (WA) 1947*.

For online information on the location of PDWSA, see <www.water.wa.gov.au> select *tools and data > maps and atlases > geographic data atlas*, then open interactive layers *environment > public drinking water source areas*.

For land planning and development purposes, three priority areas (P1, P2 and P3 areas) have been defined for use within PDWSA. They are assigned based on present land use, tenure and the vulnerability of the water body to harm. These areas are each managed with a different strategy to provide for effective water resource protection.

P1, P2 and P3 areas are assigned in *drinking water source protection plans or land use and water management strategies*. These documents are prepared by this department in consultation with other government agencies, landowners, industry and the community.

P1 areas are defined to ensure that there is *no degradation* of the water source. These areas are declared over land where the provision of the high quality drinking water for public use is the prime beneficial land value. P1 areas typically cover land under state agency control. P1 areas are managed in accordance with the principle of *risk avoidance* and so most land development and activity is normally opposed.

P2 areas are defined to ensure that there is *no increased risk of pollution* to the water source once a source protection plan has been published. These areas are declared over

land where low intensity development (such as rural use) already exists. Protection of public water supply sources is a high priority in these areas. P2 areas are managed in accordance with the principle of *risk minimisation*, and so restricted intensity development (with management conditions) and activities with a low contamination risk are accepted.

P3 areas are defined to *manage the risk of pollution* to the water source. These areas are declared over land where public water supply sources must coexist with other land uses such as residential, commercial and light industrial development. Protection of P3 areas is achieved through management measures defined via environmental guidelines (such as these notes) or via site-specific conditions that limit the contamination risk to water resources from the land use or activity. If, however, the water source becomes significantly contaminated, then water supplied from P3 sources may need to be treated or an alternative water source found.

Protection zones are also defined close to the point where drinking water is harvested or stored. These zones are known as *wellhead protection zones (WHPZ)* and *reservoir protection zones (RPZ)*. Additional constraints apply to activities in these zones to safeguard the area immediately surrounding these vulnerable water sources.

WHPZ are assigned within the immediate surrounds of water production wells and special land use restrictions apply. In these zones, groundwater moves rapidly towards wells due to aquifer depressurisation from pumping. Any contamination leaching from the ground surface could rapidly migrate into scheme water supplies (before effective remedial action can occur). In sedimentary basins, WHPZ are usually circular, with a radius of 500 metres in P1 areas and 300 metres in P2 and P3 areas. These zones do not extend outside PDWSA boundaries.

RPZ are defined over and around public water supply reservoirs or pipe-heads. Special access and land use restrictions apply. The aim is to restrict the likelihood of contaminants being deposited or washing into water sources following rainfall. RPZ within state controlled land cover an area of up to two kilometres from the reservoir top water level.

For additional explanatory information on PDWSA, see this department's water quality protection note 25 *Land use compatibility in public drinking water source areas* and note 36 *Protecting of public drinking water source areas*.

Buffers to water supply sources

Vegetation buffers should separate compatible land use operation areas from the full supply level of reservoirs, their primary feeder streams and production bores used as a source of drinking water. Advice is provided on buffer form and dimensions in our water quality protection note 6 *Vegetated buffers to sensitive water resources*.

Clearing control catchments

Special controls on vegetation clearing for salinity management purposes are provided under part IIA of the *Country Areas Water Supply Act (WA) 1947*. These controls apply in the Wellington Dam, Harris River Dam, Mundaring Weir and Denmark River catchment areas and the Kent River and Warren River water reserves.

Details on clearing controls may be obtained from our regional offices, see www.water.wa.gov.au, select *Contact us*.

Established activities in PDWSA

Many land use activities were approved and established before publication of a source protection plan or strategy. We encourage the operators of all land use activities to progressively improve their environmental management facilities and practices so the risk to water resources is minimised (factoring in practical and economic constraints).

New or expanded activities in PDWSA

Any proposed new or expanded activities that could affect drinking water sources should be referred to this department's regional office for assessment and written response. The development proposal may be approved (with or without conditions); additional relevant information sought prior to making a decision; or rejected due to a policy conflict or inadequate protective measures to safeguard the water source. To facilitate environmental approval, operators should demonstrate that under all operating conditions the materials and processes used on site do not pose a significant contamination risk to the local waters.

2 Private water supply sources

These water sources include:

- a human or stock (animal) drinking water sources
- b commercial or industrial water sources (requiring specific qualities that support activities such as aquaculture, cooling, food or mineral processing or crop irrigation)
- c urban or municipal irrigation sources (where water quality may affect vegetation performance or people's health or wellbeing).

3 Underground ecological functions

Important underground ecological functions that may be at risk include fauna and microorganisms in aquifers, sand, gravel and karst soils (such as cave fauna).

4 Waterway ecological and social values

- a Maintenance of waterways of high conservation significance described in the WA Environmental Protection Authority's guidance statement 33 *Environmental guidance for planning and development* (section B5.2.2). This statement is available online at www.epa.wa.gov.au select *EIA > guidance statements*.
- b Waterways managed by the Department of Water under the *Waterways Conservation Act (WA) 1976* (including the Avon River, Peel-Harvey Inlet, Leschenault Inlet, Wilson Inlet and Albany waterways), or Section 9 of the *Water Agencies (Powers) Act (WA) 1984*. For online advice, see www.water.wa.gov.au select *waterways health > looking after our waterways*.
- c Waterways managed by the Swan River Trust under the *Swan and Canning Rivers Management Act (WA) 2006*. For online advice, refer to www.swanrivertrust.wa.gov.au >.
- d Social values in natural waterways include their aesthetic appeal, use of watercraft, fishing, tourism, swimming and other aquatic activities.

Engineered drains and constructed water features are normally not assigned ecological values because their function and operational factors override these water values.

5 Wetland ecology

- a Ramsar wetlands are described online at <www.ramsar.org>.
- b Wetlands defined by the Australian government in the *Directory of important wetlands in Australia*, available online at <www.environment.gov.au> select *water > water topics > wetlands*.
- c Wetlands of high conservation significance described in the Environmental Protection Authority (WA) guidance statement 33 *Environmental guidance for planning and development (B4.2.2)*. This is available online at <www.epa.wa.gov.au> select *Environmental impact assessment > guidance statements*.
- d Wetlands identified for conservation value or for resource enhancement via:
 - *Geomorphic wetlands of the Swan coastal plain dataset*
 - *South coast significant wetlands dataset*
 - *Geomorphic wetlands Augusta to Walpole dataset*.

The *Geomorphic wetlands Augusta to Walpole* dataset awaits detailed evaluation.

The Department of Environment and Conservation (DEC) is the custodian of state wetland datasets, and is responsible for maintaining and updating the information. These datasets can be viewed online at <www.dec.wa.gov.au> search *maps wetlands*, or select *management and protection > wetlands > wetlands data*.

Guidance on viewing the wetlands is provided on the DEC website at <www.dec.wa.gov.au> select *water > wetlands > data* or by phoning their nature conservation division on 08 9334 0333.

Wetlands that are highly disturbed by rural land use, or have been landscaped to provide a social amenity or drainage control function in urban settings, may not have ecological conservation values unless they are being actively managed to restore these values.

Many aquifers, waterways and wetlands in Western Australia require detailed scientific evaluation and their values remain unclassified. Unless proven otherwise, any natural waters that are slightly disturbed by human activity are considered to have sensitive values.

Community support for water values, the setting of practical management objectives, providing sustainable protection strategies and effective implementation are vital to protecting or restoring our water resources for current needs and those of future generations.

Note interpretation

This note provides a general guide on issues of environmental concern, and offers solutions based on professional judgement and precedent. Recommendations made in this note do not override any statutory obligation or government policy statement. Alternative practical environmental solutions suited to local conditions may be considered.

This note shall not be used as this department's policy position on a specific matter, unless confirmed in writing. The note may be amended as needed, when new data is available.

Regulatory agencies should not use recommendations made in this note in place of site-specific conditions based on a project's environmental risks. Any regulatory conditions should consider the values of the surrounding environment, the safeguards in place and take a precautionary approach.

Where a conflict arises between recommendations made in this note and any proposed activity that may affect a sensitive water resource, this note may be used to assist negotiations with stakeholders. The negotiated outcome should not result in a greater risk to water quality than would apply if our recommended protection measures were used.

This note will be updated as new information is received or industry/activity standards change. The currently approved version is available online at <www.water.wa.gov.au> select *publications* > *find a publication* > *series browse* > *water quality protection notes*.

Appendix B - Statutory approvals relevant to this note include:

What is regulated?	Statute	Regulatory agency(s)
Development approval	<i>Planning and Development Act 2005</i>	WA Planning Commission www.planning.wa.gov.au Local government (council)
Impact on the values and ecology of the environment	<i>Environmental Protection Act 1986</i> - Part III Environmental Protection Policy - Part IV Environmental Impact Assessment	Minister for the Environment advised by the Environmental Protection Authority; www.epa.wa.gov.au
Environmental protection policies		
Materials that must not be discharged into the environment	Environmental Protection (Unauthorised Discharges) Regulations 2004	Department of Environment and Conservation www.dec.wa.gov.au
Soil sediment and water contamination	<i>Contaminated Sites Act 2006</i>	
Licence to use surface water and groundwater	<i>Rights in Water and Irrigation Act 1914</i>	Department of Water-regional office www.water.wa.gov.au
Development in declared Waterways Management Areas	<i>Waterways Conservation Act 1976</i>	
Development and operations in Public Drinking Water Source Areas	<i>Metropolitan Water Supply, Sewerage and Drainage Act 1909</i> <i>Country Areas Water Supply Act 1947</i>	
Drainage into the Swan or Canning River Estuary	<i>Swan and Canning Rivers Management Act 2006</i>	Swan River Trust www.swanrivertrust.wa.gov.au
Management of human wastes Community health issues	<i>Health Act 1911</i>	Local government; Department of Health www.health.wa.gov.au
Connection to main drains in a declared drainage district	<i>Metropolitan Water Authority Act 1982</i> ; <i>Land Drainage Act 1925</i>	Water Corporation of WA www.watercorporation.com.au
Connection to sewer	<i>Metropolitan Water Supply, Sewerage and Drainage Act 1909</i> <i>Country Towns Sewerage Act 1948</i>	
Dangerous goods storage, transport and handling	<i>Dangerous Goods Safety Act 2004</i>	Department of Mines and Petroleum www.dmp.wa.gov.au
Emergency response planning	<i>Fire and Emergency Services Authority of WA Act 1998</i>	Fire and Emergency Services Authority of WA www.fesa.wa.gov.au

Relevant statutes are available from the *state law publisher* at www.slp.wa.gov.au.

References and further reading

- 1 Australian Government Department of Environment, Water, Heritage and the Arts, National water quality management strategy papers available online at www.environment.gov.au select *water > water policy and programs > water quality > national water quality management strategy*
 - a Paper 2 *Policies and principles*, 1994
 - b Paper 3 *Implementation guidelines*, 1998
 - c Paper 4 *Australian and New Zealand guidelines for fresh and marine water quality*, 2000
 - d Paper 6 *Australian drinking water guidelines*, 2004
 - e Paper 7 *Australian guidelines for water quality monitoring and reporting*, 2000
 - Paper 8 Guidelines for groundwater protection in Australia*, 1995

- 2 Department of Environment and Conservation (WA)
 - a Wetlands policy and guidelines available online at www.dec.wa.gov.au select *management and protection > wetlands > publications*
Position statement: wetlands, 2001
 - b Contaminated sites guidelines available online at www.dec.wa.gov.au select *pollution prevention > contaminated sites > guidelines*
Assessment levels for soil, sediment and water November 2003.

- 3 Department of Water (WA)
 - a Policy available online at www.water.wa.gov.au search *policies*
 - Foreshore policy 1 *Identifying the foreshore area* 2002
 - State-wide policy 2 *Pesticide use in public drinking water source areas* 2000.
 - b Water quality protection notes available online at www.water.wa.gov.au select *publications > find a publication > series browse > water quality protection notes*
 - WQPN 03 *Managed aquifer recharge*
 - WQPN 06 *Vegetated buffers to sensitive waters*
 - WQPN 07 *Chemical blending*
 - WQPN 10 *Contaminant spills - emergency response*
 - WQPN 13 *Dewatering of soils at construction sites*
 - WQPN 20 *Industry – general and heavy*
 - WQPN 22 *Irrigation with nutrient-rich wastewater*
 - WQPN 25 *Land use compatibility in public drinking water source areas*
 - WQPN 27 *Liners for containing pollutants, using engineered soils*
 - WQPN 28 *Mechanical servicing and workshops*
 - WQPN 33 *Nutrient and irrigation management plans*
 - WQPN 39 *Ponds for stabilising organic matter*
 - WQPN 61 *Tanks for ground-level chemical storage*
 - WQPN 65 *Toxic and hazardous substances - storage and use*

- WQPN 83 *Infrastructure corridors near sensitive water resources*
 - WQPN 93 *Light industry near sensitive waters*
- c Environmental guidelines available online at <www.water.wa.gov.au> select *water publications* > *find a publication* > *series browse* > *water quality protection guidelines*
Environmental guidelines for mining and mineral processing, 2000.
- d Stormwater management publication available online at <www.water.wa.gov.au> select *waterways health* > *stormwater and drainage* > *management manual*
Stormwater management manual for Western Australia, (current edition).
- e Waterways guidelines available online at <www.water.wa.gov.au> select *publications* > *find a publication* > *series browse* > *water notes*
- WN 11 *Identifying the riparian zone*
 - WN 23 *Determining foreshore reserves*.
- 4 Engineers Australia publication available for purchase at <www.engineersmedia.com.au> search *EA books*
Australian rainfall and runoff (current edition).
- 5 Department of Environment and Climate change (New South Wales) online publications available at <www.environment.nsw.gov.au> select *environmental issues* > *water* > *stormwater* > *publications*.
- 6 Environmental Protection Authority (South Australia) online publications at <www.epa.sa.gov.au> select *publications* > *guidelines* > *stormwater management series*.
- 7 Environmental Protection Authority (WA)
- a Guidance statements available online at <www.epa.wa.gov.au> select *environmental impact assessment* > *guidance statements*
Guidance statement 33 - *Environmental guidance for planning and development*, May 2008.
- b *Environmental protection policies* available online at <www.epa.wa.gov.au>
- *Revised draft Environmental protection (Swan Coastal Plain wetlands) policy and regulations 2004*
 - *Environmental protection (Gnangara mound crown land) policy 1992*
 - *Environmental protection (Swan coastal plain lakes) policy 1992*
 - *Environmental protection (South west agriculture zone wetlands) policy 1998*
 - *Environmental protection (Swan and Canning Rivers) policy 1998*
 - *Environmental protection (Western swamp tortoise habitat) policy 2002*.
- c *State environmental policies*, available online at <www.epa.wa.gov.au> select *State environmental policies*
- *An explanatory document 2004*
 - *State environmental (Cockburn Sound) policy 2005*.

d *Position statements* available online at <www.epa.wa.gov.au> select position statements

- PS 4 *Environmental protection of wetlands*, November 2004
- PS 7 *Principles of environmental protection*, August 2004
- PS 8 *Environmental protection in natural resource management*, 2005
- PS 9 *Environmental offsets*, January 2006.

Standards Australia publication available for purchase at <www.saiglobal.com> select publications > Australian standards

AS 5667 Water quality – sampling

8 Swan River Trust publications see <www.swanrivertrust.wa.gov.au> select *resources and publications*> *Swan- Canning cleanup program*.

Environmental management and cleaner production directory for small and medium business 2005.

More information

We welcome your views on this note. All feedback is retained on our file number 15656.

To comment on this note or for more information, please contact our water source protection branch as shown below, citing the note topic and version.

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Turbidity, Total Suspended Solids & Water Clarity

What are Total Suspended Solids?

Total suspended solids (TSS) are particles that are larger than 2 microns found in the water column. Anything smaller than 2 microns (average filter size) is considered a dissolved solid.

Most suspended solids are made up of inorganic materials, though bacteria and algae can also contribute to the total solids concentration³.

Both organic and inorganic particles of all sizes can contribute to the suspended solids concentration.

These solids include anything drifting or floating in the water, from sediment, silt, and sand to plankton and algae¹. Organic particles from decomposing materials can also contribute to the TSS concentration. As algae, plants and animals decay, the decomposition process allows small organic particles to break away and enter the water column as suspended solids¹⁷. Even chemical precipitates are considered a form of suspended solids²⁰. Total suspended solids are a significant factor in observing water clarity³. The more solids present in the water, the less clear the water will be.

Some suspended solids can settle out into sediment at the bottom of a body of water over a period of time³. Heavier particles, such as gravel and sand, often settle out when they enter an area of low or no water flow. Although this settling improves water clarity, the increased silt can smother benthic organisms and eggs¹. The remaining particles that do not settle out are called colloidal or nonsettleable solids⁴. These suspended solids are either too small or too light to settle to the bottom.

Settleable solids are also known as bedded sediments, or bedload³⁷. These sediments can vary from larger sand and gravel to fine silt and clay, depending on the flow rate of water.

Sometimes these sediments can move downstream even without rejoining the suspended solids concentration. When settleable solids are moved along the bottom

Some sediment will settle to the bottom of a body of water, while others remain suspended.

of a body of water by a strong flow, it is called bedload transport⁷.

What is Turbidity?

Turbidity is an optical determination of water clarity¹. Turbid water will appear cloudy, murky, or otherwise colored, affecting the physical look of the water. Suspended solids and dissolved colored material reduce water clarity by creating an opaque, hazy or muddy appearance. Turbidity measurements are often used as an indicator of water quality based on clarity and estimated total suspended solids in water.

The turbidity of water is based on the amount of light scattered by particles in the water column². The more particles that are present, the more light that will be scattered. As such, turbidity and total suspended solids are related. However, turbidity is not a direct measurement of the total suspended materials in water. Instead, as a measure of relative clarity, turbidity is often used to indicate changes in the total suspended solids concentration in water without providing an exact measurement of solids¹.

Turbidity can come from suspended sediment such as silt or clay, inorganic materials, or organic matter such as algae, plankton and decaying material. In addition to these suspended solids, turbidity can also include colored dissolved organic matter (CDOM), fluorescent dissolved organic matter (FDOM) and other dyes¹⁴. CDOM is also known as humic stain. Humic stain refers to the tea color produced from decaying plants and leaves underwater due to the release of tannins and other molecules.

This discoloration is often found in bogs, wetlands or other water bodies with high amounts of decaying vegetation in the water. CDOM can cause water to appear red or brown, depending on the type of plants or leaves present. These dissolved substances may be too small to be counted in a suspended solids concentration, but they are still part of a turbidity measurement as they affect water clarity.

What is Water Clarity?

Water clarity is a physical characteristic defined by how clear or transparent water is. Clarity is determined by the depth that sunlight penetrates in water⁹. The further sunlight can reach, the higher the water clarity. The depth sunlight reaches is also known as the photic zone. The clearer the water, the deeper the photic zone and the greater the potential for photosynthetic production¹⁰. The photic zone (and thus water clarity) has a maximum depth of 200 m based on the light absorption properties of water.

This river owes its muddy appearance to high turbidity levels.



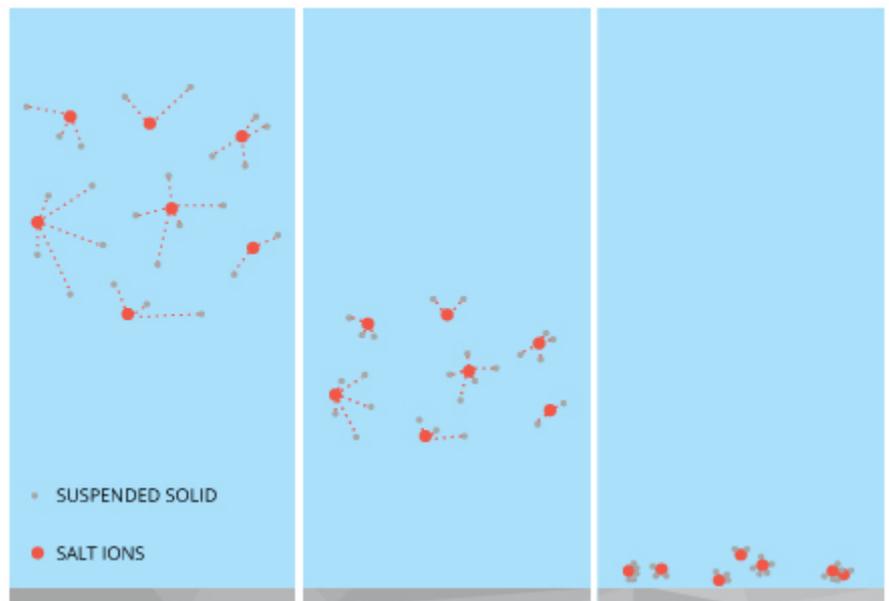
Tannins from decomposing vegetation have colored this river red.

Water clarity is directly related to turbidity, as turbidity is a measure of water clarity. The transparency of water is affected by the amount of sunlight available, suspended particles in the water column and dissolved solids such as colored dissolved organic material (CDOM) present in the water.

Salinity also affects water clarity¹⁰. This is due to the effect of salt on the aggregation and settling velocity of suspended particles. In other words, salt ions collect suspended particles and bind them together, increasing their weights and thus their likelihood of settling to the bottom. Due to this mechanism, oceans and estuaries tend to have a higher clarity (and lower average turbidity) than lakes and rivers¹⁰. These marine environments also have a higher rate of sedimentation as solids are pulled out of the water column to the seafloor.



Ocean water is usually clearer than freshwater due to the effect of salinity on suspended solids.



Salt ions can cause suspended particle to aggregate and settle at the bottom of a body of water.

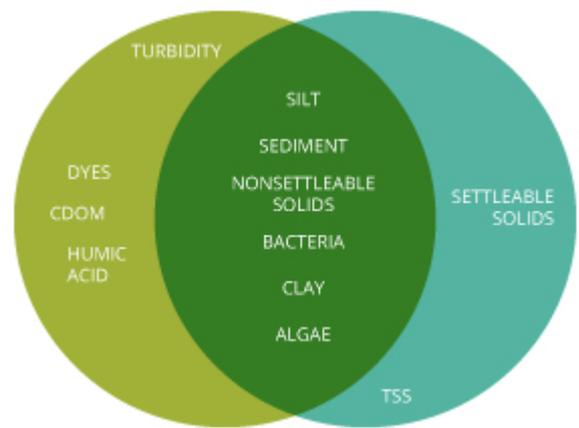
Turbidity vs Suspended Solids – What is the difference?

Turbidity and total suspended solids refer to particles present in the water column. Turbidity and water clarity are both visual properties of water based on light scattering and attenuation. All three parameters are related to particles in the water column, whether directly or indirectly.

Turbidity is determined by the amount of light scattered off of these particles⁶. While this measurement can then be used to estimate the total dissolved solids concentration, it will not be exact. Turbidity does not include any settled solids or bedload (sediment that “rolls” along the riverbed)⁷. In addition, turbidity measurements may be affected by colored dissolved organic matter⁵. While this dissolved matter is not included in TSS measurements, it can cause artificially low turbidity readings as it absorbs light instead of scattering it⁸.

Total suspended solids, on the other hand, are a total quantity measurement of solid material per volume of water⁶. This means that TSS is a specific measurement of all suspended solids, organic and inorganic, by mass. TSS includes settleable solids, and is the direct measurement of the total solids present in a ↑ water body. As such, TSS can be used to calculate sedimentation rates, while turbidity cannot^{1,6}.

Water clarity is strictly relative to sunlight penetration. While this is usually determined by the amount of suspended solids in water, it can also be affected by CDOM and other dissolved solids¹⁰. Water clarity is the most subjective measurement of these three parameters, as it is usually determined by human observation⁵.



While turbidity and total suspended solids often overlap, there are a few outlying factors that only contribute to one or the other.



Is this water clear, or murky, or just slightly opaque? Human observation of clarity allows for personal perception and judgement.

Why are Turbidity and Total Suspended Solids Important?

Turbidity and TSS are the most visible indicators of water quality. These suspended particles can come from soil erosion, runoff, discharges, stirred bottom sediments or algal blooms¹. While it is possible for some streams to have naturally high levels of suspended solids, clear water is usually considered an indicator of healthy water^{9,14}. A sudden increase in turbidity in a previously clear body of water is a cause for concern. Excessive suspended sediment can impair water quality for aquatic and human life, impede navigation and increase flooding risks⁷.

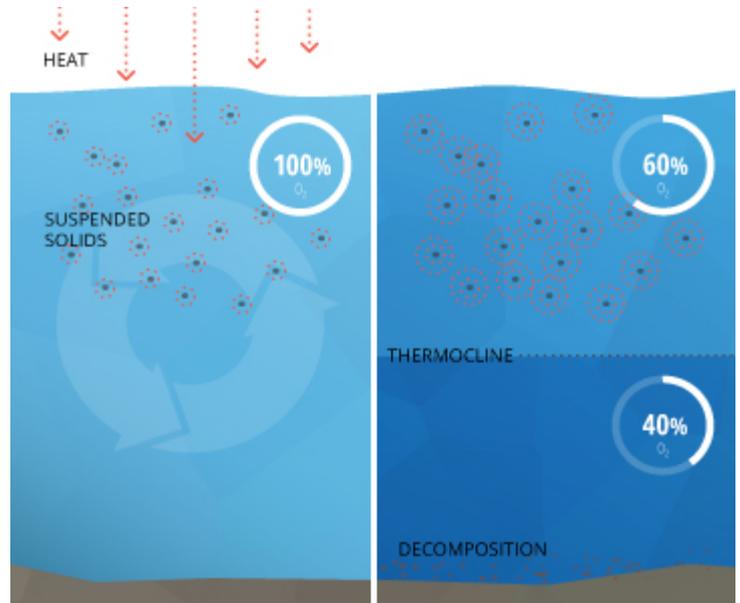


A sediment-laden river flows into Tuscaloosa Lake. Photo Credit: City of Tuscaloosa via USGS



Water Chemistry

In terms of water quality, high levels of total suspended solids will increase water temperatures and decrease dissolved oxygen (DO) levels ¹. This is because suspended particles absorb more heat from solar radiation than water molecules will. This heat is then transferred to the surrounding water by conduction. Warmer water cannot hold as much dissolved oxygen as colder water, so DO levels will drop ¹³. In addition, the increased surface temperature can cause stratification, or layering, of a body of water ³. When water stratifies, the upper and lower layers do not mix. As decomposition and respiration often occur in the the lower layers, they can become too hypoxic (low dissolved oxygen levels) for organisms to survive.

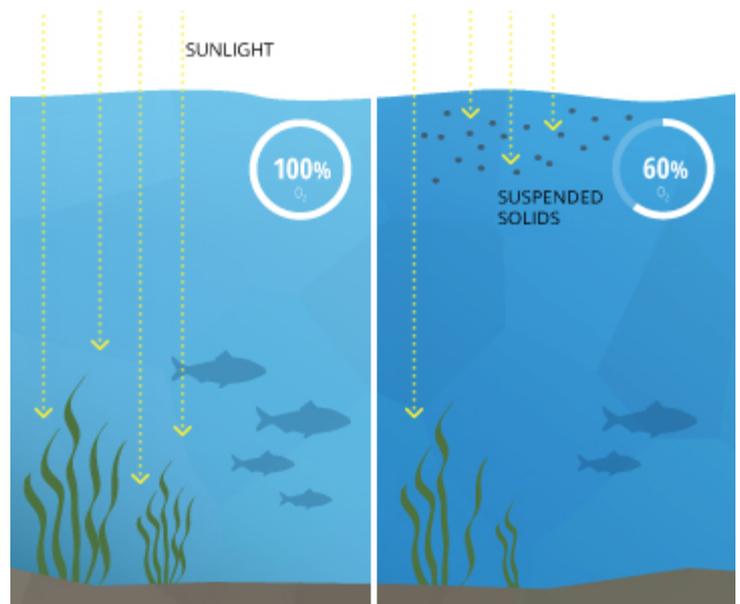


Suspended solids can increase the temperature of water as they absorb additional heat from the sun. This can also cause dissolved oxygen levels to drop below the thermocline, creating hypoxic conditions.

Photosynthesis Production

Turbidity can also inhibit photosynthesis by blocking sunlight. Halted or reduced photosynthesis means a decrease in plant survival and decreased dissolved oxygen output ⁹. The higher the turbidity levels, the less light that can reach the lower levels of water. This reduces plant productivity at the bottom of an ocean, lake or river ¹⁵. Without the needed sunlight, seaweed and bay grasses below the water's surface will not be able to continue photosynthesis and may die ¹⁶.

Underwater vegetation die-off has two main effects. First, as photosynthetic processes decrease, less dissolved oxygen is produced, thus further reducing DO levels in a body of water ¹³. The subsequent decomposition of the organic material can drop dissolved oxygen levels even lower. Second, seaweed and underwater plants are necessary food sources for many aquatic organisms. As they die off, the amount of vegetation available for other aquatic life to feed on is reduced. This can cause population declines up the food chain ²¹.



Suspended solids, particularly algae, can block sunlight from reaching submerged plants. This can cause dissolved oxygen levels to drop, as the plants rely on respiration (consuming oxygen) instead of photosynthesis.

Erosion

An increase in turbidity can also indicate increased erosion of stream banks, which may have a long-term effect on a body of water ³. Erosion reduces habitat quality for fish and other organisms. In terms of water clarity, reduced light penetration due to suspended sediment can obscure aquatic organisms' vision, ↑

reducing their ability to find food ¹⁷. These suspended particles can also clog fish gills and affect growth rates ¹³.

Erosion can contribute to shallower, filled-in lakes and streams as some of the suspended particles settle out ¹⁵. These settleable solids can suffocate benthic organisms and fish eggs ¹. In addition, the sediment may smother insect larvae and other fish food sources ¹³. When this occurs in rivers and channels, the increased sediment loads can reduce navigability for ships and boats ⁷. In cases of excessive sedimentation, settleable solids from erosion and runoff can even halt freight passage completely.

Contamination

Pollutants such as dissolved metals and pathogens can attach to suspended particles and enter the water ². This is why an increase in turbidity can often indicate potential pollution, not just a decrease in water quality. Contaminants include bacteria, protozoa, nutrients (e.g. nitrates and phosphorus), pesticides, mercury, lead and other metals ¹⁷. Several of these pollutants, especially heavy metals, can be detrimental and often toxic to aquatic life ²⁶. The addition of nutrients can encourage the development of harmful algal blooms.

When the suspended solids concentration is due to organic materials, particularly sewage effluent and decaying organic matter, the presence of bacteria, protozoa and viruses are more likely. These organic suspended solids are also more likely to decrease dissolved oxygen levels as they are decomposed ¹⁹.

Human Concerns

These microbes and heavy metals can impact not only aquatic organisms, but drinking water as well ². Organic suspended solids, such as decomposing matter or sewage effluent often naturally include high levels of microorganisms such as protozoa, bacteria and viruses ¹⁹. Such pathogens contribute to waterborne diseases like cryptosporidiosis, cholera and giardiasis ²⁵. Turbid water, whether due to organic or inorganic material, cannot be easily disinfected, as the suspended particles will "hide" these microorganisms ²⁰.

In a lake or river, turbidity may also reduce visibility of underwater structures such as logs or large boulders, negatively affecting a water body's recreational use ¹⁹. In industrial processes, turbidity can contribute to clogged tanks and pipes ²⁰. The particles can also scour machines, potentially damaging them.

What Contributes to Suspended Solids?



Bank erosion along a river can be caused by runoff, flooding or strong water flow. Photo Credit: Soil-Net photo library.



Wastewater effluent can carry pathogens and other contaminants into a water body if it is not treated properly. Photo Credit: EPA

Suspended solids in a body of water are often due to natural causes. These natural solids include organic materials such as algae, and inorganic materials such as silt and sediment. Some algae, such as phytoplankton, are regular occurrences, especially in the ocean. Inorganic materials can easily become suspended due to runoff, erosion and resuspension from seasonal water flow. However, when suspended solids exceed expected concentrations, they can negatively impact a body of water. Excess over background amounts are often attributed to human influence, whether directly or indirectly³⁷. Pollution may contribute to either organic or inorganic suspended solids, depending on the source. Algae, sediment and pollution will affect water quality in different ways depending on the quantity present.

Algae

Algae are plantlike, photosynthesizing organisms that can thrive in both freshwater and saltwater¹¹. These organisms come in different sizes, from microscopic phytoplankton to giant sea kelp forests¹². Both the phytoplankton and seaweed forms of algae will consume nutrients in the water and can increase dissolved oxygen levels through photosynthesis. When they die, however, the organic material is decomposed by microbes in the water column. This decomposition process can decrease dissolved oxygen levels to below normal levels⁴².

Seaweed and kelp are found rooted to the seafloor, but phytoplankton and other micro-algae can be found at the water's surface or throughout the water column¹¹. In particular, cyanobacteria, or blue-green algae, have floating mechanisms that keep them at the surface, blocking sunlight from the water¹⁹. These phytoplankton contribute to the total suspended solids concentration, while rooted vegetation or attached streambed-mat forms of algae do not. However, if these rooted algae become detached (usually when the algae dies or if it is forcefully removed), then their mass becomes part of the suspended solids measurement⁶.

The most obvious examples of algae's contribution to turbidity are found in algal blooms¹¹. An algal bloom occurs when an excessive amount of algae grows quickly across the surface of a body of water. These blooms usually occur due to an influx of nutrients such as nitrogen and phosphorus due to agricultural runoff or decomposition, though warmer water temperatures and longer daylight hours also contribute to their growth¹⁵. Floating algal blooms can block sunlight, release toxins, and deplete oxygen levels in a body of water¹¹.

While some algae growth occurs naturally (often seasonally), excessive growth is often attributed nutrient pollution. Turbidity monitoring can be used to determine



Turbidity is caused by include organic materials such as algae, and inorganic materials such as silt and sediment.



Different algae can float in the water or be found rooted on a riverbed. Some, like kelp and seaweed, look like underwater plants.



Algal blooms can coat the surface of the water and prevent light from penetrating.

if an increase in suspended solids is natural or due to agricultural runoff ⁶.

Sediment: Runoff and Erosion

Sediment is comprised of any solid material that can be transported by water, wind or ice ²³. It is usually defined as the soil particles (including silt, clay and sand) that are deposited on the bottom of a body of water ²¹. These particles are usually classified by size from smallest (clay is less than 0.00195 mm in diameter) to largest (coarse sand can be up to 1.5 mm) ¹⁹. Silt falls in between, ranging from 0.0049 to 0.047 mm.



Sediment particles can be fine silt or clay, sand and even gravel. Photo Credit: USGS via Massachusetts Bay Program

In areas of high flow, even rocks can be considered sediment as they are deposited in water ²². However, not all sediment is suspended. The amount and size of suspended sediment is dependent on water flow ¹⁷. The faster the flow, the larger the particle that can be suspended. Higher flow rates can also support a higher concentration of suspended solids. Particles larger than 0.5 mm usually settle out as water flow decreases ¹⁹. Most of the suspended sediment that remains (colloidal solids) consists of fine sand, silt, and clay ¹⁹.

The majority of suspended sediment present in water bodies comes from runoff and erosion ⁶. If the land surrounding a body of water has only sparse vegetation, the topsoil can easily be washed away into the water ³. Highly vegetated areas will absorb most of the runoff, keeping the body of water clearer.

In addition to collecting suspended particles from runoff, rivers and streams can slowly erode soft riverbanks due to the constant water flow. An increase in river volume and flow (due to rain or other causes) can increase the rate of erosion ¹⁸. On the other side of the spectrum, bedrock-based streams may not have much sediment available to suspend. The local geology will determine natural turbidity levels based on normal flow rates, soil type, land structure and vegetation ⁶. If the surrounding land is altered by agriculture, construction or other soil-disturbing use, it can accelerate erosion and runoff, increasing turbidity ³.



Runoff causes erosion, washing soil and other particulates into a body of water.

Pollution

Any potentially harmful substance that is added to the environment by humans, whether directly or indirectly, is considered pollution ²⁹. This can vary from bacteria riding along on a sewage plant discharge, to coal and iron ore particulates that float in from a mining zone. If these pollutants are larger than 2 μ m, they will contribute to the total suspended solids concentration.

Some of the more common suspended solid pollutants are pathogens (bacteria, protozoa, helminths), microbeads (from exfoliating soaps), wastewater effluent, sewage, airborne particulates, and road particles (e.g. asphalt and tire flecks). Colored wastewater discharge and dyes are pollutants that will affect turbidity, but not suspended solids.

Nutrients like nitrate and phosphorus are often considered pollutants, but as they are a dissolved substance, they do not contribute directly to the suspended solids concentration³⁰. Instead, they are an indirect contributor as they fuel algal blooms, which do affect TSS and turbidity.

These dissolved nutrients, along with dissolved metals, chemicals, and refractory organics, will impact the quality of a body of water²⁹. Nitrate and phosphorus can cause eutrophication (excessive plant and algae growth) which in turn causes low dissolved oxygen levels due to plant respiration and microbial decomposition. Refractory organics are often carcinogenic, while heavy metals and other chemicals can be toxic to aquatic organisms²⁹.

While these contaminants can enter the water as a dissolved substance, many of them ride along on grains of soil or other larger pieces of pollution (e.g. paint flecks or asphalt particles)²⁹. When this is the case, they can be picked up in suspended sediment samples. Chemical dyes will affect turbidity readings as the colored molecules will affect light absorption, but they will not be included in a suspended solids measurement.

Factors that Influence Turbidity

Suspended solids can be comprised of organic and inorganic materials such as sediment, algae, and other contaminants. However, there are specific factors that can affect turbidity levels in a body of water. These are water flow, point source pollution, land use and resuspension.

Water Flow and Weather

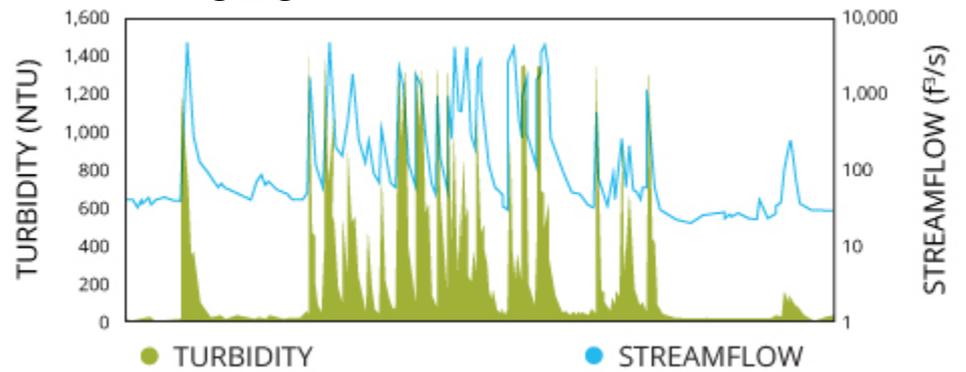
Turbidity and water flow are causally related¹⁸. High flow rates keep particles suspended instead of letting them settle to the bottom. Thus in rivers and other naturally-occurring high flow environments, turbidity can be a constant presence². In these areas, it is important to monitor for changes in turbidity at the same point each time to ensure that the data is not affected by a lower or higher water velocity¹⁸.

Weather, particularly heavy rainfall, also affects water flow, which in turn affects turbidity. Rainfall can increase stream volume and thus stream flow, which can resuspend settled sediments and erode riverbanks¹.

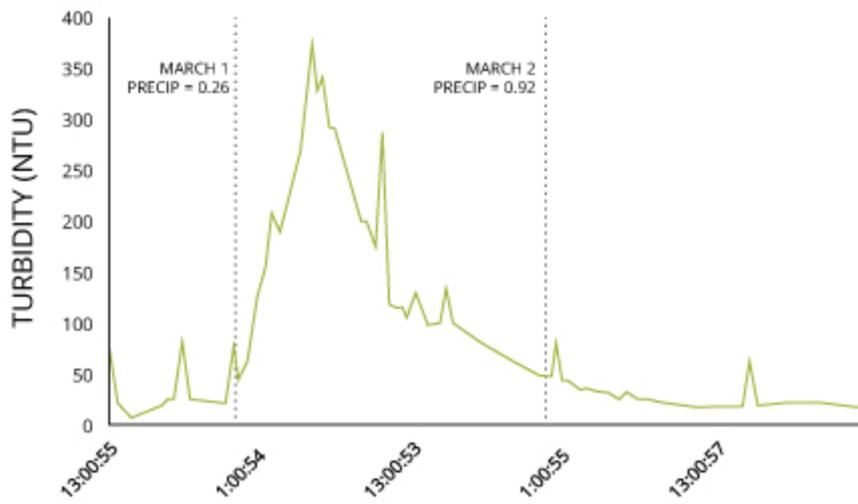


Pollution ranges from large garbage to microplastics, flecks of metal or asphalt, and chemical dyes.

Rain can also directly increase the level of total suspended solids through runoff. As water flows over a surface, it can pick up particles and deposit them in a body of water². Runoff can also wash away topsoil, and contribute to riverbank erosion³. If the flow rate increases enough, it can resuspend bottom sediments, further raising



Stream flow and turbidity are often directly related; as water flow increases, so will turbidity levels.



Heavy rainfall will cause turbidity to spike, as this storm event graph shows. This is due to increased water flow and increased sediment from runoff.

Wind-driven turbidity increases only occur in shallow zones where waves are tall enough to resuspend sediment⁴⁰. Tides, wind, and rain can influence turbidity levels due to their effect on water flow and introduced sediment loads⁹.

Tributaries can also alter turbidity. When a freshwater stream or river enters a saltwater estuary, the change in water flow can cause turbidity levels to increase. This mixing area is often called a turbidity maximum zone¹⁶. These zones tend to have little aquatic vegetation due to the high suspended solids concentrations. Estuaries are often subject to tidal influences as well, which can pull in sand and sediment from the shoreline and resuspended bottom sediments¹⁶.

TSS concentrations².

In areas of dry, loose soil or earth-disturbed sites (e.g. mining or construction areas), wind can blow dust, sediment and other particles into the water²⁹. The addition of new particles will increase the suspended solids concentration. However, wind will generally not increase turbidity levels in the water alone. In wave-dominated estuaries and coastal areas, turbidity is naturally low⁴¹. In comparison, tidal areas, where the water flow is strong enough to resuspended bottom sediments, have high natural turbidity levels.



Turbid rivers can carry their suspended sediments into the ocean. Photo Credit: NASA Visible Earth, via USGS

Point-Source Pollution

If pollution can be tracked to a single, identifiable source, it is considered point-source pollution³⁴. Point-source pollution can increase turbidity through the addition of suspended solids and colored effluent (wastewater) to a body of water. For water quality, common examples include discharge pipes from factories and wastewater treatment plants. In addition, farms can also fall under the category of point-source pollution³³. These sources can release harmful pathogens (bacteria) and chemicals into the water, in addition to suspended solids.

Many factories, wastewater treatment plants, and sewage treatment plants discharge effluent into local water bodies or sewer systems. Sometimes this water is treated or filtered before it is discharged, but sometimes it is not³³. The EPA has created several guidelines for effluent discharge, but they are all based on the technology used, and not the final impact on the local water body³². While most wastewater treatment plants include a settling period in the treatment process, this does not affect colloidal (nonsettleable) solids¹³. When this wastewater is discharged, these



suspended solids may still be present unless treated with additional filters. In addition, colored effluent cannot be trapped by a filter. While dyes and colored dissolved organic material (CDOM) are not included in a suspended solids measurement, they will contribute to turbidity readings due to their effects on light absorption.

Farms that are identified as point sources often allow fertilizer and animal waste to enter local bodies of water. Most agricultural pollution is due to runoff, and not a specific discharge. While this runoff is not intentional, it can be detrimental to water quality as these pollutants are untreated³³. Animal wastes can increase pathogen concentrations in the water, while the fertilizer can contribute to eutrophication and excessive algal growth.

Land Use

A major factor in increased turbidity and total suspended solids concentrations is due to land use. Construction, logging, mining and other disturbed sites have an increased level of exposed soil and decreased vegetation¹⁷. Agricultural areas are also considered disturbed areas after they are tilled¹⁸. Land development, whether it is agricultural or construction, disturbs and loosens soil, increasing the opportunities for runoff and erosion¹⁵. The loosened soils caused by these sites can then be carried away by wind and rain to a nearby body of water.



Construction sites loosen soil that could run off into a body of water.
Photo Credit: NCDOTcommunications via Flickr

This leads to an increase in runoff rates, causing erosion and increased turbidity in local streams and lakes⁶. Settleable solids in the runoff can be deposited on the bottom of a lake, river or ocean, damaging benthic habitats¹⁵. Erosion due to land use is considered a non-point source of turbidity. The use of silt fences and sedimentation basins at construction sites can prevent soils from reaching nearby water sources¹³.

In addition to increasing turbidity levels through suspended sediment, agricultural runoff often includes nutrients as well. Due to the presence of these nutrients, this runoff can fuel the growth of algal blooms⁹. These effects can be seen in local streams, lakes, and even estuaries like the Chesapeake Bay. Water quality can be affected anywhere that these nutrients and sediments are carried. No-till farming practices can reduce the potential for erosion and help maintain nearby water quality¹³.

Sediment- and pollutant-filled runoff can also occur in urban areas. When it rains, soil, tire particles, debris and other solids can get washed into a water system¹⁷. This often occurs at a high flow rate due to the amount of impervious surface areas (e.g. roads and parking lots). Water cannot penetrate these surfaces, so sediment cannot settle out¹⁷. Instead, the stormwater runoff flows right over the pavement, carrying the suspended solids with it. Even in areas with storm drains, these drains usually lead directly to a local water source without filtration²¹. To minimize the pollution and turbidity caused by urban runoff, stormwater retention ponds can be constructed¹³. These basins allow suspended particles to settle before water drains downstream²⁸.



Urban runoff flushes contaminants such as sediment, asphalt and tire particles. Photo Credit: Robert Lawton via Wikimedia Commons

Resuspension

Even carp and other bottom-feeding fish can contribute to increased turbidity levels¹⁷. As they remove vegetation, sediment can become resuspended in the water. Sediment at the bottom of a body of water can be stirred up by shifting water flow, bottom-feeding fish, and anthropogenic causes such as dredging. Dredging projects, which remove built-up sediment in navigation channels, are a major source of resuspended sediments in the surrounding water³. Dredging can cause high turbidity levels as it disturbs large amounts of settled sediment in a relatively short period of time. These stirred-up particles are mostly silt and sand. When they resettle, they can alter habitats, smother fish eggs and suffocate bottom-dwelling organisms.



Dredging project underway at Kings Lake. Photo Credit: Biswarup Ganguly via Wikimedia Commons

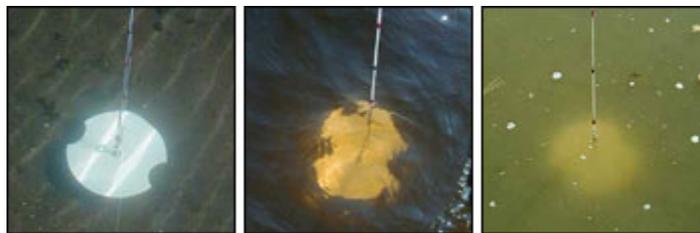
TSS and Turbidity Units

Total suspended solids, as a measurement of mass are reported in milligrams of solids per liter of water (mg/L)¹⁸. Suspended sediment is also measured in mg/L³⁶. The most accurate method of determining TSS is by filtering and weighing a water sample⁴⁴. This is often time consuming and difficult to measure accurately due to the precision required and the potential for error due to the fiber filter⁴⁴.

Turbidity, on the other hand, is most often measured with a turbidity meter. Turbidity is reported in units called a Nephelometric Turbidity Unit (NTU), or a Jackson Turbidity Unit (JTU)⁶. The JTU was the original turbidity unit based on the visibility of candlelight in a tube (Jackson Candle Turbidimeter)⁴³. However, this method is considered out of date and inaccurate in comparison to newer methods.

While some organizations consider the two units to be approximately equal, there are some specific differences²⁰. In particular, NTU is more precise and has a wider range (JTU cannot measure above 25 JTU/NTU)⁴³. In addition NTU is the standard unit of many broadband output (400-680 nm wavelength) turbidity meters. Nephelometric refers to the measurement technology used. This technology method requires the photodetector in the meter to be placed at a 90 degree angle from the illumination source¹⁴. As light bounces off the suspended particles, the photodetector can measure the scattered light.

The USGS also suggests the use of the Formazin Nephelometric Unit (FNU) if a turbidity meter only has a monochrome/infrared output, as opposed to the white/broadband output¹⁴. This applies to instruments that are in compliance with the European drinking-water protocol, including most submersible turbidity meters³⁴. Both NTU and FNU will show equal measurements when calibrating as they both use nephelometric technology, but may operate differently in the field due to the different light source¹⁴. Turbidity meters that use FNU units are able to compensate for dissolved colored materials (such as humic stain), while NTU turbidity meters cannot¹⁴.



Secchi discs are used to measure water clarity. Photo Credit: Minnesota Pollution Control Agency via NASA

Water clarity, when not measured in terms of turbidity, is measured by Secchi depth¹. This measurement is based on the depth that a black and white Secchi disc can be lowered into a body of water. At the point visibility is lost, the depth of the disc is recorded, and is known as the Secchi depth¹⁶. High Secchi depths correspond with low turbidity levels, while low Secchi depths are associated with high levels of suspended solids. This method is generally only useful in oceans, lakes and deep, low-flow rivers. In marine environments, a larger solid white disc is often used, while some shallower lakes use a black disc and take a horizontal measurement³⁹.

Due to the effects of salt on suspended sediment, ocean clarity is often much higher than lake or river clarity. Most Secchi disc records reach around 65-80 m³⁹. Water clarity has a theoretical limit of 200 m, based on light penetration and calculations with distilled and ultrapure water¹⁰. However, most Secchi discs are not large enough to be seen at that depth.

In shallower streams, a Secchi tube can be used³⁸. A Secchi tube is usually one meter long and is filled with collected water. A small Secchi disc is then lowered into the tube and read at the point of disappearance, just as it is in a larger body of water³⁸.

Turbidity Meters and Measurements

Regardless of whether readings are in NTU, FNU or other less common units, it is important to note that a turbidimeter's optical design will affect turbidity readings¹⁴. As turbidity is a measurement of light scatter, the placement and designs of the detectors with the meter can influence the readings. This simply means that raw data from two different turbidity meters cannot be directly compared without an established relationship between them¹⁴. Turbidity readings can vary based on wavelengths emitted, light source instability, high particle density or due to the presence of colored dissolved or suspended material. The more detectors present in a turbidimeter, the less variability there will be in measurements¹⁴.

Typical Levels

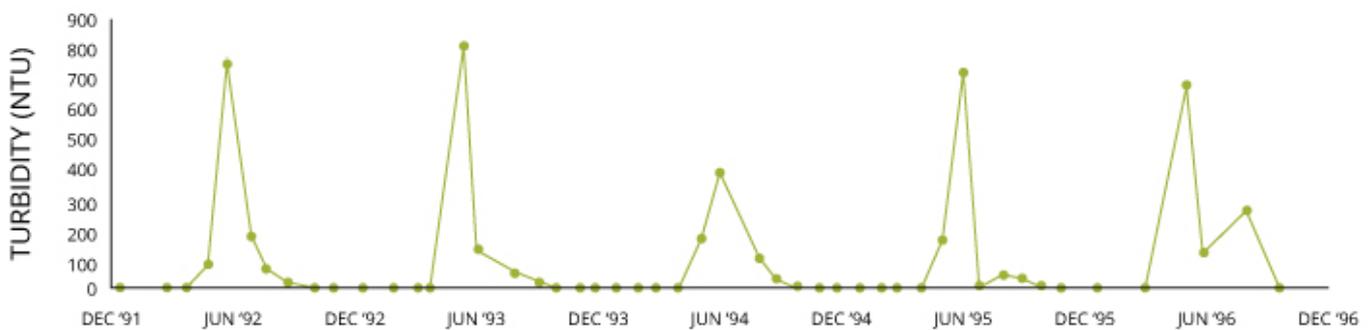
In most situations, a total suspended solids concentration below 20 mg/L appears clear, while levels over 40 mg/L may begin to appear cloudy¹³. In comparison, a turbidity reading below 5 NTU appears clear, while a reading of 55 NTU will start to look cloudy and a reading over 500 NTU will appear completely opaque².

It is important to note that this is dependent on the size and nature of the suspended solids. Typical turbidity and TSS levels are difficult to quantify due to their natural variation by season, local geology, water flow and weather events. During a low-flow period, most rivers and lakes are fairly clear with a turbidity reading below 10 NTU. These readings can easily jump into the hundreds due to runoff during a rainstorm, snowmelt or a dredging project¹.



At 5 NTU, water still appears clear. It is cloudy at 55 NTU and opaque at 515 NTU.

Photo Credit: USGS



Turbidity will often spike annually due to spring rains and snow melt.

In general, marine environments have lower turbidity levels than freshwater sources¹⁰. The salinity of the ocean or estuary will cause the suspended solids to aggregate, or combine. As the aggregate weight increases, the solids begin to sink and will settle on the seafloor¹⁰. This effect offers greater water clarity than is available in most lakes and rivers. The higher the salinity, the greater the effect¹⁰. However, in tidal zones, a turbidity maximum may occur due to the constant resuspension of these settled solids¹⁶. Freshwater sources may also carry out additional suspended particles into the delta.



Saltwater is typically clearer than freshwater.

As the concentrations of total suspended solids are difficult to measure and predict, most states do not have a set standard. Even the National Academy of Sciences only recommends that "TSS should not reduce light penetration by more than 10%"³. Kentucky does not have a quantitative standard for acceptable levels of total suspended solids. Instead, they simply state that there should be no adverse

affects to the body of water or its inhabitants³. Michigan is another example of a state with only a “narrative standard” for total suspended solids and turbidity¹³. There is no set level or concentration, only a recommendation against unnatural physical properties (e.g. turbidity, color, films, floating or suspended solids) in “injurious” quantities¹³.



Drinking water should have less than 5 NTU, preferably less than 1 NTU and ideally below 0.1 NTU.

Instead, many countries and organizations have established recommended turbidity levels from a baseline of prior measurements. In the case of drinking water, recommended levels are based on several filtration and disinfection studies³¹. The Ireland EPA advises treatment plants to have turbidity levels below 0.2 NTU, with a mandatory maximum of 1 NTU for drinking water³¹. According to the World Health Organization, water for human consumption should have turbidity levels below 1 NTU, though for some regions, up to 5 NTU is allowed if it can be proven to be disinfected^{19,20}. The American Water Works Association suggests that a level of 5 NTU or lower is acceptable for recreation purposes¹⁹. As a state example, the North Carolina code allows up to 10 NTU for trout waters, 25 NTU for non-trout streams and as high as 50 NTU for non-trout lakes.

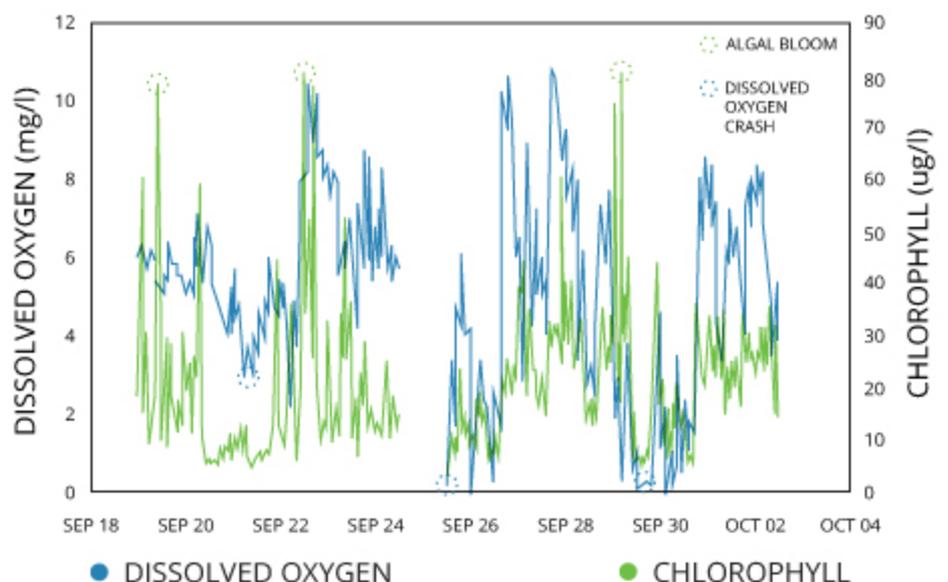
Other states have determined allowable fluctuations from an established baseline. The state of Washington does not have a standard for TSS, but it does for turbidity, depending on the body of water. In some streams, turbidity cannot increase by more than 5 NTU from the baseline. For others, turbidity may be allowed to fluctuate by up to 20%⁶.

Consequences of Unusual Levels

In addition to being a warning sign for pollution, suspended solids can harbor pathogens such as bacteria and protozoa². These microorganisms attach to the suspended particles, aiding in their transportation and hiding them from disinfectants². These pathogens can infect aquatic or human life if the sediment is not removed.

Algal Blooms

Algal blooms, while initially increasing dissolved oxygen levels, may create hypoxic conditions as they decompose⁴². When an algal bloom appears, it blocks sunlight from reaching any submerged vegetation, killing those plants and decreasing the amount of dissolved oxygen produced. Then, when the bloom dies off, microbes consume more oxygen as they decompose the organic material. This causes dissolved oxygen levels to plummet even lower, creating hypoxic (low DO) or even anoxic (no DO) conditions.



As this graph shows, the appearance of an algal bloom results in a dramatic dissolved oxygen decrease shortly thereafter.

Furthermore, some blooms produce toxins that are damaging to aquatic and human life ¹⁶. These harmful algal blooms include cyanobacteria, red tide (*Karenia brevis*) and ciguatera (*Gambierdiscus toxicus*) ²⁷.

Settleable Solids

Settleable solids can impair lakes and other water bodies. If sedimentation rates are high, they can alter and often destroy fish habitats and spawning beds ³⁷. If eggs or benthic organisms are present, they can become buried by the sediment and die. Sediment deposition can reduce egg and embryo survival by reducing oxygen supply and crusting over the egg, preventing the embryo from escaping ³⁷.

As sediment build-up increases, the shallower body of water means an increased risk of flooding and a decrease in navigability for boats and ships ²⁴. Dredging projects attempt to remove excessive sediment deposits from navigation channels, but this can be just as damaging to the local fish habitats and spawning beds.

Turbidity

High turbidity levels can diminish visibility and often feeding behaviors, in addition to physically harming aquatic life. The suspended solids may disrupt the natural movements and migrations of aquatic populations ¹³. Fish that rely on sight and speed to catch their prey are especially affected by high turbidity levels. These fish often flee areas of high turbidity for new territories ³⁷. For the fish that remain in the turbid environment, suspended sediment can begin to physically affect the fish. Fine sediment can clog fish gills and lower an organism's resistance to disease and parasites ³⁷. Some fish may consume suspended solids, causing illness and exposing the fish to potential toxins or pathogens on the sediment. If the consumed sediment does not kill the fish, it can alter the organism's blood chemistry and impair its growth ³⁷.

Turbidity will also affect submerged plant growth. Levels over 15 NTU are considered detrimental to bay grass growth in estuary zones ¹⁶. As turbidity increases, the amount of light available to submerged aquatic vegetation (SAV) decreases. Without enough light, photosynthesis will stop, and the SAV will no longer produce dissolved oxygen. In addition to reducing the dissolved oxygen concentration in the water, the plants will eventually die ⁴⁰. As the aquatic vegetation dies off, the organisms that feed on it will also decline due to the reduced food sources available ¹³. If turbidity levels remain elevated, the effects can be seen up the food chain ³⁷.

Even aquatic life that does not strongly depend on vegetation for survival will be affected by the low dissolved oxygen levels ⁴⁰. If these fish and invertebrate cannot escape the anoxic area, they will die.

Cite This Work

Fondriest Environmental, Inc. "Turbidity, Total Suspended Solids and Water Clarity." *Fundamentals of Environmental Measurements*. 13 Jun. 2014. Web. < <https://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/> >.

Additional Information

- [Turbidity Measurement Methods](#)
- [Turbidity Meters](#)
- [Turbidity Sensors](#)
- [Applications](#)
- [References](#)

Parameters

Sediment Transport and Deposition
Algae, Phytoplankton and Chlorophyll
Chromophoric Dissolved Organic Matter
Conductivity, Salinity & Total Dissolved Solids
Dissolved Oxygen
pH of Water
Turbidity, Total Suspended Solids & Water Clarity
Water Temperature
Solar Radiation & Photosynthetically Active Radiation

Measurements

Measuring Streamflow
Measuring CDOM
Measuring Dissolved Oxygen
Measuring Turbidity, TSS, and Water Clarity

Monitoring Equipment

Buoy Mooring
Scour Monitoring Equipment
Data Logger
Online Datacenter
Telemetry

Monitoring Applications

Monitoring Turbidity at Dredging Sites
Monitoring Dissolved Oxygen at Hydropower Facilities
Monitoring Scour at Bridges and Offshore Structures
Temperature Profiling in Lakes
Inland Lake Monitoring
Stream and River Monitoring
Flood Warning Systems

References



Chapter Overview

1. What is Sediment?
 - Suspended or Bedded?
 - Suspended Sediment vs. Suspended Solids
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3. What is Sediment Deposition?
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In an aquatic environment, sediment can either be suspended (floating in the water column) or bedded (settled on the bottom of a body of water). When both floating and settled particles are monitored, they are referred to as SABS: Suspended And Bedded Sediments ⁴.

Suspended Sediment vs Suspended Solids

Fine sediment can be found in nearly any body of water, carried along by the water flow. When the sediment is floating within the water column it is considered suspended. In this application, the terms “suspended sediment” and “suspended solids” are nearly interchangeable. The main difference between the two is in the method of measurement ².

Despite the similarity in meaning, the data provided by the different measurement methods are neither interchangeable nor comparable ². The suspended sediment concentration (SSC) is in mg/L by filtering and drying an entire water sample. Total suspended solids (TSS), while also measured in mg/L, are obtained by subsampling. While acceptable for homogenized or well mixed samples with very fine sediment, the TSS measurement often excludes larger suspended particles, like sand ². This means that the SSC measurement tends to be higher and more representative of a water body as a whole, often measuring within 5% of the true particle concentration ⁷. Due to the incomparability between suspended sediment measurements and total suspended solids measurements, the U.S. Geological Survey recommends SSC analysis over TSS when sampling in surface water ².



What is Sediment Transport?

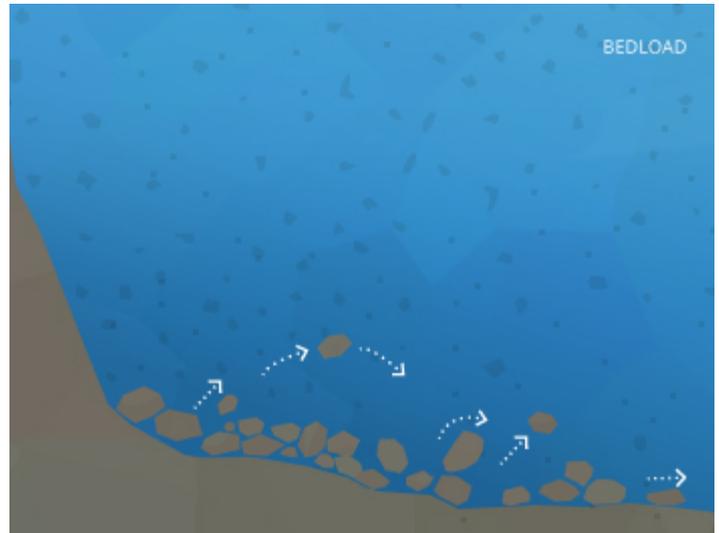
Sediment transport is the movement of organic and inorganic particles by water ¹⁰. In general, the greater the flow, the more sediment that will be conveyed. Water flow can be strong enough to suspend particles in the water column as they move downstream, or simply push them along the bottom of a waterway ¹¹. Transported sediment may include mineral matter, chemicals and pollutants, and organic material.

Another name for sediment transport is sediment load. The total load includes all particles moving as bedload, suspended load, and wash load ¹¹.



Bedload

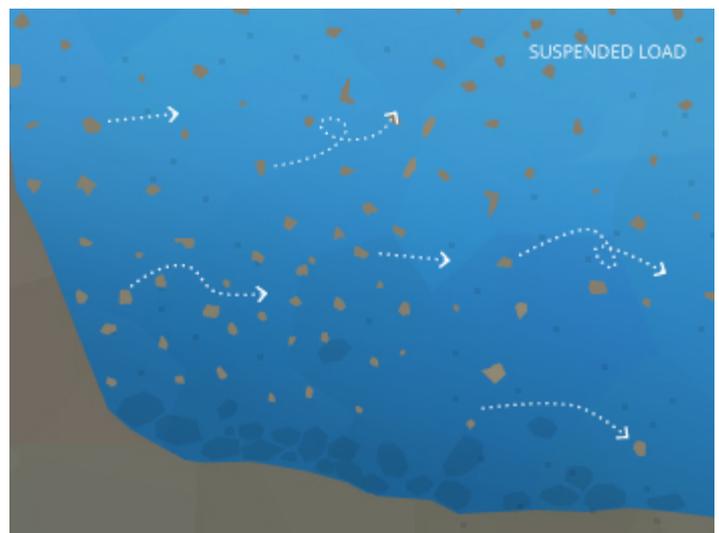
Bedload is the portion of sediment transport that rolls, slides or bounces along the bottom of a waterway¹². This sediment is not truly suspended, as it sustains intermittent contact with the streambed, and the movement is neither uniform nor continuous¹¹. Bedload occurs when the force of the water flow is strong enough to overcome the weight and cohesion of the sediment¹². While the particles are pushed along, they typically do not move as fast as the water around them, as the flow rate is not great enough to fully suspend them¹¹. Bedload transport can occur during low flows (smaller particles) or at high flows (for larger particles). Approximately 5-20% of total sediment transport is bedload¹⁰. In situations where the flow rate is strong enough, some of the smaller bedload particles can be pushed up into the water column and become suspended.



Bedload particles travel with water flow by sliding or bouncing along the bottom.

Suspended Load

While there is often overlap, the suspended load and suspended sediment are not the same thing. Suspended sediment are any particles found in the water column, whether the water is flowing or not. The suspended load, on the other hand, is the amount of sediment carried downstream within the water column by the water flow¹¹. Suspended loads require moving water, as the water flow creates small upward currents (turbulence) that keep the particles above the bed¹³. The size of the particles that can be carried as suspended load is dependent on the flow rate¹¹. Larger particles are more likely to fall through the upward currents to the bottom, unless the flow rate increases, increasing the turbulence at the streambed. In addition, suspended sediment will not necessarily remain suspended if the flow rate slows.



If the water flow is strong enough to pick up sediment particles, they will become part of the suspended load.

Wash Load

The wash load is a subset of the suspended load¹³. This load is comprised of the finest suspended sediment (typically less than 0.00195 mm in diameter). The wash load is differentiated from the suspended load because it will not settle to the bottom of a waterway during a low or no flow period¹¹. Instead, these particles remain in permanent suspension as they are small enough to bounce off water molecules and stay afloat¹¹. However, during flow periods, the wash load and suspended load are indistinguishable.

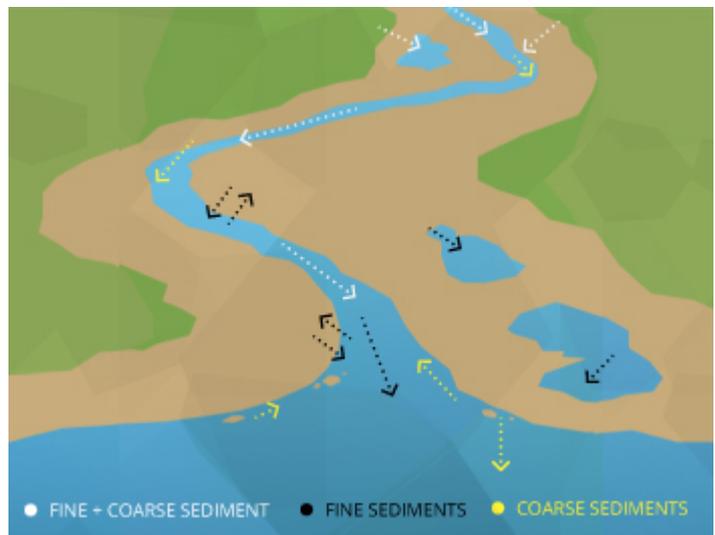
Turbidity in lakes and slow moving rivers is typically due to the wash load⁸. When the flow rate increases (increasing the suspended load and overall sediment transport), turbidity also increases. While turbidity cannot be used to estimate sediment transport, it can approximate suspended sediment concentrations at a specific location¹⁴.



The wash load is the portion of sediment that will remain suspended even when there is no water flow.

What is Sediment Deposition?

Sediment is necessary to the development of aquatic ecosystems through nutrient replenishment and the creation of benthic habitat and spawning areas¹⁰. These benefits occur due to sediment deposition – when suspended particles settle down to the bottom of a body of water. This settling often occurs when water flow slows down or stops, and heavy particles can no longer be supported by the bed turbulence. Sediment deposition can be found anywhere in a water system, from high mountain streams, to rivers, lakes, deltas and floodplains. However, it should be noted that while sediment is important for aquatic habitat growth, it can cause environmental issues if the deposition rates are too high, or too low.



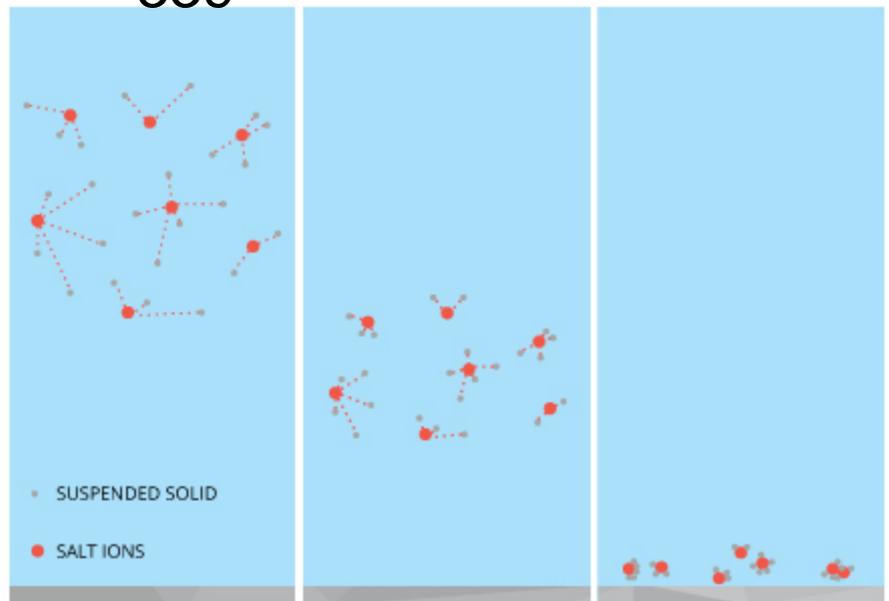
When the flow rate changes, some sediment can settle out of the water, adding to point bars, channel bars and beaches.

Settleable Solids

The suspended particles that fall to the bottom of a water body are called settleable solids¹⁰. As they are found in riverbeds and streambeds, these settled solids are also known as bedded sediment⁸. The size of settleable solids will vary by water system – in high flow areas, larger, gravel-sized sediment will settle out first. Finer particles, including silt and clay, can be carried all the way out to an estuary or delta¹⁷.

In marine environments, nearly all suspended sediment will settle. This is due to the presence of salt ions in the water. Salt ions bond to the suspended particles, encouraging them to combine with other particles in the water¹⁵. As the collective weight increases, the sediment begins to sink to the seafloor. This is why oceans and other marine ecosystems tend to have lower turbidity levels (greater water clarity) than freshwater environments¹⁵.

While estuaries and other tidal areas may be considered marine, they are not necessarily clearer than freshwater. Estuaries are the collection point for suspended sediment coming down river. Furthermore, in a tidal zone, the constant water movement causes the bottom sediment to continually resuspend, preventing high water clarity during tidal periods¹⁶. The clarity of an estuary will depend on its salinity[↑] level, as this will assist with particle deposition¹⁷.



Why are Sediment Transport and Deposition Important?

Many ecosystems benefit from sediment transport and deposition, whether directly or indirectly. Sediment builds aquatic habitats for spawning and benthic organisms¹⁰. It is also responsible for providing nutrients to aquatic plants, as well vegetation in nearshore ecosystems such as floodplains and marshes¹⁰. Without sediment deposition, coastal zones can become eroded or nonexistent.

Sediment and Aquatic Life

Sediment deposition creates habitats for aquatic life. While too much sediment can be detrimental, too little sediment can also diminish ecosystem quality¹⁰. Some aquatic habitats are even grain-size specific. Many spawning habitats require a specific sediment size (e.g. gravel) and too fine of sediment can end up smothering the eggs and other benthic creatures⁸.



Sockeye salmon and other fish require specific sediment materials (like gravel) to create its spawning bed (redd) to protect eggs without smothering them. (Photo Credit: Oregon Department of Fish and Wildlife)

Too much sediment deposition can also bury habitats and even physically alter a waterway. Excessive levels of suspended load tend to have negative impacts on aquatic life. Suspended sediment can prevent light from reaching submerged vegetation and clog fish gills⁸. If a body of water is continually exposed to high levels of sediment transport, it may encourage more sensitive species to leave the area, while silt-tolerant organisms move in⁸.

On the other hand, too little sediment transport can lead to nutrient depletion in floodplains and marshes, diminishing the habitat and vegetative growth¹⁰. While water clarity is often heralded as a benchmark of water quality, low amounts of turbidity can protect aquatic species from predation¹⁸. In addition, too little sediment deposition can lead

to the erosion of riverbanks and coastal areas, causing land loss and destroying the nearshore habitats^{10, 18}.

Where Does Sediment Come From?



Sediment comes from geologic, geomorphic, and organic factors ¹⁰. The amount, material and size of the transported sediment is a sum of these influences in any particular waterway. Sediment transported in rivers with headwaters from a mountain range often include glacial silt, while a body of water surrounded by swampland will be inundated with decomposing organic material ²³.

Sediment and Geology

Many sediment particles are mineral-based. The exact nature of the sediment is dependent on location, and the geology of that location ¹⁰. Glacial-type sediment is common in mountain ranges, while low-lying rivers are more apt to collect soil-based sediment. In high-flow waterways, sediment transport will include local gravel, pebbles and small rocks. Harder rocks are less likely to become sediment, while soft rocks erode quicker and are easily carried away by flowing water ¹³. The physical make-up of transported sediment is strongly influenced by the geology of the surrounding environment.



Glacial silt comes glaciers scraping over erodible materials. This silt is then carried away by wind and rivers. (Photo Ruth Glacier Base, Photo Credit: Richard Muller, Berkley Dept of Physics)

Specific geologic elements are typically localized, such as basalt near volcanic plate boundaries, or limestone in historically shallow marine regions ²¹. Sediment transport is often responsible for intermixing these geologic features by carrying mineral particle far away from their origin. Mountains streams full of glacial silt can transport that sediment all the way into a tidal bay ¹⁰. Likewise, rivers that run through agricultural regions can carry fertilized soil into the ocean ²⁴.

Millions of years ago, sediment deposition helped to form many of these geologic features²⁰. Sedimentary rocks such as sandstone and limestone, are created by sediment deposits, which eventually become pressurized into stone ²⁰. Once these rocks become re-exposed to water and air, the sediment transport process can begin again.

Sediment and Geomorphology

Geomorphology refers to both the surface of the Earth (terrain), and the processes acting on it (e.g. wind and rain) ²². As defined earlier – sediment is the collection of particles that can be carried away by wind, water and ice. These particles can come from the weathering of rocks and the erosion of surface materials ¹⁹. When wind, rain, glaciers and other elements scour away a rock face, the particles are carried away as sediment ¹⁰. Runoff can carry away top soils, pushing the sediment into nearby streams and rivers.

In addition to the influence of wind and rain, sediment transport is also affected by the local topography ¹⁹. The amount of sediment that enters the water and the distance that it travels is due to the terrain that a waterway runs through ¹³. Bedrock streams are less likely to contribute to the sediment load, as the channel is resistant to quick erosion ¹³. These rivers, as well as man-made channels with no sediment, are considered non-alluvial channels.

The majority of rivers however, are alluvial, or self-formed ¹³. Alluvial rivers and streams create their own path by carrying sediment away. In an alluvial stream, the depth and breadth of the waterway will depend on the strength of the water flow and the material that makes-up the channel boundaries ¹³. Rivers that run through soft soil typically have a higher sediment transport load than rivers exposed to bedrock, as much of the sediment load is taken from the sides and bottom of the channel. In addition to non-erodible bedrock terrains, highly vegetated areas are less subject to runoff erosion during flood events, as the roots of the plants hold the soil in place ¹⁹.

In addition to the effects that geomorphology has on sediment transport rates, the process itself plays a part in creating the terrain. As sediment is transported downstream, the water flow helps to shape the planet's surface by carrying away the eroded material away from some regions and depositing it in others ¹⁹.



Alluvial channels are more likely to erode and contribute to sediment transport. (Photo: Hedderwick Burn meander, Photo Credit: Richard West, licensed CC Attribution-ShareAlike 2.0 Generic).

Sediment and Organic Factors

In addition to the mineral-based aspect, sediment can be organic in source. Organic sediment comes from decaying algae, plants, and other organic material that falls in the water (such as leaves) ⁴. Bacteria attached to this detritus or other inorganic matter are also categorized as organic ¹⁸. Organic sediment transport will vary by location and season. In one estuarine study, the organic portion of the suspended load fell from 85% to 18% from February to November due to seasonal effects on sediment transport ¹⁸.

Some phytoplankton can play a unique role in their contribution to sediment loads. In addition to the organic factor they provide, specific phytoplankton (such as diatoms) can contribute an inorganic component as well ¹. This inorganic material comes from diatom frustules and calcium carbonate detritus. While this material is not specifically organic, it is organic in origin ¹.



Organic sediment can come from leaves, organic waste and other decomposing material. (Photo: Blue Jay Barrens, Photo Credit: Steve Willson)

Factors that Influence Sediment Transport

Sediment transport is not constant. In fact, it is constantly subject to change. In addition to the changes in sediment load due to geology, geomorphology and organic elements, sediment transport can be altered by other external factors. The alteration to sediment transport can come from changes in water flow, water level, weather events and human influence.

Water Flow

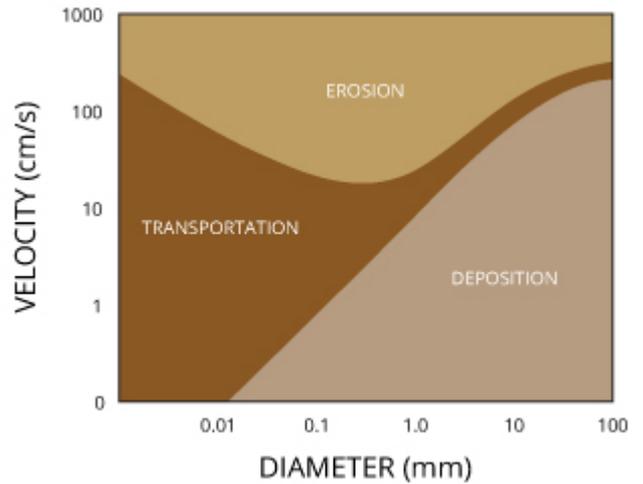
Water flow, also called water discharge, is the single most important element of sediment transport. The flow of water is responsible for picking up, moving and depositing sediment in a waterway ²⁶. Without flow, sediment might remain suspended or settle out – but it will not move downstream. Flow is required to initiate the transport ¹⁸. There are two basic ways to calculate flow. Water discharge can be simplified as area (a cross-section of the waterway) multiplied by velocity, or as a volume of water moved over time ²⁵.

Flow (ft³/s) = Area (ft²) * Velocity (ft/s)

OR Flow (ft³/s) = Volume (ft³) / Time (s)

The equations describing the relationship of water flow and sediment transport are a bit more complex. The complexity of sediment transport rates are due to a large number of unknowns (e.g. bed geometry, particle size, shape and concentration), as well as multiple forces acting upon the sediment (e.g. relative inertia, turbulent eddies, velocity fluctuations in speed and direction) ¹¹. The sediment transport rate in particular is difficult to measure, as any measurement method will disturb the flow and thus alter the reading. Most flow rate and sediment transport rate equations attempt to simplify the scenario by ignoring the effects of channel width, shape and curvature of a channel, sediment cohesion and non-uniform flows ¹¹.

The two main flow factors in sediment transport are the settling rate and the boundary layer shear stress ²⁷. The settling rate (also called Stokes settling) is the rate at which sediment falls through a liquid and it is controlled by the drag force (keeping a particle suspended) and the gravitational force (a function of the particle size) ²⁷. Understanding this relationship helps to define some of the forces that sediment transport has to overcome relative to particle size.



Whether sediment will be eroded, transported or deposited is depended on the particle size and the flow rate of the water.

$$v_s = (g * (\rho_p - \rho_f) * D_p^2) / 18\mu$$

v_s = settling velocity

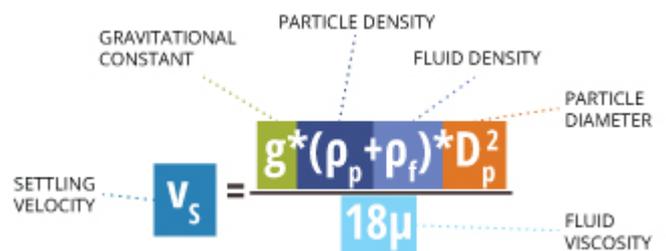
g = gravitational constant

ρ_p = particle density

ρ_f = fluid density

D_p = particle diameter

μ = fluid viscosity ²⁹



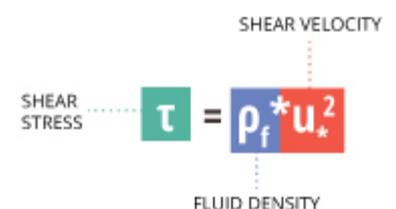
Shear stresses in the boundary layer of a sediment bed explain how much force is required for water flow to overcome relative inertia and begin sediment transport (through bedload or suspended load) ²⁷.

$$\tau = \rho_f * u_*^2$$

τ = shear stress

ρ_f = fluid density

u_* = characteristic velocity of turbulent flow (shear velocity) (see following equations) ²⁷



In a basic freshwater river system, u_* can be calculated as:

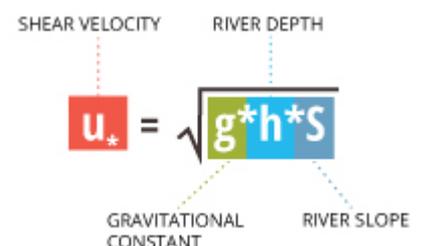
$$u_* = \text{Sqrt}(g * h * S)$$

u_* = shear velocity

g = gravitational constant

h = river depth

S = river slope ²⁷



In the ocean and in other more complex water systems, this equation is inadequate. Instead, the Von Karman-Prandtl equation should be used. The shear stress is influenced not only by the viscosity of the liquid, but the roughness of the sediment ²⁷. The turbulent eddies created at the bottom by water flow must also be accounted for. This is also known as the Law of the Wall ³⁰. ↑

$$u/u_* = (1/\kappa) * \ln(z/z_0)$$

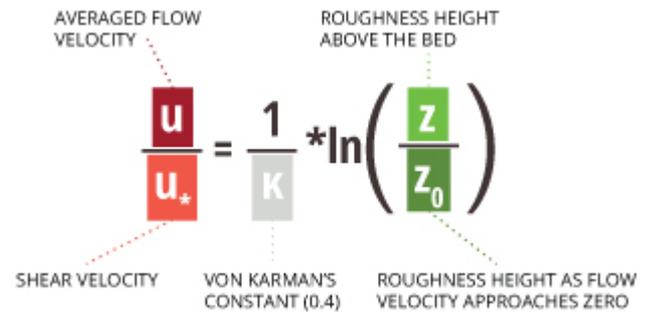
u = averaged flow velocity

u_* = shear velocity

κ = Von Karman's constant (0.4)

z = roughness height above the bed

z_0 = roughness height as flow velocity approaches zero³⁰



The above equations help to give a basic understanding of some of the forces acting on sediment in the water. To further understand the conditions required for sediment transport, the Shields stress equation can be used. Shields stress, along with the particle Reynolds number, can be used to predict how much flow is required for substantial sediment transport²⁷. The Reynolds number is an expression of a particle's resistance to viscous force²⁸. In other words, the Reynolds number demonstrates whether or not a flow is viscous enough to overcome the relative inertia of sediment. For sediment transport, the Reynolds number for flow through a sediment bed can be calculated from the boundary layer shear stress equation:

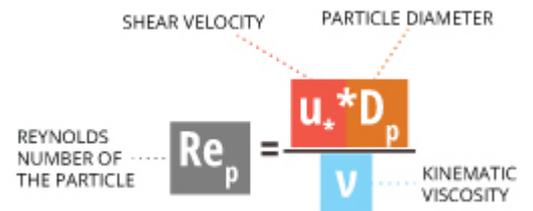
$$Re_p = (u_* * D_p) / \nu$$

Re_p = Reynolds number of the particle

u_* = characteristic velocity of turbulent flow (shear velocity)

D_p = particle diameter

ν = kinematic viscosity (viscosity/ fluid density, (μ/ρ_f))²⁷



The point at which water flow begins to transport sediment is called the critical Shields stress²⁷. This creates an empirical curve to approximate at what flow rate a sediment particle will move (based on particle size)²⁷.

$$\tau_* = \tau / (g * (\rho_p - \rho_f) * D_p)$$

τ_* = Shields stress

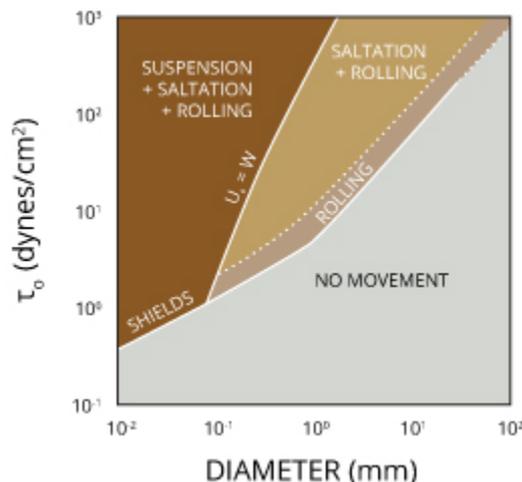
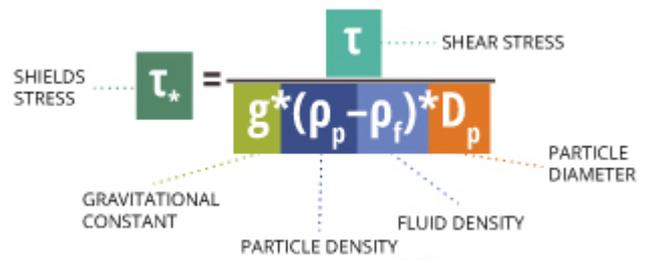
τ = shear stress

g = gravitational constant

ρ_p = particle density

ρ_f = density of fluid

D_p = particle diameter¹³



The critical Shields stress is the defining boundary between inertia and transport; when



While these equations help define minimum flow rates for sediment transportation, they do not determine sediment load and sediment transport rates themselves. One sediment transport rate equation was developed by van Rijn, for the bedload transport of particles between 0.2-2mm.

$$q_b = 0.053 * [(s-1)*g]^{0.5} * d_{50}^{1.5} * [T_*^{2.1} / D_*^{0.3}]$$

q_b = bedload transport rate

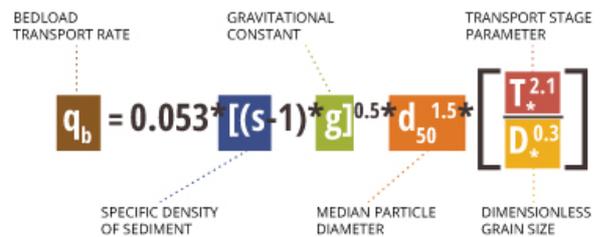
s = specific density of sediment

g = gravitational constant

d_{50} = median particle diameter

T_* = transport stage parameter

D_* = dimensionless grain size ¹⁸



The suspended load transport rate (still assuming cohesionless sediment and a sediment size of 0.2-2mm) is even more complicated:

$$q_s = u * h * c_a * [((a/h)^{Z'} - (a/h)^{1.2}) / ((1-a/h)^{Z'} * (1.2-Z'))]$$

q_s = suspended load transport rate

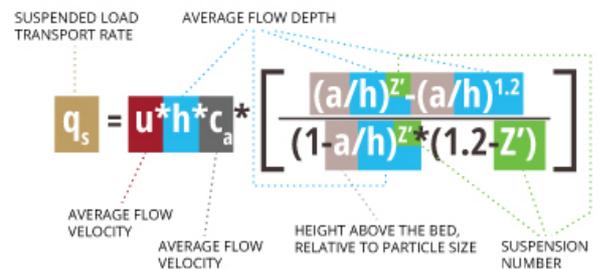
u = average flow velocity

h = average flow depth

c_a = reference concentration

a = height above the bed, relative to particle size

Z' = suspension number ¹⁸



Other sediment rating curves have been developed, but they cannot be equally applied to all water bodies ¹³. This is because in any application, there are seven main variables that have an effect on sediment transport rates ^{11,31}.

$$q_s = f(\tau, h, D, \rho_p, \rho_f, \mu, g)$$

q_s = sediment transport rate per unit width

τ = shear stress

h = depth

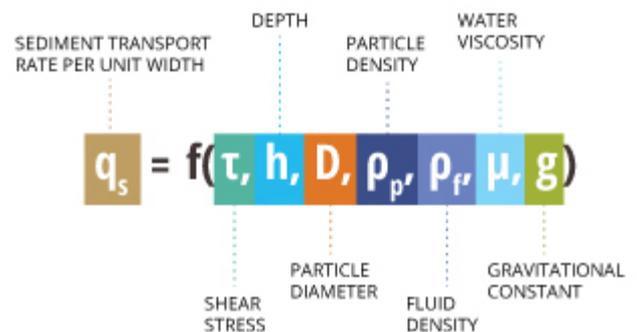
D = particle diameter

ρ_p = particle density

ρ_f = fluid density

μ = water viscosity

g = gravitational constant



The sediment transport rate is a function of these seven variables, as well as the size-shape-density distribution (often assumed as a standard deviation of the particle diameter) of the suspended particles ³¹. In addition, the largest river discharge does not automatically mean that a river will have the largest sediment load. The quantity and material of the sediment particles, as well as the geography of the local terrain will still play a contributing role in the sediment load ¹⁰.

The sediment load itself is calculated as a depth-integrated sediment mass above a unit area ¹¹. It is variable for multiple reasons, but can be estimated with a time-average collected sediment concentration ¹¹. While it is dependent on flow to initiate and continue transport, it is not calculated from flow rates, as the main variables in sediment load come from environment factors.

Weather Events and Water Level



Sediment transport relies on water flow to move a load downstream. Water flow is variable, affected not only by the local terrain (e.g. slope), but by water level which, in turn, is influenced by precipitation (or lack thereof).

Most changes in water level are due to weather events such as rainfall²⁶. Precipitation causes water levels to initially rise, and then return to previous levels (base flow) over the course of hours or days. Rainfall, whether slight or heavy can affect water flow and sediment transport. The extent to which a weather event will influence sediment transport is dependent on the amount of sediment available. Snowmelt in a glaciated area will result in a high sediment load due to glacial silt¹⁰. Heavy rainfall over an area of loose soil and minimal vegetation will create runoff, carrying loose particles into the waterway. Likewise, flooding will also pick up sediment from the local area. In fact, most of an waterway's sediment load occurs during flood events¹⁰.



Rainstorms can cause water levels and sediment transport rates to rise. (Photo Credit: Jason Hollinger, licensed CC Attribution-ShareAlike 2.0 Generic).

Increased water level creates additional volume in a channel, and increases the hydraulic radius (cross-sectional area of a waterway). The increased hydraulic radius increases the discharge rate, regardless of whether or not flow is uniform or non-uniform³¹. Increased flow will increase the stress on the bed, making it more likely for water flow to initiate sediment transport. The higher velocity also increases erosion rates as flow overcomes the shear stress of sediment¹³.

Seasonal effects are also responsible for changes in water level and flow²⁶. Most seasonal changes are due to precipitation levels and events such as snowmelt. During low precipitation and low flow periods, sediment transport falls. During the peak of snowmelt, the sediment load can increase by a factor of 15 or more¹³. Climate change can also play a role in sediment transport, as it affects both the timing and ↑ magnitude of floods and other weather events¹⁰.

Human Influence

Anthropogenic factors, such as dams and altered land use will affect both the sediment load and sediment transport rate ¹⁰. Dams affect the water flow through complete detention or restricted channels ²⁶. The restricted flow can cause the channel downstream of the dam to become “sediment-starved”, while the sediment load behind the dam builds up. A sediment-starved river will not be able to provide habitats for benthic organisms or spawning fish ³⁵. The highly silted reservoir behind the dam may face issues of too much sediment, including changes in aquatic life and the potential for algal blooms. On the other side of the spectrum, when a dam release occurs, the flow rate downstream can dramatically increase. If the release is controlled, it can refresh the bed material, building bars and other habitat areas. An uncontrolled release or dam removal can result in flooding, carrying the released sediment further downstream than is needed ¹⁰.



The Elwha Dam was removed as part of the Elwha River Restoration project. This project removed two major dams to improve natural sediment transport levels along the river, as well as opening the waterway to salmon migration and spawning. (Photo Credit: NPS)

Human land use, such as urban areas, agricultural farms and construction sites will affect the sediment load, but not the transport rate ¹⁰. These effects are indirect, as they require heavy rainfall or flooding to carry their sediment into the waterway. However, anthropogenic land use is one of the leading contributors to excessive sedimentation due to erosion and runoff ³³. This increase occurs because “disturbed sites” (logging, mining, construction and farm sites) often expose or loosen top soil by removing native vegetation ³⁴. This loose soil is then easily carried into a nearby river or stream by rainfall and runoff.

Consequences of Sediment Transport and Deposition

While sediment is needed to build aquatic habitats and reintroduce nutrients for submerged vegetation, too much or too little sediment can easily cause ecosystem and safety issues. Whether the concerns are caused by scour, erosion, build up, or simply excessive turbidity, the sediment transport rate is an

important environmental factor³⁵. In addition to the problems caused by load quantity, sediment can easily introduce pollution and other contaminants into a waterway, spreading the pollutants downstream⁴⁰.

Too Much Sediment

Large sediment loads are the most common issue seen with sediment transport rates. Too much sediment can cause poor water quality, algal blooms, and deposition build-up. For aquatic life, excessive suspended sediment can disrupt natural aquatic migrations, as well as damage gills and other organs^{8, 37}.



Sediment transported down the Rhone River into Lake Geneva can be detrimental to the lake quality. (Photo Credit: Rama, 2007, via Wikimedia)

Diminished water quality occurs with unusually high sediment transport rates. Turbidity can cause water temperatures to rise (sediment absorbs more solar heat than water does)¹. Rising water temperatures will cause dissolved oxygen levels to drop, as warm water cannot hold as much oxygen as cold water³⁷. Suspended sediment can block sunlight from reaching submerged plants, decreasing photosynthesis rates and lowering dissolved oxygen levels still further³⁸. If the increase in the sediment load is due to agricultural and urban runoff, algal blooms can occur from the increased nutrient load carried into the water body³⁶.

Regular sediment deposition can build bars for aquatic habitats, but increased sedimentation can destroy more habitats than it creates. Siltation, the name for fine sediment deposition, occurs when water flow rates decrease dramatically. This fine sediment can then smother insect larvae, fish eggs and other benthic organisms as it settles out of the water column^{1, 37}. Deposition can also alter a waterway's banks and direction as an unusually high sediment load settles out³⁵. Sediment deposition is responsible for creating alluvial fans and deltas, but excessive accumulation of sediment can build up channel plugs and levees. These deposits then block the river from reaching other stream

threads or floodplains³⁵. Increased sedimentation is considered one of the primary causes of habitat degradation³⁶. Depending on the local geology and terrain, sediment build-up can damage aquatic ecosystems not only in downstream sites, but in upstream headwaters as the deposits grow³⁵.

Sediment deposition is considered extreme when it exceeds the recommended or established total maximum daily load (TMDL). A TMDL establishes a limit for measurable pollutants and parameters for a body of water³⁵. That means that TMDLs can be created for several different elements of the sediment

load, including total suspended solids, nutrient impairment, pathogens and siltation³⁶. When developing a TMDL report, it is important to consider whether or not the waterway itself is generating the sediment load naturally, as an unstable stream channel³⁶.

Too Little Sediment

Though too much sediment is the more common concern, a lack of sediment transport will also cause environmental issues. Sediment starvation is often caused by man-made structures such as dams, though natural barriers can also limit sediment transport⁸. Without sediment transport and deposition, new habitats cannot be formed, and without some nutrient enrichment (carried with sediment into the water), submerged vegetation could not grow⁸. Too little sediment can alter an ecosystem to the point that native species cannot survive.

In addition to the effect on aquatic life, the loss of sediment transport and deposition can cause physical changes to the terrain. Downstream of dammed rivers, it is common to see receding riparian zones and wetlands due to the loss of transported sediment⁸. Erosion downstream of a barrier is common, as is coastline erosion when there is not a large enough sediment load currently carried by the water³². The flowing water will pick up new sediment from the bottom and banks of a waterway (eroding instead of refreshing habitats) as it attempts to adjust to a uniform flow rate¹¹.



Coastline erosion can be tied to sediment starvation – when rivers do not bring enough sediment to be deposited on the beach.

Contaminated Sediment

Contaminated sediments are the accumulated riverbed materials that contain toxic or hazardous substances that are detrimental to aquatic, human or environmental health³⁹. These contaminants often come from point-source pollution (such as industrial wastewater or other effluent sources), though they can also enter the water through runoff over contaminated soils (mine waste, landfills and urban areas), chemical spills, or deposits from air pollution³⁹.

As contaminants do not degrade (or degrade very slowly), they can be a source of environmental issues for long periods of time, even if they are not frequently resuspended³⁹. The most problematic contaminants in both bedded and suspended sediment are metals and persistent bioaccumulative toxics (PBTs), such as pesticides and methyl mercury³⁹.



Shipyards and other point sources can pollute a body of water. These contaminants may settle to the bottom and be released slowly over time, or be carried away with other sediment.

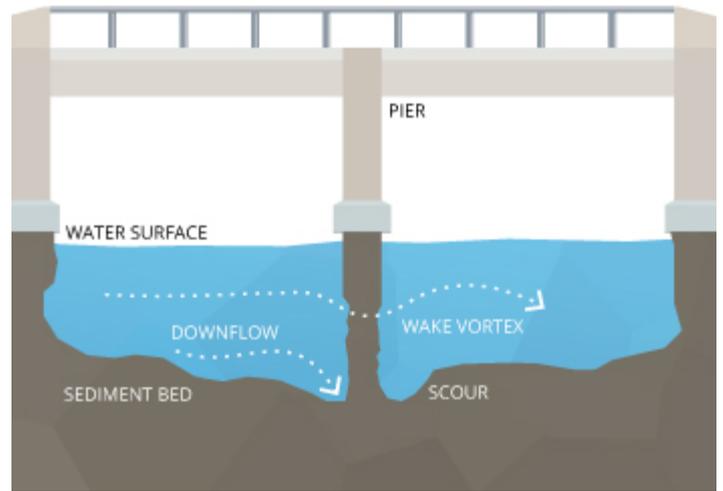
Sediment remediation may involve dredging to remove the contaminated sediment from the waterway⁴⁰.

Scour

When sediment transport removes material from a streambed or bank, the erosion process is called scour ⁴¹. Scour can occur anywhere that there is water flow and erodible material. Local scour is the engineering term for the isolated removal of sediment at one location, such as the base of underwater structures, including bridge piers and abutments ⁴². This localized erosion can cause structural failure, as bridges and overwater constructions rely on the bed sediment to support them.

While scour can occur anywhere, it is more likely to occur in alluvial waterways (erodible bed and banks), as opposed to a bedrock-based (nonalluvial) channel ⁴¹. As water flow is responsible for conducting sediment transport, scour can occur even during low flow conditions. However, critical bridge scour conditions typically

occur during periods of high flow, such as during a flood event ⁴¹. The higher flow rate can pick up more sediment, and turbulence often occurs at the base of a pier as it interrupts and accelerates the flow. This turbulence in turn will increase the forces acting on a streambed, suspending additional particles and initiating greater sediment transport ⁴¹. If too much sediment is removed, the structure can collapse. Scour due to flood-initiated sediment transport is the most common cause of bridge failure in the United States ⁴².



Local scour occurs when water flow erodes sediment away from a structure such as a bridge pier, potentially causing structure failure.

Cite This Work

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