



# Erosion and Sedimentation

*This guideline expands on what is expected by the criteria statements in the Hydropower Sustainability Tools (HST) for the Erosion and Sedimentation topic, relating to assessment, management, conformance/compliance and outcomes. The good practice criteria are expressed for different life cycle stages.*

*In the Hydropower Sustainability Assessment Protocol (HSAP), this topic is addressed in P-20 for the preparation stage, I-16 for the implementation stage and O-16 for the operation stage. In the Hydropower Sustainability ESG Gap Analysis Tool (HESG), this topic is addressed in Section 3.*

Hydropower projects may fundamentally alter the landscape and there are likely to be changes to the pre-existing erosion and sedimentation patterns in the affected river system. Not only can erosion and sediment issues have strong implications for the longevity of the hydropower installation and the maintenance costs, but

there may also be a number of social and environmental consequences if these issues are not managed well.

This guideline addresses the management of erosion and sedimentation issues associated with the hydropower project or operating hydropower facility. The intent is that erosion and sedimentation caused by the project or operating hydropower facility is managed responsibly and does not present problems with respect to other social, environmental and economic objectives; that external erosion or sedimentation occurrences which may affect the project or operating hydropower facility are recognised and managed; and that commitments to implement measures to address erosion and sedimentation are fulfilled.

Rivers naturally carry sediment loads. These are typically made up of: **bed load**, which moves along the river bottom; **suspended load**, which is carried within the water flow throughout the flow depth (some of which may only be in suspension under certain flow conditions); and **wash load**, the portion of the suspended load typically of relatively fine material that is transported entirely through the system without deposition. **Saltation** refers to when particles on the bed are lifted into suspension and fall back to the bed.

The river form or **morphology**, the flow rates and conditions (e.g. water depth, slope and velocity), and the source of sediments affect the river's sediment load and how it is mobilised or where it is deposited. Sediments may be dropped out by the river due to a reduction in river flow, an increase in-channel width, lower current velocities, or break of slope; these dropped sediments may form alluvial or flood plains. There are many terms for different types of fluvial bedforms and landforms, including bars, pools, riffles, meanders, oxbow lakes, fluvial terraces, and islands. Fluvial channels (i.e. river or stream courses) have **reaches** or lengths of a common character that can be categorised as straight, meandering, or braided. Anastomosed rivers consist of multiple channels that could be either straight, meandering, braided or a combination of these three channel planform types (an anastomosed river is considered a landform feature but not a channel type in itself). River morphology is a dynamic process, with change occurring over time, and is not one stable or static condition.

The geographic scope of erosion and sediments assessment and management must consider:

- the catchment area for the reservoir in relation to sediment yields;
- the reservoir in relation to reservoir slope stability and reservoir sediment accumulation;
- downstream river reaches below the dam and power house in relation to concentrations and loads for sediments in suspension, saltation and bed load as well as channel geomorphological conditions in the river reaches that will be affected by the project, as far downstream as the flows are significantly project affected, and the implications of changes for other river values and uses;
- the construction areas – e.g. reservoir preparation works, dams (coffer, main, saddle), adits, tunnels, power house, mitigation measures (e.g. a fish passage facility) – to determine the potential erosion and sedimentation issues;
- locations of ancillary structures and activities – e.g. labour camps, offices, concrete batching plants, water-supply intakes, material fabrication areas, supply storage areas, quarries, waste disposal areas, supply transport activities;
- locations of erosion or sediment-specific mitigation measures – e.g. slope stabilisation

works, drainage and settling ponds, catchment treatment and erosion prevention works, rehabilitation works in disturbed areas, desilting chambers, sluice gates, reservoir flushing strategies, dredging programmes; and

- locations of other mitigation measure areas and activities – e.g. reforestation activities, local benefits in relation to erosion and sedimentation issues.

## Assessment

*Assessment criterion - Preparation Stage: An erosion and sedimentation issues assessment has been undertaken with no significant gaps; the assessment identifies impacts that may be caused by the project, issues that may impact on the project, and establishes an understanding of the sediment load and dynamics for the affected river system.*

The project Environmental and Social Impact Assessment (ESIA) should include evaluation of the erosion and sediment related impacts of a hydropower project. A systematic approach needs to be taken to identifying and evaluating erosion and sediment status and potential impacts and risks from the proposed project. Professionals working in this area might include: hydraulic engineers, which is a specialty area of civil engineering focussed on the flow and conveyance of fluids and sediments including the design and effects of hydraulic structures (e.g. bridges, canals, levees); and fluvial geomorphologists, which is a specialty area of geography focussed on the response of the landscape to water movement.

Alongside the ESIA, the feasibility studies and detailed design report for the project will also address the technical risks relating to sediments. Liaison between the engineering and the environmental studies should be ensured so that data and analyses are coordinated and consistent and provide information for both areas of need.

The preparation stage assessment starts by establishing of the pre-project baseline. Studies should establish the current sedimentation regime and dynamics of the river to help determine possible assessment approaches. Baseline studies should utilise appropriate expertise for the erosion and sediment sampling design, data collection, data analysis and

interpretation. Available sources of secondary data should be identified and included, as well as local knowledge and information. More emphasis should be given to relatively recent secondary data and checks should be made to see if there have been changes in any conditions affecting that data. Primary data should be collected for:

- slope stability and erosion risk from locations in the vicinity of project activities, where land disturbance is planned, and in the catchment;
- catchment condition (e.g. area, slopes, vegetation cover, soil types) to determine present and likely future sediment yields into the reservoir;
- instream sediments (concentrations and loads of suspended and bedload sediment) using equipment and materials as per recognised standards relevant to the sediment types and amounts; and
- river channel geomorphological conditions in the project construction area and as far downstream as will experience significant flow changes from the future project.

For primary data, a strategic approach should be taken to the selection of sediment sampling sites to ensure a meaningful geographic spread and to include areas of likely change or sensitivity to impacts. Instream sediment sampling data should be collected from a minimum of four sampling locations: upstream and immediately downstream of the future reservoir, and upstream and downstream of the next major tributary downstream of the reservoir (and of the power station tailrace if located some distance away). If possible, locations upstream and downstream of other major tributaries and development activities should also be sampled. Ideally, significant variations in sediment loads from the different upstream sub-catchments should be established to inform catchment management interventions that will reduce sediment loads within the future reservoir.

During the preparation stage, sampling data should be collected over a period of at least 12 months. The number and timing of sampling trips should be designed to obtain the most representative data given the factors that could influence the result. For river sampling, this should cover all seasonal conditions of the region. Timing of sample collection should be sure to capture very different flow conditions

including during the low flow season, the onset of the wet season (noting that this is the most significant time for sediment transport), and the high flow season. Ideally the sampling efforts would be continuous throughout the minimum sampling period of 12 months, with increasing sampling frequency during low-frequency, high-magnitude events such as intense rainfall during the monsoon period. Suspended sediment sampling should be done by depth-integrating methodologies and carried out in representative verticals of the river wherever and whenever possible in accordance with a programme established by an appropriate expert on geomorphology. In each season, a representative number of samples should be analysed for particle size distribution and mineralogic content. Particle size analyses are important for understanding fluvial geomorphic processes, the potential for scouring and erosion, and for determination of potential wear on turbines and other equipment and the need for sediment exclusion devices.

Baseline sampling results should be presented and described in accordance with any legal requirements and interpreted with respect to all relevant environmental standards. During the preparation stage, sampling results should be used to clearly establish the pre-project baseline conditions and the major influences on the results. The results should explain the pre-project status, trends and issues relating to sediment transport, river geomorphological processes, and river channel condition and integrity. They should also take into account flow and water quality data, surrounding land uses (e.g. locations of settlements and industrial and agricultural activities), major tributaries, points of land disturbance or sediment stockpiling, and points of drainage discharge. Implications of findings for aquatic habitats and life cycle needs, water quality, and other uses and values should be identified and described.

The assessment of erosion and sediment related risks during construction should include the effects caused by: erosion and sediment run-off created by direct disturbance of land during construction activities; landslips caused by road works, excavations and blasting; sediment run-off from excavated waste dumps (i.e. spoil) and topsoil storage areas; erosion due to poor drainage design or maintenance; gullyng caused

by water discharge points or concentrated drainage areas; instream changes to channel geomorphology due to changes to flows or sediment movement during construction; instream changes to channel geomorphology due to dumping of excavated materials into or close to waterbodies or direct disturbance by heavy machinery; and increased sediment run-off into rivers or streams at vehicle crossing points (e.g. bridges, fords).

Reservoir filling and project commissioning stage erosion and sediment risks should include the implications of changed flow regimes on erosion and sediments in the downstream river and any potentially adverse impacts, e.g. due to reduced flows or intermittent discharges of sediment-laden water.

The assessment of erosion and sediment related risks during operation should include the effects caused by: sediment accumulation in the reservoir over time from catchment sources; erosion of the reservoir rim due to steep slopes and/or loss of stabilising vegetation; releases of sediment-laden water through the low level release valve or through flushing of the desilting chamber causing issues downstream; riverbank or bed erosion due to 'aggressive river' or 'hungry water' effects (meaning that the river's erosive capacity below the dam is enhanced due to sediment being trapped within the reservoir); riverbank or bed erosion in rivers subject to hydropeaking due to rapid water level changes; riverbank or reservoir rim erosion due to rapid draw-down of saturated banks leading to bank slumping; localised riverbed sediment accumulation due to lower flows at points where sediments continue to enter the river; and ongoing erosion issues from a lack of, or poorly implemented, rehabilitation measures on land disturbed during construction activities.

The implications of long-term temporal changes to flows and to extreme weather events, potentially induced by climate change impacts, should be considered in the assessment of erosion and sedimentation. Significant changes in flow arising from more intense weather events can create additional risks relating to erosion, sediment movement, bank collapse, landslides and mudslides. These can, in turn, have public safety implications.

Analyses for predicting reservoir sedimentation include numerical models, physical models and trapping efficiency assessments. The pattern and distribution of sediment deposition in the reservoir needs to be predicted and linked to planning for the live storage over the long-term. It should not be assumed that all sediments will be deposited in the deepest available volume, nor that reservoir life corresponds to sedimentation of the dead storage, as patterns of sedimentation tend to be more complex in practice.

Erosion and sedimentation opportunities should be identified where possible. These may include: improvements to pre-existing erosion and sedimentation issues in the project vicinity; improvements to land use planning (e.g. retention of forest cover); use of new technologies, such as for monitoring, slope treatment or rehabilitation; use of new land use practices, such as crop rotation, crop choice, or ploughing techniques; and partnerships with community catchment protection or waterway health monitoring groups.

## Assessment

*Assessment criterion - Implementation Stage: Erosion and sedimentation issues relevant to project implementation and operation have been identified through an assessment process utilising appropriate expertise; and monitoring is being undertaken during the project implementation stage appropriate to the identified issues.*

*Assessment criterion - Operation Stage: Ongoing or emerging erosion and sedimentation issues have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective.*

Erosion and sediment related issues determination during the implementation and operation stages should be based on changes to the baseline erosion and sediment condition and processes that may be or have been incurred, as well as the implications of these for other social, environmental and/or economic objectives.

Consideration of what is an issue needs to take into account that there will be landscape adjustments brought about by the hydropower project that continue for many years until a

new equilibrium is reached, particularly in the downstream river channels. Negative impacts are considered to be those erosion and sediment changes caused by the project that present problems with respect to other social, environmental and/or economic objectives, or externally caused occurrences of erosion or sedimentation that impact on the ability of the project to meet its own social, environmental and/or economic objectives.

Erosion and sediment monitoring objectives need to be clearly expressed, linked to risks and impacts, and defined separately for the construction and operation stages. The basis for the locations, timing, parameters and methodologies adopted should be clearly explained. Sampling locations and techniques used for the baseline data gathering during the ESIA work should be continued as far as practical. Parameters used for erosion and sediment monitoring may include some or all of the following:

- land stability assessments;
- aerial photo assessments or comparable;
- reservoir bathymetric surveys;
- riverbed load and suspended sediment concentrations and loads, noting that the mechanisms of transport varies depending on flow and hydraulic conditions and that sampling equipment and its uses are very specialised to transport types and amounts;
- river channel geomorphology assessments (e.g. descriptions of deep pools, gravel beds, rapids, riffles, sand bars, in-channel wetlands, riparian slopes, vegetative cover);
- riparian zone assessments (riverbanks and reservoir rim); and
- observational inspections (e.g. of sediment storage areas, rehabilitation areas, drainage channels).
- Where relevant, findings should be compared to the relevant environmental standards and interpreted in light of influential factors such as flow, water level, season, activities, and vegetation cover.

## Management

*Management criterion - Preparation Stage: Plans and processes to address identified erosion and sedimentation issues have been developed for project implementation and operation with no significant gaps.*

The erosion and sediment section of the Environmental and Social Management Plan (ESMP) needs to contain, at a minimum, the following outlined separately for construction and operation:

- all identified potential risks and impacts for erosion and sediments;
- mitigation measures for all risks and impacts listed, with the objectives and measures of success;
- monitoring schedules clearly linked to the risks and mitigation objectives;
- reporting schedules and formats;
- budgets and responsible parties, including any handover arrangements to different agencies over time; and
- audit, review and evaluation provisions.

Adaptive management measures for unpredicted erosion and sediment impacts are also ideally included. These would focus on issues that might be identified through the monitoring and surveillance and what the response would be (including responsible parties and contingency budget set aside).

There is considerable knowledge and experience globally of the mitigation measures that can be employed to avoid, minimise and mitigate erosion and sediment related impacts from hydropower developments.

Measures to address erosion and sediment risks and impacts at the construction stage could include some of the following:

- Mitigate erosion and sediment run-off created by direct disturbance of land: plans are developed prior to disturbance activities to avoid, minimise and manage erosion and sedimentation; contouring, drainage, and settling ponds are employed during

disturbance works; rehabilitation measures are implemented at the end of the disturbance activities.

- Mitigate landslips caused by road works, excavations, and blasting: land stability is assessed through geotechnical evaluations during the feasibility studies to inform planning of construction activities and potential risks; slope stabilisation works are implemented where needed; exclusion zones are created and signage employed to warn of worker and public safety risks; work in areas prone to landslip risk is subject to appropriate safety measures; landslips are treated quickly to stabilise and repair.
- Mitigate sediment run-off from spoil dumps and topsoil storage areas: sediment, spoil and soil storage areas are identified through careful planning and used according to their capacities; compaction (where appropriate), bunding, drainage and covers are used when required; downstream settling ponds are used as needed.
- Mitigate erosion due to poor drainage design or maintenance: drainage is planned at the outset for all potential erosion areas according to engineering standards; drainage is maintained to specified standards; instances of erosion are treated promptly and incorporate measures for avoidance of future incidents.
- Mitigate gulying caused by water discharge points or concentrated drainage areas: water discharge or concentrated drainage points are designed to prevent gulying, for example through cement linings and slope protection works.
- Mitigate instream changes to channel geomorphology due to changes to flows or sediment movement during construction: downstream effects of flow changes or sediment transport changes are monitored and residual flow releases made as needed to address sediment through-flow needs; channel stabilisation works.
- Mitigate instream changes to channel geomorphology due to dumping of excavated materials into or close to waterbodies or direct disturbance by heavy machinery: dumping of excavated materials in watercourses is prohibited and fines are issued if this practice occurs; permits according to the approved construction plan; controls to manage erosion and sediment into the downstream river (e.g. through settling ponds).

- Mitigate increased sediment run-off into rivers or streams at vehicle crossing points (e.g. bridges, fords): vehicle crossing points on streams or rivers are designed to minimise creation of erosion and sediment run-off, e.g. through location, gradients of approach, surface sealing, drainage.

Measures to address erosion and sediment risks and impacts at the operation stage could include some of the following:

- Mitigate sediment accumulation in the reservoir over time from catchment sources: Avoidance and minimisation: catchment protection, catchment reforestation, landslip prevention measures, sediment check dams, strict rules on land disturbance in the catchment, erosion treatment measures, sediment bypass structures. Management: density-current venting (diverting flows within the reservoir carrying higher sediment loads out through diversion tunnels, often combined with desilting chambers); sediment pass-through structures (e.g. sluice gates or low level outlets often left open for the first part of the rainy season to allow release of relatively higher sediment concentrations and accumulated sediments); sediment flushing (through bottom outlet gates used during reservoir draw-down); dredging and transport downstream (e.g. by barge or pipeline).
- Mitigate erosion of the reservoir rim due to steep slopes and/or loss of stabilising vegetation: restrictions to reservoir water level change magnitude or rates; reservoir slope treatment works; promotion of vegetation growth tolerable of water level changes on reservoir rim; restrictions to activities on the reservoir causing wave action and on the reservoir rim causing disturbance.
- Mitigate releases of sediment-laden water through the low level release valve or through flushing of the desilting chamber causing issues downstream: management plans and risk assessments for sediment-laden discharges below the dam; timing of releases avoids periods of high sensitivity to downstream ecosystems; releases planned when dilution effects from tributaries can be provided.
- Mitigate riverbank or bed erosion due to 'aggressive river' effects: sediment bypass structures (in suitable conditions) to periodically divert sediment-laden water past

the reservoir, e.g. through a tunnel used for high sediment loads at the start of the wet season; sediment management strategies to address reservoir sediment accumulation (listed above).

- Mitigate riverbank or bed erosion in rivers subject to hydropeaking, due to rapid water level changes: power station release ramp-up and ramp-down rules; maintenance of minimum flows; riverbank protection works; strategic placement of large woody debris for bank protection and habitat maintenance.
- Mitigate riverbank or reservoir rim erosion due to rapid draw-down of saturated banks leading to bank slumping: reservoir ramp-down rules to minimise rapid draw-down; potentially combined with restrictions on duration of high water levels to prevent full bank saturation.
- Mitigate localised riverbed sediment accumulation due to lower flows at points where sediments continue to enter the river: flushing release strategies from the dam or power station; localised sediment extraction from the river; erosion management works in the catchment(s) that contribute sediment loads to the downstream river.
- Mitigate ongoing erosion issues from a lack of or poorly implemented rehabilitation measures on land disturbed during construction activities: carefully planned and well-implemented rehabilitation works for construction stage land disturbance, with follow-up monitoring and further treatment when required.

## Management

*Management criterion - Implementation Stage: Processes are in place to ensure management of identified erosion and sedimentation issues, and to meet commitments, relevant to the project implementation stage; plans are in place for the operation stage for ongoing erosion and sedimentation issues management.*

*Management criterion - Operation Stage: Measures are in place to manage identified erosion and sedimentation issues.*

During the implementation and operation stages, the erosion and sediment related plans developed based on the ESIA assessment work are put into action. For projects that did not have such thorough erosion and sediment assessment work as outlined in this guideline, erosion and sediment management plans can still be developed based on assessment work focussed on identifying issues and risks.

The important management requirements at the implementation and operation stages are to ensure that processes are in place that will enable erosion and sediment issues to be identified and responded to. Such processes may include: clear statements of business commitment to erosion and sediment within an environmental or sustainability policy; dedicated staff with erosion and sediment related qualifications or role requirements, and/or a partnership with a more erosion and sediment focussed organisation; allocation of budget and resources to enable monitoring and issues identification and response; and decision-making processes to ensure that issues arising have actions assigned (e.g. through a corporate environment committee).

## Conformance/Compliance

*Conformance/Compliance criterion - Implementation and Operation Stages: Processes and objectives in place to manage erosion and sedimentation issues have been and are on track to be met with no significant non-compliances or non-conformances, and erosion and sedimentation related commitments have been or are on track to be met.*

Good practice requires evidence that erosion and sediment measures are compliant with the relevant government requirements, which may be expressed in licence or permit conditions or captured in relevant legislation. Compliance requirements may relate to, for example, standards to be met, the frequency and type of monitoring to be performed, and reporting to be submitted. Conformance refers to delivering what is in the plans. Commitments may be expressed in policy requirements of the developer or

owner/operator or in company statements made publicly or within management plans. Evidence of adherence to commitments could be provided through, for example, internal monitoring and reports, government inspections, or independent review. Variations to commitments should be well-justified and approved by relevant authorities, with appropriate stakeholder liaison.

The significance of not meeting a commitment is based on the magnitude and consequence of that omission and will be context-specific. For example, a failure to install a sediment flushing mechanism required as a licence commitment is a significant non-compliance, whereas a slight delay in delivery of a monitoring report could be a non-significant non-conformance.

## Outcomes

*Outcomes criterion - Preparation Stage: Plans avoid, minimise and mitigate erosion and sedimentation issues arising from project activities and erosion and sedimentation issues that may impact on the project with no significant gaps.*

*Outcomes criterion - Implementation Stage: Erosion and sedimentation issues during project implementation are avoided, minimised and mitigated with no significant gaps.*

*Outcomes criterion - Operation Stage: Erosion and sedimentation issues are avoided, minimised and mitigated with no significant gaps.*

To show that plans avoid, minimise, mitigate and compensate negative erosion and sediment impacts from project activities, it should be possible to directly link mitigation measures to all identified erosion and sedimentation issues and risks. The assessment and planning should be informed by appropriate expertise. The assignment of responsibilities and resource allocation for implementation, monitoring and evaluation should be appropriate to the planned actions.

An evidence-based approach should demonstrate that negative erosion and sediment impacts arising from project implementation and operation activities are avoided, minimised, mitigated and compensated with no significant gaps. The developer and owner/operator should demonstrate that responsibilities and budgets have been allocated to implement erosion and sediment plans and commitments. Monitoring reports and data in the implementation and operation stages should clearly track performance against commitments and objectives, and capture erosion and sediment impacts. It should be possible to provide examples to show how identified risks from the assessment were avoided or minimised. It should also be possible to table evidence to show that mitigation plans have been implemented and are being monitored. Implementation of measures for erosion and sediment, such as bank protection works, sediment check dams or retention ponds, and sediment flushing or bypass mechanisms, should be evident, and monitoring should show how they are achieving their stated objectives.