Water AECOM

Long Point Region Conservation Authority

Sediment Management Plan- Teeterville Dam FINAL

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Revision History

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1	28-Feb-18	ZP, BW, JLE	Client’s comments of Jan 4, 2018 were addressed.

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1. Introduction

The Long Point Region Conservation Authority (LPRCA) has hired AECOM to develop Sediment Management Plans (SMPs) for Vittoria Dam and Teeterville Dam both within Norfolk County, Ontario.

The main purpose of the study is to develop a Sediment Management Plan (SMP), to acquire the supporting information to make decisions about the dams through a future environmental assessment process. As such, the following components are being completed:

- Data Collection and Review;
- Survey and Sediment Volume Calculation;
- Sediment Testing and Disposal Options;
- Sediment Management Plan including Recommendation on Monitoring Program and Sediment Release Contingency Plan; and
- Project Coordination and Meetings

The present report provides the SMP for Teeterville Dam. It investigates feasible sediment management methods, focusing on those best suited for the reservoir, and providing recommendations for future sediment management operations and project monitoring.

2. Background Review

Teeterville Dam is located on Big Creek in the Town of Teeterville (**Figure 1**). The dam consists of an earthen berm and a concrete spillway structure controlled by wooden stop logs. The reservoir area is approximately 15 ha.

Big Creek is the largest watershed in the Long Point Region Conservation Area with a total area of 750 km^2 (Figure 1). The drainage area upstream of the dam is about 200 km^2. Landuse in the upstream area is mainly agricultural (~70%). Historically the dominant crops have been tobacco and orchard crops (LPRCA, 1978). No major industrial or commercial activity is identified on the catchment.

Downstream of the reservoir, Big Creek flows through a number of communities (the largest being Delhi) in a southerly direction, connecting with other streams before discharging into Lake Erie near the port community of Port Rowan.

Wetlands are present at the mouth of Big Creek and are part of the Long Point Wetland Complex, which covers an area of 75 km^2 and helps to reduce the nutrient and sediment contribution entering Lake Erie.

Review of historic aerial imagery (1954 and 2017) shows very little change in the catchment's features and land use (see **Figure 2**). The 1978 watershed report identified phosphorus and nitrate from fertilizers as sources of water quality impairment (LPRCA, 1978).

Pesticide use in the watershed was characterized as heavy but quantifiable data were not available. In more recent time, pesticides use has been decreased overall by 45% over the last 25 years (OMAFRA, 2008). The active ingredient of pesticide used on tobacco fields is napropamide, with a short half-life (in the order of weeks; (Cornell University, 1993), and therefore it is not expected at measurable quantities in the sediment deposits.

A Dam Safety Review and Condition Assessment (DSRCA) was completed for Teeterville Dam (AECOM Canada Ltd., 2016), including: a background review, desktop natural heritage review of terrestrial and aquatic heritage features, dam inspections, a hydrotechnical assessment (including dam break analysis and flood mapping), Hazard Potential Classification and selection of Inflow Design Flood. Previous work also included assessment of the structural integrity of the dam, geotechnical assessment, and a reservoir sediment quantity and quality assessment.

A bathymetric survey of the top of sediment in the reservoir was completed, and this information, along with an estimate of the bottom elevation, was used to estimate the sediment volume, at about 320,000 m^3.

Three sediment samples were collected in 2016 and analyzed according to the requirements of O.Reg. 153/04 (MOECC, 2011). Results indicated that sediment quality was similar to that of background soil in Ontario, and met quality requirements for release to the downstream Big Creek (in terms of sediment quality requirements) or for disposal on site. Detailed results are provided in section 3.3.

Figure 1: Location of Teeterville Dam on Big Creek, within the Long Point Region Conservation Authority (Map Source: LPRCA, 2014)

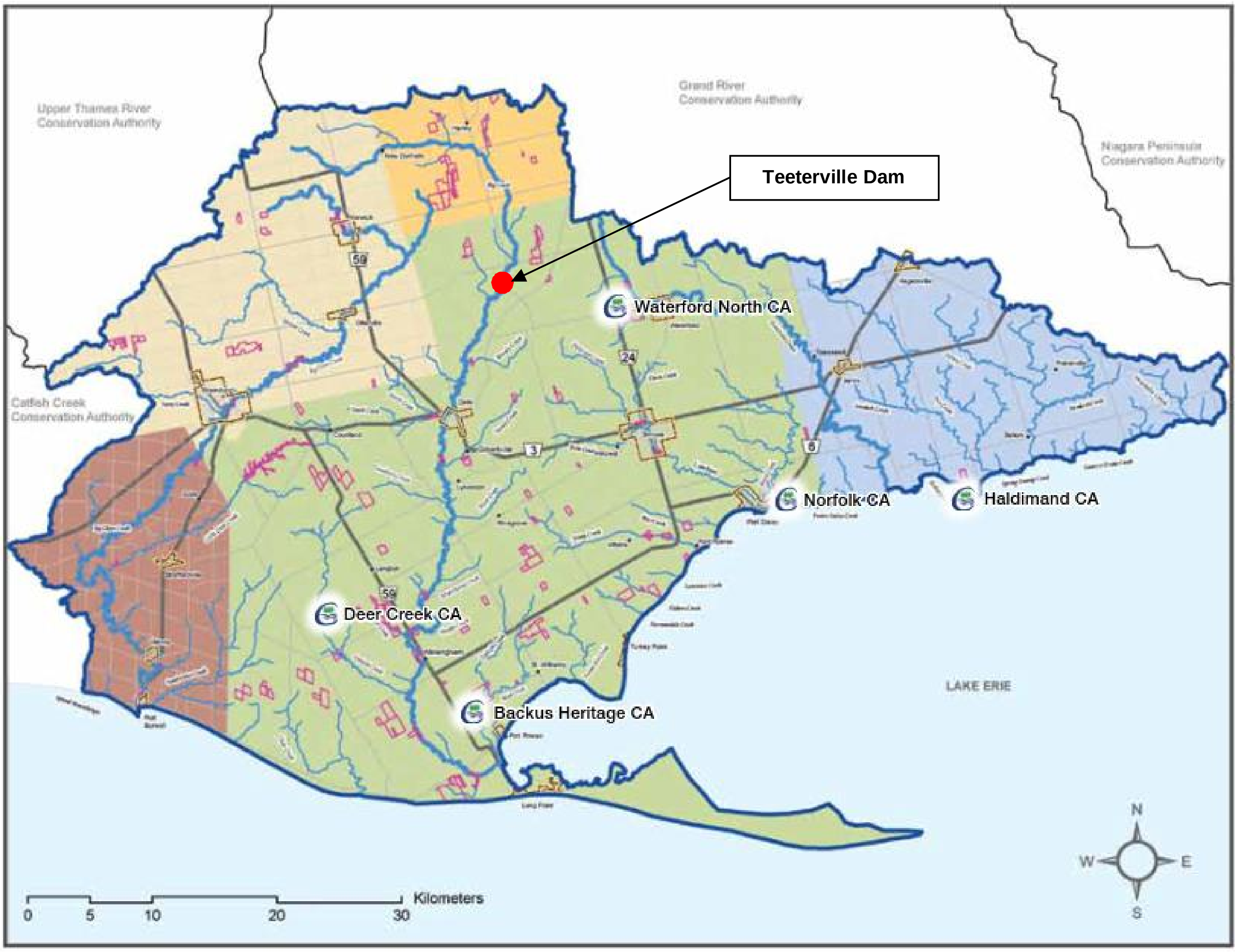
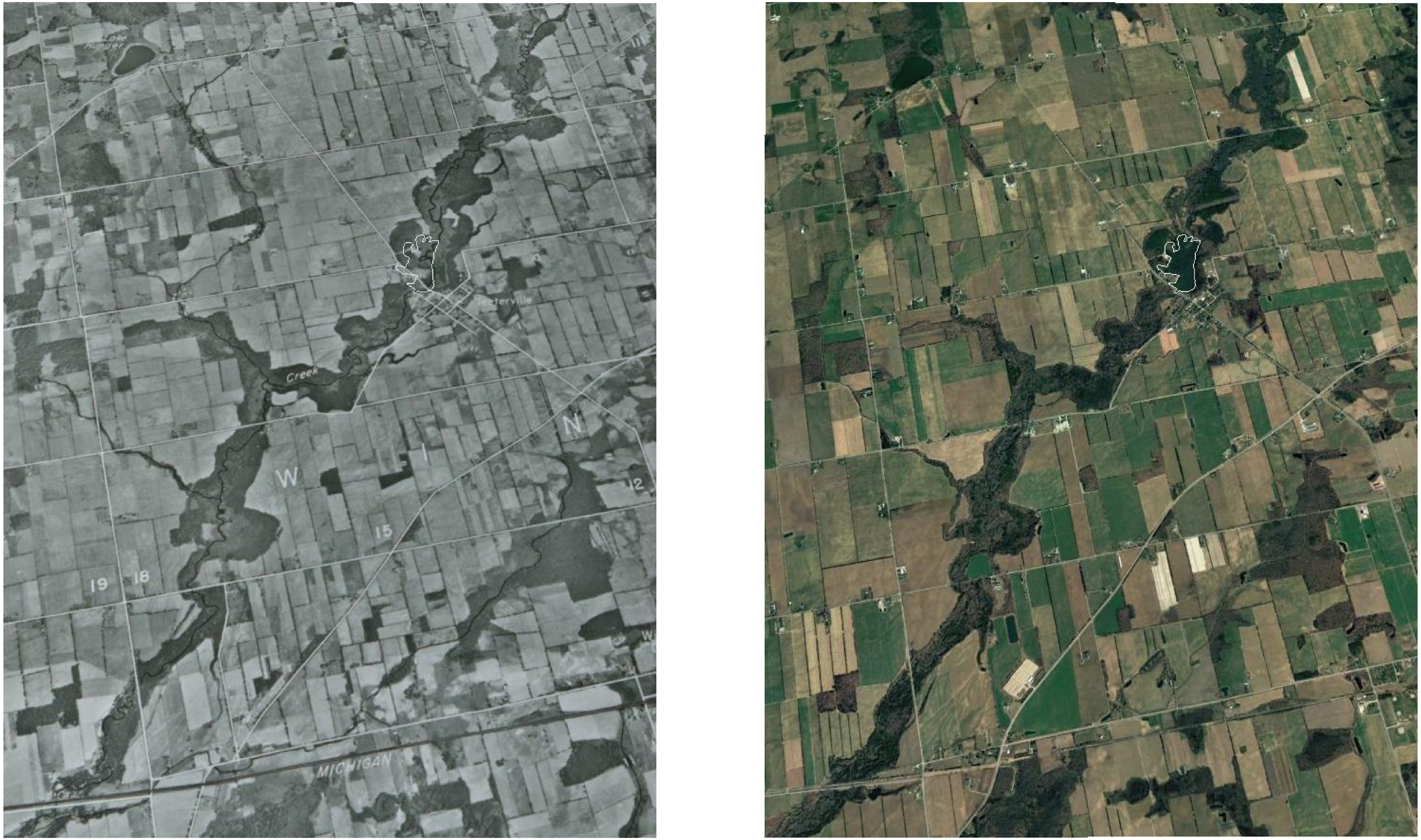


Figure 2: Aerial Imagery showing Big Creek and Teeterville Reservoir in 1954 and 2017



3. Characterization

3.1 Dam Condition and Recommended Actions

Teeterville Dam consists of a 160 m long earth berm and a 31.5 m long four bay concrete spillway structure at the south end of the reservoir. Flow is controlled with four 200 mm (nominal) wide timber stop logs at each bay. The dam consists of an upstream wall and downstream base slab supported by 3 piers and 2 abutments. The overall height of the dam from the top of the concrete base slab to the top of the piers and upstream wall is 3.1 m and 2.12 m, respectively. There are concrete wingwalls beyond each end of the structure related to the bridge. Based on the dam survey, the berm is approximately 4 m high, with side slopes of approximately 2H:1V.

The dam abutments extend northerly and are integral with the bridge abutments, with support a steel truss superstructure. Currently, the bridge is closed to public access due to safety concerns. However, the walkway is used by LPRCA staff for accessing the operating platforms located on the piers and abutments, for stop log removal and installation. The operating platforms include steel handrails. A General Arrangement Drawing of the Dam is provided in Figure 3.

The 2016 DSRCA indicated a number of issues with the Teeterville dam and recommended actions (Table 1).

Table 1: Summary of Issues and Recommended Actions

Component	Condition and Issue	Recommended Action
Bridge	Limited inspection of bearings conducted Severe corrosion of steel on the bolts, nuts, plates, and truss components connected to the bearings; pack rust and severe section loss; Some anchor bolts deformed; some surface corrosion Bottom chord members were in poor condition with medium to severe corrosion and light to medium pitting of the members; some very severe section loss Northerly three stringers were fully exposed and not supporting any decking No coating to protect steel	Limit access
Dam	Limited inspection of lower portions of foundation and upstream dam face, and abutment sections upstream Concrete abutments: medium to severe disintegration, medium scaling and spalling, and narrow to wide horizontal cracking with efflorescence staining Severe disintegration and numerous narrow horizontal cracking (with vegetation through the cracks) on the west abutment below the bridge Concrete piers downstream had light honeycombing, light to severe spalling, light to medium delamination, medium to severe erosion and exposed reinforcing steel at the base of the center and west pier.	Repair concrete on wingwalls, piers and abutments (remove up to 50 mm of concrete, abrasive blast clean and repair patches by form and pump method) Repair steel truss structure
Stop Logs	Limited inspection conducted Section loss, some decay, checks, and splitting Significant amount of water leaking between the logs	-
Downstream slab	Drilling indicated concrete was in fair to good condition Slab constructed on rock fill, which is not ideal Base slab was undermined along a large portion of the south end	Grout void below the base slab and subgrade
Foundation	Likely founded on an aggregate material, such as rock fill, which has been significantly undermined	Stability improvements, e.g. coring and grouting of soil anchors through the abutments and piers
Internal erosion	Embankment fill and underlying native soils are generally fine-grained, poorly graded, uniform sands and silts, with low plasticity, i.e. extremely erodible and offer little piping resistance; potential for the loss of fine soil particles, and internal erosion or piping	Remove trees from dam surface; divert runoff from dam surface, regular inspection

3.2 Reservoir Survey and Volume Calculation

In order to estimate the sediment volume, a bathymetric survey of the reservoir was conducted in 2016 using an eco-sounding sonar device, where depth permitted. Bathymetric survey was conducted along a longitudinal section along the middle of the reservoir as well as several sections across the reservoir. In areas shallower than 0.3 m, manual measurements were taken.

The sediment volume was calculated by creating two surfaces: one for the top of the sediments and one for the bottom of the reservoir. The surface for the bottom of the reservoir was estimated assuming a straight line connecting the bottom of the channel just upstream of the reservoir to the bottom of the channel just downstream of the dam. The total sediment in the Teeterville reservoir was estimated in 2016 to be approximately 321,500 m^3.

Figure 4 provides the results of the survey and the plan and profiles used for sediment volume estimation.

The methodology for estimating reservoir and sediment volume was improved as part of the current project to account for a more natural channel shape (U-shape) with the low points defined where the channel would be. The upstream channel is about 14 m in width, with a gentle rise of 0.1m to the bottom edges and another 0.5 m to the top of banks for a width of 16 m bank to bank. From the shoreline of the reservoir, there is an immediate drop of 0.5 m at a 1 m distance from the shoreline (shoreline bottom of the bank).

The upstream sediment depth was also changed from zero to 0.5 m based on observation during sample collection in 2017. The internal channel centerline slope will, therefore, be from ~234.34 m at the north end to ~231.74m at the south end. The new surface is shown in Figure 4. Total sediment volume was calculated at about 160,000 m^3. Total reservoir volume (with sediment) was estimated at about 224,000 m^3, indicating that 70% of the reservoir is filled with sediment.

It is recognized that, similar to the simpler methodology applied in 2016, this methodology also has limitations in terms of the bottom surface. Therefore, the average of these two values is suggested as the amount of sediment accumulated in the Teeterville reservoir, at approximately 240,000 m^3.

Figure 3: Teeterville Dam General Arrangement and Components

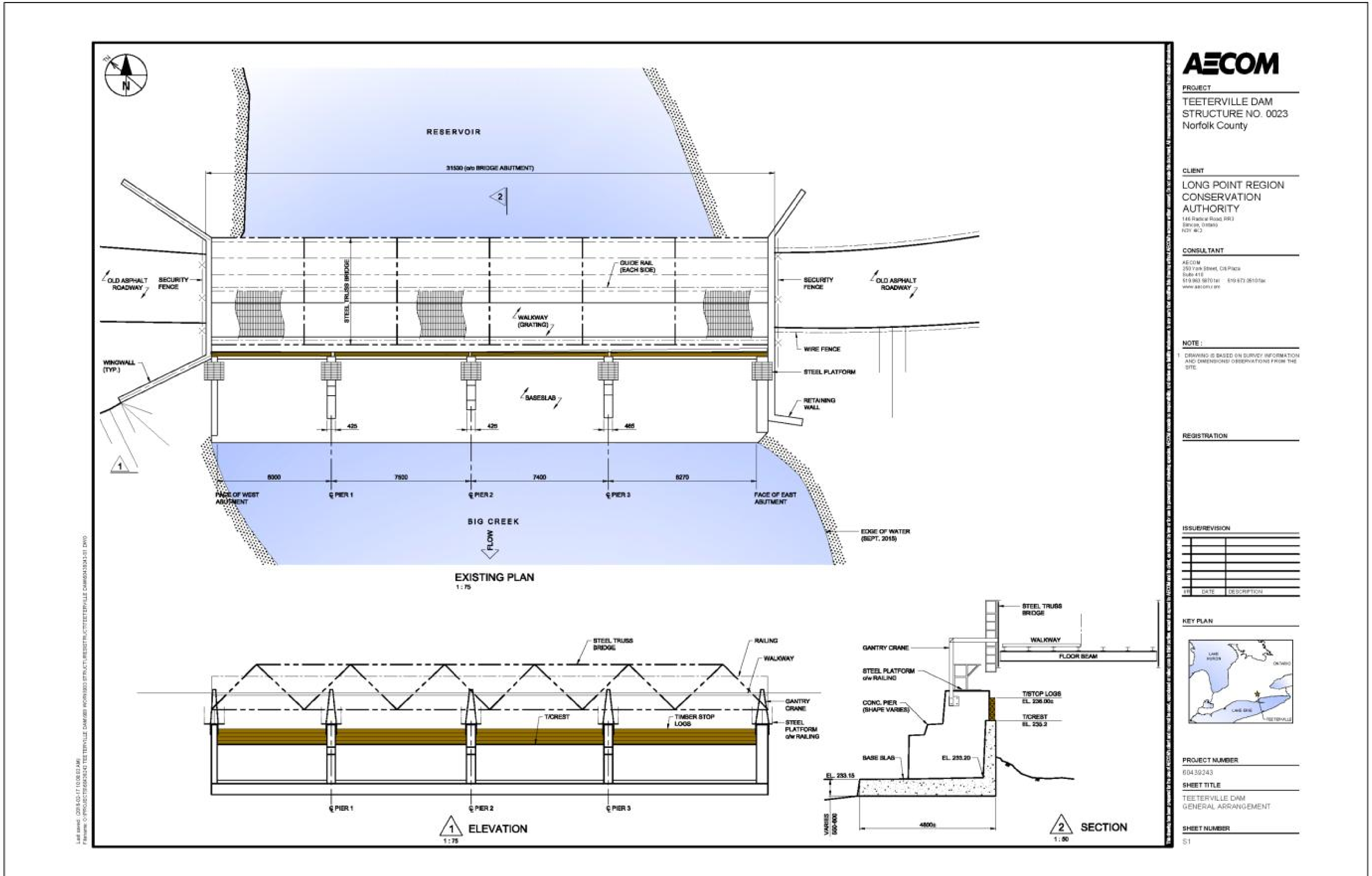
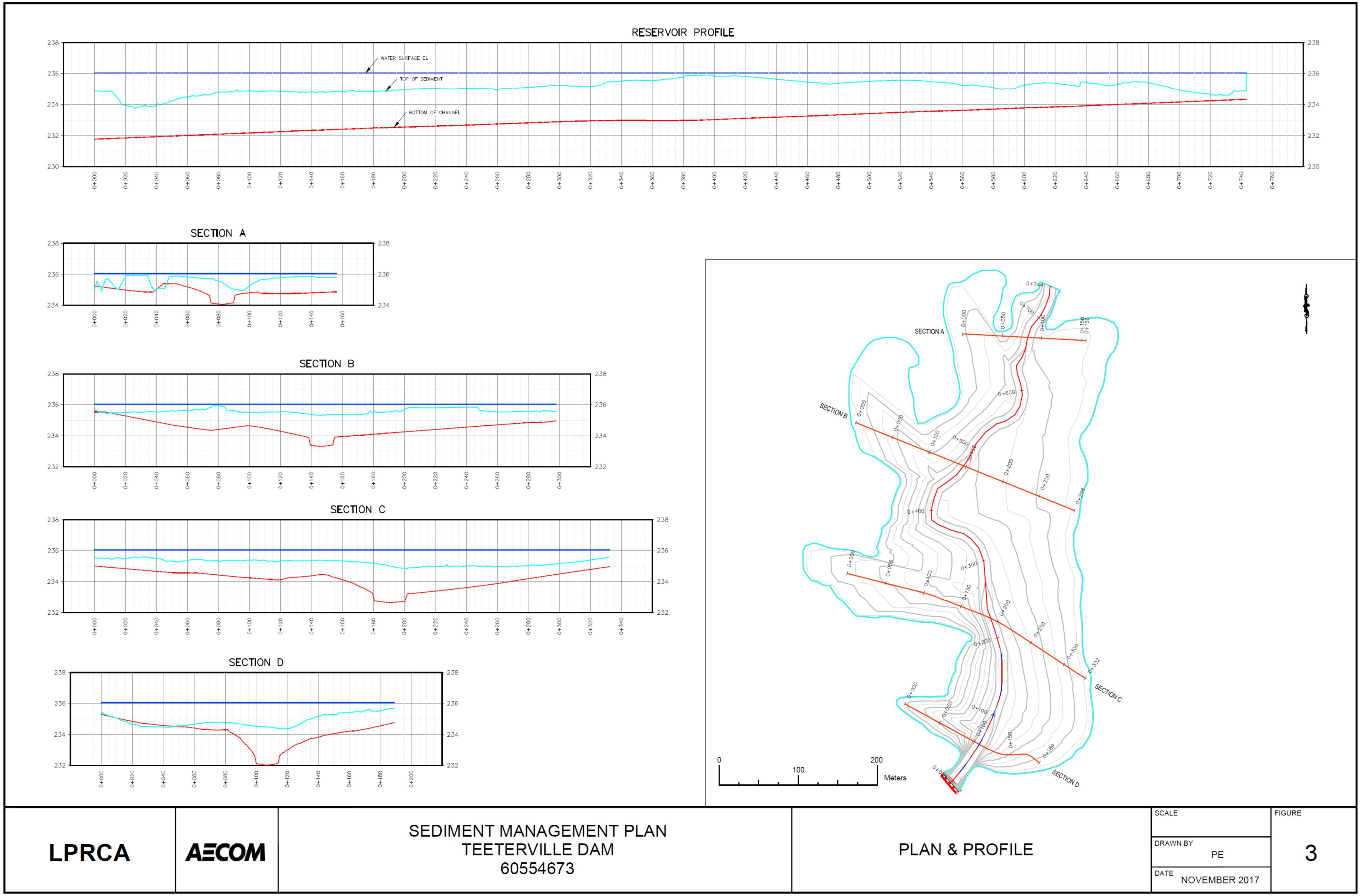


Figure 4: Teeterville Reservoir Survey (2016) and Plan and Profile (Updated in 2017)



3.3 Sediment Testing

Three sediment samples were collected in 2016 (see Figure 5 for locations) and analyzed according to the requirements of O.Reg. 153/04, indicating that sediment quality was similar to that of background soil in Ontario, and met quality requirements for release to the downstream Big Creek (in terms of sediment quality requirements) or for disposal on site.

In 2017, seven additional sediment samples were collected from Teeterville Dam's reservoir (see Figure 5), and analyzed for a variety of parameters to determine the quality of the sediment and determine its suitability for reuse or disposal, as well as to help with developing management options (see Table 2 for sediment sampling and analysis plan).

Core sampling: Samples were collected at regular intervals by advancing handheld core sampling equipment through the stratified layers of sediment. Sampling equipment was decontaminated between intervals using a distilled water rinse and methanol between samples. At each location, the coring equipment was advanced until refusal or until the base of the pond was encountered.

Composite samples: A maximum of ten subset samples were incorporated into any one discrete confirmatory sample to be submitted for laboratory analyses. The confirmatory samples were placed in dedicated sampling containers immediately following the retrieval of the sample from the core hole. The samples were placed in a cooler on ice and samples that are selected for potential chemical analyses will be delivered to a CALA (Canadian Association for Laboratory Accreditation) certified laboratory upon the conclusion of the sample collection activities. All sampling and decontamination procedures were consistent with those established by the MOECC, as documented in "Guidance on Sampling and Analytical Methods for Use at Contaminated Sites in Ontario, May 1996" (MOECC, 1996).

Comparison against MOECC guidelines was completed for four samples in locations where sediment accumulation was expected to be higher:

- Complete Metals Scan;
- Volatile Organic Compounds (VOCs);
- Petroleum Hydrocarbons (in the range of F1 to F4)/BTEX;
- Polycyclic Aromatic Hydrocarbons (PAHs);
- Organochlorinated Pesticides; and
- Grain size and bulk density
- pH, Base, Neutral and Acid Extractables

Other information that was obtained from sediment analysis included insight into the source of sediment, and transport behavior through analysis of six samples for:

- Fats, oil and grease (FOG);
- Inorganics (including TSS, TOC, Ammonium& ammonia-N, nitrate &nitrite-N, TKN, TP, available phosphorus, available potassium); and
- E-Coli

Table 2: Additional Sediment Sampling and Analysis Plan for Teeterville Reservoir (2017)

Sample ID	Location Description	Grain size and bulk density	MOECC Parameters*	FOG, Inorganics, E-coli
T1	Upstream channel/ Contaminant input	P	û	P
T2	Sediment accumulated	P	P	û
T3	Downstream of inlet/ Contaminant input	P	û	P
T4	Sediment accumulated	P	P	û
T5	Downstream of inlet/ Contaminant input	P	û	P
T6	Sediment accumulated	P	P	û
T7	Downstream channel/ Contaminant output	P	û	P

* Grain size and bulk density not included.

Figure 6 provides an overview of sediment quality results from the 2016 DSRCA. It shows all contaminants analyzed (and detected), which also have corresponding guidelines. All concentrations are below background sediment concentrations as defined by the Regulation, except for arsenic at TV-2, which is slightly above the background level. A number of organic compounds exceed background soil conditions by up to 3.5 times for TV-3. Comparison of the results to generic soil conditions indicates that only Benzo(a)pyrene is above the guidelines for Agricultural uses for TV-3.

Physical properties for 2017 samples are shown in Table 3. Based on percent of particles larger than 75 µm, samples T1, T2 and T7 were categorized as coarse while other samples are mainly fine sediment. Fine sediments have tended to accumulate in the wider downstream section of the reservoir, Table 3 also provides an estimate of the percentage of sediment quantity accumulated in each sampling area (see Figure 5). Based on these estimated percentages, about 64% of the accumulated sediment is fine. Taking into account the moisture content and density of each sample, an estimated 60,000 tons of fine solids is accumulated in the reservoir.

2017 test results for parameters detected are shown in Figure 7. All samples analyzed for compliance with O.Reg. 153 (T2, T4 and T6), met Table 1 Sediment standards, as well as agricultural soil standards, i.e. all concentrations, were below method detection limit of below background sediment concentrations and soil for agricultural uses. Benzo(a)pyrene which has been measured at elevated concentrations with respect to agricultural soil was not detected in samples collected in 2016.

Concentrations of metals regulated by Ontario for Non-Agricultural Source Materials (NASM; (OMAFRA, 2012)) were all below applicable standards.

Figure 7 also depicts parameter values for FOG, inorganics, and E-Coli. Measured concentrations are generally higher in fine sediment within the reservoir (T3 and T5), relative to the coarse sediment upstream and downstream of the reservoir (T1 and T7). Oil and grease were only measured at T3, while available phosphorus and potassium were measured at T3 and T5. NASM has definitions for levels of nutrients and organic matter that can be beneficial to soils and crops. The concentration of these constituents will be a factor in timing and duration of drawdown. For instance, while gradual release of sediment has merits (see section 4), a prolonged discharge of available nutrients may result in adverse effects downstream.

Table 3: Physical Properties of Sediment Samples

Parameter	Units	T1	T2	T3	T4	T5	T6	T7
% >75um	%	98.4	79.3	19.1	24.5	17.3	41.6	98.7
% Moisture	%	17.7	46.7	73.9	73.4	73.9	63.2	15
Density	kg/m3	1920	1420	1210	1240	1230	1270	1630
Total Solids	%	82	-	26.9	-	27	-	81.1
Percent sediment accumulated within the reservoir	%	-	18	22	16	18	26	-

Figure 5: Sediment Sampling Locations (and Associated Areas) for Teeterville Reservoir

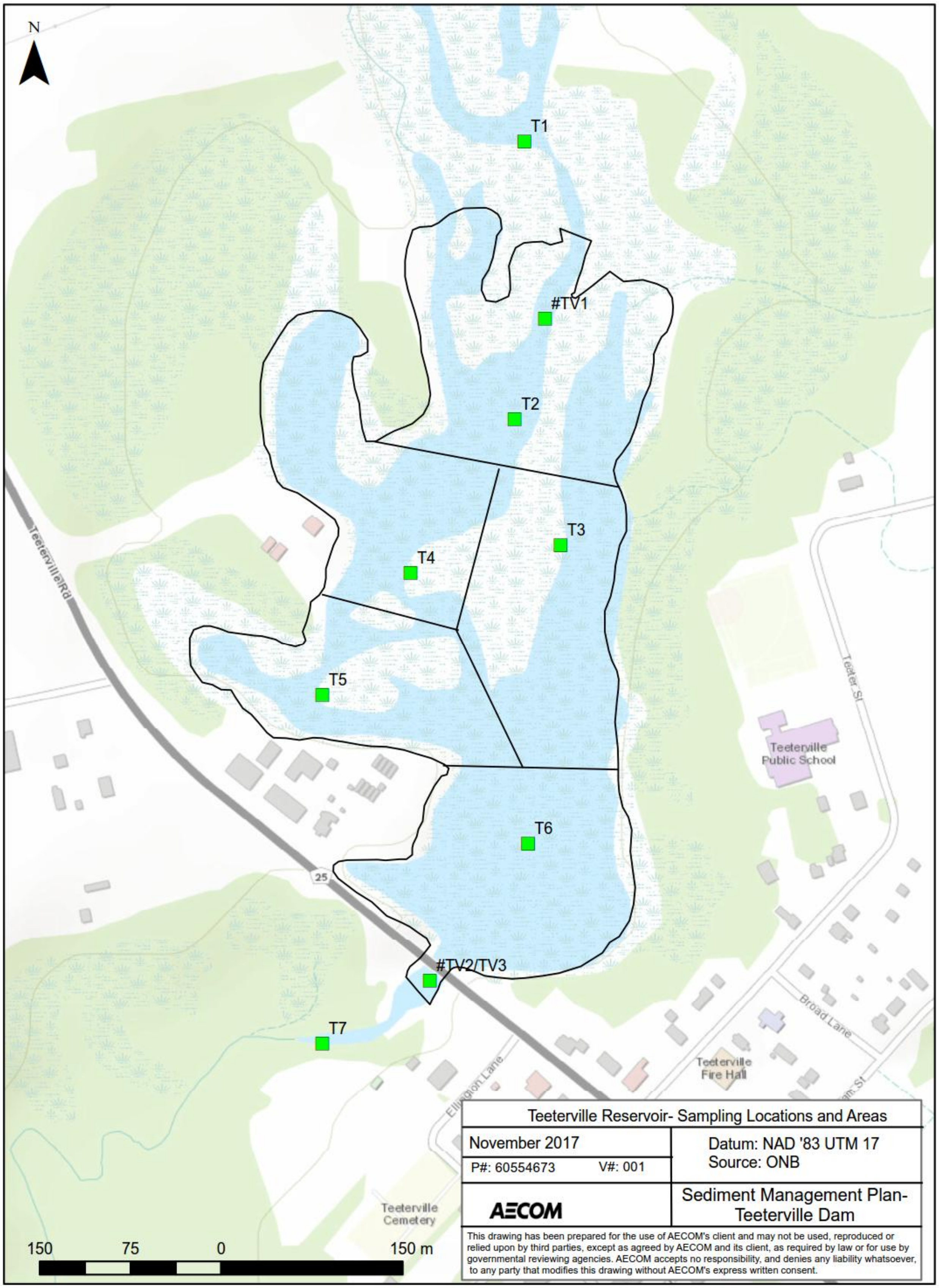
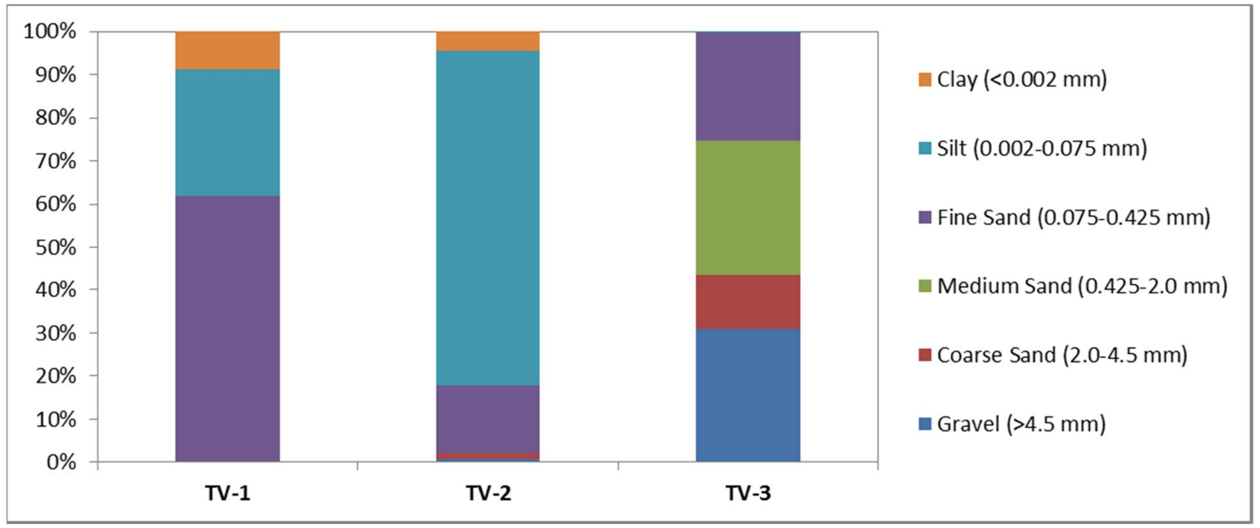
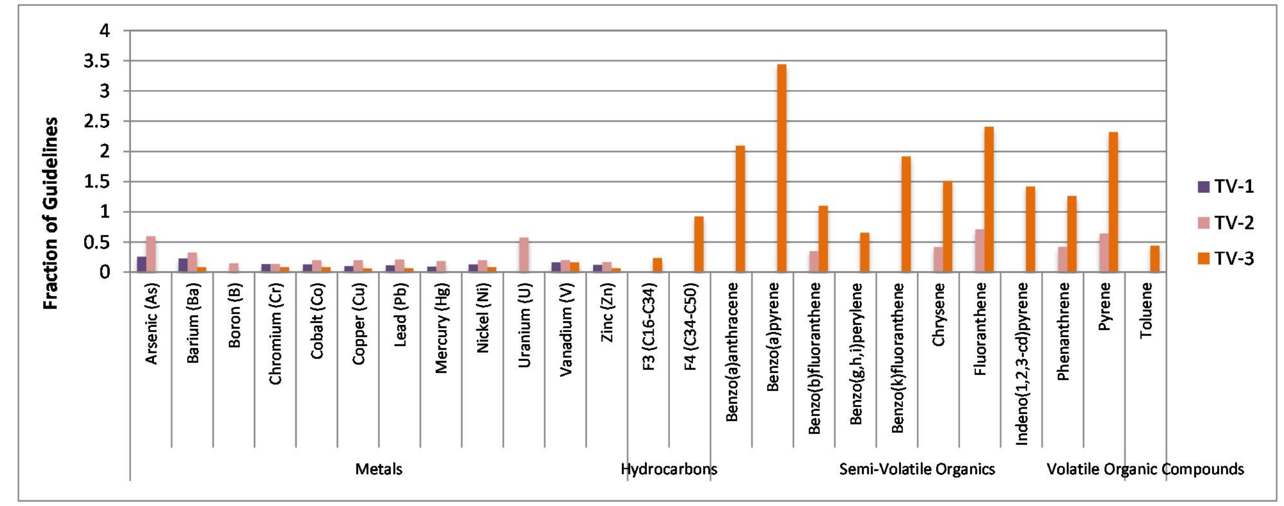


Figure 6: Sediment Quality Results for Teeterville Samples- 2016

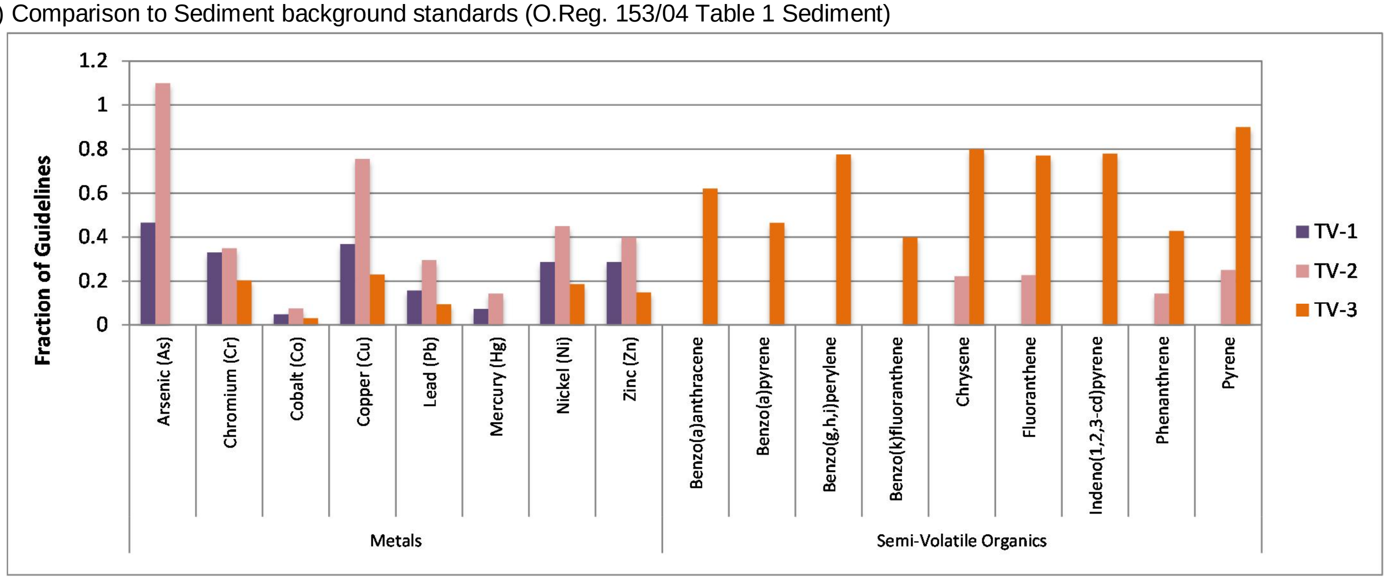
a) Grain size



c) Comparison to Soil background standards (O.Reg. 153/04 Table 1 Soil- Agriculture or other)



b) Comparison to Sediment background standards (O.Reg. 153/04 Table 1 Sediment)



d) Comparison to Soil generic standards in a potable groundwater condition (O.Reg. 153/04 Table 2 Soil- Agriculture or other)

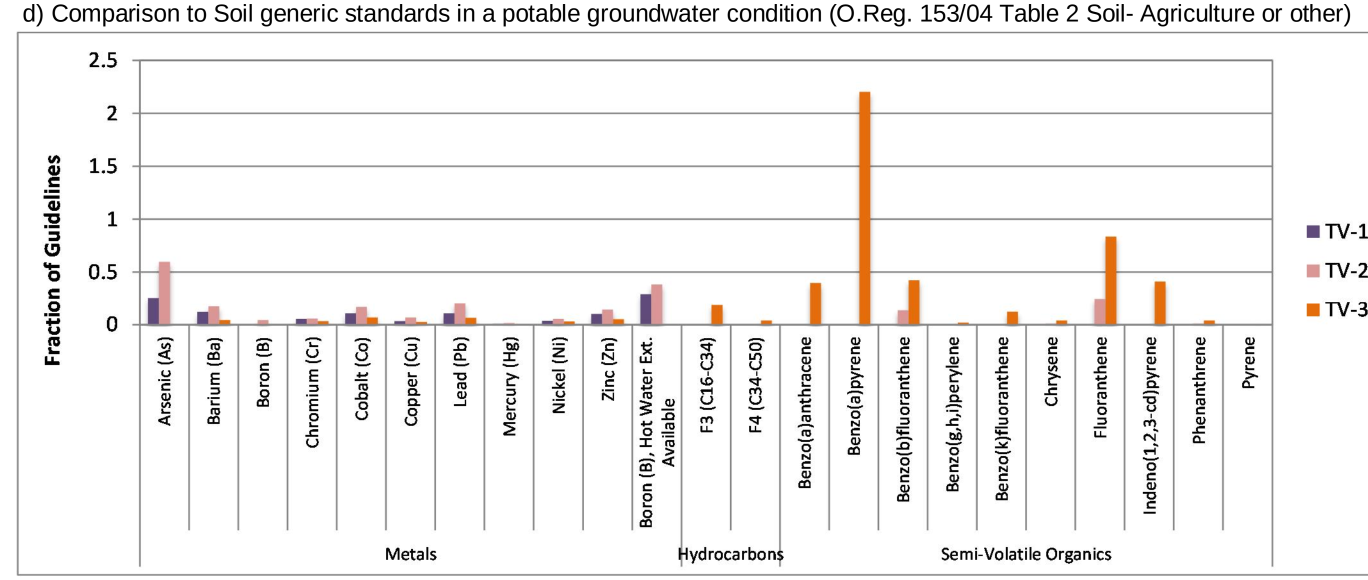
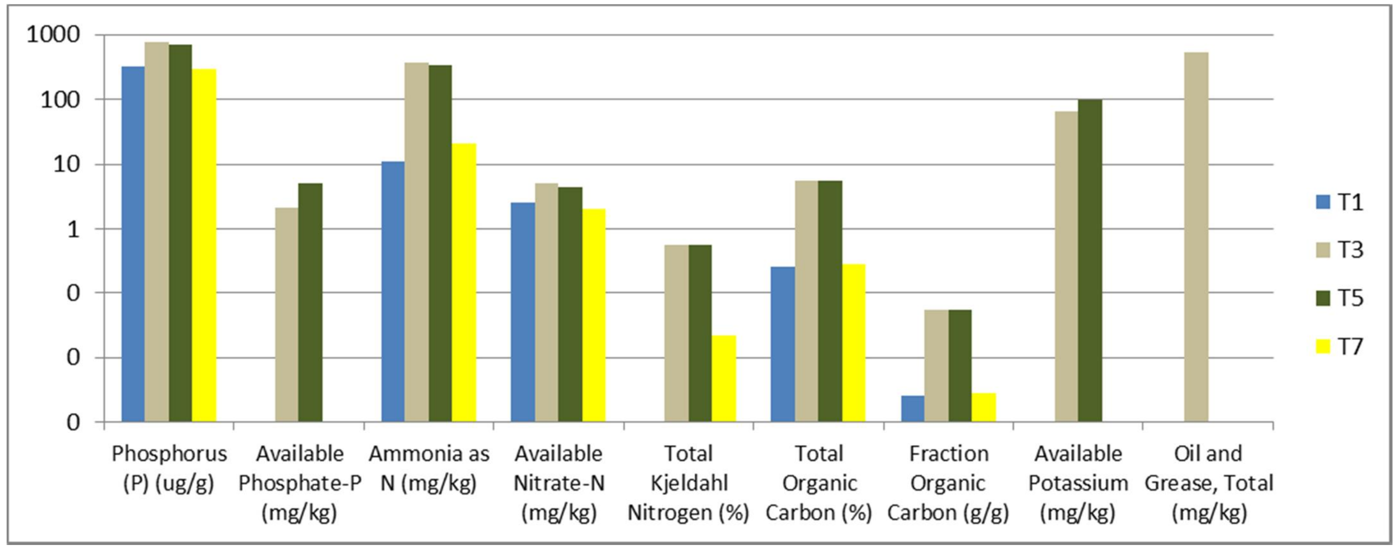
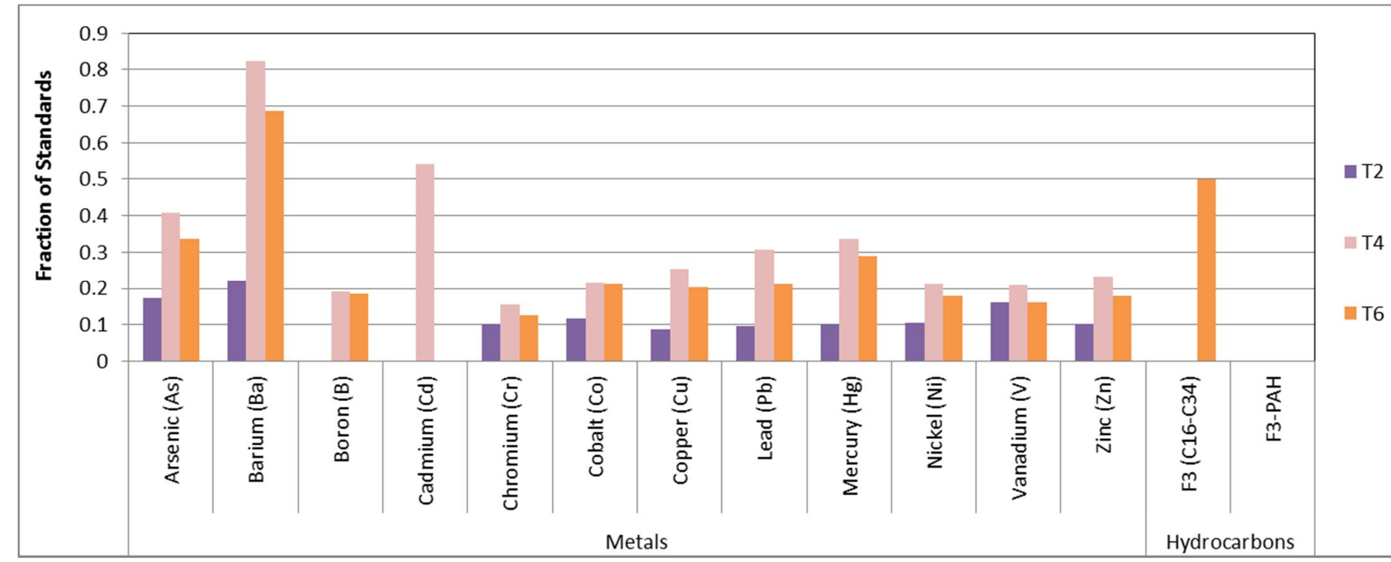


Figure 7: Sediment Quality Results for Teeterville Samples- 2017

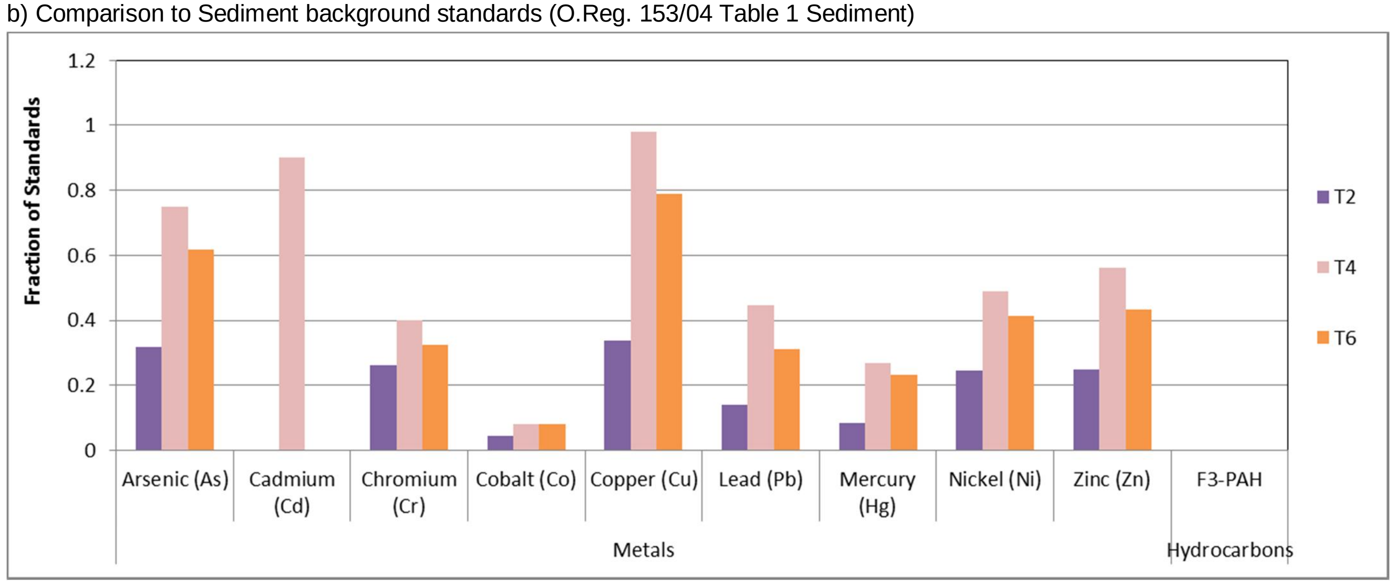
a) FOG and Nutrients (logarithmic scale)



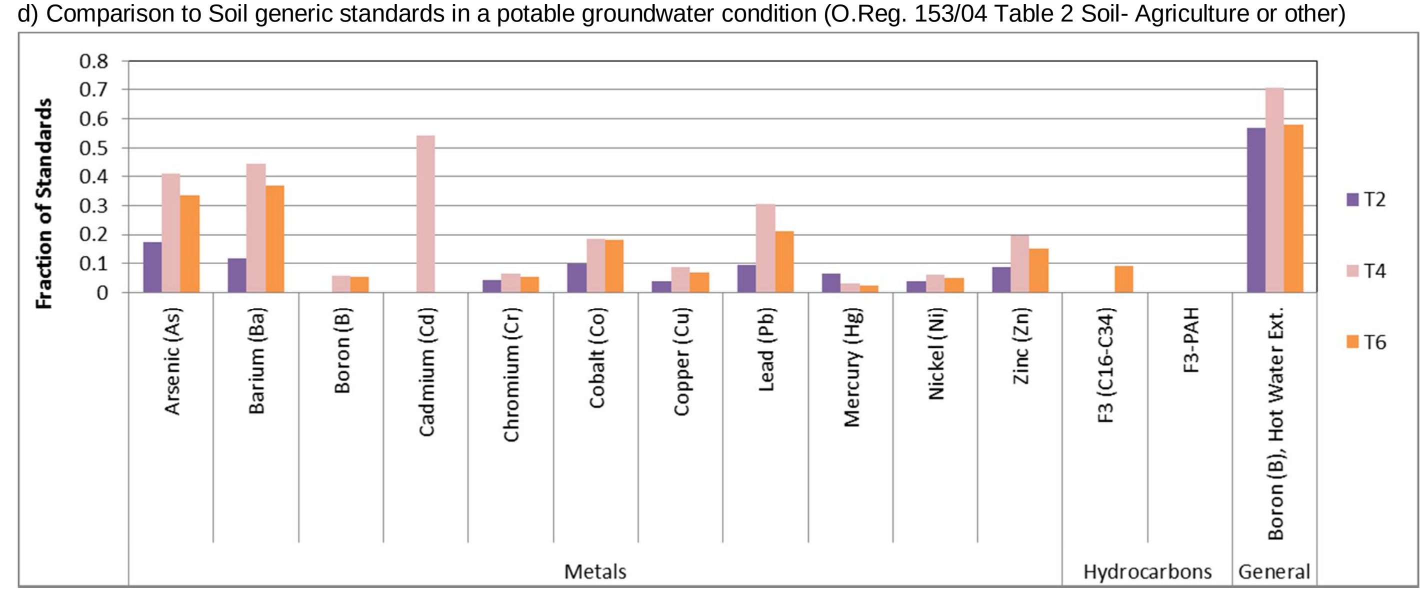
c) Comparison to Soil background standards (O.Reg. 153/04 Table 1 Soil- Agriculture or other)



b) Comparison to Sediment background standards (O.Reg. 153/04 Table 1 Sediment)



d) Comparison to Soil generic standards in a potable groundwater condition (O.Reg. 153/04 Table 2 Soil- Agriculture or other)



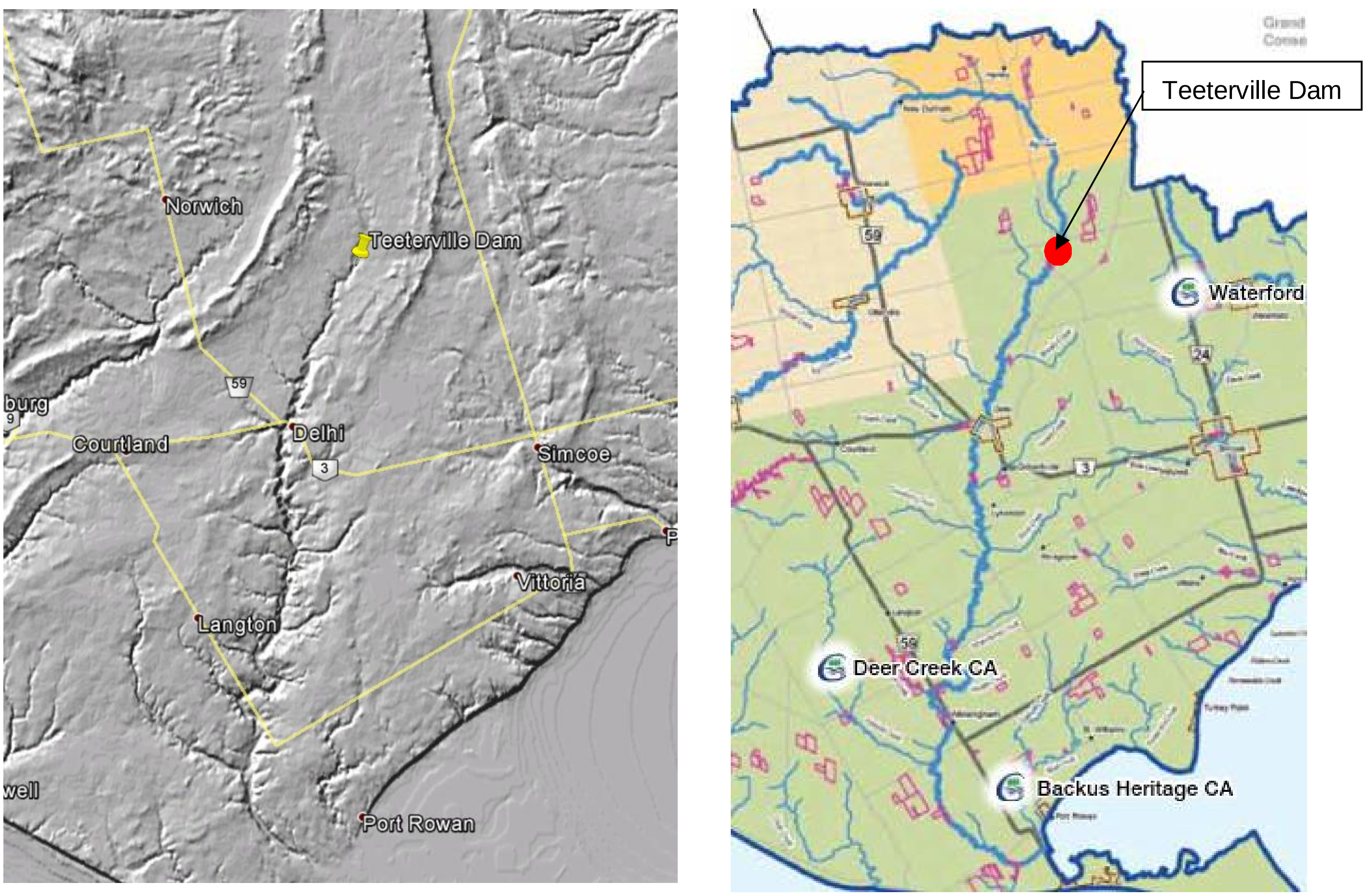
3.4 Downstream Environment and Water Users

Downstream of Teeterville dam, Big Creek flows in a general south direction, discharging to Lake Erie close to Long Point (Figure 6). The Big Creek watershed is large, spanning the LPRCA territory from north to south, and narrow, with tributaries joining the main creek particularly towards the lower end of the catchment. Teeterville Dam is located in the upper portion of the watershed – approximately 200km^2 (27%) of the 750km^2 is upstream (**Figure 6**). Downstream, Big Creek flows through glaciolacustrine deposits (sand, gravelly sand and gravel, nearshore and beach deposits) of the Sand Plains physiographic area (Chapman & Putman, 1984).

Through the DSRCA, a desktop review of background information was completed to obtain an understanding of both terrestrial and aquatic heritage features within the Teeterville Dam study area. Results from fish community surveys performed by LPRCA from 2002 to 2005 show that Big Creek receives a healthy run of migratory Rainbow trout and Chinook salmon each year. A total of 15 Species At Risk (SAR) are likely to be present within the study area, nine (9) aquatic SAR and six (6) terrestrial SAR. Provincially Significant Wetland Complex is located throughout the majority of the study area and Several Life Science and ANSI sites were identified within the study area and/or in close proximity to the study area.

Teeterville Dam itself is located within the community of Teeterville with little development in the area immediately downstream of the dam. A residential building is located immediately downstream of the dam; however, its lowest elevation appears to be above the reservoir water level. Town of Delhi is located approximately 24 km downstream of Teeterville Dam. Delhi Drinking Water System is a combination well and surface water supply (intake at Lehman Dam on North Creek, a tributary of Big Creek). The system consists of two raw water well sources, a surface water filtration plant, and

Figure 8: Shaded reflief within the Big Creek watershed (Sources: (OGSEarth); LPRCA, 2014)



4. Sediment Management Plan

4.1 Sediment Management Alternatives

The appropriate approach to sediment management at Teeterville Dam will largely depend on whether the “Operation (and Repair)” or “Dam Removal” alternatives are to be pursued in relation to Long Point Region Conservation Authority’s management of the dam itself. Alternatives for sediment management include (in approximate order of most to less costly):

- sediment removal
- installation of sediment traps (and removal)
- stabilization
- river erosion
- no action

These options are briefly outlined and a matrix highlighting their potential applicability under the “Operation (and Repair)” or “Dam Removal” approaches, together with key advantages and disadvantages, is presented in Table 4 (after Randle and Greimann, 2008; James and Schiff, 2013).

Sediment Removal- Hydraulic or mechanical dredging or conventional excavation may be used for removal of all or portion of sediment for disposal on or off-site. This is the most costly alternative, and the most conservative approach. The cost of mechanical removal may be reduced if the sediment can be removed as the reservoir is drawn down, where some of the sediment is allowed to stabilize within the reservoir. Hydraulic removal is undertaken from a barge and requires large areas of adjacent land where sediment is pumped and allowed to dry

Sediment trap- Large pits are excavated in the channel to trap sediment. This is typically effective for a limited volume of coarse sediment. Fine grained sediments would pass over sediment traps, being transported in suspension. Traps are also only effective where they can be accessed by equipment to remove the sediment. In the case of Teeterville dam, this would need to be near the dam itself.

Stabilization- Following drawdown, a river channel may be engineered through or around the reservoir sediment to prevent fluvial erosion and stabilize the sediment. The cost is typically less than for sediment removal, but greater than for the river erosion alternative. However, natural fluvial processes and topography would not be restored under this alternative, and some of the sediment may erode during future floods. Since stabilization will not replicate self-sustaining natural processes, the works will also require maintenance over time.

River erosion- This approach involves allowing the river to erode sediment from the reservoir though natural processes. This may be the least expensive alternative if the downstream impacts are considered acceptable or can be mitigated. Key impacts may include downstream riverbed aggradation and/or increased turbidity as sediment is remobilized and the river readjusts. The objective if this approach is used in dam removal, would be to recreate a more naturally functioning, self-sustaining river system, with minimal future maintenance requirements.

No Action- This alternative envisages no works being undertaken on the dam, and is applicable only to the “Operation (and Repair)” alternative. Due to the large amount of accumulated sediment, and near zero trapping efficiency, any inflowing sediment will be transported downstream of Teeterville Dam.

Table 4: Sediment Management Alternatives

Alternative	Applicability for Reservoir Alternatives		Advantages and Disadvantages	
	Operation (and Repair)	Dam Removal	Advantages	Disadvantages
Sediment removal	Sediment removed by dredging from shallow depth or by conventional excavation after drawdown	Sediment removed from shallow depth before drawdown and from deeper depth during drawdown	Low risk of sediment release (for coarse); low impact on water quality and channel aggradation downstream	High cost of removal and disposal (esp. for contaminated sediment)
Sediment trap	Pits excavated in the channel to trap coarse sediments	Pits excavated in the channel to trap coarse sediments	Low impact; low cost	Limited volume
Stabilization	Sediment remains stabilized by the dam.	Construction of a river channel through or around sediments; relocate a portion of sediment to areas within reservoir not subject to high velocity	Moderate cost; Low impact on water quality and channel aggradation downstream	Potential for failure; long-term maintenance cost; storage not restored
River erosion	Reservoir drawdown helps flush sediment; sluice gates may be installed or modified to flush sediment	Sediment is remobilized through fluvial erosion. Erosion rate depends on rate of dam removal and inflow; also ratio of reservoir with to river width	Potentially low cost; sediment supply to downstream channel	Risk of un-anticipated impacts; downstream water quality impact and channel aggradation
No action	Since trap efficiency is near zero, no further sedimentation occurs. Sediment will move towards the dam when water is lowered.	Not applicable	Low cost	Loss of storage capacity; release of fine will occur regardless

4.2 Potential Impacts of Sediment Release

Sediment removal and disposal from reservoirs can be very costly for large volumes of sediment and is often not feasible for fine sediments. Therefore, the management of reservoir sediment is often an important and controlling issue related to dam repair or removal. Sediment-related impact of such activities could occur in the reservoir, and both upstream and downstream of the river channel, especially when dealing with large quantities of sediment. The drainage area of the Teeterville Dam represents only approximately 27% of the total watershed area. There are several tributaries to Big Creek downstream of the dam. Therefore any potential impacts resulting from sediment release from the dam would be diluted by these downstream tributaries.

The major issues that need to be considered in relation to sediment management include: cost, water quality, flooding, operation and maintenance of existing infrastructure, cultural resources, aquatic habitats (including wetlands), recreation, and restoration of the reservoir area.

With effective sediment management, potential impacts can be substantially reduced and there may be even benefits from the controlled release of sediment, such as the introduction of gravel, woody debris, and nutrients for the restoration of downstream fish habitats.

4.2.1 Sediment Management Indicators

The extent of potential impacts could be estimated using sediment management indicators (Randle & Greimann, 2008). The indicator values for Teeterville dam are listed in Table 5.

The first indicator represents the reservoir sediment trap efficiency. Currently, the reservoir's remaining storage capacity is estimated at 64,000 m^3 relative to the mean-annual volume of river flow (modified for dam location based on station 02GC006 on Big Creek at Kelvin) at 80Mm^3, resulting in a ratio of under 0.1%. Based on empirical relationships developed in the US (same), the long-term trap efficiency of this reservoir is near zero.

Reservoir operations will impact trap efficiency too. If flood flows are stored, more sediment will be trapped in the reservoir. If flood flows pass, coarse sediment will deposit as a delta at the upstream end of the reservoir. If the reservoir is drawn down frequently, any clay-sized sediment that is exposed will compact.

The third indicator can be used to estimate the level of impact of sediment release on the downstream channel. As the trap efficiency at Teeterville is currently near zero, the entire load supplied by the upstream river is passing through the remaining reservoir.

The width of the reservoir relative to the river width (200-300 m to 20 m), can indicate how much sediment would be released from the reservoir. At a ratio of about 10-15, the river may not be capable of eroding the entire sediment volume.

In addition to these indicators, the rate of drawdown has a strong influence on the rate of sediment erosion and transport. Gradual release will also be important in avoiding a flood wave of reservoir water spilling into downstream channel and any landslide along the reservoir margins.

Table 5: Sediment Management Indicators

Indicator	Description and Importance	Value
1- Relative reservoir capacity	Reservoir storage capacity (at the normal pool elevation) relative to the mean-annual volume of river flow	0.08%, trap efficiency near 0.
2- Reservoir operations	Purpose of reservoir and operation	Irrigation and recreation- reservoir pool raised during the summer irrigation season
3-Relative reservoir sediment volume	Reservoir sediment volume relative to the mean annual capacity of the river to transport sediment of the same particle sizes within the reservoir	High; see indicator 1
4- Relative reservoir width	Maximum width of the reservoir relative to the active channel width of the upstream river channel in an alluvial reach of river	10-15; may not erode the entire volume
5- Relative concentration of contaminants or metals	Concentration of contaminants present within the reservoir sediments relative to the background concentrations	Close to background
Sediment management problem	-	Moderate

4.2.2 Sediment Erosion and Transport

A total of around 240,000 m^3 of wet sediment (105,000 tons in total, and about 55,000 tons of fine solids) has been accumulated in Teeterville reservoirs. Depending on the extent of work done on the dams (repair, partial or full decommissioning), and sediment management alternative (or a combination thereof) selected, some quantities of fine and/or coarse material from the reservoir and the upstream channel will be transported downstream. The exact distance and amount transported to these distances will depend on the sediment management practices implemented and may be more accurately determined through analytical methods.

The position of sediment within an impoundment helps determine whether the material is likely to erode during the drawdown. Impounded sediment deposits may include coarse deltas and forest slopes, fine or coarse bottom deposits, cohesive or organic matter and wedge deposits immediately behind the dam. Sediments behind the dam, along the face of the delta, and in the original channel are most likely to erode. Sediment along the sides of wide pools in embayment is less prone to erosion (James & Schiff, 2013). The ratio of the width of the reservoir to the width of the active river channel in the upstream can indicate the amount of sediment that would be eroded from the reservoir.

If using an alternative involving river erosion, most of the coarse material may be trapped within the reservoir or behind the dam, and the coarse material transported downstream will be deposited within a short a distance. Under this scenario, not all of the material (fine or coarse) will be eroded. The channel will slowly cut down and a large portion of the sediment closest to the shoreline will stabilize.

A schematic of where sediment would mobilize or stabilize in Teeterville reservoir is shown in Figure 9.

As a rough estimate, transport of sediment from the reservoir to the downstream may be estimated as follows:

$$v_s = \frac{8.64\,g}{18\,\mu}(\rho_p - \rho_w)\,d_p^2$$

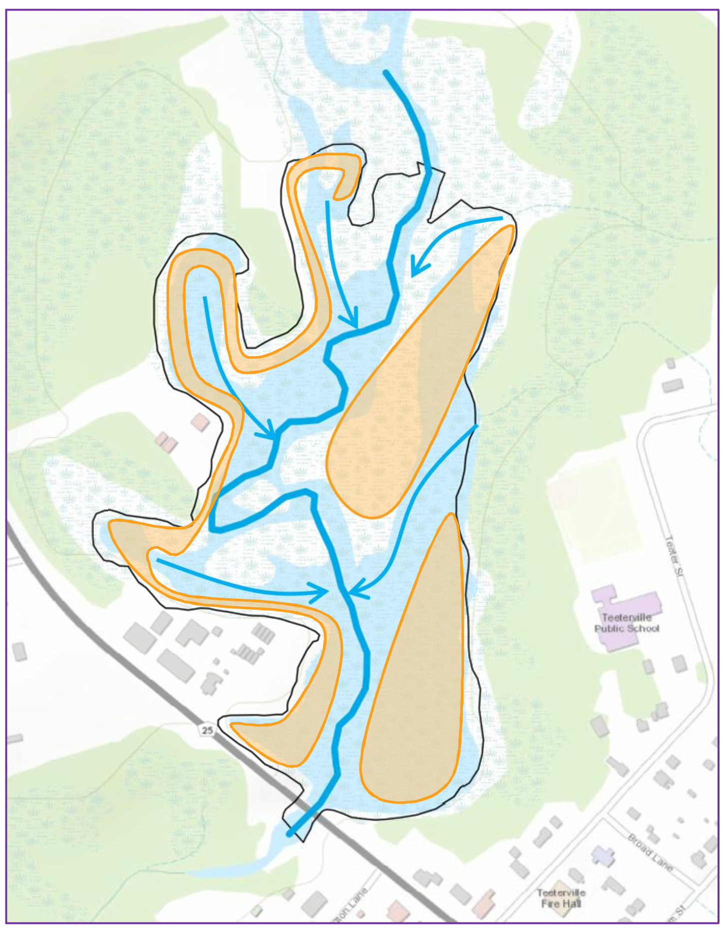
where,

v_s = Stokes' settling velocity (m/d)
g = acceleration due to gravity = 981 cm/s^2
µ = absolute viscosity of water at= 0.015 g/(cm•s)
ρ_p = particle density = 1.2 g/cm^3 for fine and 1.7 g/cm^3 for coarse
ρ_w = density of water =1 g/cm^3
d_p = particle diameter (mm)

For particles 75 µm (0.075 mm) in diameter, the settling velocity would be around 100 m/d. At a water depth of around 0.5m, time to settle would be close to 10 min, i.e. for a water velocity of 0.4 m/s (average estimate for the upstream station on Big Creek), the sediment would be settled in a distance of about 200 m. Smaller particles will travel much further, e.g., 10 µm particles would travel up to 25 km downstream, while larger particles will settle within a few meters.

Figure 9: Sediment Mobilization and Stabilization Areas

Blue line shows the original channel (based on 1954 aerial imagery)
Blue arrows show where sediment will probably mobilize during a phased breach.
Orange areas show areas of impounded sediment which would most likely revegetate.



4.2.3 Potential Impacts on Channel Form and Function and Natural Environment

4.2.3.1 Benefits of Dam Removal

An online dam, such as Teeterville Dam, represents a significant control on a creek, limiting natural channel adjustment and downstream sediment transport. Dam removal is typically of significant benefit to channel form and function, helping to re-establish natural fluvial processes in the long-term, while removing the requirement for future maintenance of the dam structure. Floodplains function to remove silts and nutrients during floods, and dam removals help restore these systems which can be starved of sediment. However, an understanding of the potential geomorphological channel response to dam removal, both upstream and downstream and in the short- and long-term, is required in order avoid unforeseen and undesirable impacts.

- Culvert and bridge blockage
- Channel avulsions
- Excessive floodplain deposition
- Habitat damage
- Reduced quality of recreation.

4.2.3.2 Remobilization of Trapped Sediment

If the dam is removed, sediment that has been trapped by the dam has the potential to be remobilized, in addition to the natural sediment load of Big Creek. The fate of this material and its potential effect within the downstream area should be understood. For example, if a large volume of coarse sediment is eroded at a rate greater than the rate of sediment transport downstream, the sediment could aggrade the downstream river channel, potentially leading to channel widening, bank erosion, and increase in flood stage.

Sediment release during drawdown may result in increased turbidity, potentially impacting the downstream aquatic environment and water users. Sedimentation often impacts turbidity, color, taste, odor and biological oxygen demand. High concentration of contaminants could also potentially impact the aquatic environment and municipal water treatment plant negatively. Sporadic smothering of habitats, smoothing of bed features, and burying of riparian wetland features in the floodplain are also possible impacts (James & Schiff, 2013). Impacts from the mobilization of fine sediments, however, are temporary following dam removal. As impounded sediment is stabilized and more natural fluvial processes are restored (sediment transport), water quality and biologic conditions will gradually improve.

4.2.3.3 Potential Downstream Impacts

Teeterville Dam reservoir and downstream provides fish and terrestrial habitat. Big Creek is a cold water system containing a diverse community with known migratory runs of Rainbow Trout and Chinook Salmon. Also, there are several known ANSI's and a Provincially Significant Wetland complex.

Potential impacts of excessive sediment release on the downstream environment may include (James & Schiff, 2013):

- Channel aggradation
- Channel widening
- Bank erosion
- Higher flood levels
- Intake and outfall obstruction
- Water quality impairment

4.3 Recommendations for Future Sediment Management Operations

4.3.1 Recommended Approach

Selection of the best approach for sediment management is a function of sediment characteristics, potential downstream impacts, and cost.

Teeterville reservoir currently contains a large amount of relatively-clean sediment, Mechanical removal of all impounded sediment will probably be a cost-prohibitive alternative.

Our recommended approach involves a controlled drawdown, combined with natural erosion and installation of a sediment trap near the dam where equipment can remove the sediment as it mobilizes towards the dam during the phased dewatering.

4.3.1.1 Controlled Drawdown and Sediment Movement

A phased drawdown approach is recommended, through removing stoplogs as the first phase, In general, the longer the drawdown, the less severe the impacts would be. If the current maintenance activity includes the removal of the top stop log during the winter months, and the Teeterville dam is going to either be repaired or removed, the stoplog should not be replaced.

It is recommended that the continued phased drawdown be conducted during the low flow time of year which is typical throughout the summer. During these lower flow conditions, turbidity impacts will be minimized as the mobilization of finer grained material will be more constant. Another advantage of dewatering during the summer months is the establishment of vegetation. As the dark sediments become exposed at the upper limits of the impoundment and along the impoundment fringe, they quickly warm and the buried seedbank rapidly germinates. This initial vegetative establishment will help stabilize the exposed sediments and can begin to uptake available nutrients.

Sediment will begin to move towards the dam after the first stoplog is removed. At a minimum, the removal of each subsequent stoplog should not be done until the impoundment has been drawn down to a static level associated with the removal of the previous stoplog removed.

If a decision is made to remove the Teeterville Dam, the continued dewatering and phased breaching would need to be accomplished by mechanical means after all stoplogs have been removed.. The most cost-effective method to complete this is with hydraulic hammers mounted to the boom of an excavator. The continued rate of breaching should be similar to the removal of stoplogs and should not exceed 0.5 meters at a time.

The sands and gravels will also slowly move towards the dam. A delta will form where the sediment meets cutting channel and this delta will continue moving towards the dam. The channel will gradually cut down then start to widen which will temporarily increase turbidity.

4.3.1.2 Sediment Trapping and Removal

As the coarse sediment (sand and gravel) delta approaches the dam, a sediment trap can be constructed where excavating equipment can remove the sediment. It may be necessary to construct a rock coffer near the spillway in order to access the sediment delta. The sediment trap is simply an excavated pit where the sediment can be removed. The rate of sediment trap maintenance will vary during the dewatering but will be more frequent during the latter stages of dewatering. There appears to be some land available on the southeast side of the spillway and north of Teeterville Road which could be used as a temporary staging area for sediment which is removed. A secondary sediment trap could be installed immediately downstream of the existing spillway. The stream is overly wide at this location would naturally collect sediment due to the large cross-sectional area. This area is easily accessible from the northwest bank and also has available land for temporary sediment drying and storage.

4.3.1.3 Permanent Disposal

As part of the sediment management plan, it will be important to identify the permanent disposal area for any sediment removed. Potential disposal areas include fringe areas of the dewatered impoundment or adjacent agricultural land.

4.3.2 Monitoring of Downstream Impacts

The Teeterville Dam is located in the upper Big Creek watershed. There are numerous contributing tributaires which enter Big Creek between the dam and Lake Erie. Each of these tributaires will provide clean water which will help mitigate any potential adverse water quality impacts associated with the phased dewatering of the dam. Monitoring is essential during reservoir drawdown to ensure that any potential downstream impacts are properly managed and can be mitigated in a timely manner. Monitoring results should be used to trigger consideration of additional BMPs and other controls as contingency measures (see section 4.3.3).

Table 7 provides a summary of the proposed monitoring parameters and locations, frequency and duration and methodology. It is recommended to conduct pre, during and post-drawdown monitoring to establish a baseline and identify any potential impacts specific to the undertaking.

Water quality-chemistry:

Water quality monitoring is recommended immediately downstream of the dam for turbidity as a trigger to collect samples at a downstream location and implement additional mitigation measures if required.

Proposed triggers (exceedance of targets) for implementation of additional measures are listed in Table 6. These are developed based on an understanding of the quality of accumulated sediment and potential downstream impacts. Targets are according to Provincial Water Quality Objectives (PWQO) or Canadian Water Quality Guidelines (CWQG) for the Protection of Aquatic Life, or long-term water quality conditions at the upstream provincial station (Big Creek at Windham). Targets have been defined for turbidity (for protection of fish and water intake), TSS (as a surrogate for many contaminants), phosphorus (nutrient), and a number of metals (those detected in sediment samples).

The downstream location is proposed at the first accessible downstream point, which is Windham West Quarter Line Road crossing. In case of trigger activation, samples should be collected at the downstream location for analysis in accordance with the trigger parameters.

Baseline conditions may be established based on the existing PWQMN station (Big Creek at Windham). This dataset may be complemented with monthly sampling downstream of the reservoir for a period one year prior to the project implementation.

During the drawdown, a frequency of bi-weekly (or as triggered by turbidity at the dam) is proposed. Monitoring frequency at the downstream point could be reduced over time considering initial data collection.

Water temperature

It is recommended to measure water temperature on Big Creek before impoundment and at dam spillway during summer months to help establish the baseline, and also demonstrate post-project benefits.

Table 6: Proposed Targets for the Downstream Point*

Parameter	Target	Rationale
Turbidity	8 NTU (long-term) and 14 NTU (short term)	Maximum increase of 2 (long-term) and 8 (short-term) from background values (defined based on long-term value at upstream station of 6 NTU); CWQG
Total Suspended Solids (TSS)	35 mg/L	25 mg/L in addition to upstream value (75th percentile of data) ; CWQG
Nutrients: Phosphorus	50 µg/L (total) and 20 µg/L (dissolved)	Based on long value at upstream station
Ammonia		
Metals:		
Arsenic	5µg/L	Interim PWQO
Boron	200µg/L	Interim PWQO
Cadmium	0.1 and 0.5 µg/L (for hardness as mg/L CaCO3 of 0-100 and >100)	PWQO
Chromium (VI and III)	1 µg/L (Cr VI) and 8.9 µg/L (Cr III)	PWQO
Cobalt	0.9µg/L	PWQO
Copper	1 and 5 µg/L (for hardness as mg/L CaCO3 of 0-20 and >20)	Interim PWQO
Lead	1, 3 and 5 µg/L (for hardness as mg/L CaCO3 of<30, 30 to 80: and >80)	Interim PWQO
Mercury	0.2 µg/L	PWQO
Nickel	25 µg/L	PWQO
Vanadium	6 µg/L	Interim PWQO
Zinc	20 µg/L	Interim PWQO
Hardness	-	
pH	6.5-8.8	

* First accessible downstream point, which is Windham West Quarter Line Road crossing.

Fish community:

It is recommended to monitor fish species composition, length and age range for the baseline and post-project periods. Fisheries data for baseline conditions may be available through MNRF. It is also worth noting that fish populations are determined by a number of environmental factors (i.e. disease, fishing pressure), and changes in the fish community may not only be in response to the release of sediment.

Channel and Aquatic Habitat:

In order to determine changes to the natural environment, existing fluvial geomorphological conditions and aquatic habitat will need to be documented to establish baseline conditions. Criteria to be recorded during the channel assessment would include:

- Channel form: bankfull dimensions, bed and bank characteristics, existing channel modifications.
- Substrate composition – bed and banks (i.e. clay, silt, sand, gravel, cobble, rock, boulder, muck, and detritus)
- Geomorphological / physical habitat units:
    - Runs - typically deep, fast-moving water with little to no turbulence of water
    - Riffles - shallow, fast moving water typically running over rocks; riffles providing areas of high oxygenation
    - Flats – shallow, slow moving water with a smooth surface
    - Pools - deep pockets of slow moving water that provide ideal habitat for fish
- Representative channel cross-sections and longitudinal profile

- Surrounding natural features and land uses (i.e. wetland, agriculture, etc.)
- Indicators of water quality: temperature, conductivity, dissolved oxygen, pH, water clarity, water color, presence and type of macrophytes and algal growth, evidence of runoff
- Basic field parameters such as pollution sources (i.e. tile drain discharges, other piped discharges and road runoff)

Once baseline data is established, it would allow for post sediment release changes to be documented.

Benthos

Benthic communities are often the first to respond to changes in habitat and sediment. Benthic sampling during the first and second years post removal would assist in quantifying the speed that the system will rebound. Sampling should be completed over three events (late spring, mid-summer, and early fall) for diversity and density.

Table 7: Proposed Monitoring and Adaptive Management Plan

Parameter	Location	Duration and Frequency	Methodology
Amount of sediment removed	Traps; mechanical removal	During sediment removal	Scales
Drawdown rate	Downstream of dam	During reservoir drawdown- continuous	Logger
Water quality (turbidity, TSS, nutrients, metals, - see Table 6)	Turbidity immediately downstream of dam; Others at downstream point*	Baseline, during and after drawdown Daily or continuous for turbidity downstream of dam Bi-weekly samples at downstream point (frequency could be reduced depending on initial results)	Continuous for turbidity; garb samples for others
Impact on natural heritage	Downstream of dam	Baseline fish community sampling and creek habitat mapping to be completed by a combined ecology/geomorphology team prior to sediment release. Fish community sampling to be completed in the year prior to sediment release and occur yearly for 5 years post release. Benthic baseline to be completed in the year prior to sediment release in spring, summer and fall at three sites.	Elements of Ontario Stream Assessment Protocol and DFO SAR fish sampling protocol Benthos diversity and density

* First accessible downstream point, which is Windham West Quarter Line Road crossing.

4.3.3 Sediment Release Contingency Planning

The water produced from or impacted by reservoir drawdown, dam repair or sediment removal and drying may exceed surface water quality standards. Unanticipated events such as flood flow during the dam repair operation may erode a substantial amount of reservoir sediment. A sediment release contingency plan is proposed therefore as a set of best management practices (BMPs) and other options to respond to such events. These are in addition to BMPs and other controls implemented during regular operation of drawdown and dam repair (e.g. phased approach and isolating sediment from flowing water, etc.) and should also balance potential benefits (e.g. an expected reduction in concentration) and costs and schedule.

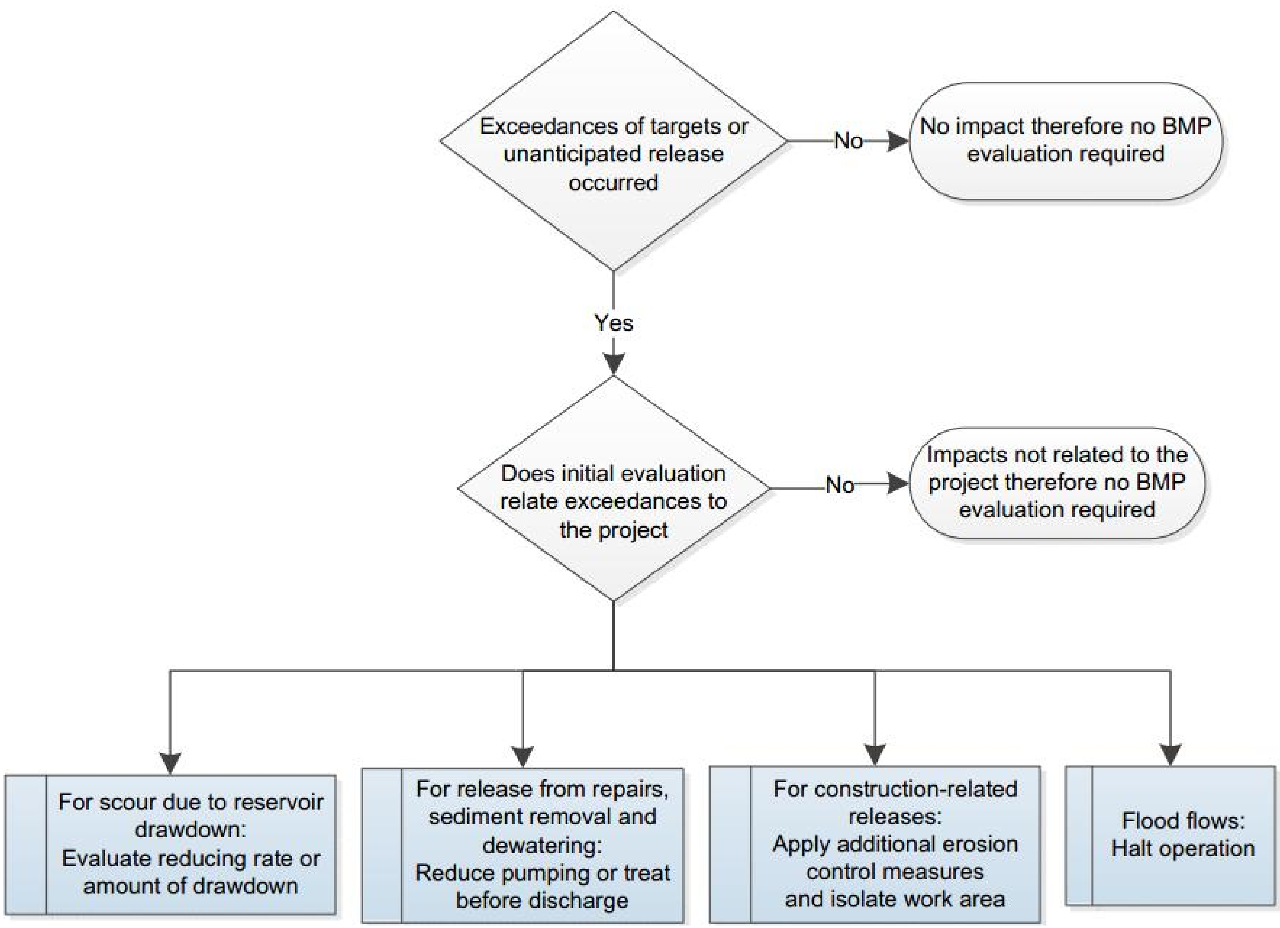
The first component of this contingency plan is an evaluation of potential downstream impacts and determining the need for and selection of additional controls. The expected effectiveness and cost of various options should be compared to various potential options available.

Additional measures to reduce potential impacts of sediment release may include:

- Reduce drawdown rate, or total amount of drawdown
- Increase frequency of sediment removal from traps
- Install additional erosion controls around work area
- Treat water or sediment porewater prior to discharge (e.g. for high concentration of metals or nutrients)
- Halt operation during flood flows

An overall logic diagram of the contingency plan is shown in Figure 10.

Figure 10: Sediment Release Contingency Plan Logic Diagram (adapted from (ENVIROCON, 2006))



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