Vaseux Lake Stewardship Association

Vaseux Lake Sedimentation Study: Final Report

Submitted by:
Claire Jackson M.Sc., P.Eng., EMBA
COO
Claire.jackson@watersmartsolutions.ca
Robert Hough M.Sc.
Environmental Scientist
Robert.hough@watersmartsolutions.ca

WaterSMART Solutions Ltd.
605, 839 5th Avenue SW
Calgary, Alberta T2P 3C8

Submitted to:
Norm Gaumont
Chairperson
Vaseux Lake Stewardship Association
216 Sundial Road,
Oliver, British Columbia,
V0H 1T2

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Executive Summary

Vaseux Lake is a shallow freshwater flow-through lake located on the Okanagan River approximately 4 km south of Okanagan Falls. The reach of the Okanagan River near Okanagan Falls is subjected to naturally high sediment loading from Shuttleworth Creek, which meets the Okanagan River at Okanagan Falls. Sediments are carried into Vaseux Lake and subsequently deposited, filling in the lake over time. The Okanagan River was channelized in the 1950's in response to widespread flooding in the area. Channelization ultimately removed meanders in the river to provide better flow conveyance through much of the Okanagan River. River meanders play an active role in sediment deposition as changes in water velocity allowed sediment to deposit during high flow events prior to reaching Vaseux Lake. A sediment basin was constructed at the mouth of Shuttleworth Creek to mitigate sediment transport from the creek to the Okanagan River; however, there is evidence to suggest the basin is not effective at capturing smaller particles (<63µm diameter) that are problematic for the lake.

Continuous deposition of silt in Vaseux Lake has resulted in several issues arising. Shallow water at the north end of the lake has resulted in higher water temperatures especially during the summer months which puts additional pressure on cold water salmonid species such as sockeye salmon, the increasing water temperature creates a temperature- oxygen squeeze in the lake which narrows, and potentially eliminates, the habitable zone for salmon. Additionally, continuous build-up of fine sediments has created an ideal habitat for invasive milfoil that bind the sediment and further accelerate sediment deposition in the lake.

This study assessed the viability of several near term (<1 year) and longer term (5-10 years) actions with the potential to slow sediment deposition and subsequent accumulation in Vaseux Lake including, reconnection of the Okanagan River its floodplain north of Vaseux Lake, change in water management, and expansion or construction of sediment basins.

It is recommended that the near term focus should be to preserve the efficiency of the existing sediment basin through more frequent maintenance. More frequent removal of material from the sediment basin will allow better capture of fine sediments throughout the year and reduce the volume of sediment reaching Vaseux Lake. Additional near term projects should include better management of milfoil which will prevent sediment build up and potentially allow natural scouring.

The recommended longer-term approach is that the Vaseux Lake Stewardship Association work with First Nations and conservation groups to restore the connection between the Okanagan River and the flood plain to the north of Vaseux Lake. Allowing this area to flood again will promote sediment deposition before it reaches Vaseux Lake. There are also several potential additional benefits to this approach including the creation of key salmon spawning habitat and improved management of invasive reed canary grass.

Contents

1.0 Introduction

The Vaseux Lake Stewardship Association (VLSA) works to protect the water quality and ecology of Vaseux Lake and have expressed concern that sediment transported via Shuttleworth Creek and the Okanagan River is causing harm to the ecology of the area through increased water temperatures and providing habitat for invasive milfoil.

The ecological, geomorphic, and societal issues within the Okanagan River Basin and Vaseux Lake are well documented. This study does not seek to repeat or validate any work done previously, instead this study has four main objectives:

- Collate information from historical studies and data sources to identify and understand the problems caused by accelerated silt deposition in Vaseux Lake.
- Identify mitigation options that could be implemented to slow the rate of sediment deposition in Vaseux Lake.
- Provide a high-level assessment of the potential sediment mitigation capability of each flood mitigation option and identify any environmental societal or practical barriers with the implementation of each option.
- Provide a recommended path forward for the Vaseux Lake Stewardship Association to reduce the rate of sediment deposition in Vaseux Lake.

To identify and conceptualize appropriate sediment mitigation options a high-level analysis of aerial and satellite imagery was undertaken to understand the trends in the approximate volume and rate of sediment deposition in Vaseux Lake over time. Detailed methodology and conclusions from the photographic analysis is contained in Appendix A: Analysis of aerial photography and historical sediment deposition.

Appendix B: Review of historical investigations contains a review of recent studies conducted in the area including watershed reports and studies undertaken on Shuttleworth Creek and Vaseux Lake. The literature review was conducted to identify the challenges of mitigating sediment deposition and identify any appropriate mitigating actions that could form part of the next steps.

Input was gathered from First Nations and key stakeholders in the area to further understand ecological and operational challenges and goals of others in the watershed. A key consideration for this study was to identify sediment mitigation options that do not negatively impact the watershed and identify any options that align well with the goals of others in the area. The information provided by the Okanagan Nation Alliance (ONA), Canadian Wildlife Services and the Ministry of Forests, Lands, Natural Resources and Rural Development is summarized in Appendix C: Input from First Nations and key stakeholders.

The information provided by the photographic analysis, literature review, and through input from First Nations and key stakeholders was used to identify several near-term and longer term sediment mitigation options.

The body of this report lays out key elements of the background of Vaseux Lake and the Okanagan Valley, along with the details in the Appendices, this background informs the sedimentation options which are laid out and ultimately collated into recommendations that form the path forward for the Vaseux Lake Stewardship Association to reduce the rate of sediment deposition in Vaseux Lake.

2.0 Background

Vaseux Lake is a shallow freshwater flow-through lake located on the Okanagan River approximately 4 km south of Okanagan Falls (Figure 1). Much of the area around the lake is part of the Vaseux-Bighorn National Wildlife Area and contains species deemed special or important (Environment Canada, 2011). The area surrounding Vaseux Lake was designated as a migratory bird sanctuary in 1923 and include the wetlands at the north end of the lake. The Okanagan River is a key spawning habitat for Sockeye and Chinook salmon and Vaseux Lake provides a migratory pathway to spawning grounds. The Okanagan population of Chinook salmon has been identified as a species at risk and in 2017 was classified as endangered (COSWIC, 2017).

The Okanagan River has a history of flooding, creating a natural environment of floodplains and wetlands, post-colonization began to significantly impact residents of the basin. Widespread and continuous flooding brought about the formation of a Joint Board of Engineers in 1943 to assess flood risk. Throughout the 20th century, multiple engineering projects were undertaken to protect against flooding including dam construction, dredging, and realignment of the Okanagan River channel. As a result of the flood mitigation projects, the Okanagan River was channelized between Okanagan Falls and Vaseux Lake.

Shuttleworth Creek meets the Okanagan River at Okanagan Falls approximately 4 km upstream of Vaseux Lake. Shuttleworth Creek produces substantial sediment, transported into the Okanagan River (Larratt Aquatic, 2019). Before its channelization, the Okanagan River meandered through a floodplain between Okanagan Falls and Vaseux Lake. Under natural conditions the meandering river channel would play a role in capturing sediments before they reach Vaseux Lake; these sediments were captured through a reduction in water velocity within the floodplain allowing sediments to settle. Deposition of sediments within the floodplain also created habitat for ecologically significant species at risk such as the Tiger salamander (Environment Canada, 2011).

In order to capture sediment at the mouth of Shuttleworth Creek before it reaches the Okanagan River an engineered sediment basin has been constructed by the government of British Columbia at the mouth of Shuttleworth Creek (Okanagan Nation Alliance, 2020). It is hypothesized that the sediment basin has not been effective at capturing sediment since sediment deposition is still observable in the north end of Vaseux Lake which has caused the lake to become shallow resulting in ecological issues that have been documented in previous studies such as growth of invasive milfoil (N. Gaumont, personal communication, May 10, 2021).

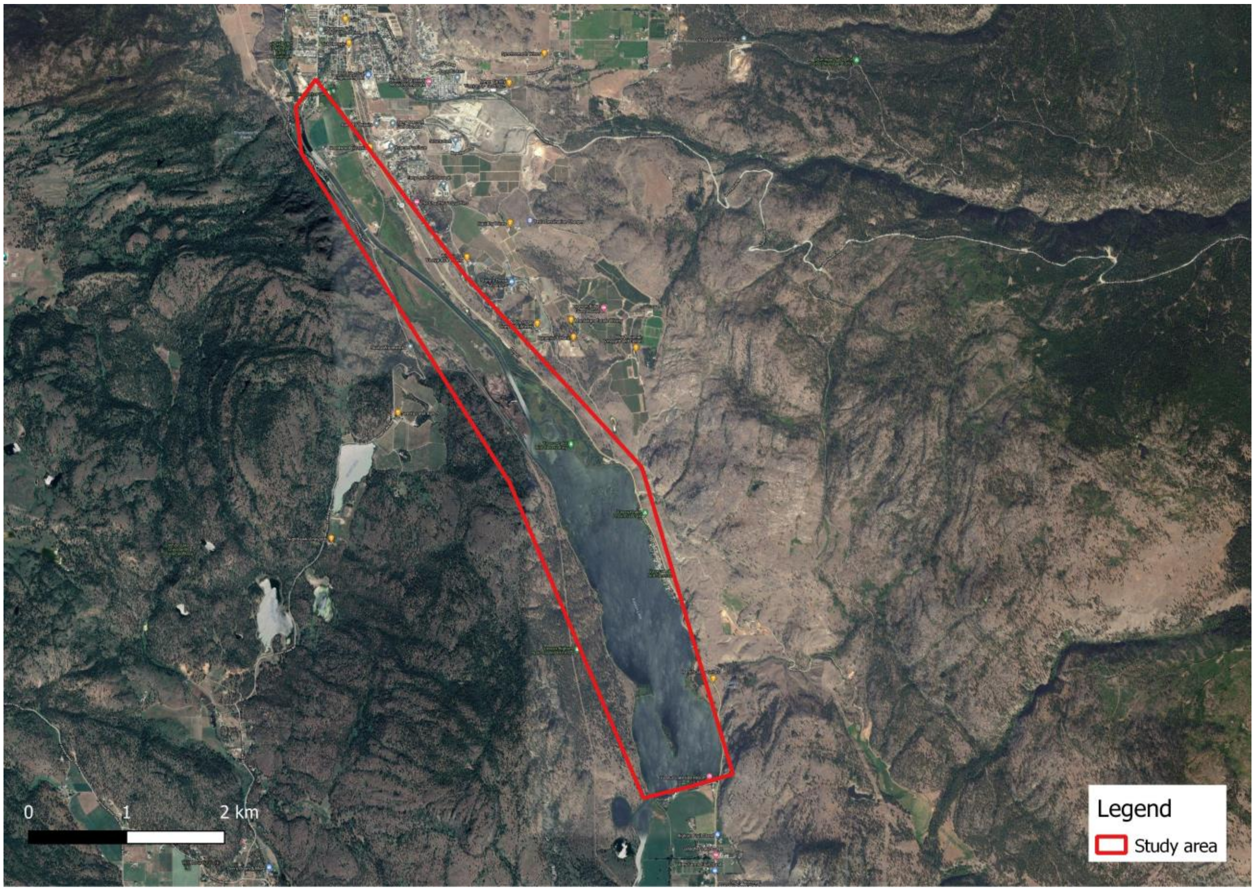

Figure 1 Outline of the Vaseux Lake sedimentation study area

To understand and contextualize the sedimentation issues in Vaseux Lake it is important to recognize how the Okanagan River Basin and Vaseux Lake itself have changed over time, what has driven water management decisions, and the ecological, environmental, and socio-economic impacts of those decisions.

2.1 The Okanagan valley

The Okanagan valley was created by glacial carving during the last ice age, as the ice retreated the Canadian portion of the Okanagan basin was filled with water. This portion later emptied as an ice dam melted. The geology of the region was shaped by the ice age with lenses of fine sediment scattered throughout the valley. Fine sediments carried nutrients and created wetlands and fertile floodplains.

The Sylix Okanagan people have lived in the Okanagan valley for thousands of years, the rapid growth of the fur trade brought European settlers and significant development of settler communities to the area (Okanagan Indian Band, 2021), (Okanagan Nation Alliance, 2017). Fertile land in the area was developed into agricultural land and the risk of significant damage to land and property from flooding increased as the settler population grew.

2.2 Channelization of the Okanagan River

Frequent flooding in the Okanagan River led to the provincial government initiating an investigation in the 1940's to determine how best to safeguard properties and residents of the basin. The outcomes of the study in the 1940's led to the construction of several dams along the length of the Okanagan River. Construction of the dams led to control of water supply not only for flood protection but also to mitigate the impact of drought and to ensure enough water was available for water users south of the border in the United States.

Predicting flood events has been historically challenging so engineers aided water management in the Okanagan region by channelizing much of the river. Channelization of the river removed the natural meanders that previously existed through the floodplain and created direct channels between reservoirs. Channelization improved the control the dam operators had over flow conveyance. Water could quickly and easily be routed to downstream reservoirs as required, this allowed reservoir operators to respond quickly to changing conditions (Alberta Water Portal Society, 2013). The ability to respond quickly can potentially mean the difference between loss of property and life and successful protection of the basin ecology.

In recent years, it has become clear that channelization of the Okanagan River has had a number of negative impacts to the ecology of the area. Loss of wetlands, scouring of the riverbed, and increased sediment transport caused by higher water velocity have been identified as problematic consequences of the channelization of the river (Okanagan Nation Alliance, 2017). The impacts of sediment deposition are particularly obvious in Vaseux Lake. The Okanagan Nation Alliance (ONA) has made efforts to address some of the ecological impacts over the past 20 years, investigations into the impacts of sediment deposition in Vaseux Lake have only recently begun to be explored (Burge Ecohydraulics, 2011) (Larratt Aquatic, 2019).

2.3 Shuttleworth Creek

The confluence of Shuttleworth Creek and the Okanagan River lies approximately 4 km upstream of Vaseux Lake. Shuttleworth Creek has a watershed area of approximately 90 km^2 with the headwaters located on a forested plateau southeast of Skaha Lake. During the deglaciation, Shuttleworth Creek transported large amounts of sediment, resulting in a high rate of sediment deposition at the confluence of the Okanagan River which resulted in the Okanagan River channel moving to the west side of the valley (Roed M.A., 2019). Shuttleworth Creek has been identified as a significant sediment source and the major contributor of sedimentation to Vaseux Lake.

In order to understand how to mitigate sediment transport and subsequent deposition, it is important to understand particle size distribution. Sediment grain sizes are classified by the Wentworth size class scale which categorizes rock and sediment sizes under colloquial names such as boulder, sand and silt.

Under the Wentworth sizing scale silt particles are between 3.9µm and 63µm in diameter (Wentworth, 1922).

The surficial geology of the Shuttleworth Creek watershed shows that stratified fine alluvial sediments are present close to the confluence of the Okanagan River. Alluvial sediments are mostly comprised of silt and mud with small amounts of sand. Further upstream, the geology is classified as sandy till, this is generally coarser material, containing mostly sand; however, lenses of fine sediment are present throughout the watershed (Geological Survey of Canada, 2013). It is likely that the lenses of sediment wash out frequently during high flow and contribute to sediment deposition in Vaseux Lake. Finer sediments such as are less likely to settle out in moving water and are likely to be carried to larger bodies of water such as lakes that allow settling to occur. Significant sedimentation deposition in Vaseux Lake has been noted in 1936, 1944, 2018 and 2020 and this coincides with high flows and washouts identified in Shuttleworth Creek (Denny Maynard & Associates Ltd., 1999). Allowing silt to settle before it reaches Vaseux Lake would likely slow the rate of sediment deposition.

Landscape conditions are also relevant to understand given that sediment source areas can change over time. Wildfires occurring in the summer of 2020 have altered the forest canopy and soils in the Shuttleworth Creek watershed. Wildfire ultimately decreases canopy interception and in some cases can dramatically alter soil conditions, resulting in hydrophobicity over several years. Further work is required to attribute changes in sediment production in Shuttleworth Creek over time. However, historical wildfires within the Shuttleworth Creek watershed may have contributed to increased sediment loading in the Okanagan River and Vaseux Lake.

The BC Ministry of Forests, Lands and Natural Resource Operations has taken steps to mitigate sediment loading in the Okanagan River from Shuttleworth Creek through the construction of a sediment basin at the mouth of Shuttleworth Creek. The sediment basin has slowed the rate of sediment deposition but not fully mitigated the issue (Burge Ecohydraulics, 2011). The sediment basin has been designed to capture gravel and sand which comprises much of the material reaching the Okanagan River. Recent studies in the area have shown that the sediment basin is not successfully capturing silt particles (Burge Ecohydraulics, 2011) . Although the proportion of silt is small in comparison to gravel and sand, the cumulative volume of silt deposition within Vaseux Lake is significant.

It is clear from the geology of the area that sediment deposition in Vaseux Lake is part of a natural process, “vaseux” is French for muddy and the lake was likely named after its murky composition from the presence of silt. Since the channelization of the Okanagan River there are now fewer natural processes to capture sediment before it reaches Vaseux Lake and it is hypothesized that the rate of sediment deposition has accelerated.

3.0 Sediment mitigation options

Several potential sediment mitigation options were identified through review of historical projects, photographic analysis, high-level fieldwork, and discussions with other parties with interests in the area. The sediment mitigation options can be categorized into near term and longer term options where near term options are those that could be implemented in less than one year and do not require significant planning or engineering. Longer term options would require more extensive planning and would likely take more than five years to implement.

This section discusses the benefits and drawbacks of near term and longer term options considering their likely sediment mitigation benefits, their impact on ecological health, and their impact operations. The identification and assessment of each sediment mitigation option drew on information provided by the photographic analysis (Appendix A: Analysis of aerial photography and historical sediment deposition), review of historical investigations (Appendix B: Review of historical investigations) and from discussions with First Nations and other key stakeholders (Appendix C: Input from First Nations and key stakeholders).

3.1 Near term options

While the longer term options identified in Section 3.2 may significantly reduce the sediment deposition in Vaseux Lake; the historical reports reviewed in Appendix B: Review of historical investigations identified some more near term actions that could potentially have an incremental benefit on sediment deposition in Vaseux Lake. These can be categorized as near term options that could be implemented in under a year. Near term options could be combined with one another and longer term options as part of a broader sediment management plan.

3.1.1 Management of aquatic macrophytes

The study conducted by Larratt Aquatic Consultants noted that the deposition of sediment in the north end of Vaseux Lake had created a habitat for invasive Eurasian milfoil and other macrophytes. As a result, milfoil had proliferated throughout the lake. The study recommended implementing a milfoil management plan to remove the invasive species from the lake which would include rototilling of the lake bed.

Implementation of a milfoil management plan to remove milfoil and other macrophytes from Vaseux Lake would likely have a small positive impact on sediment deposition in the lake. Aquatic plants bind the sediment with their root systems and prevents the scouring of sediment by the natural flow of the river. It is reasonable to assume that regular removal of aquatic plants will prevent the binding of sediments and potentially allow scouring of existing sediment to occur during periods of high streamflow which will slow the impacts of sediment deposition in Vaseux Lake.

3.1.2 Maintain operational efficiency of existing sediment basin through more frequent sediment removal

As described in Section 3.2.1 the efficiency of sediment basins relies on the basins retaining particulates for long enough to allow them to settle out. As sediment basins fill with sediment they become less efficient at capturing smaller sediment particles because the deposition of sediment causes the basin to be shallower, which in turn decreases particulate the retention time. This effect is especially noticeable during freshet when high flows result in increased sediment loading and the water flows too quickly through the sediment basin to allow sediment particles to settle.

The Burge Ecohydraulics study reviewed in Appendix B: Review of historical investigations noted that the sediment basin on Shuttleworth Creek was emptied on average every 1.8 years between 1964 and 1982. More frequent maintenance of the sediment basin will not prevent silt particles (<63 µm) from reaching Vaseux Lake but will help prevent larger sediment particles being carried into the Okanagan River during freshet. Maximum operational efficiency of the basin is likely to have a small mitigating effect on sediment deposition in Vaseux Lake overall but will likely mitigate larger unforeseen events such as the bank collapse that occurred in 2018.

Currently, the sediment basin is maintained on an as required basis by the Ministry of Forests, Lands, Natural Resource Operations and Rural Development. The Ministry noted that the ad hoc maintenance schedule was introduced due to budget restrictions and a more frequent maintenance schedule would require funding (personal comm. Shaun Reimer, November 8, 2021).

3.2 Longer term options

Assessment of the area through high-level fieldwork, aerial photograph analysis, and review of historical investigations resulted in the identification of four longer-term options that could potentially mitigate sediment deposition in Vaseux Lake. Each of these options was assessed to determine their likely impact on sediment reduction, water quality, local ecology, local infrastructure, high level capital, and operational costs and how each aligns with other priorities within the basin.

The Ministry of Forests, Lands, Natural Resource Operations and Rural Development has not prioritized the management of sediment deposition to date. Discussions with the ONA indicated that ecological conservation and specifically the reestablishment of habitat for Chinook and Sockeye salmon is of high priority in the Okanagan River Basin. Sediment mitigation options that support the ecological goals in the area have a much better chance of gaining support from the province compared to those that focus on sediment mitigation alone. Consequently, sediment mitigation options were assessed in the context of not only their sediment reduction capability but also how well they support conservation and water management goals. A full summary of input from First nations and other key stakeholders is contained in Appendix C: Input from First Nations and key stakeholders.

Reconnection of the Okanagan River with the floodplain (section 3.2.2) appears to provide the most beneficial outcomes. Reconnecting the flood plain would effectively mitigate some sediment transport while returning the river to a more natural state, meeting conservation goals. Positive impacts are also likely for the wetlands managed by Canadian Wildlife Service as reconnecting the floodplain may also help manage invasive reed canary grasses. Controlling the hydrology of an area and extending the amount of time the area is submerged can be used as a reed canary grass management strategy (Center for Invasive Species and Ecosystem Health, 2004).

3.2.1 Sediment basin

Sediment basins are temporary or permanent sediment control structures that reduce the velocity of the water and allows sediment particulates to settle. The design of a sediment basin is specific to the watercourse on which it resides, what type of sediment is being transported in that water course, and the velocity of the water. Larger particulates such as gravel and coarse sand will settle relatively quickly while small particulates such as fine sand and silt can take many hours to settle even in still water. Understanding the sediment profile is critical to sediment basin design.

Figure 2 shows a schematic comparison of the settlement of a gravel particle compared to a silt particle when flowing into a settling basin large enough to settle both particles.

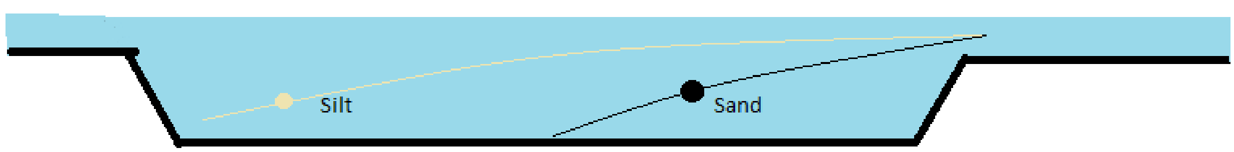

Figure 2 Schematic showing settling dynamics of sand and silt particles in a flowing sediment basin

There are several advantages to sediment basins that make them desirable for managing sediment transport in watercourses. Sediment basin construction is relatively simple and can be inexpensive provided there is minimal impact to existing infrastructure. Maintenance is simple, sediment trap can be dredged when full or regularly dredged as budget allows; maintenance costs vary depending on the size of the sediment basin. An appropriately designed sediment basin is very effective at capturing sediment depending on the sediment profile a properly designed basin can capture over 90% of sediment passing in the watercourse (Moser R., 1996) .

Sediment basins have their disadvantages and are not necessarily suitable for every sediment mitigation application. The efficiency and small size of certain sediment basins mean they may require continuous monitoring and frequent maintenance. If not maintained properly the basin will fill with sediment, which reduces the water depth and increases the velocity of water running through the sediment basin. At higher velocity there may not be enough time for particulates to settle and they are carried beyond the sediment basin.

Sediment basins may be unsuitable for water courses with high levels of fine sediment as a very large area is needed to settle fine particulates. Large sediment basins are usually not cost effective and, in most cases, more cost effective solutions can be found.

In this study two mitigation options were identified that would utilize sediment basins to mitigate sediment deposition in Vaseux lake. The Burge Ecohydraulics study noted that the sediment basin at the mouth of Shuttleworth Creek was not effectively capturing silt particles, one option is to expand this sediment basin to make it more effective at capturing silt (Burge Ecohydraulics, 2011). An alternative option is to create a large sediment basin at the north end of Vaseux Lake to capture sediment from the Okanagan River itself.

3.2.1.1 Expanded sediment basin on Shuttleworth Creek

The Burge Ecohydraulics study noted the existing sediment basin at the mouth of Shuttleworth Creek was highly effective at capturing sand, gravel, and larger particulates, however, it appears to be ineffective at capturing silt and particles defined as <63µm in diameter. Expansion of this sediment basin could further slow the water velocity and retain water long enough for silt particulates to settle (Burge Ecohydraulics, 2011).

Appropriate design of an expanded sediment basin would require a more detailed engineering study, however a rough estimate of the area and volume requirement of a more effective sediment basin can be calculated by using some reasonable assumptions, an example calculation is laid out below.

The terminal settling velocity (*v)* of a silt particle is given by Stokes Law (Equation 1). The settling rate is determined by the diameter of the particle (*d*), the density of the particle (P_p), the viscosity (μ), and the density (P_m) of the water, and the acceleration due to gravity (*g*).

Equation 1

$$v = \frac{gd^2(P_p - P_{m)}}{18\mu}$$

For an estimated calculation, an example particle of 32 µm diameter *(d)* will be used to represent a median size silt particle. Density of silt varies depending on the geology of the area; a typical density value *(P_p)* is around 1.4 g/cm^3 (U.S. Department of Agriculture). Using the above values, the terminal velocity (*v)* of the selected silt particle is 0.0002 m/s.

Sediment basin depths vary depending on the streamflow and sediment loading rate, the existing Shuttleworth Creek sediment basin has an average depth of 2.6 m. Complete settlement of a 30 µm silt particle in a pond of 2.6 m depth would take 3.6 hours. This value is known as the retention time of the sediment basin.

Historical studies have noted that the highest sediment deposition in Vaseux Lake occurs during high flow (Burge Ecohydraulics, 2011); in this estimated calculate, to be more effective than the existing sediment basin the expanded sediment basin will need to capture silt during high flow events. Limited data are available for flows on Shuttleworth Creek, however an inactive Water Survey Canada gauge station recorded partial flow data up to 2010 at the mouth of the creek near Okanagan Falls; this station records the highest flow as 5.1 m^3/s recorded in May 1921. Using the maximum flow rate recorded in 1921 it is possible to estimate the volume and area requirements of an expanded sediment basin. Retention time (R), sediment basin volume (*V*), and flow rate (*Q*) are related by Equation 2.

Equation 2

$$R = \frac{V}{Q}$$

To settle the 32 µm diameter silt particle the sediment basin volume requirement would be 66,100m^3. It is assumed the average depth of the new sediment basin is 2.6 m, which is the same as the existing basin, therefore the area requirement for the expanded basin would be 25,421 m^2. Figure 3 shows the theoretical area requirement overlaid on a map of Okanagan Falls.

Figure 3 Approximate area requirement for an expanded sediment basin on Shuttleworth Creek

It is likely that a sediment basin of this size in this area would impact residences close to Shuttleworth Creek. As currently presented in Figure 3 the expanded sediment basin would likely require the removal of homes on Cedar Street. Should residences be impacted then compensation costs and the removal of utilities significantly add to the capital costs of the project meaning this is likely not a feasible option for sediment mitigation.

Expansion of the sediment basin on Shuttleworth Creek does not align well with the ecological and conservation goals of the province or other groups in the area as there are no significant ecological benefits to expanding the sediment basin.

3.2.1.2 Sediment basin on the Okanagan River

A sediment basin could be placed at the northern end of Vaseux Lake on the Okanagan River. Although the area requirement in this location would be larger it was theorized that there may be enough space to accommodate the sediment basin without negatively impacting buildings in the area.

The method outlined in Section 3.2.1was used to estimate the approximate volume and area requirements of a new sediment basin on the Okanagan River. A silt particle of 32 µm and density of 1.4 g/cm^3 were used to size the Okanagan River sediment basin.

The new sediment basin would be required to capture sediment during high flow events. A Water Survey Canada gauge station (08NM002) has recorded data between 1964 and 2019 on the Okanagan River at Okanagan Falls; this station shows the highest recorded flow of 89.1 m^3/s was recorded in 2017, this represents the most extreme event recorded (Environment and Climate Change Canada, 2021). A flow of 75.0 m^3/s was used to size the sediment basin, this flow representing a significant peak flow which is likely to occur in this reach of the Okanagan River.

Under the conditions outlined above the volume of the sediment basin would need to be 972,000 m^3. Using an average depth of 2.6 m the area required for the new sediment basin would be 374,000 m^2. Figure 4 shows the area requirement of the new sediment basin overlaid on the wetlands at the north end of Vaseux Lake.

Figure 4 Area requirement for a new sediment basin on the Okanagan River

The area required to construct an effective sediment basin on the Okanagan River is extremely large and would negatively impact the habitat of species at risk in the conservation area managed by Canadian Wildlife Service. Operational costs would be high as the sediment basin would require regular dredging, the dredging process will disturb the water and have an adverse effect on water quality in the Okanagan River and Vaseux Lake.

A sediment basin in this location does not align well with the conservation goals of the Okanagan Nation Alliance or Canadian Wildlife Service and there would be a negative impact to the ecology of the area through the destruction of wetlands and migratory bird habitat.

3.2.2 Re-connection of the Okanagan River floodplain

Since the channelization of the Okanagan River in the 1950's there are no natural processes preventing sediment transport between Okanagan Falls and Vaseux Lake. Reintroduction of natural sediment mitigation processes could reduce the volume of sediment deposited in Vaseux Lake, especially during high flow events. Natural processes that would increase the rate of sediment deposition upstream of the lake include introducing meanders into the river and reconnecting the Okanagan River with the flood plain to the north of Vaseux Lake. Allowing the area to flood would encourage natural deposition of sediment within the floodplain. This natural process of sediment deposition originally created the wetlands that exist today and provide essential habitat for migratory birds, reptiles and amphibians.

Reconnection of the Okanagan River with the floodplain would also have several ecological benefits. The Okanagan River Restoration Initiative (ORRI) project facilitated by the ONA has proven that a more naturalized system provides beneficial conditions for the migration and spawning of Sockeye and Chinook salmon as well as other key aquatic and terrestrial species. Canadian Wildlife Service indicated that reconnection of the Okanagan River with the floodplain could be beneficial for managing reed canary grass, an invasive grass species which is becoming prevalent in wetland areas.

Reconnection of the floodplain could take on several forms, future discussions with the ONA and Canadian Wildlife Service should seek to understand how to maximize the ecological benefits in the area. Canadian Wildlife Service have indicated that the managed ponds and channel containing habitat for key amphibious species such as the Tiger Salamander could not be directly connected to the river at any time as fish may prey on the vulnerable species. A detailed future investigation would be required to assess how the ponds could be protected during a flood.

Figure 5 shows a conceptual schematic of how the Okanagan River could be re-connected to the floodplain by removing the berm on the western bank of the Okanagan River and reconnecting a historical side channel. The red hatched area denotes where flood protection would be needed to protect the managed ponds.

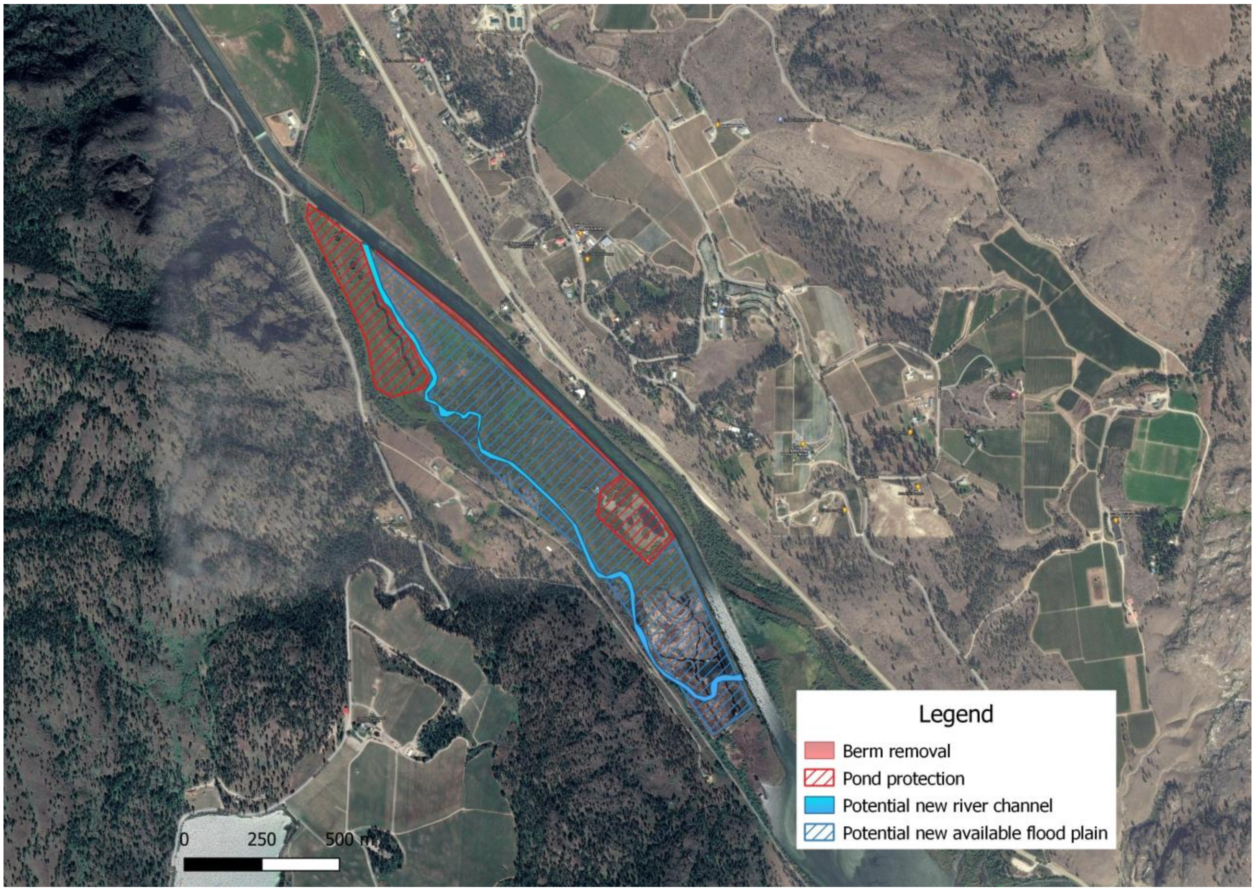

Figure 5 Conceptual schematic of the reconnection of the Okanagan River to the floodplain

The Ministry of Forests, Lands, Natural Resource Operations and Rural Development noted that reconnection of the flood plain could potentially impact the rate at which water can be moved through the Okanagan River system, if this is the case then changes to reservoir operations may be required to accommodate this change in flow rate which could present challenges elsewhere in the Okanagan Basin.

Capital costs of removing the dikes along the river channel and adding flood protection to the Canadian Wildlife Service ponds would likely be high, detailed engineering design work would be required to determine the exact cost. Maintenance activities would likely include continuous monitoring of the reconnected floodplain and maintenance of the engineered pond protection. The operational cost of these activities would likely be comparatively low compared to other mitigation options and alignment with ecological goals and the priorities of the province may make the reconnection of the floodplain a feasible option despite the high initial investment required.

3.2.3 Expansion of the outlet channel at McIntyre Dam

McIntyre Dam is situated at the south end of Vaseux Lake and is operated to control the water level in Osoyoos Lake and Vaseux Lake to ensure enough water is available for irrigation of the land surrounding Vaseux Lake.

Expanding the outlet channel on McIntyre Dam would potentially allow basin operators to let more water through McIntyre Dam during high flow which means a higher flow velocity could be maintained through Vaseux Lake, a small increase in the velocity of water moving through Vaseux Lake could draw small sediment particles through the lake and prevent them settling in Vaseux Lake. Increasing the velocity of water moving through Vaseux Lake coupled with a milfoil management plan (section 3.1.1) could also increase the natural scour of existing sediment although the scouring effect would likely be small.

Expansion of the outlet channel on McIntyre Dam would be most effective at mitigating sediment during high flow, effectiveness is highly dependent on how the basin is operated during flood season. Managing the basin for sediment mitigation is not a priority for infrastructure operators (personal comm. Shaun Riemer, November 8, 2021). Unless carefully managed there is a risk that sediment will be deposited towards the south end of Vaseux Lake further extending the area of concern.

3.2.4 High-level evaluation of longer term options

Figure 6 lays out a summary of the options and the high-level assessment of each option. Assessment categories were weighted with the ability of the option to successfully mitigate sediment deposition weighted the highest, weighting shows the mitigation options ranked relative to one another. The weighting and ranking for each option were multiplied to produce an overall score out of 100. The option with the highest score indicates the most suitable based on this high-level assessment. Further investigation and engineering feasibility work would be required to provide a detailed assessment of assess any option of interest. A more detailed explanation each of the criteria and their weighted contribution to the total score for each option is contained in Appendix D: Criteria chosen to assess longer term sediment mitigation options

The high-level assessment indicates that the most favourable longer-term option is the reconnection of the Okanagan River to the floodplain. Reconnection of the floodplain would likely have the most beneficial sediment reduction impact on Vaseux Lake and has the greatest number of potential secondary benefits including improvements to water quality as well as benefits to local ecology.

Options	Reconnect Okanagan River to the floodplain	Create a sediment basin on the Okanagan River	Expand sediment basin on Shuttleworth Creek	Expand the outlet channel on McIntyre Dam Lake
Capital cost estimate ($)	>1 million	>1 million	<500,000	<100,000
Operational cost estimate ($/yr)	<20,000	>50,000	<50,000	0
Estimated area requirement	30,000m^2	40,000m^2	10,000m^2	0
Estimated engineering timescale	<10 years	<10 years	<5 years	<2 years
Relative impact to local ecology	positive	negative	neutral	neutral
Relative impact to Vaseux Lake water quality	positive	positive	positive	unknown
Impacts local infrastructure e.g. houses	No	No	Potential	No
Sediment reduction capability	very good	very good	very good	poor
Basin Priority	Moderate	Very Low	Very Low	Low
SCORE	**84**	**53**	**64**	**66**

Figure 6 Decision matrix for potential Vaseux Lake sediment mitigation options

4.0 Conclusions & Recommendations

Vaseux Lake is located along a portion of the Okanagan River with particularly high sediment loading due to its proximity to Shuttleworth Creek. Sediment deposition and subsequent infilling of the lake are a natural part of the lifecycle of Vaseux Lake; however, there are several reasons action should be taken to slow the rate of sediment deposition as much as possible. Shallow water in the north end of the lake is causing high water temperatures leading to a temperature squeeze for sensitive salmon species. The deposition of fine sediments has created a habitat for invasive milfoil which is binding the sediment reducing the impact of natural scouring and decreasing flow velocity leading to increased rate of sedimentation deposition. The infilling of the lake through sedimentation is also causing a loss of open water surface area and loss of a key recreational area. The Shuttleworth Creek sediment basin is not effective at capturing fine silts (<63μm diameter) during high flow or when not frequently maintained and this has resulted in fine sediments being carried into the Okanagan River and depositing downstream in Vaseux Lake.

The review of historical reports, photographic analysis and information from First Nations and stakeholders indicated that there is no single sediment mitigation solution that will eliminate the deposition of fine sediments in the lake. The recommended mitigation plan laid out below provides a number of near term and longer term recommendations which, will likely result in a more natural sediment deposition rate when implemented in conjunction with one another. The recommended mitigation plan will also result in beneficial outcomes for native fish species and for the management of invasive species.

4.1 Near term recommendations

4.1.1 Maintenance of the Shuttleworth Creek sediment basin

Historically deposited material from the Shuttleworth Creek sediment basin has been more frequently than it is currently (Burge Ecohydraulics, 2011) . Frequent maintenance stopped in 1982 due to limitations in provincial budgets and no regular maintenance schedule is currently in place. As the basin fills it becomes less efficient at capturing fine sediments, so to maintain peak efficiency sediment must be removed form the basin on a regular basis. It is recommended that more frequent maintenance of Shuttleworth Creek sediment basin is resumed. Returning to a regular maintenance schedule will ensure the sediment basin consistently operates at peak efficiency and prevent unforeseen events such as bank collapse from overwhelming the sediment basin before maintenance can be performed.

The most significant barrier to implementing this will be funding as the province has limited budget to perform maintenance.

4.1.2 Active management of macrophytes

Actively managing aquatic plant growth in the north end of Vaseux Lake will not impact the volume of sediment reaching the lake but it may help maintain water velocity during high flow which will naturally scour existing sediment and prevent the binding of sediment through plant growth which will slow the creation of islands. An additional benefit from this action is the removal of invasive milfoil from the lake.

It is understood that the VLSA is already in the process of gaining permission to rototill the north end of the lake and a pilot project is proposed to ensure there are no water quality issues resulting from milfoil removal. It is recommended that the proposed rototilling pilot is undertaken and if appropriate results are shown that rototilling of the affected area is conducted at an appropriate frequency. Continuous monitoring of aquatic plant growth should be undertaken by the VLSA and rototilling should be performed on an as required basis going forward.

4.2 Longer term recommendations

4.2.1 Reconnection of the Okanagan River with the floodplain

It is recommended that the VLSA work with First Nation and conservation groups in the area to reconnect the Okanagan River to the flood plain to the north of Vaseux Lake. Reconnection of the floodplain will allow sediment carried into the river during high flow to settle out before reaching Vaseux lake reducing the volume of sediment reaching the lake. An ideal scenario would allow for complete reconnection of the flood plain through the removal of the berm on the west bank of the Okanagan River.

First Nation and conservation groups in the area have expressed an interest in the reconnection of the flood plain through a phased approach. A number of options are currently under consideration by the ORRI committee including connection via pipe through the existing berm and dike removal. From a sediment management perspective it is beneficial to reconnect as much of the floodplain as possible, however, there are a number of considerations that need to be addressed including how to protect key habitats, ensuring sediment deposition does not block outlet channels and managing the minimal change in elevation within the floodplain that could limit water flow into the area.

The reconnection of the floodplain with the Okanagan River has the potential to reduce the rate of sediment deposition most significantly in compared to the other options outlined in this report and appears to align well with other ecological goals in the area.

It is recommended that the VLSA continue to work collaboratively with the ONA and conservation groups and continue to be actively engaged in the Okanagan River Restoration Initiative. The VLSA should use the information provided in this report to inform the collaborative process going forward.

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Appendix A: Analysis of aerial photography and historical sediment deposition

The extent of historical sediment deposition in Vaseux lake was evaluated using a combination of aerial and satellite imagery to provide a high-level estimate of the rate of sediment deposition in Vaseux lake and the trends in deposition over time. Understanding the trends in the rate and approximate volume of deposition events informs the identification of conceptual mitigation options.

Aerial photographs were obtained from the British Columbia aerial imagery library for 1963, 1976, 1987, 1994 and 2000 (Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2021). High resolution satellite imagery was available to perform the analysis in the 21st century, satellite images were obtained from Google Earth for 2004, 2010 and 2018. Aerial and satellite images were selected for their quality, coverage of the study area, and time period. The historical imagery covers the study area since the channelization of the Okanagan River in 1950's. Adequate imagery was not available before the channelization of the river.

Aerial and satellite images were manually georeferenced so they could be overlayed. The extent of the sediment plume in each year was measured by analyzing the observable sediment plume in each image and measuring the area. By measuring the extent of sediment encroachment into Vaseux Lake it is possible to assess the rate at which sediment deposition is occurring, estimate if that process has accelerated over time, and indicate the magnitude of change.

A high-level quantitative analysis of the area of the observable sediment plume was conducted by manually assessing the area of sediment present in each photograph. This assessment included measuring the area of any permanent islands that were present because of sediment deposition.

A-1 Aerial imagery analysis results

In 1963, the sediment plume was observed to be approximately 12,812 m^2 (0.4% of the total surface area of the lake). By 2018 sedimentation was observed to cover approximately 46,451 m^2 (approximately 1.5% of the total surface area of the lake).Figure A- 1 shows a comparison between the sedimentation estimated in 1963 and 2018. In 1963, sediment appeared to be localized within the vicinity of the northern shore of the lake. By 2018, several permanent islands had formed within the lake some distance from the northern shore. The development of islands indicates that sediment is not being transported through the lake. The islands allow aquatic plants to use the shallow water and nutrients carried by the sediment to establish themselves. The roots of these aquatic plant species bind the sediment preventing scouring during high flow events. The establishment of a permanent shallow lakebed can increase the velocity of the water flowing and allow sediment to be deposited further from the mouth of the Okanagan River. However, the presence of aquatic plants creates more complex flow dynamics and can cause the deposition of sediment sooner thus establishing the islands.

Figure A- 1 Vaseux Lake sediment plume in 1963 (left) compared to sediment plume in 2018 (right)

The area of observable sediment deposition in each image was compared to assess how the rate of sediment deposition has changed over time. Figure A- 2 shows that over the 55-year period analyzed the deposition of sediment has increased. High deposition events appear to have occurred in certain time periods between data point most notably 1976-1987, 2000-2004, and 2010-2018. The peaks observed in the aerial analysis for 2004 and 2018 align with known sediment deposition events in Vaseux Lake. High rainfall in June 2004 triggered numerous small debris flows which deposited in Vaseux Lake (Tannant D., 2012). The study carried out by Larratt Aquatic Consulting in 2018 noted a landslide on Shuttleworth Creek upstream of Okanagan Falls resulted in significant debris reaching the Okanagan River (Larratt Aquatic, 2019). The landslide in 2018 was likely due to high flows in Shuttleworth Creek, the gauge station located on the Okanagan River at Okanagan Falls reported an extended period of high flow between March and August 2018 peaking at $77m^3/s$ (Environment and Climate Change Canada, 2021).

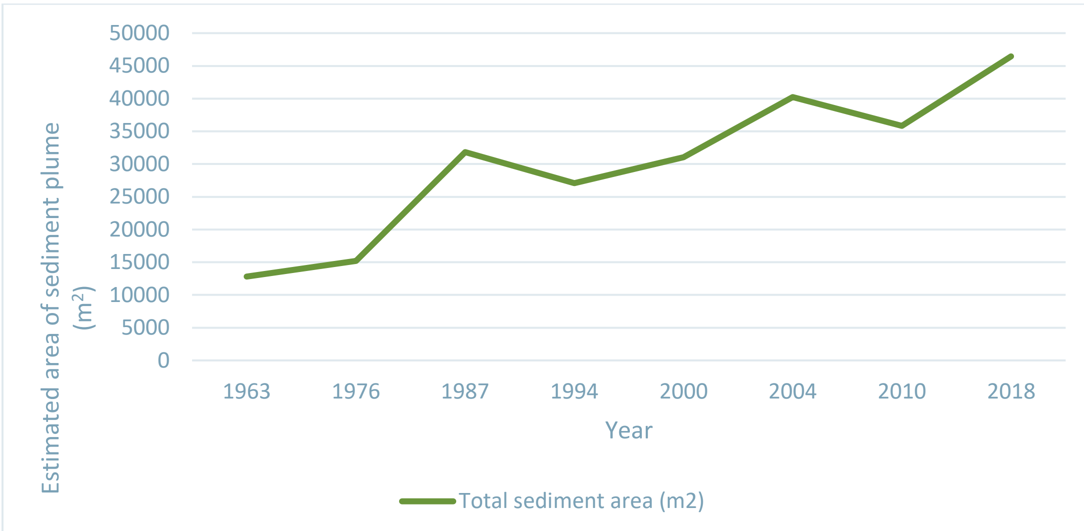

Figure A- 2 Estimated total area of observable sediment plume in Vaseux Lake between 1963 and 2018

The photographic analysis shows that the majority of sediment in the lake is deposited through large infrequent events often correlating to debris flows in Shuttleworth Creek. The photographic analysis shows the rate of sediment deposition does not appear to be increasing over the 55-year time period. The photographic analysis indicates that the most effective mitigation options are likely to be those that prevent sediment deposition during high flow events.

A-2 Limitations of photographic analysis

It should be noted that the water level in Vaseux Lake changes on a seasonal basis and is dependent on how upstream infrastructure is operated. As such an accurate comparison between aerial photographs in not possible; however, it is possible to compare the general trends across the 55-year time period.

Another potential source of uncertainty in the aerial photograph analysis is that sediment is not distributed evenly throughout the lake over time, this is most observable when islands are formed where deposition is highest. A 55-year time span of imagery analysis was selected to mitigate the impact of localized deposition rates since a general trend should still be observable over a 55-year time span.

Appendix B: Review of historical investigations

Several historical reports have investigated the impacts of sediment deposition in Vaseux Lake and Shuttleworth Creek. Historical Watershed reports have assessed the health of the watershed and identified key challenges in other areas of the watershed that are now also being observed in Vaseux Lake.

Larratt Aquatic Consulting conducted a study to investigate the impacts of nutrient loading in the Okanagan River and how this coupled with sediment deposition led to the proliferation of invasive milfoil in Vaseux Lake.

A study led by Dr. Leif Burge and Burge Ecohydraulics consultants conducted a detailed investigation of the sediment loading in Shuttleworth Creek. The primary goals of this study were not to mitigate sediment deposition in Vaseux Lake but reestablish fish habitat and migratory pathways in Shuttleworth Creek (Burge Ecohydraulics, 2011). The report is key to understanding the capabilities of the existing sediment basin on Shuttleworth Creek and the particle size distribution reaching Vaseux Lake.

B-1 Watershed reports

In 2008, the Okanagan Water Stewardship Council published the Okanagan Sustainable Water Strategy Action Plan (Okanagan Water Stewardship Council, 2008). The plan identified risks to water supply, water quality and the environment throughout the Okanagan River basin. The Action Plan identified sediment as a point source pollutant and recognized that transport of sediment causes several issues in the basin. The report notes that sediment deposition in Osoyoos Lake is high, this has caused lower water levels in the northern end of the lake. Shallower water has resulted in the proliferation of invasive aquatic plants and resulted in a temperature-oxygen squeeze in Osoyoos Lake.

A temperature-oxygen squeeze is a seasonal occurrence in lakes in the Okanagan Basin that impacts key fish species such as Sockeye salmon. In the summer high temperatures warm the surface of the lake, salmon are a cold-water fish and move deeper into the lake to escape the warming conditions. Simultaneously, organic decomposition on the lakebed consumes oxygen creating an oxygen deprived zone at the bottom of the lake. The fish cannot survive in oxygen deprived conditions and the survivable habitat narrows as the fish are forced to avoid high temperatures and low oxygen conditions. Figure B- 1 illustrates the temperature-oxygen squeeze observed in Osoyoos Lake.

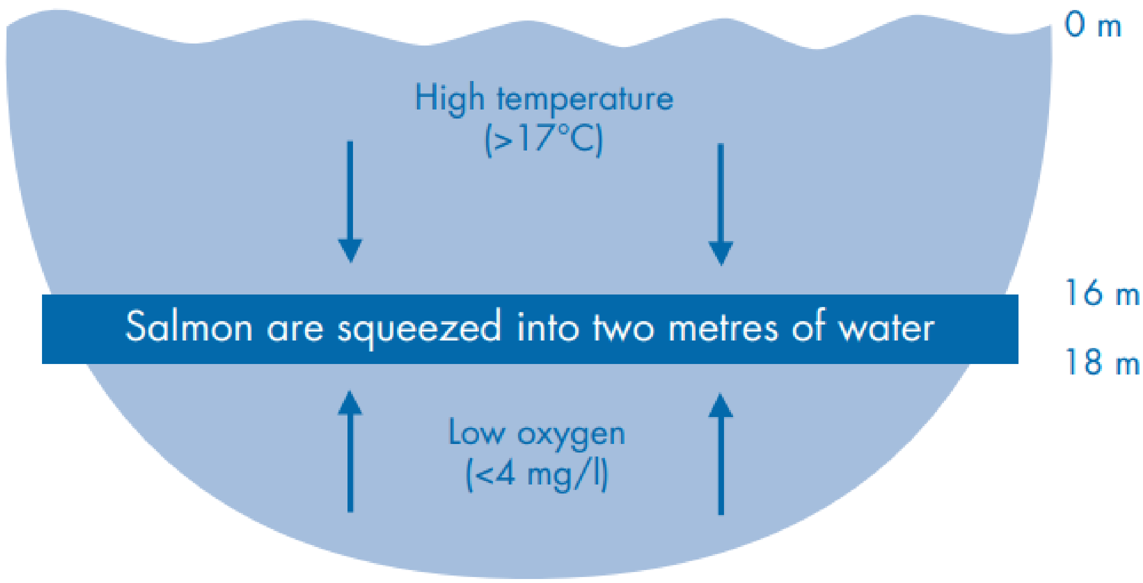

Figure B- 1 Schematic illustrating temperature-oxygen squeeze in Osoyoos Lake (Okanagan Water Stewardship Council, 2008)

There are notable parallels between Osoyoos Lake and Vaseux Lake including the existence of shallow water and proliferation of invasive aquatic plants. Anecdotal evidence suggests that in 2021 high temperatures observed in July and August eliminated the habitable zone entirely in certain areas of Osoyoos and Vaseux Lakes resulting in fish death.

Although the Okanagan Sustainable Water Strategy Action Plan documents the issues resulting from sediment loading in lakes in the Okanagan basin, no mitigation strategies are suggested that directly address the issue of sediment deposition in the lakes.

B-2 Sedimentation, Nutrient Loading, and Invasive Milfoil – Larratt Aquatic Consulting

A two-year investigation was conducted by Larratt Aquatic Consultants (LAC) in 2017 and 2018 to identify likely sources of sediment and nutrient loading that are contributing to the proliferation of invasive milfoil and filamentous algae growth in Vaseux Lake.

The LAC study mapped the extent of sediment deposition using aerial imagery and measured the extent and rate of deposition by comparison of ariel photographs with preceding years. This qualitative assessment of sediment loading did not yield an exact sediment loading rate but allowed the project team to visually gauge sediment deposition and identify areas of increased sediment deposition into the north end of the lake. Small sediment basins were installed in the north end of the lake in 2017 to provide a quantitative assessment of sediment loading rates, however, poor weather meant that these were unable to be retrieved before the conclusion of the project.

The LAC project team identified Shuttleworth Creek as the major source of sedimentation based on a review of previous literature and acknowledged the sediment basin installed in the lower reach of Shuttleworth Creek played a significant role in mitigating sediment deposition in Vaseux Lake and in fall 2017 the sediment basin was dredged. In 2018 a large spring freshet caused a major slope failure in the Shuttleworth Creek watershed, the sediment released from this failure exceeded the capacity of the recently dredged sediment basin and resulted in significant sediment deposition in Vaseux Lake. The study noted that most of the sediment deposition occurs during spring freshet, this is expected due to the alluvial nature of the Shuttleworth Creek watershed accelerated erosion will occur during high flow periods.

Along with sediment deposition, LAC also studied the proliferation of invasive milfoil and filamentous algae. The study notes a close linkage between sediment deposition and macrophyte growth as fine sediments act as a substrate for growth as well as a transportation vector for essential nutrients needed for aquatic plant growth. Aquatic plant mapping was undertaken in 2017 and 2018, concluding that the shallow waters in the north end of Vaseux Lake provided an ideal habitat for macrophytes. It is likely that macrophytes would flourish in this area regardless of the invasive milfoil density.

Milfoil and other macrophytes growing in deposited sediment will bind the sediment bed and stabilize it establishing a permanent new lakebed and promoting the formation of islands. The formation of several islands has been observed in Vaseux Lake since the 1950's. Once the sediment is stabilized by macrophytes it is much more difficult to remove, natural processes will no longer scour the sediment and mechanical methods such as dredging becomes much more challenging.

The LAC project team recommended that a hydrological study on Shuttleworth Creek investigate the likelihood of future slope failures. Understanding the risk better would allow better mitigation against slope failures which result in large volumes of sediment deposition in Vaseux Lake.

The LAC study also recommended that the sediment basin at the mouth of Shuttleworth Creek be expanded to capture smaller sediment particles and prevent silts depositing in Vaseux Lake. More frequent maintenance of the sediment basin was also recommended, as the sediment basin fills it becomes less effective at capturing smaller sediment particles and these are carried into the Okanagan River and deposited in Vaseux Lake.

An additional recommendation of the study was to conduct extensive monitoring of plant species and density presence in Vaseux Lake. Understanding the species and density of plant life could facilitate the creation of effective management plans which would aim to restore balance in the ecosystem and protect habitat for native plant and fish species.

B-3 Analysis of sediment deposition and sediment mitigation strategies for Shuttleworth Creek

A comprehensive sediment deposition and mitigation analysis was conducted by Burge Ecohydraulics led by Dr. Leif Burge of the University of British Columbia (UBC). The objective of this study was to analyze the sediment deposition in the Shuttleworth Creek sediment basin, assess the historic and current performance of the sediment basin and provide assess potential strategies that could be implemented to improve the ecological environment for the spawning of sockeye salmon which rely on gravel and sediment deposition for spawning. This work was carried out in collaboration with the Okanagan Nation Alliance (ONA). (Burge Ecohydraulics, 2011)

The historical assessment noted that maintenance on the sediment basin was performed more frequently between 1964 and 1982 with the average time between extractions being 1.8 years with an average sediment extraction volume of 5,435 m^3/year. From 1982 to 2011 sediment removal was performed on average every 9.8 years with an average extraction volume of 1,397 m^3/year. The authors note that some of this difference is likely accounted for by budgetary constraints limiting the frequency of extractions; however, there is a clear trend indicating there is less sediment being deposited in the sediment basin.

Table B- 1 shows the results of the grain size analysis from samples taken within the sediment basin during April and July, 2011. D_{16} denotes that 16% of the particulates are less than the grain diameter noted in millimeters. D_{50} denotes the median grain size D_{84} denotes 16% of particulates exceed the diameter shown. Percentage particulate classifications follow the Wentworth sizing categories.

Table B- 1 particle size distribution in Shuttleworth Creek sediment basin (Burge Ecohydraulics, 2011)

	XS 44 sand, right bank	XS 45 sand, left bank	XS 46 sand, right bank	XS 46 sand, left bank	XS 47 sand, right bank	XS 47 sand, left bank	XS 48 sand, center bar	XS 50 sand, thalweg	XS 51 sand, mouth
D_{16}	0.01	0.07	0.06	0.06	0.06	0.11	0.74	0.10	0.05
D_{50}	0.05	0.30	0.12	0.11	0.14	0.24	0.46	0.24	0.28
D_{84}	0.10	2.80	0.29	0.25	0.26	0.64	3.39	0.74	0.50
Sorting	1.40	3.93	1.43	1.33	1.46	1.38	3.46	1.93	1.91
% Sand	100.00	79.35	99.30	99.79	99.56	96.77	75.59	98.43	98.56
% Gravel	0.00	20.65	0.70	0.21	0.44	3.23	24.41	1.57	1.44
% Cobble	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The analysis of sub-surface samples taken indicate that the sediment basin is highly effective at capturing particulates larger than 0.05mm in diameter but less effective at capturing particulates classified as silt (<0.05mm diameter). This outcome is unsurprising because silt particles can take hours to days to settle out.

Burge Ecohydraulics team analyzed suspended sediment size distribution to understand the grain size of particulates that were carried by the streamflow during spring freshet. Samples were collected between

May 10 and June 23, 2011. Analysis of the 23 samples collected indicated a maximum sediment concentration of 7.56 g/l, the study noted this is high compared with comparable water courses in central B.C. 92-99% of sediment captured in each sample was classified as sand while 1-8% was classified as silt. As previously noted, the sediment basin is designed to capture sand but is not highly effective at capturing silt. It is reasonable to speculate that during the 2011 freshet 1-8% of total sediment passed through the sediment basin and into the Okanagan River.

The Burge Ecohydraulics study suggested several mitigation options that would meet the goal of improving fish habitat in the area including installation of multiple sediment basins upstream of Okanagan Falls. Installation of multiple sediment basins would potentially maintain favourable fish habitat closer to the Okanagan River. Multiple sediment basins are often favoured in mining applications where sediment loading rates are high and there is a large range in particle size. The Burge Ecohydraulics study concluded that multiple sediment basins would be unsuitable for the Shuttleworth Creek reach as there is no specific source of sediment within the watershed and few suitable locations to place multiple basins upstream of Okanagan Falls.

The Burge Ecohydraulics study considered the impacts of removing the sediment basin from Shuttleworth Creek entirely. This would improve the habitat in the creek for fish and promote natural gravel deposition in the Okanagan River which would improve spawning habitat for critical fish species. The Burge Ecohydraulics study recognized that removal of the sediment basin would adversely impact the operation of the hydraulic drop structures on the Okanagan River and potentially affect water management in the river as well as allowing large amounts of sediment to deposit in Vaseux Lake. Consequently, removal of the sediment basin was not recommended as part of the study.

The Burge Ecohydraulics study recommended that the existing sediment basin in Shuttleworth Creek be retained and modified to enhance fish passage. This option presented the least risks to Okanagan River flow capacity. The study recommends that the redesign of the basin should aim to capture gravel and cobble, but sand should be allowed to pass through into the Okanagan River. If the sediment basin were modified in this way, it would likely result in increased sediment deposition in Vaseux Lake as sand particulates would be transported into the lake by the Okanagan River.

Appendix C: Input from First Nations and key stakeholders

The Vaseux Lake Stewardship Association is one of several parties with an interest in the health of Vaseux Lake and the Okanagan River. Canadian Wildlife Service and Ducks Unlimited have conservation interests in the wetland area to the north of Vaseux Lake. The Okanagan Nation Alliance (ONA) is working on multiple projects within the Okanagan River basin to restore a more natural environment that is suitable for the migration and spawning of native fish species.

The provincial Ministry of Forests, Lands, and Natural Resources operates key infrastructure along the Okanagan River and is responsible for balancing the agricultural, ecological, and environmental needs of the Okanagan basin within Canada and ensuring obligations to the United States are met with respect to water supply.

As a minimum requirement any sediment mitigation solutions for Vaseux Lake should not negatively impact the ecological goals of other groups in the area or hinder the operations of existing infrastructure in the basin. To understand the goals, challenges and potential common alignments between sediment mitigation options and other ongoing projects in the basin input was gathered from the ONA, Canadian Wildlife Service and the Ministry of Forests, Lands, Natural Resource Operations and Rural Development.

C-1 B.C. Ministry of Forests Lands, Natural Resource Operations, and Rural Development

The Ministry of Forests, Lands, Natural Resource Operations and Rural Development (the Ministry) is responsible for the management of water supply in the Okanagan Basin, this includes the operations of large infrastructure such as reservoir operations and maintenance of smaller infrastructure such as the sediment basin at the mouth of Shuttleworth Creek.

Sediment transport can be influenced by how reservoirs are operated, altering reservoir operations could potentially alleviate some of the impacts of sediment deposition in Vaseux Lake. The Ministry identified many competing priorities within the basin that govern how reservoirs are operated. The highest priority is preserving life by mitigating the impacts of floods and droughts. Another high priority is maintaining adequate water supply for all water users in the system. Maintaining water levels for environmental and ecological purposes was also identified as a high priority activity.

The Ministry has certain obligations to the United States to maintain adequate flow in the Okanagan River under the Columbia River Treaty. Changes to operations in British Columbia can have consequences for water users across the border which increases the complexity of managing water in the Okanagan River basin.

Managing the reservoirs to mitigate sediment transport and deposition was not identified as a high priority, however, the Ministry expressed support for sediment mitigation options that would not negatively impact reservoir operations.

C-2 Okanagan Nation Alliance

The Okanagan Nation Alliance (ONA) represents the interests of 8 First Nation communities including the Okanagan Indian Band, Upper Nicola Band, Westbank First Nation, Penticton Indian Band, Osoyoos and Lower, and Upper Similkameen Indian Bands. As part of this project a preliminary discussion with ONA Fisheries occurred, any future management option selected would require broader input from indigenous communities in the area.

The ONA have undertaken several projects along the Okanagan River to protect key chinook and sockeye salmon spawning habitat. One example of this is the Okanagan River Restoration Initiative (ORRI) the main goal of which is to restore the Okanagan River to a more natural state by reintroducing riffles, meanders and reconnecting the river to its flood plain. Restoration of the river allows the creation of pools, gravel deposition and more complex flow regimes in the river channel which create a more suitable environment for fish spawning.

The first phases of the ORRI were completed on a section of the Okanagan River near Oliver which lies downstream of Vaseux Lake. Phase 1 of the initiative created gravel bars, riffles, and split flows within the existing river channel while Phase 2 of the initiative reconnected a small section of the river to a natural side channel. These initial phases were completed in 2013 and continuous monitoring was undertaken between 2014 and 2018. As result of the river restoration survival rates for fish eggs have improved and more spawning fish have been seen in the ORRI project area. Additionally, over the monitoring period the engineered spawning beds were augmented by natural sediment deposition indicating successful restoration of a natural system.

Based on the success of the initial phases of the ORRI, the ONA has received approval to conduct similar restoration projects in the section of the Okanagan River between Okanagan Falls and Vaseux Lake. The current phase of the ORRI will focus on introducing riffles in the river channel between Okanagan Falls and Vaseux Lake and removing the existing drop structures for improved fish migratory pathways. The riverbed depth will be altered in sections to create meanders within the existing river channel. This will promote deposition of gravel and a more natural flow regime to improve spawning habitat.

The current phase of the project is expected to have little impact on reducing sediment deposition in Vaseux Lake; however, a future phase of work may consider reconnecting the Okanagan River to the floodplain to the north of Vaseux Lake. The ONA have expressed their support for any sediment mitigation strategies that mutually support their ecological goals in the Vaseux Lake area.

C-3 Canadian Wildlife Service

The Vaseux Lake Migratory Bird Sanctuary was established in 1923 and encompasses the wetlands to the north of Vaseux Lake. Canadian Wildlife Service has a mandate to protect migratory birds, species at risk and their habitat.,. Canadian Wildlife Service manages several ponds and a channel in the wetlands at the north end of Vaseux Lake which could contain species at risk including the Tiger Salamander and Great Basin Spadefoot.

Canadian Wildlife Service indicated they were supportive of mitigation strategies that re-established the connection between the Okanagan River and the flood plain to the north of Vaseux Lake. Re-connection of the flood plain will assist their goal of re-establishing wetlands and could help prevent the establishment of reed canary grass an invasive grass species of concern in British Columbia.

Any mitigation strategies implemented within the wetland area would need to ensure the populations of species at risk such as the Tiger Salamander are protected. Connection of the ponds managed by Canadian Wildlife Service to the Okanagan River could result in fish entering the ponds and preying on amphibians placing these populations at further risk. Should the re-connection of the flood plain option be explored further engineering teams will need to explore protection of these ponds during high flow events to ensure the ponds and channel remain fish-free.

Appendix D: Criteria chosen to assess longer term sediment mitigation options

A total of nine criteria were used to provide a high-level assessment of the longer term sediment mitigation options. The criteria were defined as follows:

- **Capital cost estimate:** an order of magnitude indication of the cost of construction of the proposed option.
- **Operational cost estimate:** an approximate estimate of the annual cost of operating the proposed option.
- **Estimated area requirement:** an approximate estimate of the physical footprint of the proposed option.
- **Estimated engineering timescale:** an approximate indicator of the amount of time required to plan, design and construct the proposed option.
- **Relative impact to local ecology:** an indicator of the scale of impact the potential option may have to local ecology.
- **Relative impact to Vaseux Lake water quality:** an indicator of the scale of impact the potential option may have to local water quality.
- **Impacts local infrastructure:** an indicator of the extent of impacts to local infrastructure if the potential option were constructed. This includes potential impacts to houses, roads, bridges and pump houses.
- **Sediment reduction capability:** an indicator of the options ability to prevent sediment settling in Vaseux Lake.
- **Basin priority:** an indicator of how well each option appears to align with the objectives of others in the basin.

Each criteria denotes an important consideration when selecting a suitable option, however, not all criteria are necessarily of equal importance. For this high-level assessment the most important criterion was the ability of each option to reduce sediment in the basin. Table D- 1 shows the weighting of each criteria used for the assessment. Should an option be chosen for further investigation the criteria and weighting below can be used as a starting point for a more detailed assessment of potential sediment mitigation options.

Table D- 1 Weighting of criteria used for the assessment of longer term options

Criteria	Contribution to total score (%)
Capital cost estimate ($)	5%
Operational cost estimate ($/yr)	5%
Estimated area requirement	5%
Estimated engineering timescale	5%
Relative impact to local ecology	10%
Relative impact to Vaseux Lake water quality	10%
Impacts local infrastructure e.g. houses	10%
Sediment reduction capability	30%
Basin Priority	20%