STANDARDS RESEARCH

Turbidity Monitoring: Addressing Gaps for Erosion and Sediment Control in Canada

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Executive Summary

Construction activities can result in soil erosion and the transport of sediment beyond the limits of an active work area. Sediment generated from the exposure of erodible soils on construction sites can be carried by stormwater runoff and is ultimately released to watercourses, wetlands, important natural features, private property, and existing drainage infrastructure. This can then lead to the degradation or destruction of aquatic and terrestrial biota and associated habitats, the loss of structural integrity and functionality of watercourses and other natural features, flooding, and costly infrastructure maintenance.

To help prevent both short-term and long-term adverse impacts to the environment throughout the lifespan of a construction project, it is important that effective, industry-wide practices that foster the proper inspection and monitoring of erosion and sediment control (ESC) measures be developed. These practices, coupled with effective and dynamic ESC plans are critically important components of successful construction projects, and when implemented and properly maintained, can effectively minimize impacts to infrastructure and the environment.

The recently published CAN/CSA-W202, *Erosion and Sediment Control Inspection and Monitoring* is a first of its kind National Standard of Canada. While it goes a long way towards harmonizing a set of national requirements for inspecting and monitoring ESC measures, there exists an opportunity to provide further guidance on implementation. Specifically, while the standard provides turbidity monitoring performance targets, it does not instruct users as to how to conduct monitoring or how to set up ESC measures to meet the prescribed targets. As such, the objective of this research project was to help ESC stakeholders in Canada better understand what it takes to meet their turbidity monitoring targets in terms of ESC measure implementation and the use of various technologies available to monitor their project sites. Through a series of case studies (both literature-based and survey-based), this research demonstrates the challenges and successes experienced on past construction projects where turbidity monitoring was a requirement. In doing so, the report provides readers with context that will allow them to make informed decisions about their site management, ESC methods, and turbidity monitoring efforts.

Based on the results of the case studies, the most common challenges associated with turbidity and total suspended solids (TSS) monitoring were identified as equipment maintenance, accounting for natural variability in telemetry-based monitoring technologies, and meeting standard targets based on pre-development levels of turbidity and TSS in receiving watercourses. This report provides recommendations to improve ESC effectiveness and turbidity, and TSS monitoring protocols specifically to address such challenges. Turbidity and TSS monitoring successes were associated with using continuous data collection equipment, reprogramming telemetry-based systems to account for natural variability, as well as reducing the duration of turbidity and TSS exceedances.

This report also provides a description of "lessons learned" when applying various turbidity monitoring technologies across different scenarios. Based on issues commonly experienced on-site, recommendations to inform successful site management and turbidity and TSS monitoring, were provided. These recommendations included incorporating project phasing and considering weather constraints, identifying sediment sources and considering these locations in monitoring station setup, and maintaining open and effective communication during ESC projects.

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1 Introduction

Changes in sediment load, such as through erosion or deposition, are a key factor influencing physical channel processes in bodies of water such as rivers and streams. Observed changes, or potential changes over time, may be attributed to natural processes (e.g., runoff) or anthropogenic processes (e.g., construction-related activities). There are correlations that exist between changes in sediment load and changes in total suspended solids (TSS) and turbidity. Elevated levels of total suspended solids (TSS) (both inorganic and organic) and their surrogate parameter, turbidity, have several potential environmental impacts on receiving waters and aquatic species. From an ecological perspective, the effects of excessive TSS on aquatic organisms, such as fish and aquatic invertebrates, include [1], [2]:

- Direct effects to physiology or behaviour;
- Prevention of successful growth or reproduction;
- Modification of movement or migration; and
- Habitat degradation.

Erosion and sediment control (ESC) measures are implemented to reduce the potential for adverse impacts associated with increased turbidity and TSS levels due to construction-related activities. As such, the priorities of stormwater management and water quality are to control the frequency and magnitude at which suspended solids enter nearby waterways [3]. Many jurisdictions, including several in Canada, have implemented guidelines and regulations for water quality standards to mitigate the potential adverse water quality impacts associated with construction sites, particularly in urban settings. These guidelines include benchmark criteria for turbidity and TSS levels that ESC protocols are required to achieve.

Turbidity and TSS targets are often derived based on determined tolerance limits of the receiving aquatic ecosystems. The guiding principle of ESC monitoring is no net increase in the turbidity of the receiving stream above natural levels as a result of construction activities and site effluent. This principle assumes that if ESC practices and monitoring are conducted effectively, the amount of soil loss from a construction site would be limited, which should prevent negative impacts on aquatic life within the receiving ecosystem [4]. Unfortunately, guidelines place little emphasis on how to assess these targets (in terms of practicality and attainability) using current best management practices.

Although ESC protocols have been required on construction sites for two decades, in many cases they have proven insufficient to meet ecological targets for water quality measures [5]. The purpose of this report is to explore the common ESC methods implemented in Canadian jurisdictions, identify current turbidity and TSS monitoring protocols and targets used in the industry, and summarize the challenges and successes associated with meeting such targets. This research will then identify potential gaps in ESC methods, monitoring, and implementation, and present recommendations to enhance turbidity and TSS monitoring programs moving forward.

2 Methods

A review of recent and relevant literature was conducted to identify current turbidity and TSS targets in multiple jurisdictions across Canada and internationally. Searches were conducted through a review of academic literature (e.g., peer-reviewed journals), government repositories, and Google search for relevant literature that could inform the most common practices for turbidity and TSS monitoring; identify the advantages and disadvantages associated with turbidity and TSS monitoring practices; and summarize turbidity and TSS targets currently established for monitoring programs. Search terminology included keywords associated with ESC and turbidity and TSS monitoring practices, such as erosion and sediment control measures, turbidity, TSS, sampling protocols, continuous and discrete monitoring, and successes and challenges. Research was completed to understand turbidity monitoring practices through time and, as such, both historical and more recent literature were considered.

Several case studies from the literature (peer-reviewed academic literature and publicly available government documents) that explore industry experiences and practices with ESC methods and monitoring techniques were also identified. The case studies selected for analysis were within various Canadian jurisdictions. Case studies for turbidity and TSS monitoring were assessed to identify the current state of practice in ESC, implementation and monitoring, and to determine whether targets are currently being implemented and met. The literature-based case studies that were reviewed focused on turbidity and TSS monitoring to identify the impact of sediment control pond design on sediment removal efficiency [6] and the effectiveness of a turbidity and TSS monitoring program to mitigate effluent from construction-related activities (Keeyask Generation Project).

To supplement the literature-based case studies, a preliminary survey was conducted with stakeholders across multiple Canadian jurisdictions to identify additional experiences and best practices in ESC methods and monitoring techniques. Survey participants were selected based on their experience with turbidity and TSS monitoring and their representation across various Canadian jurisdictions. Survey participants were recruited by GEO Morphix and with support from other agencies, and at various industry conferences that included the Toronto and Region Conservation Authority and the International Erosion Control Association (TRIECA), and the Erosion and Sediment Control Association of British Columbia (ESCA BC).

The survey comprised a series of questions to explore the characteristics and unique constraints of the subject site, the type of construction activities, the ESC measures on-site, the applicable turbidity and TSS targets, the monitoring protocol used, the successes and limitations related to monitoring, and any additional information or recommendations for turbidity and TSS monitoring moving forward. All survey responses were discussed further during a follow-up phone interview. All phone interviews were semi-structured based on the standard survey sheet. However, depending on the project type and scope of the project, interview questions varied. Stakeholder responses were analyzed and interpreted to inform turbidity and TSS monitoring for ESC in Canada.

3 Literature Review

3.1 Existing Guidelines and Standards for ESC Monitoring

To ensure that runoff from construction-related activities does not negatively impact receiving watercourses, appropriate ESC practices must be designed, executed, and maintained for all works that disturb local soil or sediments [7]. Protocols must be in place to monitor the water quality condition of receiving watercourses, capture a representative record of turbidity and/or TSS, and inform the effectiveness of ESC practices in place [8]. This representative record is used to determine the impact that construction-based activities have on nearby watercourses. It is important to note that construction projects and sites are highly variable and, as such, the suitability of ESC practices varies [8]. Turbidity and TSS targets exist at regional, provincial, and national levels to provide a measure of effectiveness for ESC practices. Such targets are established to support healthy aquatic ecosystems and prevent environmental impacts stemming from construction activities.

3.1.1 Turbidity and TSS Targets

TSS quantifies the total amount of suspended sediments in water [9]. Turbidity often provides a surrogate for TSS. This measurement is useful and important for determining light penetration in a system and, subsequently, ecological productivity [10]. Turbidity and TSS contributions are commonly linked to nearby water works, such as where construction and development activities are adjacent to water bodies [11]. This is due to sediment transport and the transfer of pollutants and organic compounds to receiving waters [11]. Many factors contribute to sediment runoff and increased turbidity and TSS levels, including weather (e.g., floods and snow melt), mechanical disturbance of sediments, as well as overland flow from adjacent lands [12].

Turbidity and TSS targets are determined based on background conditions established pre-construction [13]. Typically, baseline monitoring is completed to understand the system prior to modification or construction activity. As such, targets vary across jurisdictions [13]. Further, targets may differ depending on the spatial and temporal scales of the work. For example, specific turbidity and TSS targets exist for short-term and long-term monitoring objectives. Similar turbidity and TSS targets were identified from the literature across jurisdictions and are presented in Table 1 and Table 2, respectively [14-20].

Implementing turbidity and TSS targets and using them to inform the effectiveness of ESC measures for water quality control requires appropriate monitoring protocols. A performance-based approach to ESC monitoring is appropriate for determining the extent to which an ESC plan is meeting turbidity and TSS targets [22]. According to the Toronto and Region Conservation Authority (TRCA) [22], the following benefits are

Table 1: *Summary of Turbidity Targets Across Multiple Canadian Jurisdictions*

Jurisdiction	Location	Reference(s)	Short-Term Targets (<24hr)	Long-Term Targets (>24hr)	Target when Background < 80 NTU	Target when Background > 80 NTU	< 25 mm rainfall in 24 hours	> 25 mm rainfall in 24 hours
National	Canada	[14], [15]	< 8 NTU above background	< 2 NTU average above background	< 8 NTU increase	< 10% increase	Not indicated	Not indicated
Provincial	British Columbia	[21]	< 8 NTU above background	< 2 NTU average above background	< 5 NTU increase	< 10% increase	Not indicated	Not indicated
	Ontario	[22]	< 8 NTU above background	< 2 NTU average above background	< 5 NTU increase	< 10% increase	Not indicated	Not indicated
	Alberta	[23]	< 8 NTU above background	< 2 NTU average above background	< 5 NTU increase	< 10% increase	Not indicated	Not indicated
Regional	City of Abbotsford, BC	[20]	Not indicated	Not indicated	Not indicated	Not indicated	< 25 NTU after rainfall	< 100 NTU after rainfall
	City of Coquitlam, BC	[24]	Not indicated	Not indicated	Not indicated	Not indicated	< 25 NTU after rainfall	< 100 NTU after rainfall
Regional	Township of Langley, BC	[25]	Not indicated	Not indicated	Not indicated	Not indicated	< 25 NTU	< 100 NTU after rainfall

Table 2: *Summary of TSS Targets Across Multiple Canadian Jurisdictions*

Jurisdiction	Location	Reference(s)	Short-Term Targets (<24hr)	Long-Term Targets (>24hr)	Target when Background 25-250 mg/L *25-200 mg/L	Target when Background > 250 mg/L * > 100mg/L	During Wet Months (May-September)	During Dry Months (October – June)
National	Canada	[14], [15]	< 25 mg/L above background	< 5 mg/L average above background	< 25 mg/L increase	< 10% increase	Not indicated	Not indicated
Provincial	British Columbia	[21]	< 25 mg/L above background	< 5 mg/L average above background	< 25 mg/L increase*	< 10% increase*	Not indicated	Not indicated
	Ontario	[22]	< 25 mg/L above background	< 5 mg/L average above background	< 25 mg/L increase	< 10% increase	Not indicated	Not indicated
	Alberta	[26]	< 25 mg/L above background	< 5 mg/L average above background	< 25 mg/L increase	< 10% increase	Not indicated	Not indicated
Regional	City of North Vancouver, BC	[27]	Not indicated	Not indicated	Not indicated	Not indicated	< 25 mg/L above background	< 75 mg/L above background

associated with a performance-based approach to ESC monitoring:

- Provides context for monitoring efforts by establishing a set target to be achieved;
- Focuses on the desired outcome (less sediment leaving the site) rather than the performance of individual controls;
- Promotes more rigorous and frequent inspection and monitoring of the site;
- Reduces the magnitude and duration of events; and
- Is more appropriate to the dynamic nature of construction projects, as it allows for the ESC plan to evolve as necessary to achieve the set targets.

Monitoring protocols vary across multiple Canadian jurisdictions depending on the physical environmental/landscape conditions, the turbidity/TSS targets established (if applicable), the technology applied, the spatial scale of the work, and seasonal conditions (e.g., wet/dry months, ice accumulation). In some cases, previously collected monitoring data can inform the targets for effective turbidity and TSS monitoring protocols. Nevertheless, all monitoring approaches have advantages and disadvantages; therefore, it is important to select the most suitable approach on a project and site-specific basis.

3.1.2 Turbidity Monitoring Using Discrete and Continuous Methods

Two primary approaches exist for monitoring turbidity: discrete and continuous monitoring. The discrete turbidity monitoring approach involves conducting on-site turbidity measurements through grab sampling or using a portable, hand-held sensor [28]. Grab sampling involves collecting water samples on-site and processing them in a turbidimeter. Hand-held sensors measure turbidity when submerged.

The most commonly used unit of measurement for turbidity in Canada (North America) is Nephelometric Turbidity Units (NTU) [29]. Turbidity monitoring is typically completed at the point of discharge, as well as in the waters upstream and downstream of the site [30]. This allows for a comparison between water flowing into the system (influent) and water flowing out of the system (effluent). In some cases, where turbidity levels are high, zones of impact are identified and sampled. The similarity or difference between these two values provides insight into how construction-related activities are impacting the receiving watercourse [30]. When turbidity levels in effluent are greater than those in influent, it is evident that sediment is not being effectively maintained on-site.

Frequent site visits are required for discrete turbidity monitoring to ensure turbidity levels are not exceeding targets. To compile a turbidity record that is representative of site conditions throughout the year, site visits and inspections are required weekly during the wet seasons (October to April) and biweekly/monthly during the dry season (May to September) [31]. This general sampling schedule allows consultants to quickly identify any issues that arise following rainfall and snowmelt events, and to further monitor watercourse characteristics with limited inputs following consecutive days without precipitation [31]. The specific number of wet and dry events captured should be determined on a site-specific basis and will depend on project requirements and/or project stage (i.e., active vs. inactive construction); however, more frequent site visits and inspections may be required following significant rainfall events [31].

Continuous monitoring techniques involve installing online sensors or in situ multi-parameter water quality sensors to capture ongoing measurements of turbidity [32]. Typically, sensors are programmed to collect turbidity measurements within a specific time interval [32]. Across multiple jurisdictions, it is common to collect turbidity measurements every 15 minutes using continuous monitoring protocols [33]. The online sensors may require off-loading at a specific time interval (e.g., weekly or biweekly), or remote real-time access to data may be possible.

To identify suspended sediment levels sourced from in-stream or surrounding works, online sensors are installed in the outlet of the associated sediment control pond and at the upstream and downstream receiving waters [30]. It is important that sensors be installed so that they are submerged for the majority of the season where flows are active and collect data that are representative of the system [32]. In many cases, it is common for sites to become dry during the dry months, at which point turbidity measurements cannot be collected. The placement and positioning of the equipment allow changes in turbidity levels resulting from in-stream or surrounding works to be detected [32]. To ensure proper equipment function and productivity, site visits and inspections should be conducted immediately following large rainfall events greater than 25 mm [22], [19]. Depending on the spatial scale of the feature, more frequent or less frequent inspections may be required.

An important consideration for both discrete and continuous turbidity monitoring is ensuring the bed of the waterbody is undisturbed during the time of sampling [28]. Grab samples should be taken at an appropriate distance away from the bed and sensors should be fully submerged while not disturbing bed materials. Additional precautions should be taken to reduce disturbance at the sampling site, including collecting samples from flow moving upstream to downstream and, if possible, not entering the watercourse [28]. In the event that samples are collected from a location with disturbed bed materials, excess sediments can yield a non-representative turbidity value. It is important that turbidity not be over-estimated or under-estimated, as inaccurate measurements may have implications for evaluating site performance and the meeting of targets, requirements for additional ESC measures, flagging issues on-site, or identifying ESC effectiveness. Typically, a minimum of three turbidity samples are collected, from which an average turbidity level is calculated. This practice accounts for outlying turbidity measurements. Similar protocols should be followed at all sampling locations to avoid sampling bias. Sampling protocols should be well described as part of the monitoring plan.

Based on the concentration and duration of data collection, continuous turbidity monitoring can provide a more complete understanding of system and site conditions (due to the ongoing record) than discrete sampling methods. Additionally, data are logged throughout the day and night, providing observations that would otherwise be unrecorded. In terms of concentration comparability, the temporary/permanent installation location associated with online sensors provides high precision and comparability between turbidity and TSS. This differs from discrete sampling methods, where samples are taken in generally the same location at each site visit. Discrete sampling protocols are preferred for identifying specific problem areas on-site, as various locations can be selected for

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data collection. For example, the standardized (inlet, on-site, outlet) sampling locations can be addressed, and then other locations flagged as potential sediment sources can be examined as well.

The equipment costs associated with discrete and continuous monitoring differ, with portable hand-held monitoring devices being lower in cost and more robust for year-round use. Continuous monitoring equipment is more expensive and is typically not suitable for winter monitoring. Due to environmental exposure, it may require more maintenance and monitoring. The suitability of discrete and/or continuous turbidity monitoring depends on the resources available and the monitoring objectives for the given site and project. A complete list of the advantages and disadvantages associated with discrete and continuous turbidity monitoring is provided in Appendix A.

In addition to monitoring turbidity and TSS, a representative with a professional designation, or certificate for inspection, is required for identifying ESC method effectiveness. A Canadian Certified Inspector of Sediment and Erosion Control (CAN-CISEC) is an individual who has demonstrated the ability to observe, inspect, and report on the implementation of ESC methods, and who can understand and prepare ESC reports and plans [34]. An understanding of the technology employed for turbidity monitoring is also beneficial.

3.1.3 Sampling Frequency for Turbidity Monitoring

Standard sampling frequencies are indicated for both discrete and continuous monitoring protocols. Differences in sampling frequency exist across jurisdictions and several factors introduce variations that must be considered when employing a standard frequency. These factors include (but are not limited to) seasonal variation, site activity, and maintenance. For example, sampling can be reduced from weekly to biweekly sampling during the transition from wet to dry months.

Where construction projects are scheduled to be inactive[1] for more than four months, it is possible that site status can be changed to "inactive". The site must be considered "protected"[2] and, from there, an inspection schedule/sampling frequency can be determined based on local site conditions and the site-specific ESC measures in place. In the City of Surrey, British Columbia, there are three factors that contribute to determining the suitable monitoring interval:

1. The stability of ESC facilities (i.e., if facilities are well-constructed and do not require ongoing maintenance);
2. The type of coverage (i.e., if ESC measures are temporary or permanent); and

[1] No construction works on-site [31].

[2] The ESC plan must be implemented and all best management practices (BMPs) must be maintained [31].

3. Season (i.e., site visits may be required to confirm inactivity during the summer months, and the status of the project during the summer may not reflect that of the winter) [35].

It is also possible to change the status of a construction project from active construction to "ongoing maintenance" [3]. For construction sites on-maintenance, sampling frequency can be reduced according to regional climate and erosion potential. For example, sampling frequency may be reduced to 30-day intervals in the summer (i.e., during characteristically dry months) and 14-day intervals in the winter (i.e., during characteristically wet months) through the west coast of Canada [31]. However, sampling frequency is dependent on regional climate, and is therefore variable across Canada. Generally, it is likely that more frequent site visits are required during wet months to ensure ESC measures are functioning optimally. In the event that ESC measures are not stable and, as such, the construction site is not protected, sampling frequency will need to be increased.

If any site deficiencies are noted, monitoring requirements and sampling frequency return to the standard practice (weekly). It is important that modifications to ESC are implemented as soon as possible, where necessary, to address deficiencies. According to the City of Surrey [35], identified deficiencies must be corrected within seven days following notice of issues. Once deficiencies are addressed, no new deficiencies have developed, and the site is considered protected, sampling can return to the alternative monitoring frequency.

3.2 Technologies Available for Erosion and Sediment Control

Many methods exist for erosion and sediment control on construction sites. The suitability of a given method is based on the project goals, site conditions, and temporal needs. ESC methods can address temporary, permanent, minimum requirement, or best management practice needs [36]. Temporary methods reflect those that are implemented during the construction phase but are removed once permanent methods are installed and/or vegetation is established [36]. Permanent measures are incorporated into the overall design and are established for long-term, post-construction ESC on-site [36]. In terms of installation, temporary ESC measures should be on-site prior to and during construction, while permanent ESC measures should be on-site during or at construction completion [36]. Depending on project phasing, it is likely that additional measures will be required throughout the project timeframe. The structural performance and efficiency of ESC technologies relies on proper installation and appropriate materials [37]. Depending on the ESC technology used on-site, the most appropriate monitoring technique to flag turbidity and TSS exceedances should be applied. Commonly used technologies for ESC (e.g., physical barriers, surface and erosion protection, chemical treatment, and phasing and site management) are provided in Appendix B.

Based on the results of the literature review, it was determined that turbidity and TSS monitoring practices (including targets, sampling method, sampling frequency, inspections) differ based on jurisdiction, scale, location, and project type. Specifically, turbidity and TSS monitoring targets differ across Canadian jurisdictions and background conditions. Additionally, depending on the ESC method/infrastructure implemented to reduce sediment contributions, the efficiency of monitoring techniques differs (e.g., continuous versus discrete turbidity monitoring). It was determined that standard sampling frequencies exist but can be altered depending on construction site activity and background conditions. In all cases, acceptable turbidity and TSS monitoring inspections are to be completed by trained personnel with a professional designation. Given the differences associated with turbidity and TSS monitoring, it is likely that many practitioners have had unique, site-specific experiences. By completing an analysis of case studies associated with turbidity and TSS monitoring experiences, it is possible to identify successes and challenges associated with the practice. Further, these results can inform best practices and recommendations for successful turbidity and TSS monitoring in the future.

[3] Construction works are completed and turbidity and TSS monitoring is in place [31].

4 Case Studies from the Literature Review

4.1 Case Study #1: Designing Sediment Control Ponds for Sediment Removal Efficiency

With the increase in construction-related activities in the Greater Toronto Area, the design criteria of sediment control ponds were evaluated [6]. This research expanded on earlier works completed at Ballymore Pond in Richmond Hill, Ontario. A sediment control pond in Markham, Ontario (Greensborough Pond) was selected and monitored to determine stormwater runoff quantity and water quality (influent and effluent) during site development. The subject sediment control pond was designed and constructed based on the Ontario Ministry of the Environment (MOE) Stormwater Management Planning and Design Manual 2003 to meet a target of 80% total suspended solid removal (an "enhanced" level of protection) [3]. Pond geometries are available in Table 3.

Table 3: Pond Design Geometries (width to depth ratio)

Pond	Pond Design (width to depth ratio)
Ballymore Pond (Richmond Hill)	2:1
Greensborough Pond (Markham)	8:1

Turbidity and TSS monitoring practices were employed to understand the sediment dynamics in the ponds (Table 4). Specifically, the monitoring data were used to inform ESC effectiveness and determine how pond size and geometry design impact functionality. A hydrodynamic sediment-transport model[4] was also used to understand the effect of pond geometry on sediment removal.

The current designs for sediment control ponds in Richmond Hill and Markham did not meet "enhanced" protection turbidity and TSS targets proposed by the MOE [3]. Rather, both ponds exceeded the 80% TSS removal target (Table 5). The analysis of the pond design indicated that the length-to-width ratio of ponds can impact the efficiency of suspended sediment removal. The Greensborough Pond in Markham (with a length-to-width ratio of 8:1) performed better in terms of removal efficiency than the Ballymore Pond in Richmond Hill (with a length-to-width ratio of 2:1). This case study signifies the importance and need for research-based monitoring of ESC measures (e.g., sediment control ponds) to inform future design considerations that can improve suspended sediment removal efficiency. Research-based monitoring, where possible, should be used to identify the successes and challenges associated with current ESC measures and to contribute to technology improvements. Further, turbidity and TSS monitoring methods can be adapted for use in future projects to understand ESC effectiveness.

4.2 Case Study #2: Employing a Turbidity and TSS Monitoring Program to Mitigate Effluent from Construction-Related Activities

The Keeyask Generation Project involves the construction and operation of the Keeyask Generating Station (GS) at Gull Rapids on the Nelson River in northern Manitoba where Gull Lake flows into Stephens Lake. A sediment management plan (SMP) was developed to account for in-stream construction. The SMP involves monitoring suspended sediments in the watercourse, which may be affected by construction and operation of the project. The SMP was implemented during the construction phase of the project and includes real-time monitoring of turbidity. Additionally, ESC technology, including a sediment trap, was installed. Where in-stream construction and project activity cause turbidity measurements to exceed specific thresholds, mitigation efforts are implemented. In terms of the spatial extent of the project, boundaries are based on the open-water hydraulic zone of influence. Monitoring is completed both upstream and downstream of the Keeyask Generation Project (where most of the flooding and related project effects occur) to determine if in-stream works are influencing suspended sediment levels (Table 6). The results of the monitoring activities support Keeyask Hydropower Limited Partnership (KHLP), government regulators, local First Nations communities, and the general public in understanding how the Keeyask

[4] A tool to understand deposition and scour.

Table 4: *Turbidity and TSS Monitoring Protocol Applied at Each Pond*

Type of Water Quality Sensors	Location of Sensors	Frequency of Sampling	Analysis
Automated water samplers, triggered by rain gauge signal during storm events greater than 1 mm	Upstream and downstream from pond	Hourly	TSS*, particle size, turbidity
	Pond inlet	10 minutes	
	Pond outlet	30 minutes	
Grab sampling	Upstream and downstream from pond	Site visits	

** Water quality variable of interest in the study*

Table 5: *TSS Removal Results from Influence and Effluent Monitoring*

Pond	Average Influence Peak TSS Level (mg/L)	Average Effluent Peak TSS Level (mg/L)	Average Sediment Removal Efficiency (%)
Ballymore Pond (Richmond Hill)	7,955	318	91
Greensborough Pond (Markham)	7,735	98	98

Generation Station's construction and project activity affect the physical environment. At present, monitoring results are available from 2015 to 2016.

During three field visits over the winter 2015 to 2016 season, discrete turbidity readings using a separate check probe were consistently greater than the value from the continuous probe. It was suggested that the continuous probe likely had a low bias, and therefore the continuous values were adjusted (increased) by 4.3 NTU to better align with discrete readings. This observation highlights the importance of equipment calibration and understanding the differences between equipment used to collect the same data. Without considering these factors, turbidity and TSS may be over-predicted or under-predicted, which ultimately reduces the effectiveness of the monitoring program and creates a challenge for accurately linking site conditions to turbidity and TSS targets.

During the winter 2015 to 2016 season, there were periods of abnormally low and high turbidity and TSS measurements. It was suggested that low turbidity levels were due to additional water level staging as well as interference from ice and differences in under-ice erosion conditions. Additionally, it was proposed that high TSS levels may have resulted from ice accumulation at the entrance to Stephens Lake, which can redirect flows and increase flow velocities over erodible bed material, causing sediment to be suspended in the water.

Influences from construction were also identified during the winter season, including the upstream ice-boom. The upstream ice-boom was suspected to reduce the accumulation of ice at the entrance to Stephens Lake, which reduces the effects of TSS due to under-ice flow redirection. These factors demonstrate the importance of considering seasonal variations in turbidity and TSS measurements, where high turbidity and TSS levels may not be caused by construction activities, but by natural variation or instrument error due to weather conditions.

Table 6: *Turbidity and TSS Monitoring Specifications*

Sampling Method	Probe Placement	Sampling Frequency
Continuous	2 m below water surface upstream and downstream from project	Every 3 weeks
Discrete	20% and 80% depth locations in the water column (50% depth in shallow locations)	2–4 times per open-water season (within the same time period as continuous turbidity monitoring)

During the summer 2016 season, results from continuous turbidity monitoring were consistently slightly higher than readings obtained from the hand-held probe used for discrete readings. The hand-held unit used for discrete sampling is typically considered more accurate because it experiences less exposure to the elements and is more frequently maintained. As such, continuous turbidity sensors were calibrated downward (3.2 NTU and 2.8 NTU) to match the discrete sampling equipment measurements. Additionally, one continuous sensor demonstrated an abrupt 2.5 NTU downward shift at 6:00 pm on September 21, 2016. This introduced a bias that caused the remainder of the data to be too low. To account for this, all data after that time were adjusted upwards by 2.5 NTU.

Project managers also identified variations in turbidity, which were linked to fluctuating wind conditions. Using hourly wind data extracted from Environment Canada, various peaks in the average wind directly corresponded with turbidity increases. It is noted that the response of turbidity to wind depends on several factors, including magnitude and duration of higher winds creating the peak, wind direction, and local wind variability. The findings of this case study highlight the importance of equipment calibration and understanding the differences between sampling techniques. These are important considerations for obtaining accurate turbidity and TSS measurement data. Where required, data processing should be undertaken to account for signal variability such as bias, drift, and noise.

5 Case Studies from Stakeholder Surveys

A survey was prepared and distributed to stakeholders as a preliminary measure to identify commonly used ESC measures and associated turbidity and TSS monitoring protocols among various Canadian jurisdictions and landscapes (Appendix C). The purpose of the preliminary survey was for stakeholders to introduce a project (e.g., linear infrastructure project, small-scale and large-scale residential/commercial development projects), indicate the ESC methods implemented, and describe turbidity and TSS monitoring protocols used on-site – including any challenges and successes.

Following completion of the surveys, phone-based interviews were conducted with each participant. Phone interviews lasted approximately one hour and followed a generic list of questions (Appendix D). Based on the specific aspects of each project, follow-up questions were posed to gain more detailed information regarding the activities, benefits, and challenges involved. For example, if there were deficiencies in turbidity and TSS monitoring on-site, a more in-depth discussion on background conditions and the ESC technologies used would follow. The phone interviews were transcribed and, when necessary, stakeholders followed up with additional background information and project details to supplement their preliminary survey and interview responses.

In total, three case studies from stakeholder surveys were completed. Both linear infrastructure and residential development projects were included. Several types of ESC measures were described, turbidity and TSS monitoring protocols were shared, and experiences with monitoring were varied. The case studies from each stakeholder survey are summarized below and may be used to inform appropriate ESC methods, turbidity and TSS monitoring protocols, and recommendations for addressing targets for future projects.

5.1 Case Study #3: Victoria, BC Linear Infrastructure Project

Introduction

A stakeholder survey and case study were completed for a large-scale linear infrastructure project in Victoria, British Columbia, that involved the construction of a major highway interchange. The site is mainly located within the Nanaimo Lowland – Coastal Lowlands physiographic region of British Columbia. Land use surrounding the project site included recreational and residential areas. A detailed design was completed in 2016, construction began in 2017, and works were expected to finish in late 2020.

Construction Activities

The highway interchange was approximately 2 km and 0.5 km in length and width, respectively. The associated construction works included:

"Three case studies from stakeholder surveys were completed. Several types of ESC measures were described, turbidity and TSS monitoring protocols were shared, and experiences with monitoring were varied."

- Traffic and pedestrian overpass structures;
- Highway ramps;
- Retaining walls; and
- Noise fencing.

The location of the new interchange was immediately adjacent to a watercourse, which drained into a bay feature. Land use surrounding the watercourse was dominated by forest, agriculture, and increasingly urbanized areas. Existing water quality issues and other impacts of impervious surface areas had deteriorated the overall health of the watercourse. There was also a minor tidal tributary within the project site.

Erosion and Sediment Control

To reduce the impact on nearby waterways, ESC measures were implemented throughout the project site. ESC measures and their placement included:

- Silt fencing around the perimeter of the site using straw bales and rock check dams;
- Ground and slope cover using native seed mix; and
- Berm to provide an interface between the construction site and watercourses.

During the initial phases of the project, the contractor was responsible for covering disturbed soils. However, there was no timeline for this to be completed, which resulted in most areas within the project site being exposed at once. Additionally, in the first phase of the project, earthworks were completed during both dry and wet months of the year. This made it difficult for water resource managers to effectively deal with erosion and sediment transport and address water quality issues during rainfall events.

A berm was constructed to reduce erosion and provide a location for depositing materials throughout the project. Additionally, the berm was meant to provide isolation and stabilization for the site. Based on the earthworks experiences in the first phase of construction, sediment contributions to the berm were limited to the dry months of the year (May to September) to reduce the likelihood of poor water quality from site runoff. During that time, materials were deposited near the watercourse with a lower risk of runoff from rainfall events. Scheduling the deposition of materials based on the season and the weather patterns was a novel approach to development of the berm.

Turbidity and TSS Monitoring

As part of the project contractual agreements, monitoring was required during construction and was completed by the contractor's hired inspectors. Monitoring was required for water quality, including turbidity and TSS sampling. Initially, field staff were responsible for collecting discrete water samples only when required. However, due to project deficiencies associated with sediment release, continuous sampling was implemented as a supplementary measure.

Continuous automated turbidity sensors were used at a total of six water sampling stations throughout the project site. Sensors were installed at the following locations:

- Upstream and downstream from construction works;
- At the outlet of associated watercourses;
- Relatively low within-channel beds to capture turbidity during low water levels; and
- Near-channel banks to avoid disturbance from small watercrafts.

The sensors were installed seasonally and required downloading on a monthly basis. Data collection specifics are provided in Table 7. During the period of deployment, the monitoring auditors were responsible for sampling equipment calibration and monitoring.

Table 7: *Data Collection Specifics for the Automated Turbidity Sensors Installed Within the Project Study Site*

Data	Setting
Burst Interval	240 seconds
Samples to Average	10
Sample Interval	1 second
Wipes per Burst	1

Despite the capabilities of the automated turbidity sensors for collecting data without extensive field data collection requirements, individuals completed manual sampling for other water quality measures. Manual sampling was completed biweekly at the outlet and the main branch of the associated watercourse. Additionally, with 25 mm of rainfall in 24 hours, monitoring was completed before, during, and after the rain event to ensure quality control.

Experiences with ESC and Turbidity/TSS Monitoring

Targets for turbidity and TSS were not explicitly set in the beginning stages of the project. Initially, the contract language was generic for impact mitigation, indicating that British Columbia water quality guidelines for aquatic life would apply in the receiving environment. Following project complications, specific discharge criteria were developed for the second phase of works. An absolute discharge criterion of 15 NTU (in flows exiting the site) was established. Turbidity and TSS monitoring were completed with the automated sensors and manually during site visits. No on-site water treatment facilities were available until the field infiltration area was constructed and large volumes of water and sediment were discharged into the system. The system was overwhelmed and there was no capacity to treat the high volume of water on-site. Agencies (including the Department of Fisheries and Oceans and the Ministry of the Environment) were alerted of the issues on-site by stakeholders and members of the public. It was quickly recognized that an additional level of water treatment was necessary for effective water quality management and to ensure that turbidity and TSS targets were met.

Three chemical treatment tanks were introduced on-site to treat water with turbidity/TSS levels of 15 NTU or above. Chemical treatment systems are appropriate where physical erosion control methods are not meeting water quality standards for construction site runoff [38]. It is important to note that chemical treatment systems are not intended to replace the use of traditional ESC methods, which are noted as more important and cost-effective solutions for reducing sediment load [38]. The chemical treatment approach is uncommon, particularly for projects associated with highway and linear infrastructure works due to the high cost of equipment. In this case, the MOE decided to implement the chemical treatment, and because it was beyond the scope of the contractor's plan, the MOE also covered all associated costs. This was a valuable lesson in both turbidity and TSS monitoring, as well as contract development. The MOE typically avoids being overly prescriptive in contract language as it urges contractors to be innovative and provide cost savings where possible. However, the results of this project indicated that turbidity and TSS targets need to be measured and audited conscientiously to stay within water quality guidelines.

Despite the level of ESC measures on-site, lessons learned, and changes made from the first phase of the project to the second, there were still a number of exceedances following implementation of turbidity monitoring and enhanced ESC measures. It was suspected that exceedances stemmed from human error, including improper use of equipment and isolated incidents. In terms of human error, all individuals completing ESC monitoring are qualified professionals, and have specific qualifications for working with ESC measures. However, the approach to addressing ESC concerns was more reactive, as opposed to proactive and, as such, challenges persisted through the project.

Conclusions

The challenges and successes of ESC measures associated with this project can inform best management practices moving forward. The following items should be considered in future works associated with ESC and monitoring turbidity/TSS on-site:

1. Contract language should explicitly indicate the expectation for water quality management, ESC measures, and targets for turbidity and TSS monitoring. This reduces the amount of emergency works and problem-solving required when water quality is at risk.
2. Timing restrictions should be placed on action items that may deteriorate water quality given weather conditions (e.g., limiting earthworks to dry months of the year).
3. Maintain stakeholder and public engagement, as well as open communication, throughout the project duration. This will help identify issues as they arise and identify innovative solutions to benefit the project as a whole.

5.2 Case Study #4: Township of Langley, BC Residential Development Project

Introduction

A stakeholder survey and case study were completed for a small-scale residential development project in the Township of Langley, British Columbia. Spatially, the project lands included approximately 4.5 hectares. The site was mainly located within the Uplands physiographic region of British Columbia [39]. The Uplands are underlain by glacial sediments, and surficial geology is characterized by silty clays of marine and glaciomarine origin [39]. Land-use surrounding the project site was residential.

Construction Activities

Construction of a 623-unit condominium complex began in 2018 and was targeted to be completed in 2020. At the time of reporting, project stages varied from excavation to structural framing, depending on the area within the site. Infrastructure associated with construction included:

- Road network that surrounds all buildings;
- Temporary sales center; and
- Park features that extend through the middle of the condo complex.

The development was in close proximity to a creek and two separate tributaries. One watercourse was identified as an ecologically sensitive area. At the project site, all water was released at one location to an existing vegetated roadside ditch.

Erosion and Sediment Control

A sediment pond and perimeter ditch were introduced as ESC measures to manage water from the site. During the wet seasons (spring and fall), a constructed sediment pond transferred excess water to increase drainage to the outlet. However, during the dry seasons (summer and winter), rain was typically absorbed into the soil, ultimately negating the need to pump. A perimeter ditch was established surrounding the active construction site to reduce runoff potential. Low flows were directed around the site, although in most instances, minimal flows were observed.

Construction phasing was also implemented to manage the stages of work, including clearing, excavating, infrastructure and structural construction, and monitoring. There were challenges associated with phasing the construction of the condominium complex.

At the start of the project (2018), the site was completely cleared, with earth grading being completed for only certain areas. The exposed soil and topography of the site resulted in sediment being transported into the nearby ditch. To stabilize the project lands during and post-construction, trees, mulched straw, and organic mulch (hogweed mulch) were incorporated as ground cover. In addition to sediment ponds and phasing, stormwater management ponds (SWMPs), water treatment facilities for effluent, sand filters, flocculent socks, and settling ponds were active on the project site.

The Township of Langley provided ESC monitoring requirements[5]. Specific to this project, the requirements included:

- Weekly inspections of ESC measures and within 24 hours of significant rainfall;
- Immediate reporting of failures and maintenance requirements;
- Visual monitoring of discharge quality when water is turbid;
- Immediate reporting of permit violations to the Township of Langley coordinator (if applicable); and
- Reading and understanding the permit (if applicable).

Turbidity/TSS Monitoring

The Township of Langley required that monitoring be completed on-site throughout the project duration (Table 8). During dry months or after 24 hours following rainfall, turbidity targets were set at 25 NTU. When precipitation was greater than 25 mm within 24 hours, or during similar significant rain events, turbidity targets were set to 100 NTU.

Discrete sampling was completed to monitor turbidity levels. Samples collected by the project team were taken through grab sampling, and samples collected by the Township were taken using a probe. The turbidity values were not consistent between the different sampling methods. This is a common scenario where various instrument types are used to compile a turbidity record and highlights the importance of recording instrument types in all metadata documents [40]. Measures were taken to ensure each instrument was functioning properly, including:

- Completing daily calibration processes prior to use (and logging calibration details); and
- Where questionable turbidity values were collected, a follow-up test was completed.

Water sampling depth for collection can vary depending on rainfall and the volume of water in the system. In all cases, staff collected samples in locations where the bed was not disturbed. This reduced the possibility of collecting extra sediment in the sample and ultimately yielding non-representative data.

Experiences with ESC and Turbidity/TSS Monitoring

There were challenges associated with ESC measures keeping turbidity levels below targets at this site. One of the most significant challenges was the limited capacity of water treatment facilities for treating effluent. The suitable number of water treatment facilities is determined on a site-specific basis, where a local engineer and water treatment company calculate and identify the required storage. In this project, two large water treatment tanks were recommended. Sand filtration and flocculent socks were also required to manage water resources on-site. In particular, a "treatment train" was introduced, where water on-site passed through the SWMPs, water treatment facilities, sand filters, flocculent socks, and settling ponds before ultimately reaching the ditch feature. Although greatly reduced, turbidity exceedances were still recorded.

Township staff were highly involved in the development process. During high-risk periods – or "wet" months – and when issues were most common, reports were prepared and sent to the Township on a weekly basis to provide updates. The timeline for providing reports to the Township varied depending on the severity of the issue.

[5] British Columbia has local watercourse-based regulations and bylaws that are specific to each municipality for environmental management. Furthermore, it is the responsibility of townships and cities to ensure regulations are being met. The Township of Langley includes ESC as a required component of their construction project permitting processes. This includes providing ESC plans to the Township for review and revisions. Typically, there is correspondence between agencies until the plans are accepted. At that point, the ESC plan is stamped and the ESC measures are approved for implementation

Table 8: *Turbidity and TSS Sampling Frequency*

Weather	Site Characteristics	Site Visit Frequency	Sampling Frequency
Wet months	Water discharging off-site	Weekly	Weekly
Dry months	Water not discharging off-site	Weekly	Only following rainfall
Significant rainfall event	Water discharging off-site	Within 24 hours	Within 24 hours

For example, if a quick solution was available, mitigation measures were implemented immediately, and reporting was completed later. However, if flows leaving the site were completely opaque, the Township was informed and a follow-up plan for addressing the issues was prepared immediately. Additionally, the Township completed occasional site visits. Any reports sent to the Township were provided to the developer/client to maintain a level of transparency while addressing issues on-site. During low risk periods (dry months) there were no requirements for reporting and therefore follow-up with the Township was not necessary. Importantly, the relationship and communication between the consultant and the contractor on-site was well-established. Site walks were occasionally completed together, and where problems on-site were identified, the contractor prioritized action on these issues immediately. Although there were no formal site meetings with the contractors, conducting informal site walks benefited the work of all groups in terms of knowing what was going on on-site, identifying issues to watch for, reviewing mitigation measures in place, and discussing next steps in development phases.

Conclusions

The challenges and successes associated with this project provide lessons learned that should be considered to enhance future ESC and turbidity monitoring projects.

1. **Phasing of construction during development:** Ensuring construction is phased in a way that limits prolonged periods of exposed soil will reduce the opportunity for sediment transport into nearby watercourses. This will ultimately decrease the potential for turbidity levels to exceed local targets or impact channel form and function.
2. **Consideration of rainfall frequency and intensity:** The resources required for ESC and turbidity monitoring are influenced by rainfall frequency and intensity. It was noted in the current case that rainfall events in Langley, British Columbia, have been heavier and less predictable in recent years. As such, recent trends in local weather conditions should be considered as part of ESC and turbidity monitoring efforts.
3. **Open communication:** Well-established relationships and open communication with the contractors on-site provided efficiency in identifying issues on-site, determining effective mitigation and/or management approaches, and completing follow-up monitoring. With effective communication, the frequency and magnitude at which issues arise can be reduced.

5.3 Case Study #5: Silt Smart

Introduction

A stakeholder survey and case study were completed for a large-scale residential development project located in Vaughan, Ontario. The site included approximately 65 hectares of land located within the Peel Plain physiographic region of Southern Ontario [41]. Physiographic landforms in this region include till plains (drumlinized), and the surficial geology is characterized by fine-textured glaciolacustrine deposits and till [41]. In terms of bedrock geology, the study site was dominated by shale, limestone, dolostone, and siltstone [41].

"To ensure conformance with permits and limit potential adverse impacts within the subject property, particularly during construction, a dynamic approach to ESC technology was implemented."

The project site was adjacent to two confined valley systems and included two cool-water tributaries. Land use surrounding the project site was both residential and agricultural. The watercourse within the subject property was occupied by Redside dace[6] *(Clinostomus elongatus).* Prior to construction works, both tributaries had evidence of significant erosion, widening, downcutting, and lateral migration. The Silt Smart[7] monitoring protocol was implemented to monitor turbidity levels and inform ESC effectiveness on-site.

Construction Activities

To support the residential development, the following construction activities were completed:

- Earthworks;
- Installation of underground infrastructure (e.g., watermain, storm sewers, etc.);
- Construction of stormwater management facilities (SWMF); and
- Construction of a pumping station, road network, housing and commercial buildings, and linear infrastructure works (including the construction of two large pedestrian bridge crossings over the valley lands and watercourse).

Erosion and Sediment Control

Multiple proponents were associated with this project, including a landowner's group that actively participated in development site activity. Prior to construction, letters of advice were acquired for permitting through the Ontario Ministry of the Environment, Conservation, and Parks (MECP) (under the Environmental Protection Act) and the Ontario Ministry of Natural Resources and Forestry (MNRF) Endangered Species Act. To ensure conformance with permits and limit potential adverse impacts within the subject property, particularly during construction, a dynamic approach to ESC technology was implemented. ESC technologies on-site included:

- Silt fence
- Silt socks
- Temporary sediment basins
- Interceptor swales
- Sediment traps
- Check dams
- Hydroseeding
- Erosion control blankets
- Silt Smart monitoring protocol

[6] Redside dace are small-bodied minnow fish species that have *endangered species* status according to SARA (2011) and COSEWIC (2017).

[7] Telemetry-based turbidity monitoring system.

Turbidity and TSS Monitoring

The Silt Smart monitoring protocol was introduced to continuously monitor turbidity levels at five locations between both tributaries. The control stations that monitored the background levels were located upstream of the active construction area in each tributary. The turbidity levels at the stations located downstream of the site were measured against the upstream levels with exceedances being communicated to a remote server. Notifications were then sent to the respective contact group. Turbidity targets were based on pre-construction site conditions that were determined by monitoring active channel erosion not impacted by external construction inputs. In consultation with the permitting agencies, a target of 40 NTU was used to compare downstream turbidity levels against upstream turbidity levels for initial alarms.

When turbidity levels downstream exceeded the upstream turbidity levels by greater than 40 NTU for a sustained period greater than 30 minutes, the Silt Smart monitoring system notified the assigned contact group by email. There were three different alarm scenarios based on turbidity exceedance and duration of exceedance:

1. Turbidity level exceedance greater than 40 NTU for 30 minutes;
2. A first alarm scenario that has stayed active for greater than ten hours; and
3. Turbidity levels exceeding 330 NTU for 30 minutes.

An overview of the Silt Smart protocol is available online [19].

Experiences with ESC and Turbidity/TSS Monitoring

During the earthworks phase, silt fence was installed, consisting of two rows of filter fabric reinforced with straw bales for areas adjacent to the valley lands. At the low points of the site where water was expected to collect, interceptor swales and sediment traps were employed. In the steeper gradient interceptor swales, a series of silt sock check dams were installed to trap sediment before flowing into the stilling basin. A staked silt sock was installed on the valley side of the silt fence to provide an additional measure of filtration at the known discharge locations. These areas were carefully monitored with recommendations being made to the site engineer if any deficiencies were noted or improvements were identified during the site inspections. The monitoring alarms that were triggered during this phase were generally the result of site runoff from these low points. With established vegetation along the valley land slopes, many of the issues in these areas were mitigated with the installation of additional sediment controls such as silt socks and/or straw bales and identified silt fence repairs.

Construction of two large pedestrian crossings commenced as the earthworks phase was underway. The pedestrian crossings spanned the valley and crossed over one of the tributaries, requiring large footings and abutments to be constructed. In these areas, multiple sections of double row straw bale-reinforced silt fence were used to intercept sediment down these steeper valley slopes. The tributary was isolated with double row straw bale-reinforced silt fence and the areas around the footing construction were isolated with a single row of heavy-duty silt fence. Once the slopes were disturbed to facilitate the pedestrian crossing construction, erosion in these areas was exacerbated during rain events by the steep slope. Additional straw bales and silt socks were installed to reinforce the silt fence in observed areas of failure. Additionally, flexible PVC piping was used to convey site runoff into straw bale dissipation areas at the bottom of the slope to avoid ongoing erosion of the slope and prevent damage to the sediment controls along the slope. These areas were actively inspected during Silt Smart alarms as the disturbed soils and steep slopes likely contributed to some of the overall turbidity exceedances.

As earthworks progressed, the future SWMF locations were excavated and used as temporary sediment basins during the underground infrastructure construction works. Within the temporary sediment basins, perforated vertical drains were constructed with a clear stone collar at the inlet and a stabilized stone outlet used to receive flows at the discharge end. Additionally, these outlets were constructed within the silt fence limits, providing additional filtration of water following settling time in the respective temporary sediment basins.

During the construction phase, excavations required for the storm sewer installation retained water following rain events. These excavations became ponded and required unwatering following rain events. The best management practice (BMP) associated with large-scale valley land sites is to discharge any pumped water through a filter bag to a non-erodible surface that drains into a temporary sediment basin. If unwatering was needed, the Silt Smart monitoring system was a valuable tool in identifying these situations with corrective action being taken immediately in most circumstances. As the site construction moved through the road construction and into the housing phase, the alarm notifications from the Silt Smart system were reduced significantly. This reduction in alarm notifications was attributed to fewer sediment contributions from near-water works (i.e., construction activities).

Although Silt Smart provides a level of immediate response following alarm notifications, "false alarms" are problematic. False alarms occur when exceedances of turbidity are from natural sources and variability, or non-construction related sources. Consideration of the natural sources of sediment within a system is required for defining targets. Even with BMPs, and rapid response and intervention, there were periods where turbidity targets were exceeded. These events resulted from compromised ESC measures during heavy rain events. To differentiate between "false" and "true" alarms, the Silt Smart code was modified to identify "false" alarms associated with natural variability[8]. Without this programming to account for false alarms, it is likely that alarms would be daily or weekly, resulting in alarm "fatigue" and decreased response times.

Conclusions

Overall, Silt Smart was recognized as an effective tool for monitoring turbidity levels and informing ESC effectiveness throughout project phases. This project demonstrated that, even with well-managed sites, turbidity exceedances in receiving watercourses from on-site activity can occur. By implementing continuous, telemetry-based turbidity monitoring, a level of trust between agencies and proponents was developed. Issues on-site identified by alarms were communicated to all parties through alarm

6 Discussion and Recommendations

The literature review and case study analysis provided an understanding of turbidity and TSS monitoring experiences, as well as gaps for erosion and sediment control stakeholders across Canada. Common challenges and successes associated with turbidity and TSS monitoring were identified. Challenges ranged from equipment uses/misuses to standards currently set in place by governing authorities and agencies (e.g., conservation authorities). Further, successes ranged from technological advances to efficiency in turbidity and TSS monitoring protocols. Additionally, recommendations to improve future turbidity and TSS monitoring were provided. Recommendations were identified based on lessons learned from practitioners across multiple Canadian jurisdictions, whereby issues on-site required alternative approaches to ESC and turbidity and TSS monitoring practices.

6.1 Challenges and Successes of Turbidity and TSS Monitoring

6.1.1 Challenges: Equipment Maintenance, False Alarms, and Targets

Equipment maintenance. Continuous systems provide a level of convenience for water quality monitoring. As they are deployed for long periods of time, this does introduce challenges for equipment reliability and data accuracy. Unlike hand-held water quality samplers, which are used for collecting discrete water quality measurements on a weekly/biweekly/monthly basis

[8] A peak-detection algorithm was developed to assess the differential between turbidity from upstream and within the study area. In cases where the magnitude of turbidity causing an alarm within the subject site was similar or slightly lesser than observations at a control location upstream, and occurred in the study area within an appropriate time frame, then the alarm is likely not a result of activities within the subject site. Rather, it is a consequence of natural processes or activities outside of the study site. As such, an ESC inspection should not be required, ultimately reducing requirements to address "false" alarms.

(depending on the season), continuous systems are exposed to elements for long durations and equipment maintenance can be less frequent. This introduces a challenge with ensuring quality data collection, which is evident when continuous and discrete turbidity/TSS levels differ at the same sampling location.

False alarms. One of the main challenges associated with turbidity and TSS monitoring is accounting for natural variability. Weather events (e.g., rainfall, wind) and seasonality can influence sediment dynamics on the channel bed, which are reflected in both continuous and discrete water quality sampling. It is inaccurate to suggest that all fluctuations are attributed to construction-related activities without identifying all sources of sediment to the system. Even with robust telemetry-based technologies to monitor turbidity levels, such as those used in the Silt Smart monitoring protocol, differentiating natural variability from construction-related variability is problematic. Targets are in place to recognize when turbidity and TSS levels exceed an allowable limit based on data collected upstream and downstream from subject sites. However, when natural variations in turbidity and TSS levels exceed the allowable limit, telemetry-based monitoring systems can create false alarms.

Targets. As is evidenced in the case studies presented in this report, turbidity and TSS targets can be difficult to achieve reliably with the most commonly used ESC practices. Given many turbidity targets are established from pre-development conditions, this assumes changes to the sediment load during and post-construction will potentially cause increases in turbidity and TSS levels. Pre-development levels represent a site-specific, best-case scenario in terms of turbidity and TSS, and further, do not account for natural variability in the pre-existing ecosystem. The results of this analysis highlight that many turbidity and TSS targets established for ESC practices can underestimate the natural variability in turbidity/TSS, thereby leading to an assumption that the ESC practices employed are ineffective. The turbidity and TSS targets should ideally account for natural variability in sediment fluctuations, the soil conditions on-site that may influence sediment dynamics, as well as additives from in-stream or nearby works. This may be achieved by establishing several pre-development turbidity and TSS levels to account for natural variability through time.

6.1.2 Successes: Continuous Data Collection, Reprogramming to Reduce False Alarms, and Reducing the Duration of Events

Continuous data collection. Using continuous data collection equipment for turbidity monitoring introduces a level of trust between contractors, clients, and agencies in terms of knowing that sites are being monitored immediately following any issues of concern. Continuous sampling methods provide an ongoing record of water quality conditions on-site, as opposed to discrete water quality sampling, where data are collected on a weekly/monthly basis or following rainfall. A continuous record of water quality is not only useful for identifying contributions of effluent, but for determining how other factors influence sediment suspension in watercourses. For example, variations in suspended sediment may be linked to weather conditions (e.g., rainfall, wind), historical antecedent conditions, and other activities in the vicinity of monitoring (e.g., recreational, commercial). This information provides a level of confidence to predict sediment sources, whether they are from construction-related activities, natural variability, or other contributing factors.

Reprogramming to reduce false alarms. Although false alarms for turbidity exceedances introduce challenges for ESC monitoring, technologies can be reprogrammed to increase the allowable limit prior to alarm. This avoids flagging turbidity due to natural variability, and ultimately reduces the number of false alarm occurrences. As expected, when false alarms occur often at a subject site, the response time to address the alarms fatigues all parties. This becomes problematic for instances where construction-related activities are negatively impacting the subject watercourse, and mitigation efforts are required immediately. Telemetry-based systems can be reprogrammed to account for natural variability in the system based on various patterns in turbidity and TSS levels during pre-construction monitoring. Reducing the influence of natural variability can ensure that alarms are more likely related to in-stream or nearby works and ensure that inspector response times are efficient.

Reducing the duration of events. Magnitude and duration are two important factors that influence the impact of turbidity and TSS levels on aquatic systems [42]. Where both magnitude and duration are high, the impacts of turbidity values/TSS levels are more detrimental. During such periods, immediate mitigation actions are needed. Monitoring turbidity and TSS levels does not result in a decrease in magnitude; however, it can result in a decrease in duration where levels are exceeding pre-construction conditions. Decreasing the duration of turbidity values/TSS level exceedances ultimately reduces the impact to aquatic ecosystem form and function. Employing effective ESC monitoring techniques that reduce the duration of turbidity and TSS exceedances can therefore improve aquatic system productivity.

6.2 Recommendations for Future Site Management and Monitoring

6.2.1 Project Phasing and Weather Constraints

Phasing of construction-related activities is an organizational approach to site management that involves developing a plan (pre-construction) for the step-by-step process in which project components will be completed. Depending on the scale of the project, construction phasing typically begins with dividing the project site into areas where work will begin and finish. Optimizing time and materials is a key factor in phasing so construction activities are completed efficiently and cost effectively. For example, timing restrictions may require in-water works to be completed before earthworks, therefore the first phase of the project would focus on in-water areas. Once work is in motion or a project phase is complete, contractors can move to the next phase. Clearing and grading phases are critical for minimizing environmental impacts and reducing sediment transport to nearby waterways, particularly in terms of erosion and sediment control [43]. Recommendations for phasing to improve turbidity and TSS monitoring for future projects were identified based on case study results (Table 9).

In summary, appropriate site management and construction phasing can reduce sediment export and suspended sediment contributions to nearby waterways [44], albeit, this may be difficult where substantive/large linear infrastructure is required to be installed along with larger scaled earth movement [45], [46]. Nevertheless, an appropriate phasing plan for ESC projects should be established and executed where possible, keeping in mind the environmental impacts that result when ESC measures are not in place prior to construction activities [46]. Specifically, appropriate phasing should be completed at identified high-erosion or high-risk locations, where possible [47]. Further, the phasing plan should consider the location of watercourses susceptible to increases in turbidity and TSS levels, as well as weather

Table 9: *Recommendations for Phasing to Support Turbidity and TSS Monitoring*

Case Study	Recommendations for Phasing to Support Turbidity and TSS Monitoring
Case Study #4 (Residential Development Project, Langley, BC)	**ISSUE:** The phasing of project components led to major issues with sediment transport into nearby waterways and, ultimately, exceedances in turbidity and TSS targets. **RECOMMENDATION:** Clearing should be limited to designated areas where grading and earthworks can follow soon after. There are fewer contributions to nearby waterways when sediment exposure is limited, thereby making turbidity and TSS levels more manageable. Further, ESC methods are more capable of controlling effluent.
Case Study #3 (Interior Lower Mainland Transmission Project, BC)	**ISSUE:** Earthworks were completed during both wet and dry weather conditions. Working in wet conditions contributed excessive loads of sediment to nearby waterways. **RECOMMENDATION:** Phasing schedules should consider weather constraints and seasonality, and earthworks (including sediment movement and dumping) should be limited to dry months only, where feasible. It is understood that this is not always possible. This will limit increases in turbidity and TSS levels, and reduce resources required for monitoring and ESC reinforcements.

patterns (e.g., rainfall, snowmelt) that may exacerbate sediment contributions [47]. Maintaining vegetated buffers where possible and stabilizing portions of sites as soon as feasible, should also be considered during the planning and implementation phases.

6.2.2 Sediment Sources and Contributions to Turbidity and TSS Target Exceedances

Turbidity and TSS targets are established as a tool to mitigate adverse environmental impacts of construction-related activities and earthworks near watercourses. Monitoring stations are established upstream and downstream from construction sites, or at specific release or outlet points to determine if activities increase turbidity levels and TSS concentrations. Targets allow us to evaluate effectiveness and provide mitigation targets to strive towards. Exceeding targets is not a failure, but instead a way of identifying when intervention is required. It is important to note that a variety of factors influence sediment transport and suspended sediment contributions to nearby waterways, yet not all factors are considered in the targets. Recommendations for turbidity and TSS targets to improve turbidity and TSS monitoring for future projects were identified based on case study results (Table 10).

There are various sediment characteristics, sources, and external factors that contribute to turbidity and TSS exceedances. As such, it is recommended that established turbidity and TSS targets be used with additional measures to identify how construction-related activities impact associated watercourses.

6.2.3 Open and Effective Communication During ESC Projects

Communication was a common theme throughout all case studies to ensure effective ESC measures and monitoring, and a successful project overall. Open and effective communication must be established at the beginning of a project and be maintained through

Table 10: *Recommendations for Turbidity and TSS Targets to Support Turbidity and TSS Monitoring*

Case Study	Recommendations for Turbidity and TSS Targets to Support Turbidity and TSS Monitoring
Case Study #1 (Greensborough Pond, Markham, ON)	**ISSUE:** Despite following the design criteria for "enhanced" level of protection, as outlined by MOE (2003), sediment removal in stormwater facilities did not meet established targets. Turbidity and TSS target exceedances were not a product of construction-related activities, but of ESC design and implementation. **RECOMMENDATION:** Turbidity and TSS targets should consider the design and implementation of ESC methods where exceedances are experienced. For example, if sediment control ponds are used but are not designed and maintained for optimal performance, turbidity and TSS levels are not representative of sediment contributions from construction-related activities. Further research is required to develop more robust design and maintenance requirements.
Case Study #5 (Residential Development, Vaughan, ON)	**ISSUE:** "False" alarms were initiated through the Silt Smart system, however the turbidity and TSS exceedances were not always associated with construction-related activities on-site. Rather, the false alarms coincided with large rainfall events, which contributed to a natural variability in turbidity temporarily within the watercourse. **RECOMMENDATION:** Turbidity and TSS targets should consider landscape (sediment composition and type), sources of sediment, and climate patterns, to account for natural variation in turbidity within watercourses. Further, there may be several pre-construction condition targets to account for natural variability through time. Given these background conditions, telemetry-based systems should be programmed to release alarms mainly associated with construction-related activities to reduce alarm response fatigue.
Case Study #3 (Interior Lower Mainland Transmission Project, BC)	**ISSUE:** Turbidity and TSS target exceedances were primarily attributed to a lack of capacity for water treatment on-site and human error. **RECOMMENDATION:** The extent of necessary ESC methods and treatment trains should be identified on a site-specific basis, rather than being based on commonly used technologies. For example, although flocculants and coagulants are not commonly used in linear infrastructure works, they were most effective in this case study. Further, a training protocol for those completing turbidity and TSS monitoring should be mandatory for all projects.

all project phases. Communication can be achieved through discussions; written contract language and documentation; monitoring systems; between project proponents, contractors, and agencies; and with the general public. Recommendations for communication to improve turbidity and TSS monitoring for future projects were identified based on case study results (Table 11).

Open and effective communication is necessary in all ESC projects and can be achieved through various outlets. Communication must include monitoring and measurement protocols, triggers, steps for rectification of deficiencies, and documentation of correction measures. Communication must be established during initial project phases and be maintained until project completion. In addition to discussion and documentation/reporting, using ESC monitoring technologies and a telemetry-based system can enhance trust, reliability, and communication among stakeholders for large-scale projects. Finally, to increase time and resource efficiency, communication between agencies and consultants is required.

Table 11: *Recommendations for Communication to Support Turbidity and TSS Monitoring*

Case Study	Recommendations for Communication to Support Turbidity and TSS Monitoring
Case Study #2 (Keeyask Generation Project, Gull Rapids, MB)	**ISSUE:** Sampling frequency was maintained until it was reported that ESC methods were effective, and turbidity and TSS levels were stable. **RECOMMENDATION:** Communication regarding site conditions (documents, reporting, photographs) should be provided regularly to agencies, stakeholders, and project team members so they can make informed decisions regarding site management and monitoring requirements moving forward. Where turbidity and TSS levels are within pre-construction conditions and stable, sampling frequency requirements can be reduced. Through effective communication, and by reducing sampling frequency, allocated time and resources to turbidity and TSS monitoring efforts can be reduced while still ensuring maintenance where required.
Case Study #5 (Residential Development, Vaughan, ON)	**ISSUE:** Initially, effective communication networks were not established, and a more reactive approach was taken to address turbidity and TSS level exceedances. **RECOMMENDATION:** Telemetry-based ESC technology can be applied, where appropriate, as a communication tool between proponents, contractors, project managers, and agencies. Alarms should be inspected to ensure that stakeholders are only informed to limit false alarms. Communication protocols should include when alarms are triggered, who receives communications, and identify what steps are required to address deficiencies. When alarms are activated to flag exceedances in turbidity and TSS, a notification goes to multiple project team members, and details of the alarm are recorded for future reference. This ensures an immediate response to issues on-site, informs project team members when a follow-up site visit and inspection was completed to address issues, and what the alarm was attributed to. Additionally, the maintained record of all alarms can be referenced to ensure environmental compliance and learn for future projects.
Case Study #4 Residential Development Project, Langley, BC)	**ISSUE:** Residential development was in close proximity to a high-traffic area, and therefore the general public often informed the Township of Langley and project staff about turbidity and TSS issues on-site. **RECOMMENDATION:** Collaboration between the general public, contractors, and project managers should be required to ensure issues are identified promptly. This will reduce turbidity and TSS target exceedances by taking a proactive approach to monitoring ESC effectiveness on-site.
Case Study #3 (Interior Lower Mainland Transmission Project, BC)	**ISSUE:** Turbidity and TSS targets were not established at the beginning stages of the project and as such, they were not explicitly stated in the contractual agreements with the selected contractor. Rather, the contract language was generic, and solely indicated that the British Columbia water quality guidelines for aquatic life would apply in the receiving environment. Due to issues with turbidity and TSS exceedances, targets were established in later phases of work. **RECOMMENDATION:** Language regarding expectations for ESC measures and turbidity and TSS monitoring (specifically to reduce the number of target exceedances) should be included in tender and contractual agreements and during initial discussions with the contractor. This would limit ESC methods becoming overwhelmed in the early phases of work, reduce requirements for remediation efforts, and limit the number of turbidity and TSS target exceedances overall.

"The likelihood of contributing additional sources of sediment to nearby waterways is exacerbated where construction-related activities are occurring."

7 Conclusions

Excessive suspended sediment levels in waterways can have adverse impacts on the morphology and aquatic ecology of systems. The likelihood of contributing additional sources of sediment to nearby waterways is exacerbated where construction-related activities are occurring. Site managers and inspectors are expected to execute pre-construction, during, and post-construction monitoring to ensure suspended sediment levels are within an appropriate range to maintain habitat, channel form and function, and not impair water quality. Monitoring practices, as well as ESC methods, are common and varied, but all work to reduce excessive suspended sediment levels from entering nearby waterways. The most commonly used metrics to assess suspended sediment is turbidity and TSS (NTU and mg/L, respectively). As such, targets are established for allowable turbidity and TSS levels (Tables 1 and 2, respectively), which ESC methods are developed to meet.

Targets for turbidity and TSS levels vary depending on jurisdictions across Canada (i.e., national, provincial, regional), target duration, rainfall, and season/weather patterns. There are two main types of turbidity and TSS monitoring methods: continuous and discrete. In many cases, continuous and discrete measurements are used together, applying both telemetry-based and hand-held systems. Based on a review of the relevant literature, case studies, and surveys completed by stakeholders, it was determined that advantages and disadvantages exist for both techniques. In terms of continuous monitoring, since the equipment is deployed for long periods of time, exposure to the elements and lack of maintenance can influence the productivity and accuracy of the instrument. In most cases, where both continuous and discrete turbidity measurements were completed, the discrete data were more accurate, while the continuous data were overestimated or underestimated. Since the discrete data are collected with hand-held sensors, calibration and maintenance are conducted routinely, and as such, the resulting data are more reliable. This speaks to the requirements of maintenance of continuous monitoring. Continuous monitoring requires additional cost and time, which should be considered before selecting this approach.

Case studies extracted from both literature and stakeholder surveys were assessed to understand different experiences with turbidity and TSS monitoring, the successes and limitations associated with turbidity and TSS monitoring, and the challenges associated with meeting turbidity and TSS targets. A variety of project types across Canada were included in the case study assessment, including large-scale and small-scale projects, residential developments, and linear infrastructure works. In all cases, site-specific targets were identified for turbidity and TSS within nearby watercourses, and multiple ESC measures were in place to limit exceedances of such targets.

To set appropriate targets for turbidity and TSS monitoring, background conditions need to be well understood. The literature-based and stakeholder-based case studies indicated that current environmental targets are difficult to meet throughout the lifespan of many projects, which is likely attributed to the natural variability that is associated with pre-construction conditions. Targets that are cognizant of limitations of ESC methods, as well as alternative monitoring protocols, need to be considered at the onset of planning and may need to be adjusted during implementation.

From the literature-based and stakeholder-based case studies, lessons to support turbidity and TSS monitoring practices across Canada were identified. Key lessons included (1) the importance of project phasing and weather constraints during earthworks, (2) considering sediment sources when developing turbidity and TSS targets, and (3) maintaining open and effective communication among project team members, contractors, stakeholders, agencies, and the general public. As such, future work should include greater emphasis of communication protocols, pre-planning and phasing to address potential deficiencies, and adaptive management strategies throughout the project duration. Considering these points in future projects will help close current gaps in ensuring ESC effectiveness, support turbidity and TSS monitoring protocols, understand turbidity and TSS exceedances, and improve the efficiency of identifying and addressing issues on project sites should they arise.

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Appendix A: Advantages and Disadvantages Associated with Discrete and Continuous Turbidity Monitoring

Turbidity Monitoring Method	Title	Advantages	Disadvantages
Hand-held for grab samples	**Site discharge points**	▪ Straightforward ▪ Low equipment cost ▪ Direct measurement of site runoff = greater accountability ▪ Problem areas can be pinpointed ▪ Can be carried out even in the winter	▪ Staff costs for sampling ▪ Limited to locations where grab sampling is possible ▪ Potential for error due to poor sampling technique ▪ Duration is not assessed
	Receiving water D/S and U/S of site	▪ Low equipment cost ▪ More readily comparable to existing CWQG for aquatic life ▪ Can be carried out even in the winter	▪ Need to determine pre-construction background turbidity ▪ Staff cost for pre-construction and during construction sampling
Continuous online turbidity measurement	**Outlet of sediment control pond**	▪ Concentration & duration = more accurate assessment ▪ Convenience – data logged at all times of day and night ▪ Set location means higher precision and comparability	▪ Higher equipment cost ▪ Staff costs for data QA/QC ▪ Site visits required to retrieve data – delays problem response ▪ Only pond effluent is assessed ▪ Not operational during winter
	Receiving water D/S and U/S of site	▪ Concentration & duration = more accurate assessment ▪ Convenience – data logged at all times of day and night ▪ Set location means higher precision and comparability ▪ Readily comparable to existing CWQG for aquatic life	▪ Higher equipment cost ▪ Staff costs for data QA/QC ▪ Site visits required to retrieve data – delays problem response ▪ Need to determine pre-construction background turbidity ▪ Staff cost for pre-construction and during construction sampling ▪ Not operational during winter ▪ Higher equipment cost ▪ Staff costs for data QA/QC ▪ Site visits required to retrieve data – delays problem response ▪ Need to determine pre-construction background turbidity ▪ Staff cost for pre-construction and during construction sampling ▪ Not operational during winter
Continuous online turbidity measurement with remote real-time access to data	**Outlet of sediment control pond**	In addition to those listed above: ▪ Convenience of remote access ▪ Opportunity for faster problem response	▪ Highest equipment cost ▪ Staff costs for data QA/QC ▪ Only pond effluent is assessed ▪ Not operational during winter
	Receiving water D/S and U/S of site	In addition to those listed above: ▪ Convenience of remote access ▪ Opportunity for faster problem response	▪ Highest equipment cost ▪ Staff costs for data QA/QC ▪ Need to determine pre-construction background turbidity ▪ Staff cost for pre-construction sampling ▪ Not operational during winter

Source: *Toronto and Region Conservation Authority (TRCA) [22].*

Appendix B: Commonly Used Erosion and Sediment Control (ESC) Technologies

Physical Barriers

Sediment Fence

Sediment fence is classified as a perimeter control or sediment retention device [48]. It is typically a non-woven geotextile that is fastened to a post with wire fence for support. A sediment fence is typically installed on construction sites to retain sediment and reduce construction effluent from entering nearby waterways. It is meant to act as a barrier to create ponding, thereby settling out soil particles as opposed to filtering runoff [22]. As such, it is applied to only receive a moderate amount of sheet flow , as opposed to flows that are concentrated [22]. To be most effective, a sediment fence should be installed on a level contour with additional controls such as cut-off swales or vegetative strips required if it must be used on slopes [22]. The sediment fence is trenched or keyed in with the geotextile material pulled taught between the supporting posts.

Silt Sock

Silt sock is a three-dimensional, tubular, sediment-trapping device that includes filtration material to reduce contributions of sediment to watercourses associated with near-water works. Commonly used in Ontario, Canada (North America), SiltSoxxTM (Filtrexx® Sustainable Technologies, Akron, Ohio) was introduced by Filtrexx™ as an ESC and pollutant removal. Typically, a silt sock is used in locations where diverting, cleaning, and filtering stormwater runoff is required. Additionally, silt sock is commonly used in combination with other ESC technologies to enhance the efficiency of the system for reducing turbidity levels [49].

Turbidity Curtain

Turbidity curtain is a geotextile that remains vertically suspended within generally larger, slow moving water bodies by being fastened to a floatation/buoy on top, secured to the bottom of the water body with anchors, and held in place with rope or cables [22]. They are most effective when installed parallel to the flow and are not recommended for applications where flows are perpendicular to the curtain. The large curtains generally require the use of heavy equipment to place and remove. Once removal is required, unexpected movements of the curtain can result in resuspension of the sediment, so careful removal is required [22].

Straw Bales

Straw bales are permeable barriers that intercept suspended sediments by reducing flow velocities when used along low gradient (less than 5 %) slopes. Installation on steep slopes is not recommended. When used in swales and ditches, two rows of straw bales should be used to form a continuous permeable flow barrier and should be extended up the sides to prevent outflanking. Straw bales are used in conjunction with other sediment controls such as a sediment fence, silt sock, vegetative strips, etc. [22]. Straw bales need to be installed so they maintain good contact with the ground surface by staking with T-bars or wooden stakes. When straw bales are removed or replaced, they can be used as mulch by breaking them apart [22].

Straw or Wood Fibre Logs

Straw or wood fibre logs are permeable barriers that intercept suspended sediments by reducing flow velocities when used along low-gradient (less than 5 %) slopes. Installation on steep slopes is not recommended. They have many applications, including along slopes to minimize sediment displacement; within ditches, swales, and channels to function as a small check dam; and to protect drains and inlets from sediment-laden water [22]. The logs are installed so they can maintain good contact with the ground surface and can be staked into the soil well with T-bars or wooden stakes.

Surface and Erosion Protection

Sediment Traps

Sediment traps are used to trap suspended sediment by intercepting sediment-laden runoff. They are a depressional area that is generally located in low-lying areas with a stable outlet spillway [22]. Sediment traps can treat up to two hectares of disturbed soils and should be constructed with 125 m^3 of storage capacity per hectare [22]. The embankments are mechanically stabilized or vegetated and need to be inspected and cleaned out regularly.

Sediment Basin

Sediment basins are used to treat disturbed runoff for drainage areas greater than two (2) hectares. They can be either excavated to form a depression or constructed with compacted earth to form an embankment with the banks being stabilized with vegetation [22]. They are efficient in trapping sediment and are ideal for long term construction phasing. Sediment basins are usually located in a low point, receiving both overland flow and flows from other ESC controls [22]. An outlet structure is used to control the release of the detained stormwater, typically in the form of a perforated riser outlet pipe with an outlet control/plate (in Ontario, commonly referred to as a Hickenbottom® pipe from Hickenbottom® Inc., Fairfield, Iowa) [22]. The sediment basin should be constructed with a forebay, using a turbidity curtain or berm to separate the forebay and outlet structure, and an emergency spillway with the ability to pass a 1:100 storm event[10] [22].

Erosion Control Blankets

Erosion control blankets and mats are rolled erosion control products that consist of prefabricated material layers that are typically biodegradable or photodegradable. They are applied to a disturbed soil surface to provide immediate stabilization and to help promote the growth of newly seeded areas [22]. Typically, blankets are woven fibres formed to make a thick fibre blanket within photodegradable netting whereas mats consist of natural fibres like coconut husk fibres that form a more robust and heavier material layer [22]. Erosion control blankets need to be installed with continuous soil contact and be secured with an adequate number of wooden stakes, biodegradable stakes, or metal staples [22]. The specifications and installations requirements differ between products.

Mud Mat

A mud mat is a vehicle tracking control used to prevent sediment from being transported off the site and onto paved surfaces. It should be constructed of large granular material at the full width of the site entrance for sites greater than one hectare, thereby providing a stabilized access and departure area. The granular material is a minimum of 20 m in length with a minimum depth of 300 mm. The mat requires periodic replacement depending on the level of contamination by vehicles [22]. To maximize sediment removal from a vehicle's wheels, a wheel washing system is often considered as an additional measure.

[10] *An event that has a 1% chance of occurring in any given year.*

Rock Check Dams

Rock check dams are flow interruption measures used to reduce runoff velocity and erosion potential within ditches and water drainage features. They are not particularly effective for settling out sediment as they don't allow for water to pond for prolonged periods of time [22]. A non-woven geotextile is incorporated into a rock check dam as an additional sediment control measure. Additionally, the sides of the dam are positioned approximately 0.5 m higher than the centre of the dam, with approximately 15 cm notched in the centre to concentrate flows into the centre, thereby reducing outflanking or undermining of the dam [22].

Interceptor Swales

Interceptor swales are intended to either convey site runoff away from disturbed slopes or to collect runoff from disturbed slopes to a sediment trap or basin at the downstream limit of the swale [22]. They are temporary graded measures that can be implemented any time during the construction period and are generally stabilized with seed, rip rap, or an erosion control blanket, especially if they are expected to function for more than 30 days [22]. They are generally used for low-gradient applications and are constructed with flow interruption measures such as rock check dams or silt socks, particularly when used in higher gradient situations.

Chemical Treatment

Flocculants and Coagulants

When physical barriers and surface and erosion protection methods do not meet water quality guidelines in terms of turbidity and TSS, chemical treatment systems are sometimes employed as a method of ESC [38]. The purpose of implementing chemical treatment systems is to reduce the amount of suspended sediment in stormwater that would be released using more traditional methods of ESC [38]. To reduce the amount of clays and fine-grained sediments in the system, chemical flocculants and coagulants are introduced. Chemical systems are used for a variety of water and wastewater treatment purposes and can be used to reduce total suspended solid levels in effluent from construction sites. Specifically, flocculants and inorganic coagulants neutralize the negative electrical charge on particles, which destabilizes the forces keeping colloids apart [50]. Further, flocculants gather the destabilized particles and cause them to agglomerate and drop out of the solution [50].

Phasing and Site Management

Construction site phasing is a management tool used by proponents and regulators to effectively implement erosion and sediment control on construction sites. Each project component is organized in a sequence to reduce the amount of sediment exposed at a given time. By utilizing only a portion of the construction site at a time, construction site phasing protects existing vegetation and reduces the time between initially clearing and final grading [22].

Appendix C: Preliminary Stakeholder Survey

Turbidity Monitoring: Addressing Gaps for Erosion and Sediment Control Stakeholders in Canada

Study Purpose

Identify and address existing knowledge gaps associated with the recently published CSA Standard for *Erosion and Sediment Control Inspection and Monitoring CSA/W202* (Canadian Standards Association, 2018).

Main Objectives

- Gain a better understanding of turbidity monitoring requirements across Canada.
- Identify challenges and successes experienced during specific construction projects where turbidity monitoring was a requirement.

Study Contact

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Survey Portion

Participant:

Name and Affiliation:

Participant Contact Information:

Project Location and Pertinent Site Information:

City/Township:

Surrounding Land Use:

Surficial Geology:

Ecologically Sensitive Areas:

Endangered or At-risk Species:

Other Information:

Project Type:

☐ Linear Infrastructure
☐ Residential Development
☐ Commercial Development
☐ Resource Extraction
☐ Other (Please specify)

Project Proponent:

☐ Single Proponent
☐ Multiple Proponents

Project Scale: (e.g., area of development; number of housing units; size of proposed infrastructure, etc.)

Brief description of activities occurring on-site:

Permitting Requirements:

☐ Department of Fisheries and Oceans Federal Fisheries Act
☐ Department of Fisheries and Oceans Species At-Risk Act
☐ Ontario Ministry of the Environment, Conservation and Parks Environmental Protection Act
☐ Ontario Ministry of Natural Resources and Forestry Endangered Species Act
☐ Others (Please specify)

Turbidity, TSS, or Ecological Targets: (e.g., 8 NTU Turbidity; 25 mg/L TSS; Maximum 24° Celsius water temperature, etc.)

ESC Measures on-site:

- ☐ Sediment Fence
- ☐ Silt Sock
- ☐ Siltation Basins and Traps
- ☐ Sediment Ponds
- ☐ Portable Water Quality Facility
- ☐ Aquatank
- ☐ Chemical Treatments
- ☐ Erosion Control Blankets
- ☐ Turbidity Curtain
- ☐ Straw Bales
- ☐ Filter Bag
- ☐ Mud Mat
- ☐ Rock Check Dam
- ☐ Interceptor Swale
- ☐ Coir Logs
- ☐ Vegetative Strip
- ☐ Others (Please specify)

Monitoring Protocol: (e.g., Discrete spot sampling; continuous, telemetry-based turbidity monitoring)

Brief Summary of Issues on-site: (e.g., compromised ESC measures; threshold exceedances, etc.)

Agency Response to Issues on-site:

Lessons Learned:

Additional Information or Recommendations for ESC Monitoring:

Appendix D: Generic Discussion Questions

1. What is the connection between the development and nearby watercourse?
2. Are any drainage features coming from offsite onto site? Local drainage?
3. Is there flow redirection around the site?
4. Can you describe the form and function of the associated watercourses?
5. Is there community involvement in the project?
6. What is the extent of infrastructure in the study site?
7. Is construction site phasing in place?
8. Cut and fill balance for the site to start with?
9. What type of seed mix is used for stabilizing?
10. Is there nurse crop to stabilize the area?
11. How long (temporally) is the site from initial clearing to finalization? How long will this take?
12. When did the survey participant start actively being on-site?
13. Are there third-party reviewers for ESC measures and monitoring? Or is this internal?
14. Does all drainage go to one location?
15. What type of permitting (if any) is required?
16. Does the province have local conservation authorities?
17. With regards to turbidity and TSS monitoring, what are the requirements for monitoring? (i.e., Where do you have to monitor? How often? What kind of equipment? Standard protocol for sample collection?)
18. How often is equipment calibrated?
19. Where in the water column is sampling completed?
20. Is there a specific time that water sampling must be completed following a rainfall event?
21. Is there a specific distance from the outfall where water sampling is completed?
22. Do you take water samples from the channel itself?
23. Are there issues with other inputs?
24. Is there a timeline for rectifying issues on-site?
25. How many units are available for treating effluent?
26. After ESC was installed, were there still exceedances in turbidity and TSS targets?
27. Are there concentration targets that ESC measures must stay below?
28. When there are issues on-site, is there more interaction with Agency staff?
29. Do local Agencies have monitoring guidelines that are standard for each site?

30. When there are issues on-site, is there immediate response? Is follow-up reporting required?

31. What is the response time of the contractor for major issues?

32. What is the weather link? Are flashy rainfall events common?

33. Are there any key lessons learned from this project to guide future ESC works?

34. Do you complete both ESC measure inspections and water quality sampling? Or, is water quality sampling the only proxy for identifying issues on-site?

35. Is there a certain level of training required for staff to complete ESC monitoring?

CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.