WATER SCIENCE SERIES

Assessment of Groundwater – Surface Water Interactions on the Vaseux Creek Alluvial Fan, Oliver, B.C.

Chani Welch, Schafer Montgomery, Colette Louie, Nicole Pyett, and John Pogson

July 2025

BRITISH COLUMBIA

syilx Okanagan Nation Alliance

No. 2025-06

The **Water Science Series** are scientific technical reports relating to the understanding and management of B.C.'s water resources. The series communicates scientific knowledge gained through water science programs across B.C. government, as well as scientific partners working in collaboration with provincial staff. For additional information visit: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series.

ISBN: 978-1-0399-0156-8

Citation:
Welch, C., Montgomery, S.S., Pyett, N., and Pogson, J. 2025. Assessment of Groundwater – Surface Water Interactions on the Vaseux Creek Alluvial Fan, Oliver, B.C. Water Science Series, WSS2025-06. Prov. B.C., Victoria B.C.

Author's Affiliation:
John Pogson, P.Geo.
Ministry of Water, Land and Resource Stewardship
102 Industrial Place, Penticton, B.C.

Nicole Pyett, M.Sc., P.Geo.
Ministry of Water, Land and Resource Stewardship
102 Industrial Place, Penticton, B.C.

Colette Louie, Cert. Fisheries Tech.
Osoyoos Indian Band
1155 SenPokChin Boulevard, Oliver, B.C.

S. Schafer Montgomery, P.Geo.
Okanagan Nation Alliance
101-3535 Old Okanagan Highway, Westbank, B.C.

Chani Welch, PhD
Okanagan Nation Alliance
101-3535 Old Okanagan Highway, Westbank, B.C.

Cover Photograph:
Nicole Pyett

Acknowledgements

The report authors would like to thank Osoyoos Indian Band and Okanagan Nation Alliance field staff, Groundwater Technician Jeff Corrie for project field support, Groundwater Protection Officer Laura Maclaren for report contributions, and Stephanie Drake for providing technical review.

Funding was provided by Province of B.C. Water Stewardship Program, Watershed and Aquifer Science, Thompson Okanagan Region, Department of Fisheries and Oceans Habitat Stewardship Program, Okanagan Basin Water Board, and Okanagan College Grants-In-Aid of Research. In-kind support was provided by snʕax̌əlqaxʷiyaʔ, sq̓awsitkʷ, SORCO, and the Nature Trust of British Columbia.

EXECUTIVE SUMMARY

snʕax̌əlqaxʷiyaʔ (Vaseux Creek), located less than 10 km north of nʕaləmʼxnitkʷ (Oliver), B.C. in Syilx territory, is a location of known water scarcity during summer and fall with a documented presence of ecologically and culturally significant salmonid species. Groundwater-surface water interactions along the Vaseux Creek alluvial fan have been impacted by human channel and land use modifications, sediment movement and flow changes related to natural processes, and water diversion and use. Research in this area was undertaken to refine the understanding of groundwater – surface water interactions across the Vaseux Creek alluvial fan and to provide publicly available reporting to inform water management decision-making related to water allocation, drought response, and ecosystem restoration.

Groundwater – surface water interactions on the fan are spatially and temporally complex. Complementary methods employed in this project included seeking Syilx TEKK guidance, a review of available reports and water use, installation of hydrometric stations and groundwater observation wells (co-located where possible), testing and analysis of sediment, hydraulic conductivity testing, environmental tracers in surface and groundwater, completion of longitudinal stream discharge and chemistry surveys, and an elevation survey. These methods were combined to assess water sources and flow paths, groundwater – surface water connectivity, and water exchange across the alluvial fan.

Vaseux Creek flow is primarily sourced from catchment uplands, although the sq̓awsitkʷ (Okanagan River) also contributes via groundwater flow in the lower fan under specific combinations of creek and river stage. Generally, Vaseux Creek loses water between the apex and the mouth with loss concentrated in the central braided and lower channelized sections of the fan. Three sources of groundwater were identified using environmental tracers: mountain block recharge, the Okanagan River mainstem including akspaqmix (Vaseux Lake), and Vaseux Creek with creek recharge spreading radially out from the fan apex (and potentially traveling up to 800 m northwest) with vertical infiltration dominating in other areas. A wedge of creek water appears to sit over river- and/or mountain block recharge-sourced water in the central and lower fan. This wedge retreats upstream as creek discharge declines. Lithology and water level measurements did not suggest an independent alluvial fan aquifer exists above B.C. Provincial Aquifer No. 255.

The drivers of connection vary spatially across the fan. Shallow depth to bedrock, high creek discharge during freshet, and a combination of high creek discharge and river stage define the relationship at the apex, the central fan, and the lower fan, respectively. Transitional and potentially disconnected states are otherwise present on the central and lower fan.

The naturalised rate of stream loss is a function of creek stage, wetted area, time since freshet, continuity of creek flow (antecedent moisture conditions when events occur), and groundwater level due to river stage rise. The actual loss of water from the creek is greater due to surface water diversions that resulted in stream losses on average five times greater than licensed volumes in 2022 and 2023. Additional losses due to diversion operation were sufficient to reduce creek flow below the threshold required for continuous flow to the mouth in 2022; in 2023, diversion losses increased the frequency and duration of dry periods. The impacts of adjacent groundwater use on flows in the lower fan are not well understood but could be further investigated through the establishment of groundwater level monitoring on the south side of the creek accompanied by further work to characterize extraction volumes, timing, and locations of groundwater use.

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ACRONYMS

AMS	accelerator mass spectrometry
AQ	aquifer
BP	before present
CEFT	Critical Environmental Flow Threshold
CGVD	Canadian Geodetic Vertical Datum
CMWL	Canadian Meteoric Water Line
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CSRS	Canadian spatial reference system
DO	dissolved oxygen
EC	electrical conductivity
EFN	Environmental Flow Needs
GW	groundwater
GWE	groundwater elevation
HDPE	high density polyethylene
ICP	inductively coupled plasma
ID	identifier or identification number
LTMAD	long term mean annual discharge
MASCOT	Management of Survey Control Operations and Tasks
MASL	metres above sea level
MBR	mountain block recharge
NAD	North American datum
OBMEP	Okanogan Basin Monitoring and Evaluation Program
OBWB	Okanagan Basin Water Board
OKR	Okanagan River
OMWL	Okanagan Meteoric Water Line
ONA	Okanagan Nation Alliance
OW	observation well
PET	polyethylene terephthalate
PVC	polyvinyl chloride
RDOS	Regional District of Okanagan Similkameen
SOLID	South Okanagan Lake Improvement District
SORCO	South Okanagan Rehabilitation Centre for Owls
STB	streambed
STP	sewage treatment plant
SW	surface water
SWE	snow water equivalent
TEKK	Traditional Ecological Knowledge Keeper
TU	Tritium Units
UBCO	University of British Columbia Okanagan
VL	Vaseux Lake
WSA	Water Sustainability Act
WSE	water surface elevation (surface water)
WUC	Water User Community

NSYILXCEN PLACE NAMES

Indigenous Peoples (of the Okanagan) are the exclusive owners of their cultural and intellectual properties as reiterated through the United Nations Declaration on the Rights of Indigenous Peoples (2007).

nsyilxcen	English
kłusxnitkʷ	Okanagan Lake
sq̓awsitkʷ	Okanagan River (between Okanagan Lake and Osoyoos Lake)
nʕaləm’xnitkʷ	Oliver
snpintktn	Penticton
snʕax̌əlqaxʷiyaʔ	Vaseux Creek
akspaqmix	Vaseux Lake

1. PROJECT OVERVIEW

1.1 Project Background

There is considerable interest in how water use and the flow dynamics of alluvial fans affect stream flows in creeks. As a stream flows across its alluvial fan, it gains and/or loses water to the underlying aquifer at different rates at different times of the year depending on the state of connection, hydraulic gradient, aquifer properties, vegetation, and other stressors such as surface water diversions and groundwater pumping. snʕax̌əlqaxʷiyaʔ (Vaseux Creek) is frequented by endangered species including Chinook salmon (in COSEWIC process) and Steelhead (Endangered Species Act-listed in the USA). It also has a long history of water diversion and land use change. Syilx Traditional Ecological Knowledge Keeper (TEKK) guidance asserts that the creek is drying up more frequently than occurred previously. Knowledge of the dynamics between groundwater and streams is essential for effective water management yet remains a recognized knowledge gap in the Okanagan.

In Western science, the relationship between streams and groundwater is commonly defined in terms of hydraulic connection. Groundwater and stream hydraulic connectivity may be defined as (e.g., Brunner, 2010 and references therein):

- Connected. Groundwater elevation at or above streambed. Saturated flow from stream to aquifer. Stream gains water from or loses water to the groundwater based on the hydraulic gradient between stream and groundwater elevations.
- Transitional. Groundwater elevation below streambed, but fluctuations bring it closer to the streambed periodically. Variably saturated zone between streambed and groundwater. Stream loses water to groundwater. The infiltration flux asymptotically approaches a maximum, although it remains dependent on the depth of water in the stream.
- Disconnected. Groundwater elevation always below streambed. Unsaturated zone between streambed and groundwater. Stream loses water to the groundwater at a maximum rate that fluctuates with the depth of water in the stream and/or hydraulic conductivity of the streambed and aquifer sediments; however, fluctuations in the groundwater table, such as those caused by pumping, no longer affect the infiltration rate at this location. Extraction may, however, alter the length of stream that is transitional or disconnected by increasing infiltration upstream and downstream in connected reaches.

The 2016 implementation of the *Water Sustainability Act* (WSA, 2016) brought with it provisions for the protection of ecosystems requiring Statutory Decision Makers to consider the impacts of proposed surface water use, or groundwater use in a hydraulically connected aquifer, on the environmental flow needs of a stream during decision-making (WSA, 2016). In contrast, connectivity is inherent to Syilx world views. As outlined in the Syilx Siwɬkʷ Declaration, water, in all its forms, connects and sustains all life through time and must be treated with reverence and respect (ONA, 2014).

Quantitatively, stream–groundwater relationships can be expressed as estimates of exchange flux at different scales across a fan (i.e., point to reach scale). For effective management, identification of the drivers of the spatial and temporal variability in this exchange flux is required. Exchange flux can be estimated using a variety of techniques, each with associated limitations (Kalbus et al., 2006). On alluvial fans in the Okanagan, complex depositional history, low stream flows, and multiple anthropogenic impacts make water balance techniques such as differential flow gauging difficult to interpret in isolation. Including water chemistry and isotopic tracer measurements enables quantification of gross rather than net stream gains and losses across the fans which can then be linked to water quality and availability at critical times and stream locations. This data can also be used to identify water sources and flow paths, and hence drivers of exchange. Installation of co-located surface and groundwater monitoring stations can extend observation of the spatial pattern across time (e.g., Eddy-Miller et al., 2012), which is necessary in this semi-arid environment with a highly variable flow regime. By using multiple methods simultaneously on the same stream/fan system, estimates generated using different methods can be compared and recommendations made for investigations on other fans across the Okanagan Valley and other geomorphically similar systems.

1.2 Project Objectives

The objectives of this project were to:

- Refine the understanding of groundwater – surface water interactions across the snʕax̌əlqaxʷiyaʔ (Vaseux Creek) alluvial fan; and
- Develop publicly available reporting to inform water management decisions including water allocation, drought response, and ecosystem restoration activities.

1.3 Project Scope

The scope of this project included:

- Enhancement of the understanding of snʕax̌əlqaxʷiyaʔ (Vaseux Creek) alluvial fan lithology.
- Development of a water budget estimate for Vaseux Creek on the alluvial fan (‘the fan’) through evaluation of exchange flux.
- Assessment of the spatial and temporal variability in the magnitude and direction of exchange flux and connectivity state between Vaseux Creek and for B.C. Provincial Aquifer No. 255 (AQ255).
- Assessment of creek and groundwater water sources and flow paths.

This project did not include the development of a water budget for AQ255, nor did it include any water management decision making or statutory decisions under the WSA.

2. SITE DESCRIPTION

2.1 Site Location

The snʕaẋəlqaxʷiyaʔ (Vaseux Creek) alluvial fan is located south of akspaqmix (Vaseux Lake) and north of nʕaləm'xnitkʷ (Oliver) within the Okanagan Valley, British Columbia. It is bounded by the sq̇awsitkʷ (Okanagan River) to the West and the Okanagan Highlands to the East (Figure 1; Figure 3).

2.2 Climate

The project area is semi-arid with an average annual precipitation of 329.7 mm and average annual temperature of 10.3°C in the valley bottom (Government of Canada, 2022). Precipitation generally peaks in June and is lowest in September (Figure 2), falling as snow in winter due to frontal systems, rainfall in May and June from cold low-pressure systems with August and September as convective, recycled precipitation (Toews, 2007; Wassenaar *et al.*, 2011).

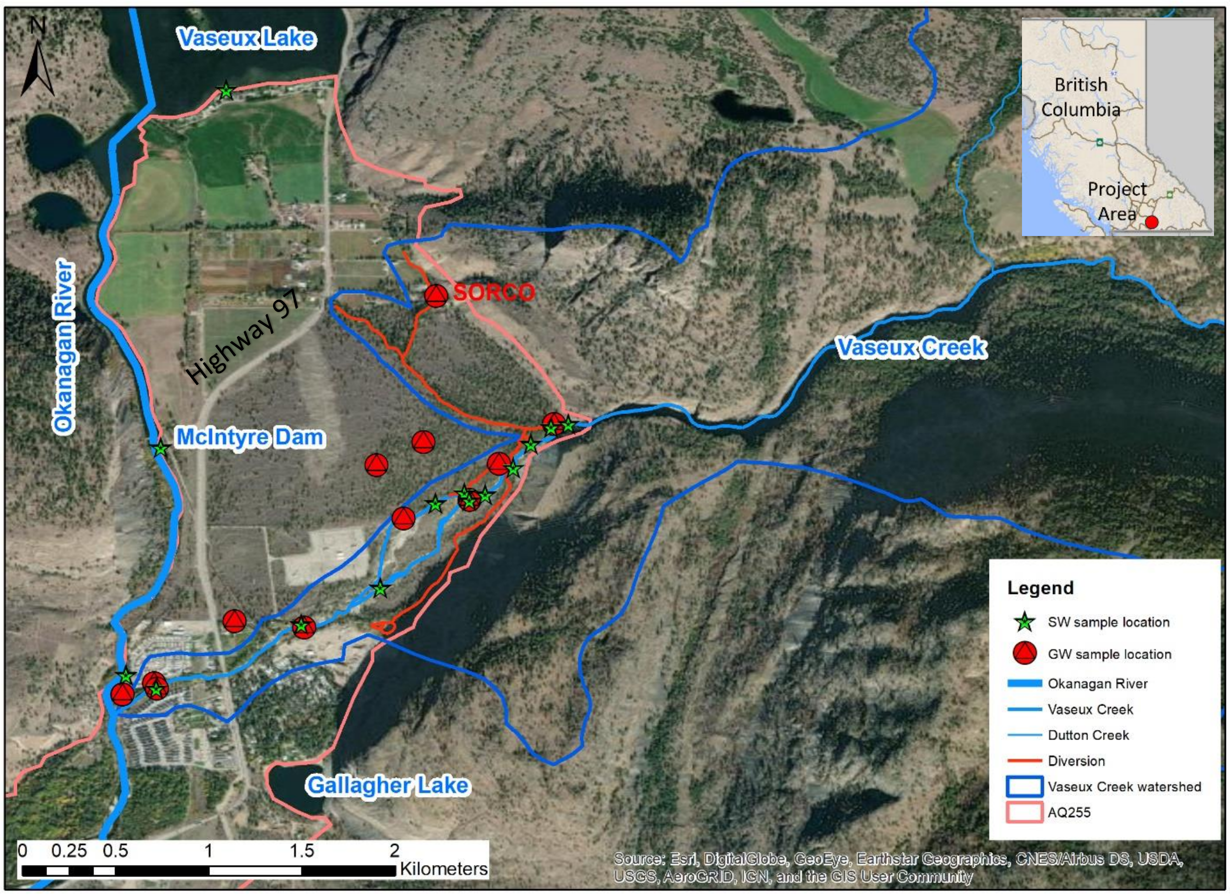

Figure 1: Lower Vaseux Creek catchment, AQ255 that also encompasses the alluvial fan in this area, and monitoring locations.

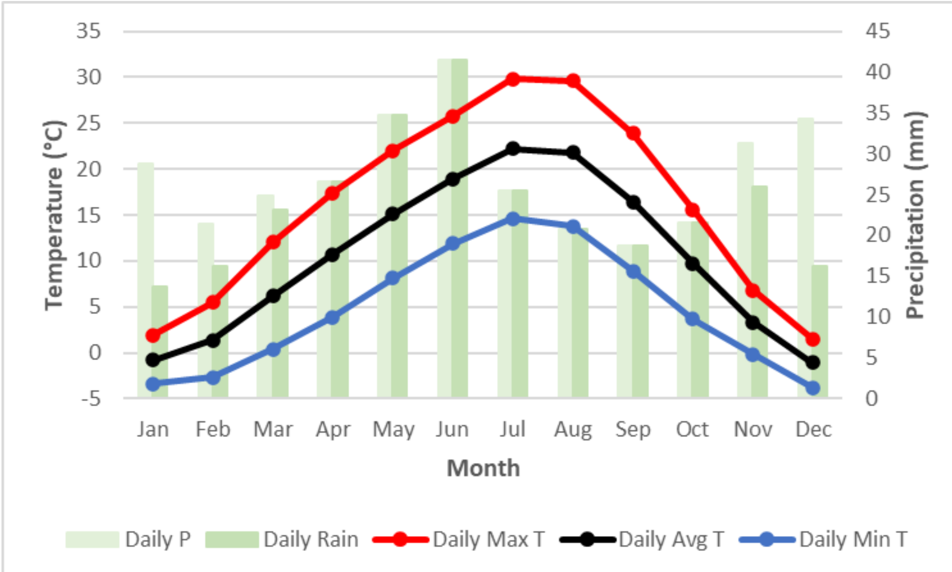

Figure 2: Climate Normals 1981 - 2010 Oliver STP (Government of Canada, 2022).

Although not currently measured in the snʕax̌əlqaxʷiyaʔ (Vaseux Creek) catchment, precipitation increases with elevation while temperature generally decreases in surrounding catchments. For example, in the Penticton Creek watershed, also located on the east side of Okanagan valley 25 km to the north, annual average precipitation increases to 784 mm at 1650 m and 824 mm at 1900 m, whereas the average temperature decreases to 2.0 °C at 1650 m and 1.4 °C at 1900 m (2000 – 2018; Winkler et al., 2021). The historical record from a manual snow survey site at 1400 m (2F20 – Vaseux Creek) indicates that peak snowpack snow water equivalent (SWE) is generally reported in March (Government of British Columbia, 2024).

2.3 Hydrology

snʕax̌əlqaxʷiyaʔ (Vaseux Creek) flows from the Okanagan Highlands in the east (maximum elevation 2300 m at Mt Baldy) to the sq̓awsitkʷ (Okanagan River) in the west downstream of McIntrye Dam and akspaqmix (Vaseux Lake) at an elevation of 316 m. The Vaseux Creek catchment area is 294 km^2, with a median elevation of 1,535 m. The main tributary, Solco Creek, enters Vaseux Creek upstream of a canyon. Vaseux Creek flows through this canyon before discharging onto an alluvial fan, where it braids across the central fan and is confined to the southern margin of the lower fan where the creek was straightened and diked for flood control purposes.

Multiple channels are active across the upper and central portion of the fan during high flows; in low flows, this reduces to one or two main channels. The primary channel has shifted from north to south in the past five to ten years. The annual hydrograph consists of a snow and sometimes precipitation-driven freshet peak between April and June declining to low flows for the remainder of the year. Historical data indicates that Vaseux Creek frequently dries up between Highway 97 and the mouth over summer and intermittently through the winter (ONA, 2020).

The Okanagan River flows from north to south with water levels controlled locally by McIntrye Dam (Figure 1). Overall, however, discharge in the Okanagan mainstem is controlled upstream at snpintktn (Penticton) at the kłusxnitkʷ (Okanagan Lake) dam according to the Okanagan Lake Regulation System based on interdisciplinary inputs designed to balance flood, drought, and aquatic health risks through application of the Fish Water Management Tool (Anon., 1974; Hyatt et al., 2015).

Real-time hydrometric monitoring of the Okanagan River is available upstream of the confluence with Vaseux Creek at Vaseux Lake (08NM243; Water Survey of Canada (WSC)) and below McIntyre Dam (08NM247; WSC) and along Vaseux Creek in the Okanagan Highlands above Solco Creek (08NM171; WSC) and near the mouth (08NM246-HDS; ONA/OBWB). A manual hydrometric station is located at the canyon outlet/fan apex (08NM708; ONA/OBWB).

2.4 Geology

Underlying bedrock in the study area is comprised of the Okanagan Metamorphic and Plutonic Complex which includes gneissic rocks and younger intrusive volcanic rocks (Okulitch, 2013). Geological Survey of Canada mapping indicates the Vaseux gneiss is lower Proterozoic in age (up to 2.5 billion years BP) and the intrusive rocks may be mid-Cretaceous (87 – 130 million years BP), (Journeay et al., 2000). The bedrock is overlain by late Pleistocene (Fraser Glaciation; 25,000 – 10,000 years BP) glaciofluvial deposits and recent fluvial and alluvial sediments (Nasmith, 1962). These combined unconsolidated deposits form the sediments of AQ255 (Lowen Hydrogeology Consulting Ltd., 2016).

Bedrock outcrops on the creek banks at the fan apex, but drops to greater than 65 m below surface in the distal fan, at an elevation lower than 255 m. A 1972 seismic survey attempted to identify the bedrock surface within the fan. An apparent steep bedrock surface and localized gravel beds made interpretations unreliable, and drilling was not attempted (Le Breton et al., 1972). Glaciofluvial benches are also present at the fan apex where the creek exits the canyon.

2.5 Hydrogeology

B.C. Provincial Aquifer No. 255 (AQ255) is approximately 14 km^2 in size and is delineated along the Okanagan Valley bottom between akspaqmix (Vaseux Lake) in the North to Tuc-el-Nuit Lake in the South (Figure 3). AQ255 is a Subtype 1A (aquifers found along major rivers), moderately productive, unconfined aquifer comprised of sand and gravel with flow assumed to travel from the North to the South but with a strong river water level influence near the sq̓awsitkʷ (Okanagan River; Lowen Hydrogeology Consulting Ltd., 2016). The aquifer is assumed to be recharged by direct precipitation, interactions with the Okanagan River and tributaries, and upland areas in the East and the West. AQ255 discharges to B.C. Provincial Aquifer No. 254.

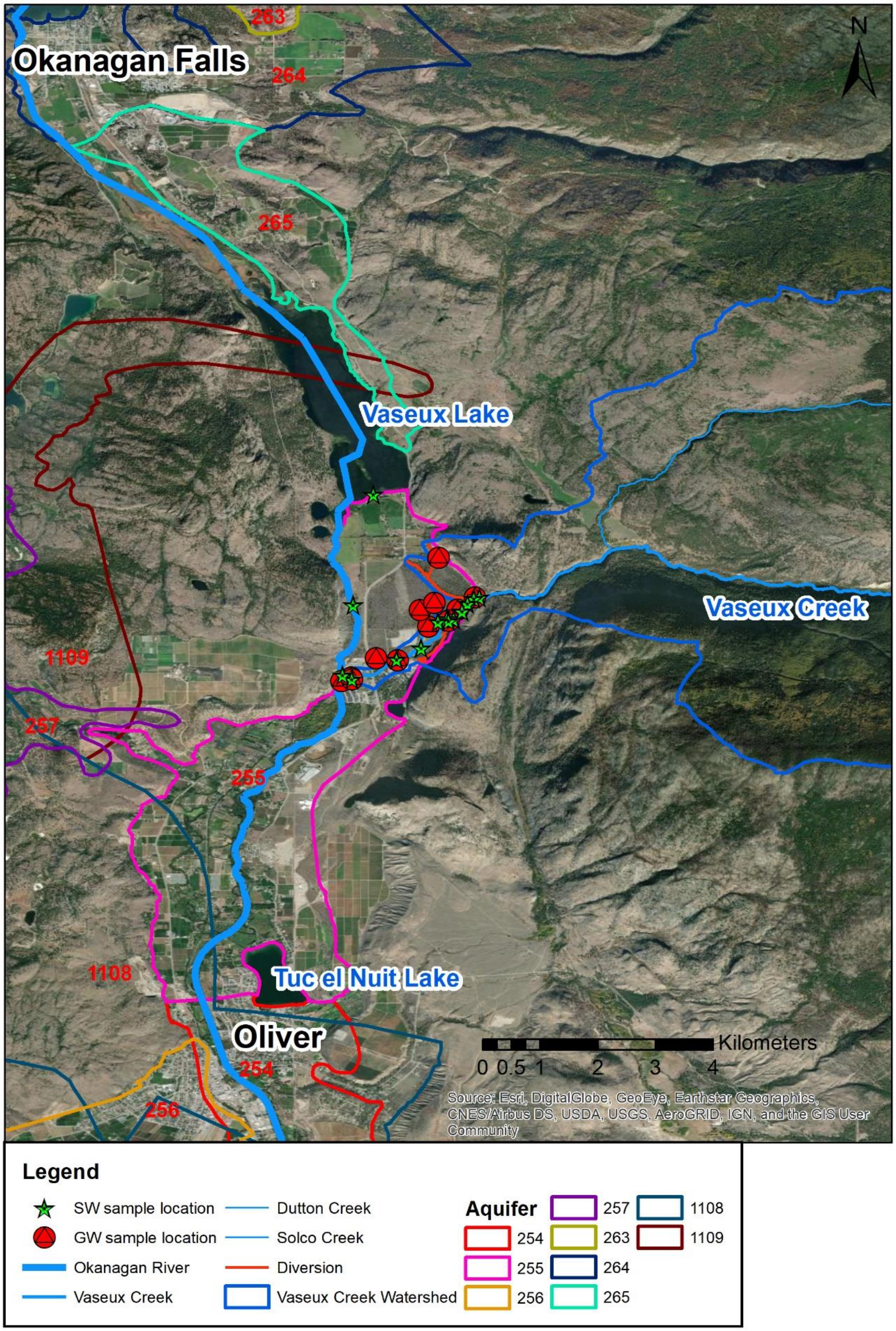

Figure 3: Aquifers of the Vaseux area.

2.6 Habitat

The project is located within the Bunchgrass biogeoclimatic zone (BGxh1; Government of British Columbia, 2018). Bunchgrass, antelope brush, and cactus dominate the fan landscape.

Native resident salmonid species in snʕax̌əlqaxʷiyaʔ (Vaseux Creek) include:

- sćwin (Sockeye; *O. nerka*)
- qʷəyqʷəyʕaćaʔ (Steelhead; *O. mykiss)*
- x ʷuminaʔ (Rainbow Trout; *O. mykiss*)
- skilwist and ntitiyx (Chinook Salmon, *O. Tshawytscha*)

Additional species present include Mountain Whitefish, Bridgeglip Sucker, Longnose Dace, Prickly Sculpin (ONA, 2020). Beavers are also active, especially on the central fan. Bears are regularly sighted, and bighorn sheep reside on the slopes above the creek.

Downstream of Highway 97 Vaseux Creek is diked, entrenched, the bank completely armoured, and urban encroachment present to the north and south, which has impaired riparian function by removing riparian vegetation and hence the supply of large woody debris and shading (ONA, 2020).

In 2020, Environmental Flow Needs (EFN) values and Critical Environmental Flow Thresholds (CEFT) were calculated for Vaseux Creek using the Okanagan Tennant and Wetted Usable Width methods (ONA, 2020; Table 1).

Table 1: EFN summary table for Vaseux Creek (ONA, 2020).

Species & life stage	**Time period**	**Recommended EFN** (m^3/s)				**Critical flow**	
		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
O. Mykiss parr & Chinook Fry rearing, insect production [a]	April 1 – Oct 31	0.150	12%	0.150	1.15	0.064	5%
Steelhead spawning	April 1 – Jun 25	1.50	117%	0.191	6.61	0.477	37%
Rainbow spawning	May 20 – Jul 10	1.50	117%	1.50	6.61	0.477	37%
Chinook migration	July 1 – Aug 26	0.313	24%	0.200	1.50	0.257	20%
Chinook spawning	Aug 27 – Sep 30	0.200	16%	0.200	0.200	0.129	10%
Sockeye spawning	Sep 16 – Oct 31	0.150	12%	0.150	0.200	0.129	10%
Overwintering salmonids	Nov 1 – March 31	0.070	5%	0.025	0.133	0.064	5%

[a] while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15 - Sept 30.
LTMAD = Long-term mean annual discharge.

2.7 Stream History

Human modification since the 1800s and natural processes have impacted snʕax̌əlqaxʷiyaʔ (Vaseux Creek; formerly McIntyre Creek) and the sq̓awsitkʷ (Okanagan River) adjacent to the Vaseux Creek alluvial fan in multiple ways that have affected, and continue to affect, the volume of surface water flowing across the fan (Table 2). These changes also affect creek stability and function, and potentially the interrelationship with groundwater.

Table 2: Modifications to Vaseux Creek and Okanagan River adjacent to Vaseux Creek fan.

Year	Modification	Source
1887	Northern diversion established	Appendix A
1919	Initial construction of McIntyre Dam on Okanagan River and construction of the South Okanagan Lake Improvement District (SOLID) irrigation flume from McIntyre Dam to the Canada/USA Border crossing Vaseux Creek upstream of Highway 97	Okanagan Historical Society, 1958 Long and Newbury, 2006
1942	Major flood in Vaseux Creek and channelization in mid-1940s	Long and Newbury, 2006, Figure 4
1954	McIntyre Dam upgraded	Associated Engineering, 2006
Mid-1950s	Vaseux Creek channelization from the mouth to the irrigation canal Vaseux Creek diking from the mouth to current substation (left bank) and the mouth to the monitoring location C4 shown on Figure 6 (right bank) Channelization and diking of Okanagan River upstream of McIntyre Dam	Long and Newbury, 2006 Air photo, AI6663 124, 1959 (all modifications) Associated Engineering, 2006
1959	Southern diversion established for irrigation (orchard) and domestic purposes	Appendix A
1970s	Country Pines Mobile Home Park and Cottonwood Mobile Home Park established south of Vaseux Creek, east of Highway 97	RDOS Electoral area “C” Official Community Plan Bylaw 2452, 2008
1982	Gravel road in use across Vaseux Creek downstream of the Highway 97 bridge	Air photo, bcc310-024 August 24, 1982
1988	Dike expansion for the Aquila Networks Canada Ltd/B.C. Hydro substation built over the active segment of northern braid	Long and Newbury, 2006 Air photo, bcc90028-080 July 4, 1990
1993-1994	Land cleared and re-graded north of Vaseux Creek, west of Highway 97 for Deer Park Estates development	Air photo, bcb94010-020 May 6, 1994
Late 1990s	Gravel pit development north of irrigation flume, immediately west of the orchard	Air photo, bcb00001-066 March 24, 2000
1998	Fish ladder constructed over SOLID canal. Ladder consisted of large boulder weir. Active erosion of the streambed was threatening weir integrity and blocking fish passage	Long and Newbury, 2006
2000	Land surface cleared and re-graded north of Vaseux Creek between the irrigation flume and Highway 97	Air photo, bcb00001_074 March 24, 2000

Table 2 Cont.: Modifications to Vaseux Creek and Okanagan River adjacent to Vaseux Creek fan.

Year	**Modification**	**Source**
2000-2004	Gravel pit expansion gradually removed orchard	Air photo, bcc04004-131 July 12, 2004
Early 2000s	Gravel road constructed across Vaseux Creek from gravel pit to substation site (adjacent to monitoring locations BBR/C2 in the mid fan)	Air photo, bcc04004-131 July 12, 2004
2003-2004	Aquila Networks Canada Ltd/B.C. Hydro Vaseux Lake substation construction in central fan	Air photo, bcc04004-131 July 12, 2004 RDOS corporate board minutes, October 16, 2003
2014	Agricultural land, south of Vaseux Creek, west of Highway 97 developed into Gallagher Lake Village Park (modular home development)	Air photo, bcd18101-812-25 September 25, 2018 RDOS planning and development committee second quarter report, 2014
2015	Deer Park 30 lot expansion	RDOS Electoral area "C" Official Community Plan Bylaw 2452, 2008
2018	Bank erosion at Deer Park. Bank armoured by rip rap and channel bed modified by April 2019.	OBMEP photo archive

Note: air photos were obtained from the Digital air photos of B.C. collection and the Canada Earth Observation Data Management System).

McIntyre Creek, looking up-stream from Provincial Highway, April 26th, 1946.

Figure 4: Channelization of Vaseux Creek (formerly McIntyre Creek) in the mid-1940s (Oliver Archives). Riparian vegetation evident.

2.8 Water Use

2.8.1 Surface water

There are two points of surface water diversion on the snʕax̌əlqaxʷiyaʔ (Vaseux Creek) fan (Figure 5; Figure 6):

- Northern diversion: diverts water from Vaseux Creek at the apex of the fan to a control structure approximately 80 metres from the apex and conveys it to the Vaseux Creek Water User Community (WUC) via an earthen channel. The licensed volume totals 268,020 m^3 per year, with diversion for irrigation permitted from April 1st through September 30th. The water use purpose is overwhelmingly Irrigation-Private with two domestic purpose licences associated with the diversion. These are the oldest surface water licences on this part of Vaseux Creek, with many of the priority dates as early as January 6, 1887.
- Southern diversion: diverts water from Vaseux Creek approximately 0.47 km from the fan apex and conveys it to the water user via an earthen channel. The licensed volume total for irrigation purpose is 59,207.04 m^3 per year, with diversion permitted from April 1st through September 30th. Additional volume associated with this licensed diversion includes 2.27305 m^3 per day for domestic use purpose (829.66 m^3 per year), permitted January 1st through December 31st. The priority date for these licences is November 2, 1959 (total licensed volume 60,037 m^3 per year).

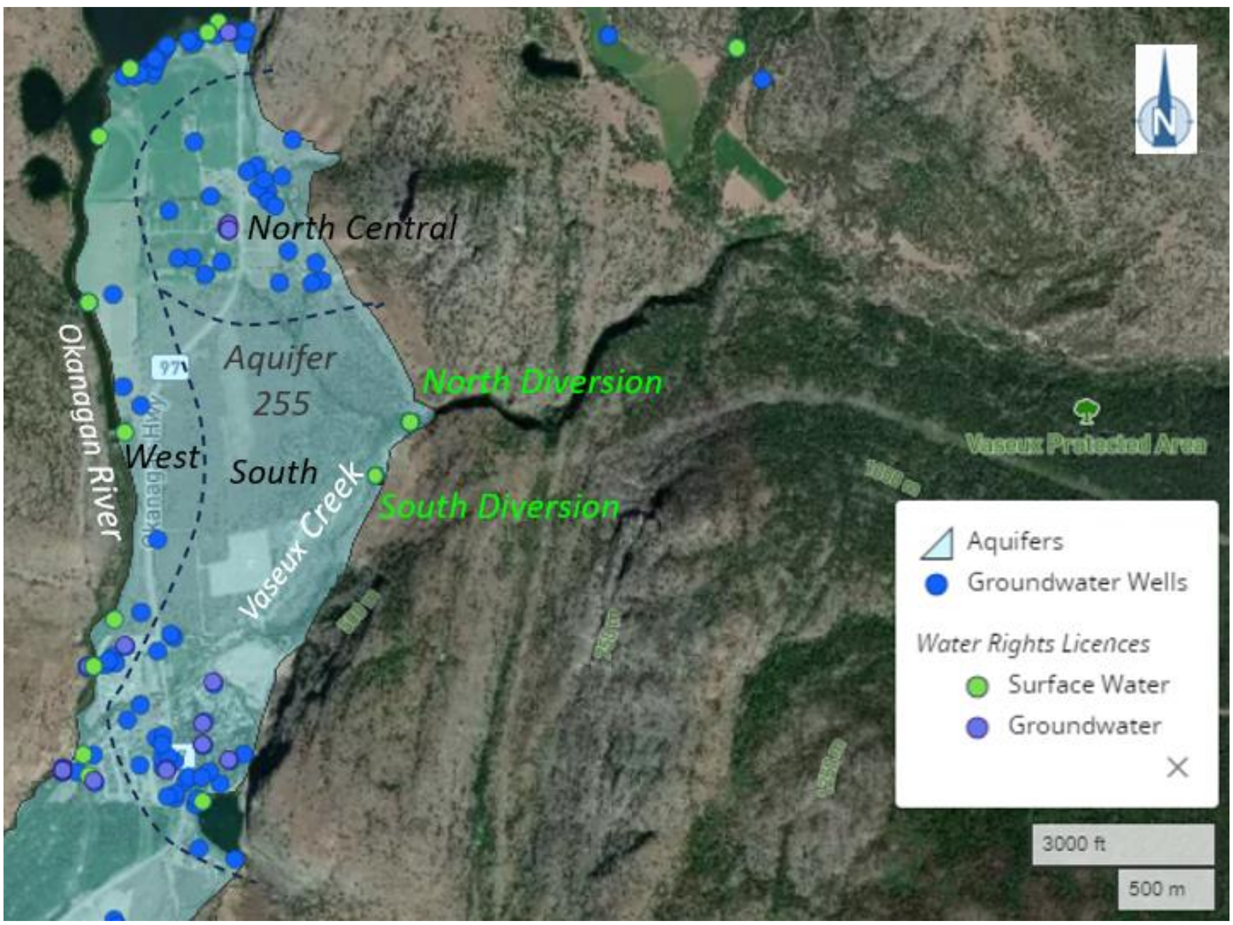

Figure 5: Groundwater wells and licensed points of water diversion from AQ255 and the Vaseux Creek alluvial fan.

The total quantity of water licensed to be diverted from Vaseux Creek is 328,057 m^3. Surface water use is currently under review through a formal WSA Beneficial Use Declaration process. A table with surface water licensing information is provided in Appendix A. Measured diversion fluxes as part of this study are presented in Section 5.

2.8.2 Groundwater

A review of groundwater wells records from the provincial GWELLS database identified 99 water wells in the northern portion of Provincial Aquifer AQ255, underlying the snʕax̌əlqaxʷiyaʔ (Vaseux Creek) fan. Approximately 62% of these wells were constructed prior to 1985 with the oldest constructed in 1949. Groundwater wells are grouped into three areas and shown on Figure 5: wells proximal to Vaseux Creek and Gallagher Lake (South); wells adjacent to akspaqmix (Vaseux Lake) and sq̓awsitkʷ (Okanagan River; West); and the concentration of wells on the north and central portion of Vaseux Creek fan (North Central).

A summary of licenced and unlicenced groundwater diversions is provided below.

- Diversion near Vaseux Creek/Gallagher Lake (South): There are 32 water wells identified proximal to Vaseux Creek and Gallagher Lake. One well is Provincial Groundwater Observation Well No. 506. Three water licences for Commercial Enterprise water use purpose permits diversion of up to 45,625 m^3/year from January 1st to December 31st.
- Diversion on the North Central fan (North Central): There are 25 water wells identified in the North Central fan area – two are associated with an irrigation water use purpose licence for 35,376 m^3/year from April 1st to October 31st.
- Diversion near Vaseux Lake and Okanagan River (West): There are 42 water wells identified proximal to Vaseux Lake and Okanagan River – eight are associated with licenced use. Irrigation water use purpose accounts for up to 1,652,863 m^3/year from April 1st through November 30th. Additional licenced groundwater use for miscellaneous industrial use and commercial enterprise use totals 4,460.3 m^3/year from January 1st through December 31st. Licenced lawn, fairway and garden watering use includes 454 m^3/year from February 1st through November 3rd.
- Unlicenced use from 82 groundwater wells across the Vaseux Creek fan is inferred to represent private domestic use purpose. Assuming a daily demand of 2 m^3/day/well, annual demand is estimated to be 59,860 m^3.

The total quantity of groundwater licensed to be extracted from AQ255 under the Vaseux Creek alluvial fan is 1,738,779 m^3. Further details on groundwater licensing are provided in Appendix A.

2.9 Monitoring Locations

Surface water and groundwater monitoring locations and drilling locations are indicated on Figure 6 and detailed in Table 3.

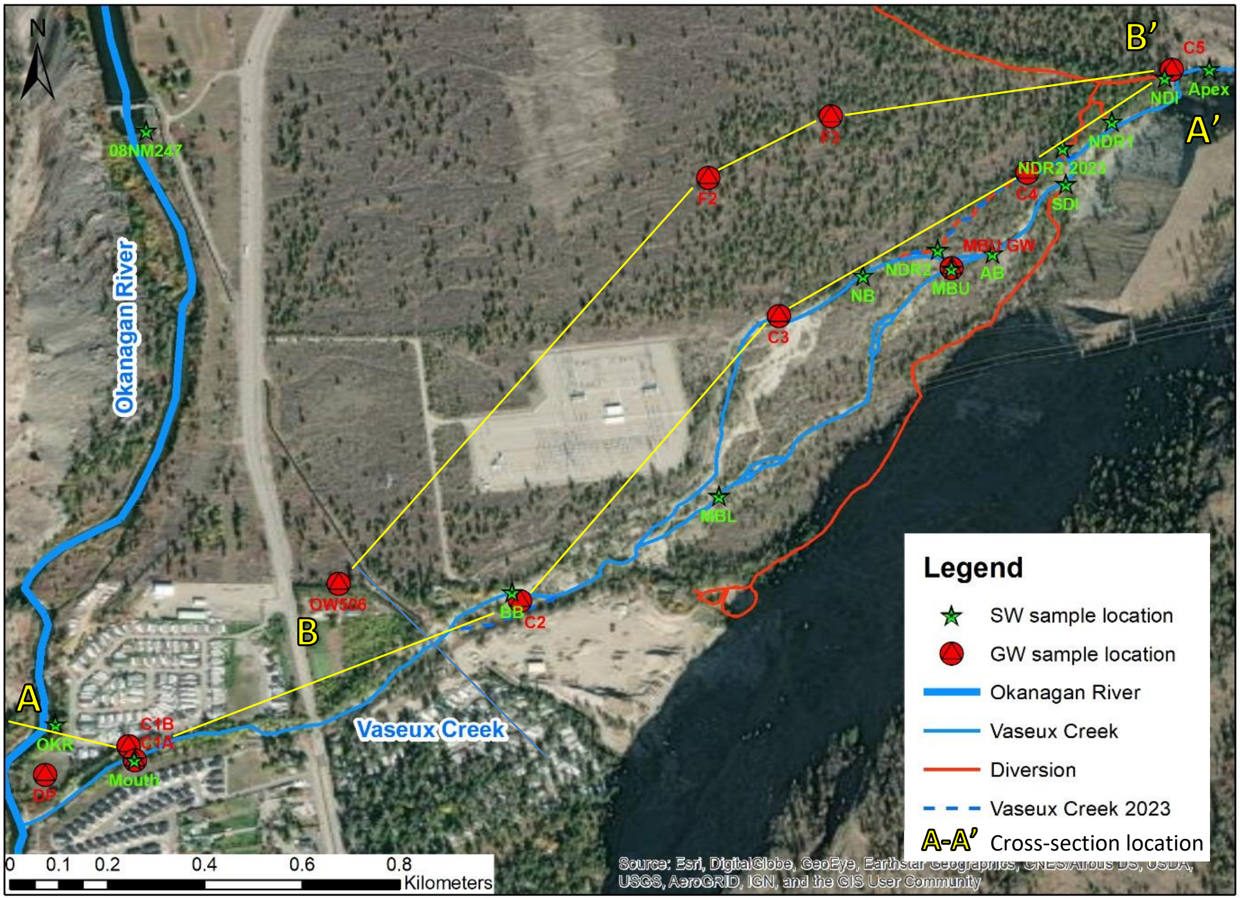

Figure 6: Monitoring locations in the southern portion of the fan.

Table 3: Monitoring Locations. Sample types include surface water (SW) and groundwater (GW).

Fan Location	Sample Type	Code	Northing (m)	Easting (m)	Elevation (m)
Fan apex (08NM708)	SW	Apex	5459122	317486	378.4
Fan apex	GW	C5	5459121	317435	380.6
Northern diversion inflow	SW	NDI	5459106	317425	375.8
Upper fan	GW	C4	5458915	317234	365.0
Northern diversion return 1	SW	NDR1	5459018	317351	370.5
Southern diversion inflow	SW	SDI	5458891	317277	362
Above the main braid	SW	AB	5458751	317184	358.6
Northern diversion return 2	SW	NDR2	5458756	317112	356.6
Northern diversion return 2 (2023)	SW	NDR2 2023	5458946	317268	366
Northern Braid	SW	NB	5458722	317024	352
Central fan (substation)	-	C3	5458632	316889	347.8
Main Braid Upper	SW	MBU	5458721	317137	354
Main Braid Lower	SW	MBL	5458339	316863	343
Below the main braid	SW	BB	5458058	316522	329.4
Below the main braid	GW	C2	5458059	316522	328.6
Mouth (08NM246-HDS)	SW	Mouth	5457751	315992	318.0
Mouth – streambed	GW	Mouth STB	5457752	315992	318.0
Mouth – shallow	GW	C1A	5457778	315985	319.7
Mouth – deep	GW	C1B	5457778	315985	319.7
Distal fan – west	GW	DP	5457714	315850	318.6
Central fan	GW	F2	5458920	316804	352.6
Central fan – east	GW	F3	5459040	316973	360.1
Northern fan	GW	SORCO	5459831	317037	356
Lower fan west (permanent)	GW	OW506	5458103	316279	326.2
Okanagan River above Vaseux Creek*	SW	OKR	5457828	315888	317.4
Okanagan River below McIntrye Dam (08NM247)	SW	08NM247	5459063	316072	325
Vaseux Lake near the Outlet (08NM243)**	SW	08NM243	5460879	316315	326

* Water level and temperature monitoring only.

** Water level monitoring only.

3. METHODS

3.1 Syilx TEKK Guidance

Syilx Traditional Ecological Knowledge Keeper (TEKK) guidance regarding snʕaxəlqaxʷiyaʔ (Vaseux Creek) fan was initiated through the Osoyoos Indian Band's Nk'Mip Desert Cultural Centre. This guidance does not constitute a complete TEKK assessment of the creek or area.

3.2 Hydrometric Stations

Hydrometric and temperature stations consisted of Onset HOBO water level and temperature loggers installed in stilling wells attached to the stream bank and were programmed to record at 15-minute intervals (SW sample type in Table 3 unless otherwise noted). Discharge and water level surveys were obtained across an adequate range of streamflows (generally five per year) to construct rating curves for each location to convert the water level measurements to stream discharge. Stream discharge was estimated from measurements of water velocity using a SonTek FlowTracker2 or SonTek FlowTracker1 equipped with wading rod using the velocity to area method. A measuring tape was extended across the creek as a tag line. Measurements were repeated until less than 10% of flow was contained in each measurement or 10 cm intervals. Measurement uncertainty was calculated using the Interpolated Variance Estimation approach available in the FlowTracker2 (SonTek, 2019). Rating curves were developed in Aquarius.

3.3 Groundwater Observation Well Installation

One Provincial Groundwater Observation Well (OW506) and seven piezometers (C1A, C1B, C2, C4, C5, F2, and F3) ranging in depth from 10.7 to 39.3 metres below ground surface were constructed to support this project. OW506 was drilled by Steve Robbins and registered water well drillers Rob Crampton (WD 05062301) and Richard Ticknor (WD 20012801) of Robbins Drilling and Pump Limited using an air rotary drill rig on November 17, 2021. Piezometers were installed by Mud Bay Drilling Co. Ltd., operating under the direction of registered well driller Brent Seymour (WD 05092802), between January 17, 2022 and January 22, 2022 using a sonic drill rig. Piezometers were constructed from 5 cm (2 inch) diameter Schedule 40 PVC with 1.525 m (5 foot), 10-slot (0.010") Schedule 40 PVC well screens. Filter packs (10/20 frac sand) were set to approximately 0.3 m (1 foot) above the top of screen, and the annulus above filled to 0.3 m (1 foot) below ground surface with bentonite chips. Concrete was installed above the bentonite to anchor the monument or flush-mounted surface completion.

Drilling at location C3 could not be achieved in January due to ground conditions (snow) and was reattempted on March 7, 2022. Drilling reached a depth of 25.9 metres below ground surface but the casing could not be set after two attempts due to heaving sand; hence no piezometer was installed. Further well construction information and well lithology is available in Appendices B and C respectively.

All project piezometers were developed using a Waterra pump system and actuated either by hand or using a Waterra Hydrolift tubing actuator. Development proceeded until discharge water was clear and free of sediment. Each piezometer was instrumented with paired pressure transducers (one Levelogger and one Barologger) to monitor water levels.

Further information regarding the construction and testing of OW506 is available through the publicly available well construction report (https://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=59878). Well construction logs for piezometers are included in Appendix B and lithology logs in Appendix C.

OW506 and project piezometers were constructed in compliance with the Water Sustainability Act and the Groundwater Protection Regulation. Neither bedrock nor artesian flowing well conditions were encountered during construction.

3.4 Sediment Analysis

Sediment was collected in freezer bags and mason jars during the sonic core drilling campaign in January 2022. Sediment samples were chosen for grain size analysis based on lithology observations recorded while drilling. Samples with visible rock flour (pulverized cobbles and pebbles) were removed.

Samples were oven dried at 110^{o}C until at constant mass then dry sieved using Ro-Tap RX-30 and four screens (4mm, 2mm, 1mm and 0.5mm). The material collected beneath the 0.5mm screen was subsampled for wet dispersion particle size analysis using a Mastersizer 3000 with a Hydro LV dispersion attachment in the Bioreactor Technology Group Laboratory at the University of British Columbia Okanagan (UBCO). Dry sieving (gravimetric analysis) and wet dispersion (volumetric analysis) results were combined to calculate grain size percentages from 4 mm to 0.002 mm.

Woody material was recovered from approximately 40.5 feet (12.34 m) below surface within a clayey silt unit at C1 in the distal fan. The wood and clayey silt materials were collected in a freezer bag and sealed in a 1 L mason jar for storage. The wood was prepared for radiocarbon analysis by isolating the sample from the sediment, then drying the waterlogged wood piece at 60^{o}C for 48 hours. The dried wood sample was scraped with a scalpel to remove all sediment, humic material, and potential wood bark. 0.113 g of material was subsampled and submitted to the Andre E. Lalonde AMS Laboratory, Radiocarbon Laboratory at the University of Ottawa. The subsample was pretreated by washing with alkali (NaOH, 0.2N, 80^{o}C, 30 mins), followed by acid (HCl, 1N, 80^{o}C, 30 mins), then alkali washed again. The sample was carbon dated using an Ionplus AG MICADAS accelerator mass spectrometer (AMS). The $^{14}C/^{12}C$ ratio in the sample is compared to the $^{14}C/^{12}C$ ratio of a standard measured within the same data block. Results are reported in ^{14}C year BP (BP = AD 1950). Analysis error for the snʕax̌əlqaxʷiyaʔ (Vaseux Creek) wood sample was +/- 30 years (1σ).

3.5 Hydraulic Conductivity Testing

Hydraulic conductivity testing was completed on all project monitoring wells with sufficient water. Testing was completed by rapidly raising the water level in the well by introducing a calibrated solid slug below the water table and measuring the response. Similarly, the water level in the well was rapidly lowered by removing the solid slug and monitoring the response. Water levels were recorded using level loggers. Water level data was analyzed using a Springer and Gelhar solution (Springer and Gelhar, 1991) or a modified Bouwer and Rice method (Bouwer and Rice, 1976; Butler, 2020).

3.6 Longitudinal Stream Discharge and Chemistry Surveys

Longitudinal stream discharge and chemistry surveys consisted of the measurement of stream discharge and collection of water samples from the creek mouth to the fan apex in a single day in an attempt to sample under quasi steady-state flow conditions. Stream discharge was estimated as described in Section 3.2. Groundwater samples were collected from co-located observation wells on the same day, and at fan wells within two weeks.

Surface water samples were collected directly from the creek, diversion, or diversion inflow. Sample containers were rinsed, then held below the surface of the stream until filled. Groundwater samples were collected from observation wells using a submersible pump after purging a minimum of three well volumes or once field parameters had stabilized.

Field measurements of pH, electrical conductivity (EC) and dissolved oxygen (DO) were obtained by inserting the probes directly into the flowing creek or into a sampling vessel for groundwater.

Samples for radon-in-water analysis were collected in glass vials fitted with septa lids for groundwater and 1 L or 2 L polyethylene terephthalate (PET) bottles for surface water. Samples for analysis of ^{2}H and ^{18}O were collected in 30 mL high-density polyethylene (HDPE) bottles and sealed with electrical tape.

3.7 Analytical Methods for Water Chemistry

Water samples were analysed for alkalinity and anions at Caro Analytical Services and Na, Ca, K, and Mg at the Fipke Laboratory for Trace Element Research at UBCO or dissolved elements at Caro. Water samples were filtered through disposable 0.45 μm filters prior to analysis. Alkalinity was measured by titration and anions by ion chromatography. Na, Ca, K, and Mg elemental abundance were measured by Inductively Coupled Plasma (ICP) – Optical Emission Spectrometry (UBCO) or ICP – Mass Spectrometry (Caro).

Water samples were analysed for ^{222}Radon (radon) content and $\delta^{2}H$ and $\delta^{18}O$ at UBCO. Radon analyses were conducted using a Durridge Rad7, which is an electronic radon detection device that utilizes a solid state alpha detector (Durridge, 2021). The $RadH_2O$ and Rad7 Big Bottle Systems were used to extract radon from water for gas phase analysis within 48 hours of sample collection on average. Results were adjusted to account for radioactive decay. $\delta^{2}H$-H_2O and $\delta^{18}O$-H_2O analysis was conducted by laser spectroscopy using a Los Gatos Research liquid water isotope analyzer.

Water samples were analysed for tritium at the Andre E. Lalonde AMS Laboratory, Tritium Laboratory at the University of Ottawa using a Perkin Elmer Quantulus 1220 Ultra Scintillation Spectrometer calibrated to National Institute of Standards and Technology-certified Standard Reference Material 4926E. Sample and data processing was handled by the Tritium Information Management System. Samples were decay corrected to their respective collection dates. Given the variable zero that occurs due to background at very low levels of activity, both the Critical Level Activity and Minimum Detection Activity were reported for each sample.

3.8 Elevation Survey

Surface water survey benchmarks and groundwater observation wells were surveyed using a Real Time Kinematic Differential Global Positioning System and calibrated to Geodetic Control Markers integrated to the NAD83(CSRS) 4.0.0.BC.1 datum (horizontal) and CGVD28BC datum (vertical) obtained from B.C. Management of Survey Control Operations and Tasks (MASCOT). A thalweg survey was also completed in 2021. Horizontal and vertical coordinate absolute accuracy is approximately 5 cm to 10 cm.

A single benchmark was selected as the control benchmark at each cluster of infrastructure to increase the accuracy of elevation measurements and relative elevations determined using automatic level and stadia rod.

3.9 Water Exchange and Connectivity

At the point scale, two features were obtained from data collected at co-located stations:

- Direction and qualitative magnitude of exchange:
    - Hydraulic head difference between groundwater and surface water elevations. A positive value indicates a gaining system; a negative value indicates a losing system; and circum-neutral values indicate a neutral system.
    - The magnitude of the exchange flux was qualitatively assessed using temperature and chemistry data.

- Groundwater to stream hydraulic connectivity:
    - Elevation difference between groundwater and the adjacent streambed. Positive values indicate a connected system, whereas negative values indicate a transitional or disconnected system.
    - The likelihood of disconnection was further assessed based on the distance of the observation well from the edge of the streambed and temperature and chemistry data.

Net reach-scale exchange (*ΔQ*) was estimated using a water balance approach from discharge measurements collected during longitudinal surveys and continuous discharge estimated from rating curves:

$$\Delta Q = Q_2 - Q_1$$

where Q_1 and Q_2 are the discharges at the upstream and downstream end of the reach, respectively. Hence, a positive value for ΔQ indicates a net gain in water in the creek, and a negative value indicates a net loss of water from the creek. To determine the natural rate of exchange, all surface outflows (diversions, subtracted) and inflows (diversion returns, added) were obtained and included in the calculation ($Q_{3\ldots n}$). The uncertainty (*u*) in *ΔQ* was calculated as (Taylor, 1997):

$$u_{\Delta Q} = \sqrt{(u_{Q_1})^2 + (u_{Q_2})^2 + (u_{Q_3})^2 \ldots + (u_{Q_n})^2}$$

which assumes that each *Q* is independent and follows a normal distribution.

The concentration of radon dissolved in groundwater reaches equilibrium with the aquifer sediments once the water has been in the subsurface for longer than three weeks (Bourke et al., 2014). The equilibrium concentration is a function of the mineralogy of the aquifer sediments. Hence, time series radon plots may be used to assess 1) water source in surface water or groundwater, 2) travel time since infiltration into the subsurface, 3) groundwater discharge to a surface water body, or 4) hyporheic exchange.

δ^2H-H_2O and $\delta^{18}O$-H_2O are isotopes that are part of water molecules in ratios that depend on the source of precipitation and phase changes undergone by the water. In the Okanagan valley bottom, bi-plots of δ^2H-H_2O and $\delta^{18}O$-H_2O can be used to identify water sources recharged at different elevations or from the mainstem and water sources subject to evaporation. Results are plotted with reference to the Okanagan Meteoric Water Line (OMWL; Wassenaar et al., 2011), a representation of precipitation in the Okanagan Valley through all seasons and the Canadian Meteoric Water Line (CMWL; Gibson et al., 2005), a representation of precipitation Canada-wide, and representative of high elevation precipitation unaffected by valley processes.

4. RESULTS

4.1 Syilx TEKK Guidance

Some Syilx TEKK key messages for snʕax̌əlqaxʷiyaʔ (Vaseux Creek) include:

- The nsyilxcn name for Vaseux Creek below the canyon is protected due to traditional significance.
- The common name for the creek is McIntyre Creek.
- The creek is not healthy due to a lack of water.
- Historically, the creek had a thriving riparian area and good fishing. In more recent years it has become very dry and you cannot fish there anymore. There used to be lots more fish of diverse species.
- The riparian area (Figure 7) in the past was greener with lots of birds that could be heard while the water was flowing indicating that it was thriving. Rose bushes and saskatoon were also present in the transition zone to the antelope brush.
- Water in the creek comes from springs and snowmelt.
- The creek has dried up due to climate change, including very hot summers, and water being diverted for irrigation.
- Underwater systems feed into Gallagher Lake.

Figure 7: Riparian vegetation evident in Vaseux Creek under flood conditions (Joint Board of Engineers, 1946).

4.2 Hydrographs

Annual hydrographs at the fan apex and mouth of snʕax̌əlqaxʷiyaʔ (Vaseux Creek) are presented on Figure 8 with precipitation for 2022 and 2023. Precipitation is for snpintktn (Penticton) as Oliver STP data was not available after May 2022. The monitoring period ended in October 2023.

In general, the hydrograph is typical of a snowmelt driven hydrograph, increasing to a peak discharge in freshet with snowmelt and decreasing to summer, fall and winter low flow, with the rate of decrease dependent on the amount of precipitation in late spring and summer. Field observations indicated that the wetted area increased during freshet to include more braids and side channels and contracted back to the main braids/channels as discharge reduced. The creek froze dry intermittently over winter. This occurred more frequently in winter 2021 after a drier summer than in winter 2022 when creek flow was more continuous despite similar or lower discharges at the apex. An inter-annual comparison between 2022 and 2023 is presented in Table 4.

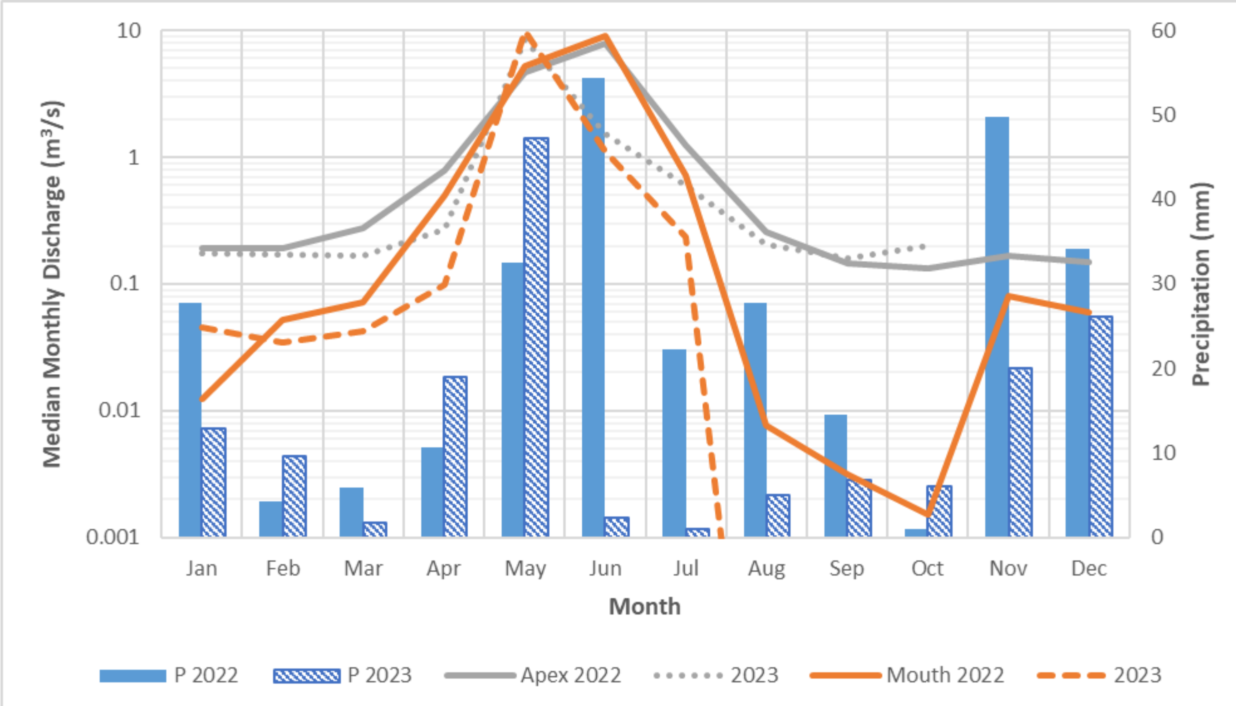

Figure 8: Median monthly discharge at the fan apex and mouth and monthly precipitation totals.

Table 4: Inter-annual comparison of hydrologic data. Winter is defined as November 1 to March 31.

Parameter	Winter 2021/22	Apr – Oct 2022	Winter 2022/23	Apr – Oct 2023
Maximum SWE at 1,400 m (mm)	128	-	152	
Precipitation (mm)	80.1	163.1	108.2	87.4
Peak instantaneous Q (m^3/s)	-	28	-	46
Q > 2 m^3/s (days)	0	69	0	38
Dry at Mouth (days)	9	24	1	91

In 2022, Vaseux Creek freshet instantaneous peak discharge was approximately 28 m^3/s in mid-June due to rainfall. Vaseux Creek dried up downstream of the Highway 97 bridge (between BB and Mouth; Figure 6) for short periods (generally 5 to 10 days) in late August, September, and October 2022. The northern braid also dried up in mid-August and did not reconnect to the main channel until freshet of 2023. Hydrographs indicated increased discharge into diversions on April 1, 2022. Vaseux Creek discharge increased on October 1, 2022, when discharge into the northern diversion decreased. Beaver activity in the northern diversion in August 2022 increased the proportion of discharge returning to the creek at NDR1.

In 2023, warm April temperatures resulted in a rapid melt and instantaneous peak discharge of approximately 46 m^3/s in early May. Freshet caused multiple channel changes, including:

- scour and aggradation throughout the creek,

- connecting the main braid with a portion of the northern diversion such that AB was no longer above the braided section, and
- repositioning the main channel to the south at BB and continuous flow in multiple braids up to this section dried up.

With no late spring/summer precipitation, discharge rapidly receded, and Vaseux Creek dried up progressively from the mouth to approximately 50 m downstream of MBL (Figure 6). The mouth remained dry from July 31 to the end of October 2023 when the monitoring period ended, except for one short flow event on August 7 and 8. Flow ceased at BB on August 4 and resumed continuously on September 27; there were two short flow events August 7 through 12 and August 30 through September 1. The short flow events were driven by increased discharge at the apex. The northern braid also dried up progressively from mid August to upstream of C3 (Figure 6) and had not reconnected with the main channel by October.

In contrast, sq̓awsitkʷ (Okanagan River) peaked at 70 m^3/s in June through July 2022 compared to 51 m^3/s in late May 2023. Water level in the river progressively dropped to approximately 10 m^3/s in September 2022 but had already stabilised at this discharge in mid-July 2023.

4.3 Aquifer Materials and Properties

The surface of the snʕax̌əlqaxʷiyaʔ (Vaseux Creek) fan is comprised of coarse alluvium and colluvium generally thicker and coarser near the fan apex. Lobes of coarser sediment visible at surface exemplified alluvial fan building processes and created challenging surface topography for manoeuvring drilling equipment. Beneath the boulders and cobbles is primarily sand (with some gravel and lenses of finer materials) inferred to extend to bedrock at an unknown depth (Figure 9 and Figure 10). A noteworthy gravel was identified at 37.5 metres below ground surface, buried below approximately 20 m of sands and finer materials. The gravel, which encompasses the entire screened portion of F3, was well rounded suggesting glacially reworked materials rather than a direct deposit of recent alluvium. There is no notable separation between sands comprising sediments in AQ255 and overlying alluvial fan materials. Lithology and water level measurements did not suggest an independent alluvial fan aquifer exists above AQ255 though some finer sediments (comprised of up to 60% silt and clay) observed in the mid fan (F3, F2) may assist in the lateral movement of upgradient groundwater recharge to downgradient areas in the North and West of the apex. Cementing was often observed in sands in proximity to those finer sediments, likely from water-mediated downward movement of finer materials. No notable silt or clay layers were observed in C2, C3, or C4. Grain-size analyses completed on select C2 samples reported fine sediments (grain size <0.100 mm (fine sand)) comprised less than 10% of each sample.

Proglacial features are highly visible from the study area with partially eroded glaciofluvial benches along the bedrock near the fan apex, striations along McIntyre Bluff, and a kettle lake (Gallaghers Lake) directly to the South. Carbon dating of wood found in sediments recovered during drilling (C1, 307 masl, 8,910 ^{14}C y BP ± 30 y (UOC-23021) ~8,982 y BP) and abrupt changes in the vertical sequence between coarse and fine sediments found in lithology at boreholes closer to the sq̓awsitkʷ (Okanagan River; C1 and OW506) are consistent with a highly dynamic proglacial and later fluvial environment. Colluvium may also be present near the mouth as higher elevation bedrock is found within 200 m to the west but was not encountered during drilling.

Lithology logs and further grain size analysis information are available in Appendices C and D, respectively.

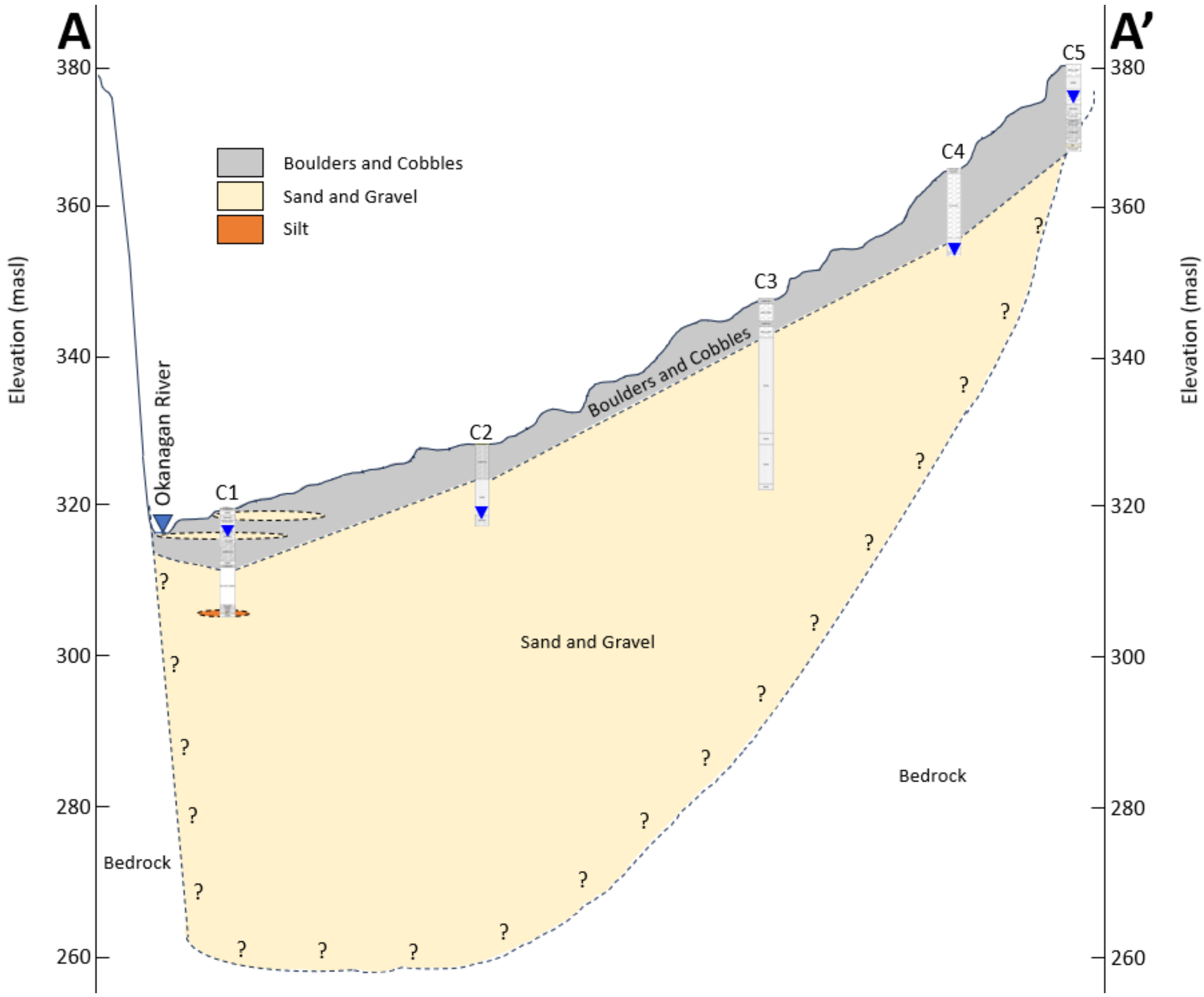

Figure 9: Geologic cross-section A-A'.

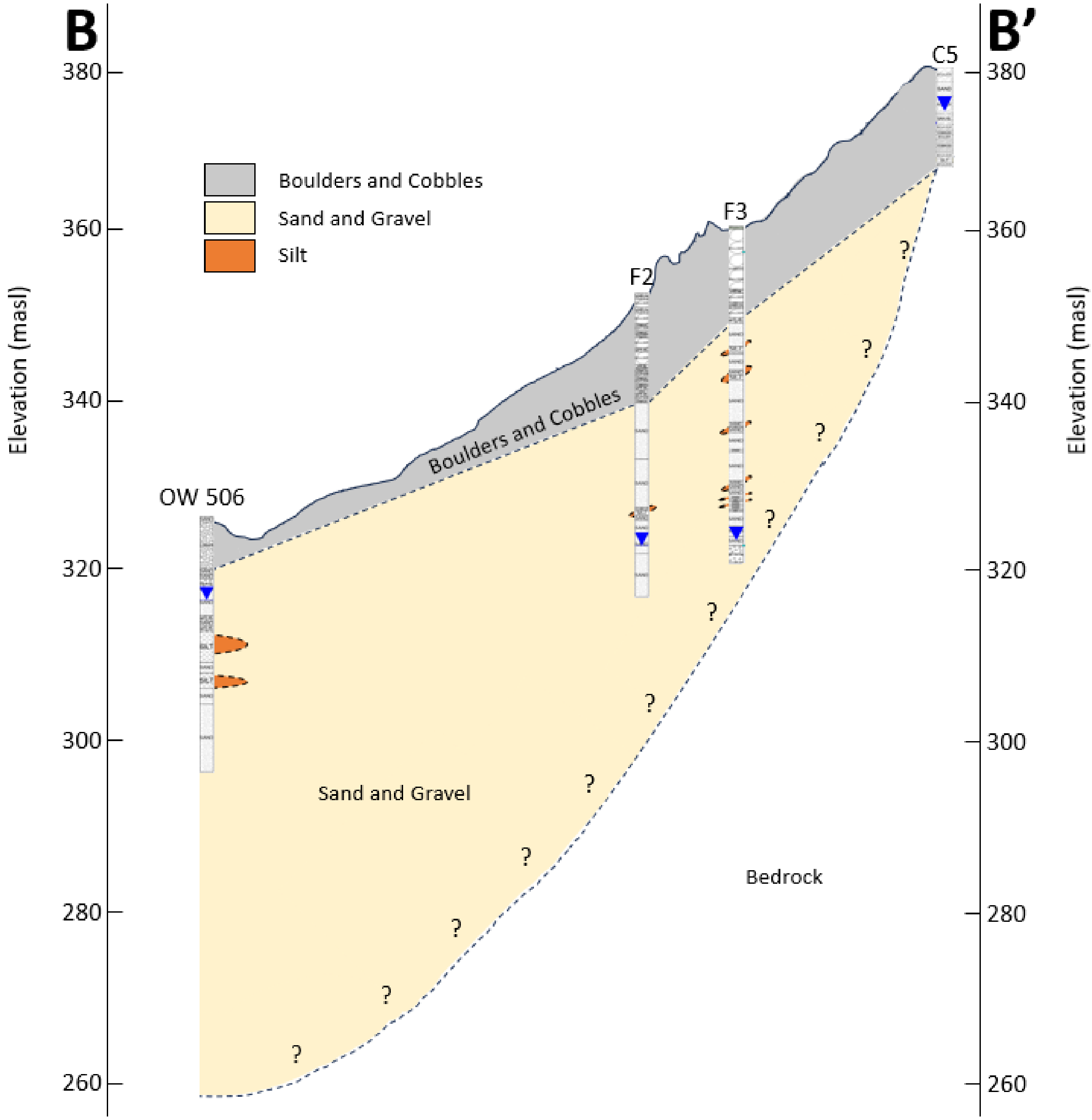

Figure 10: Geologic cross-section B-B’.

Table 5 contains estimates of hydraulic conductivity for aquifer materials in screened intervals obtained from slug tests. Where more than one test was evaluated, the arithmetic mean ($\bar{K}$) of the estimated values is also provided. Detailed results are provided in Appendix E. The hydraulic conductivity obtained for OW506 from pumping tests is provided for reference.

Hydraulic conductivity values were within the range of expected values for the sands and gravels (Freeze and Cherry, 1979) encountered during the drilling program.

Table 5: Hydraulic conductivity of aquifer materials.

Station ID	Hydraulic Conductivity (m/s)	Comments
C1A	1.12×10^{-3}	
C1B	6.65×10^{-4}	
Deer Park (ONA)	$\bar{K} = 3.09 \times 10^{-3}$ $(2.92 \times 10^{-3}, 3.25 \times 10^{-3})$	Well construction unknown.
C2	$\bar{K} = 4.28 \times 10^{-4}$ $(4.02 \times 10^{-4}, 4.53 \times 10^{-4})$	
C4	-	Insufficient water.
C5	$\bar{K} = 4.43 \times 10^{-5}$ $(4.32 \times 10^{-5}, 4.53 \times 10^{-5})$	Likely partially screened in regolith.
F2	$\bar{K} = 3.53 \times 10^{-3}$ $(3.69 \times 10^{-3}, 3.37 \times 10^{-3})$	
F3	$\bar{K} = 1.13 \times 10^{-3}$ $(9.61 \times 10^{-4}, 1.29 \times 10^{-3})$	
OW506	3.16×10^{-4}	Pumping test.
Mouth STB	$\bar{K} = 1.3 \times 10^{-4}$ $(1.3 \times 10^{-4}, 1.4 \times 10^{-4})$	Modified Bouwer and Rice method.

4.4 Groundwater Flow Across Fan

snʕax̌əlqaxʷiyaʔ (Vaseux Creek) is a steep mountainous stream, with an average gradient of 2.65%. A longitudinal profile of the creek and cross section depicting groundwater level across Vaseux Creek alluvial fan is presented on Figure 11. The groundwater level appeared to drop rapidly away from the canyon.

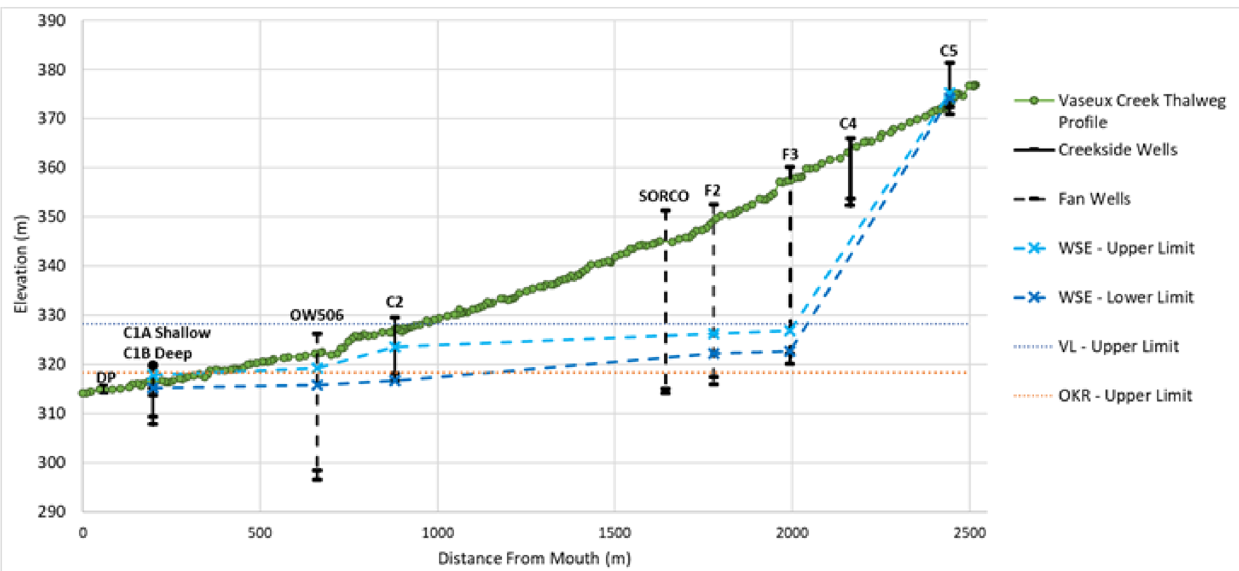

Figure 11: Longitudinal thalweg profile of Vaseux Creek with groundwater wells projected to the profile line. Horizontal markers depict the upper and lower boundaries of well screens. The upper and lower water surface elevation (WSE) limits, Vaseux Lake (VL) and Okanagan River (OKR) high water level are included for hydraulic context (Montgomery, In Prep.).

Time series water level data from the network of observation wells is presented on Figure 12. Data gaps due to logger malfunction are filled with point measurements where available. C5 is excluded due to the substantially higher elevation (approximately 375 m; Figure 11). The water table was consistently below the base of C4 (352.84 m). Low flow surface water elevation in the C4 area ranged from 357.5 m at AB to 356 m at NDR2.

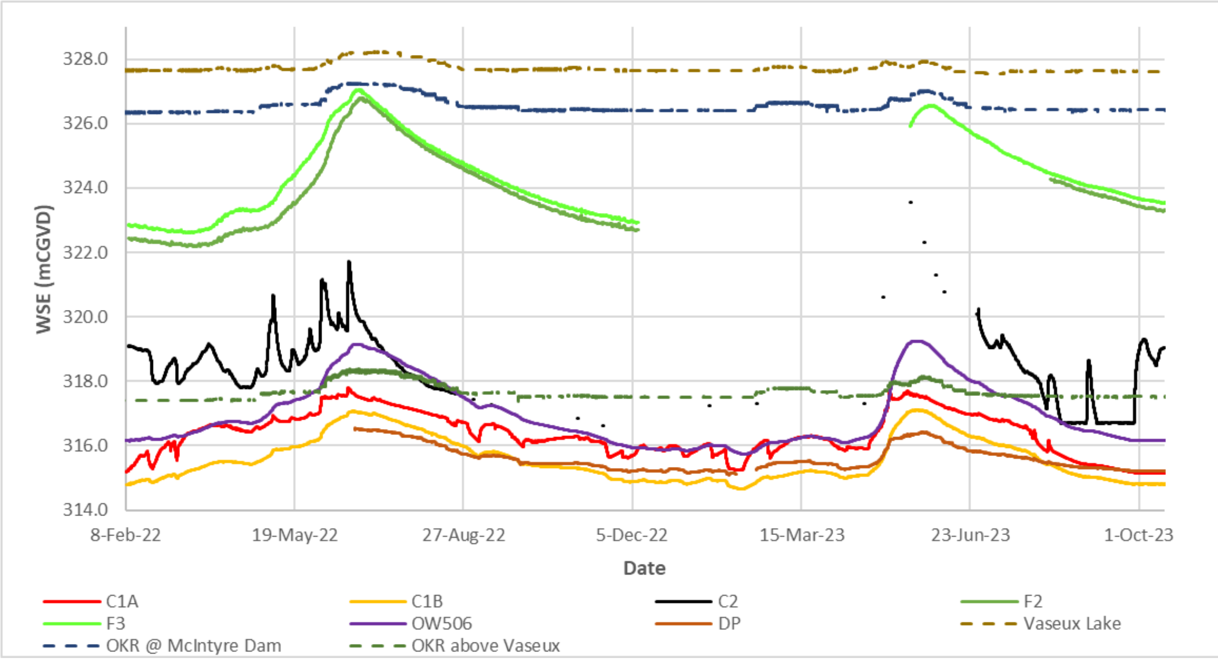

Figure 12: Groundwater level data across the fan. Vaseux Lake, OKR at McIntyre Dam and OKR above Vaseux Creek are included for reference.

Regional groundwater is inferred to flow from north to south, controlled by akspaqmix (Vaseux Lake) in the north, sq̓awsitkʷ (Okanagan River) in the west, the mountain block in the east, and Vaseux Creek where it exits the canyon from the east and travels southwest along the southern flank of the fan. Groundwater elevation contour maps are provided in Appendix F.

Hydraulic responses to flow events (water level change) in Vaseux Creek were greatest closest to the creek (C5, C2, C1A) and reduced with distance and depth (C1B, OW506, Deer Park (DP); Figure 13). The timing of water level changes at Vaseux Lake and in Okanagan River were similar and could not be distinguished in aquifer responses (Figure 12). Hydraulic responses to Okanagan River mainstem water level changes were observed throughout the fan, except for C5 and C2, and interacted with creek responses in the mid and lower fan (e.g., C1A in June 2022; OW506; Figure 13). Response times varied from minutes to hours at shallow creekside wells up to weeks at F2 and F3.

Separating the effects of mainstem and creek stage rises at the latter locations was problematic due to the similarity in hydrographs and lag and dampening that occurs in pressure transmission; however, the effects of both mainstem and creek stage rise appeared to be additive. Hence, the peak groundwater level at F3 was lower in 2023 with a lower peak river stage despite higher peak stage in Vaseux Creek. Peak groundwater levels at creek-controlled sites C5 and C2 were higher in 2023 in response to the short, sharp freshet that reached a higher stage; at C1 where interaction with the river occurs, the peak levels were similar between years. Connectivity between creek, river, and groundwater responses are discussed in detail at co-located stations in Section 4.6. In both September 2022 and September 2023, groundwater levels increased at lower fan wells first and then OW506 in the absence of either creek or river stage rise. This potentially indicated a seasonal alteration to groundwater extraction in the area.

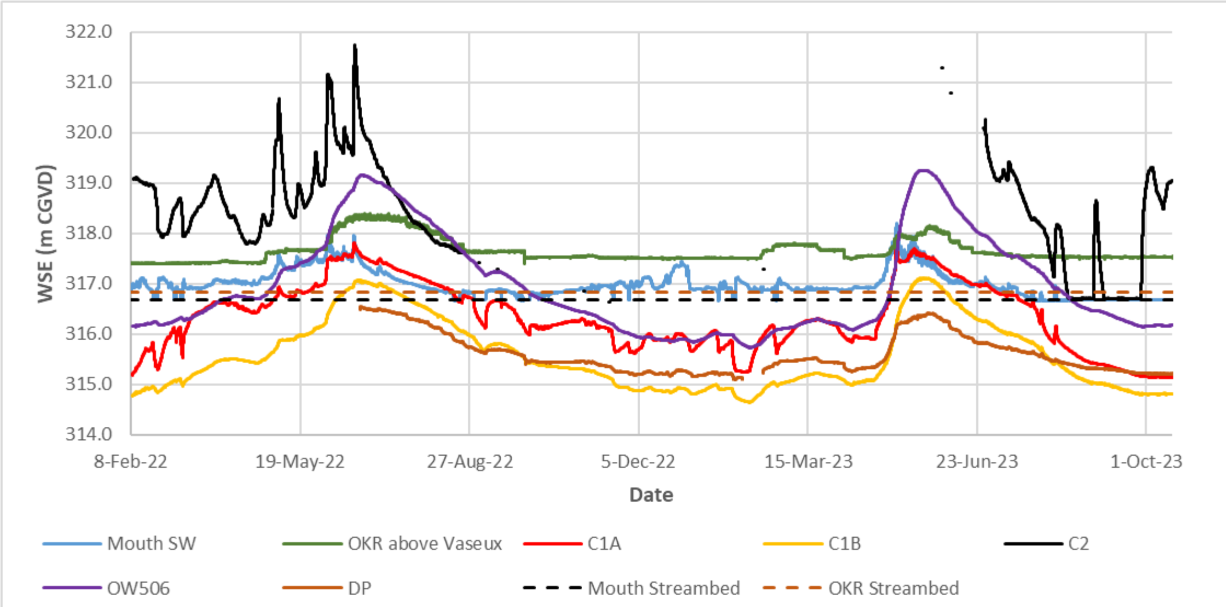

Figure 13: Vaseux Creek groundwater level data in the mid – lower fan. Vaseux Creek (labelled as Mouth SW) and OKR above Vaseux Creek are included for reference.

4.5 Water Sources and Mixing

Surface water and groundwater were dominantly neutral to slightly alkaline calcium bicarbonate type water. Three distinct sources of snʕax̌əlqaxʷiyaʔ (Vaseux Creek) groundwater were inferred (Figure 14; Figure 15, Appendix G):

1. Mountain block recharge discharging along the upper edge of the fan.
2. Vaseux Creek infiltrating vertically and spreading radially.
3. sq̓awsitkʷ (Okanagan River) mainstem recharging from the river southwest into the fan, and potentially south from akspaqmix (Vaseux Lake).

Mountain block recharge (MBR) and Okanagan River waters were relatively chemically and isotopically consistent through time. The position of the MBR end member (SORCO) on the ^{2}H-H_2O and ^{18}O-H_2O bi-plot indicates a well-mixed flow path with water generally recharged at a lower elevation (or with less snowmelt) than supplies creek water (Figure 15). In September of both years, lower EC and altered isotopic signatures suggested the arrival of creek-sourced water at SORCO with a four month travel time delay. As the MBR values sit below the linear mixing line between creek- and river-sourced groundwater, there was no indication of mainstem-sourced water in this area.

Vaseux Creek surface water chemistry varied temporally, becoming fresher and isotopically depleted during freshet in response to snowmelt contributions. Creek surface water chemistry was generally consistent across the fan from the apex to below the braided section (BB), indicating a general absence of groundwater inflow. Chemical and isotopic variation across the lower fan occurred around the time (before, during, after) hydraulic data indicated the lower portion of the creek had the potential to gain groundwater. Radon spikes and ^{2}H and ^{18}O values confirmed that creek was gaining groundwater, and that the area where this occurred moved upstream towards Highway 97 over time as regional groundwater levels reduced but remained sufficiently elevated to intersect the streambed upstream of C1. The effect was pronounced in 2022 when Vaseux Creek discharge peaked before the river but was muted in 2023 by dilution.

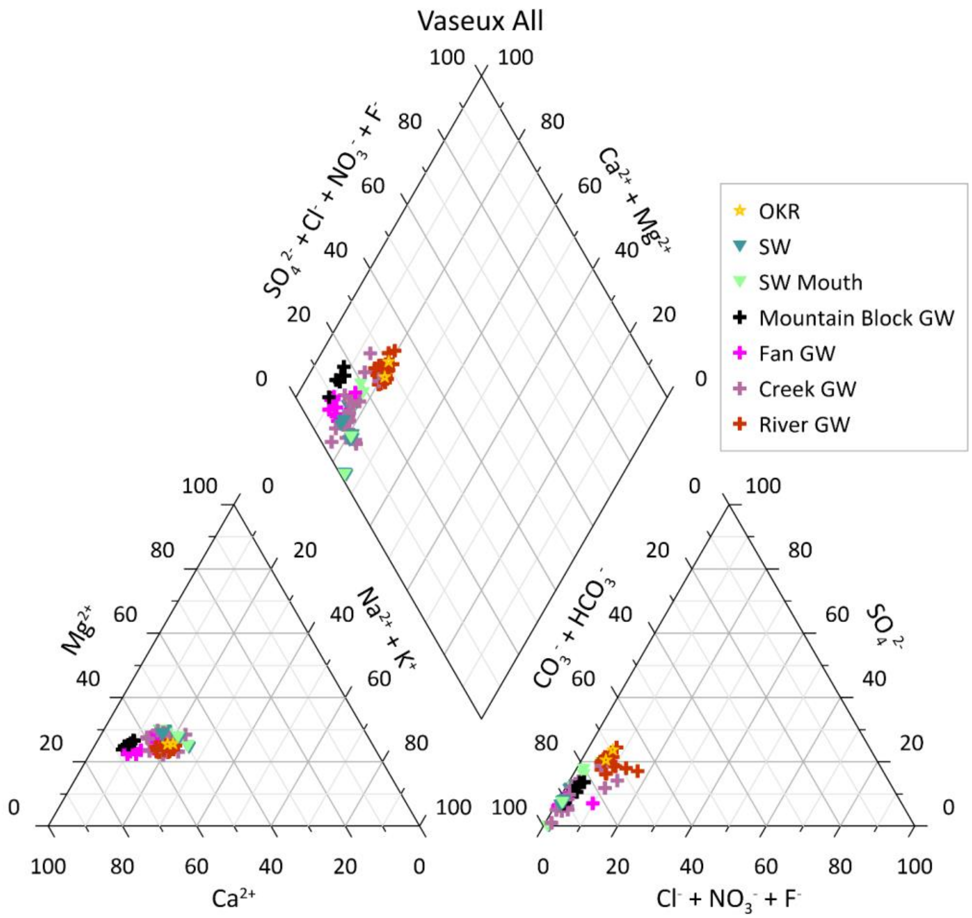

Figure 14: Vaseux Creek Piper plot. SW includes all surface water monitoring locations except for the mouth (SW Mouth) and Okanagan River above Vaseux (OKR). Creek-sourced groundwater (GW): C5, C2, C1A and Mouth STB. River-sourced GW: C1B, OW506 and Deer Park. Mountain Block GW: SORCO. Fan GW: F2 and F3.

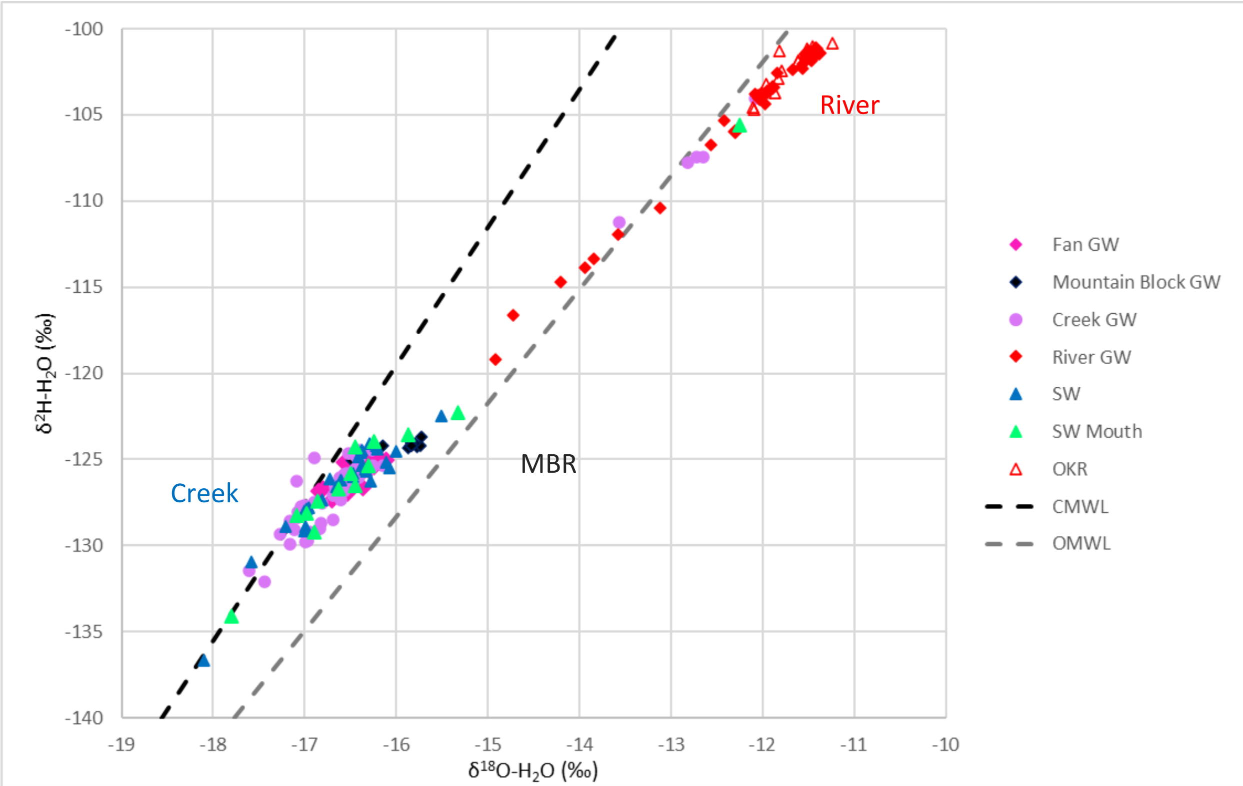

Figure 15: Bi-plot of δ^2H-H_2O and $\delta^{18}O$-H_2O for all sampling events at all locations. Categorization as per Figure 14.

Spatial and temporal variability in groundwater chemistry reflected mixing between the three sources. By location:

- At the apex (C5), groundwater was sourced from Vaseux Creek, with the temporal variability observed in the creek also observed in the groundwater. Higher radon values than other creekside locations outside the freshet period may indicate the presence of longer residence time hyporheic flow paths in the shallow alluvial aquifer or diffusion from the bedrock.
- Away from the creek in the upper fan, groundwater was a mixture of creek-sourced water and mountain block recharge. F3, located closer to the mountain block, was more consistently mountain block. Times series chemistry and isotope plots indicated a two- to four-month travel time for water from the creek, with potential confounding mountain block recharge at F3.
- Beneath the creek in the mid fan (C2) groundwater was solely sourced from Vaseux Creek. It is unknown whether this creek-sourced recharge is underlain by river-sourced water at this location.
- Beneath the creek in the lower fan (C1A, Mouth STB), groundwater was sourced from Vaseux Creek, except when creek flow reduced and upgradient groundwater levels were relatively high at which times groundwater was sourced from the river.
- In the mid to lower fan, river-sourced groundwater was observed consistently at OW506 and Deer Park, and generally at C1B (except during freshet when creek water mixed through).

Time series plots of EC (Figure 16) and radon (not shown) and the bi-plot of δ^2H-H_2O and $\delta^{18}O$-H_2O (Figure 15) indicated that the shift to river-sourced recharge at C1A started in July 2022, when water levels indicated that the creek was gaining groundwater on the lower fan and the river stage had risen. The early mixing period with high radon but intermediate EC indicated that the first water discharged to the creek was likely creek sourced recharge that had previously infiltrated. In 2023, the period of dilution associated with freshet at C1A was likely short, and sampling occurred only after the river contributions had arrived. Tracer data at the piezometer installed in the streambed at the mouth (Mouth STB) indicated groundwater was mixing with creek water in the streambed, and hydraulic data indicated a flow through system was in place, with groundwater flowing into creek from north and flowing out as a mixture of river-sourced groundwater and creek water to the south.

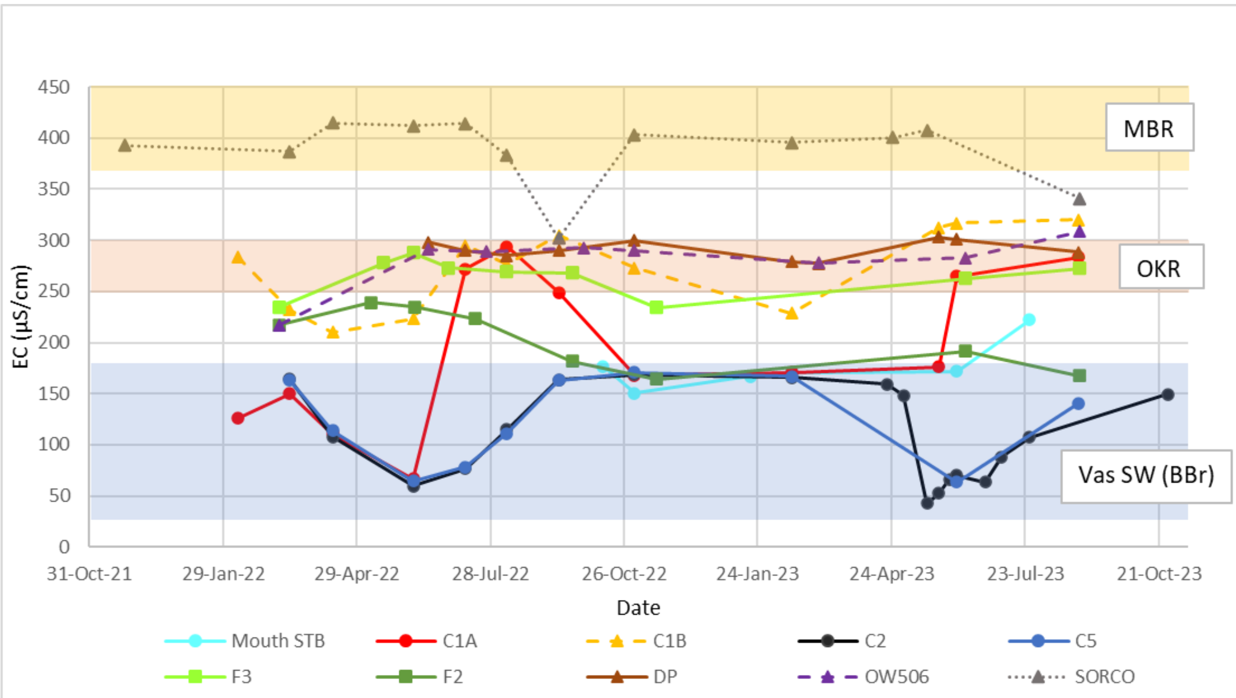

Figure 16: Groundwater EC plotted with surface water sources over time. Solid lines represent shallow wells, dashed lines, deep wells. EC ranges of the three water sources are represented by shading.

Tritium values were all less than or equal to 1.5 TU, indicative of mixed groundwater age (i.e., some waters recharged before the bomb peak and some more recently; Lindsey et al., 2019; Appendix G3). Interestingly, results for September 2022 indicate some modern precipitation input at OW506, as found in Vaseux Creek and other creekside wells. When sampled in March 2023, results indicated no input of modern precipitation in the Okanagan River mainstem at snpintktn (Penticton; Welch and Montgomery, 2024). Deer Park results in September 2022 and February 2023 suggest this is common for the main stem. Samples from C1B also indicated some modern precipitation input on both sampling events, even in February 2023 when C1A, C5 and C2 did not. Larger volume samples, a local estimate of the ^3H input signal and analysis of a suite of age-dating tracers would be required to define the age distribution of groundwater more accurately on the fan.

To summarise, the groundwater flow direction in AQ255 appeared to be from the north. Groundwater contributed by mountain block recharge likely flowed west to meet and mix with mainstem or creek contributions. Groundwater recharged from Vaseux Creek in the east flowed beneath the creek and northwest, before turning south when it intersected and mixed with aquifer contributions from the river in the mid – lower fan. During freshet, a wedge of groundwater contributed by Vaseux Creek flowed over the river-sourced recharge in the lower fan and penetrated the deeper portion of the aquifer. The creek contribution to the aquifer reduced as streamflow reduced. The period over which the creek gained groundwater from river-sourced recharge in the lower fan was determined by the interaction between the river stage and Vaseux Creek freshet.

4.6 Point-scale Exchange and Connectivity

At the point-scale, hydraulic data indicated that snʕax̌əlqaxʷiyaʔ (Vaseux Creek) both lost water to the underlying aquifer across the whole fan and gained water in the lower fan under specific conditions (Figure 17). The timing of loss and gain and connection state varied by location across the fan. Temperature and environmental tracer data provided further insight into connection state, magnitude and direction of flux.

At the fan apex (C5, 10 m laterally from creek and diversion all year; Figure 17A), the direction of flux was consistently from the stream to the groundwater (losing; Figure 18). Groundwater level and chemistry data both indicated that the stream and groundwater were connected, and most likely via saturated flow. The water table was generally within 1 m of the top of the streambed (above during freshet; Figure 19), and daily water level fluctuations in the creek propagated into the groundwater without substantial dampening. Peak to peak translation of hydraulic responses for both daily fluctuations and larger events occurred within three to eight hours of flow events in the creek. Groundwater EC decreased with surface water EC through freshet and then rose as surface water EC rose (Figure 16). The simultaneous decrease/increase in radon concentration over this period indicated increased then decreased magnitude of local surface water flux into the groundwater. Temperature data also indicated the system was tightly coupled, with the groundwater temperature slightly damped and lagged from the seasonal variation observed in surface water. Peak groundwater level was higher in 2023 than 2022, as would be expected from the difference in stage in the creek in a closely coupled system. Drilling logs indicated that the base of C5 likely drilled into the regolith, and hence, the aquifer thickness above the bedrock is small at this location.

In the mid fan (C2; Figure 17B), the lateral distance to the creek varied between 2022 (18 m all year, except during freshet when second channel flowed on south side five to 10 m from well) and 2023 (during high flows, 1 m from well, decreasing to creek channels 18 m to the north and 5 m to the south). In 2023, flow in both channels persisted until this reach dried up. As at the apex of the fan, the direction of flux was consistently from the stream to the groundwater (losing; Figure 18). Here, the creek appeared to be hydraulically disconnected from the underlying groundwater, yet closely coupled to it. The creek was perched between 3.5 m and greater than 11 m above the groundwater (Figure 19). Groundwater elevation changes were up to five times the creek stage increase for individual events where monitoring data was available, which is only possible when systems are not connected (Shanafield et al., 2012). The pronounced hydraulic responses and fast recessions were representative of a system with low specific yield and high hydraulic conductivity. The largest groundwater elevation increases relative to creek stage increases occurred after dry antecedent conditions, consistent with filling of available pore spaces. Despite the disconnection, hydraulic response times were rapid. For example, in August 2023, the time from flow arrival on the dry creekbed to groundwater level rise was just four hours. Temperature data also indicated rapid movement of surface water to groundwater: although diurnal fluctuations were not observed, event fluctuations on approximately the week scale were transferred to the groundwater. Similarly, the change in shallow groundwater EC over freshet was largely consistent with the dilution observed at C5 (Figure 16). In addition, once the streambed dried up, the rate of decrease in groundwater level increased. Response times to events in late August and September 2023 indicated that the regional water level represented by OW506 likely provided a lower limit for groundwater level decline in dry periods and suggested that creek infiltration may be present as a wedge above river- or mountain block sourced recharge in this area. Despite the metres between the creekbed and groundwater level at the observation well, isotopic data indicated that the creek and groundwater were connected for a short period around freshet, indicating a combination of essentially vertical infiltration, groundwater mounding, and the potential for saturated flow directly below the streambed. Isotope data also indicated variable transitional states on either side of freshet depending on the degree of saturation derived from continuous vs ephemeral flow in the creek (Montgomery, *in prep*).

On the lower fan (C1, 18m laterally north from the creek; Figure 17C), the direction of flux varied between all states over the course of each hydrologic year, from gaining (connected) in the latter part of freshet when the river stage was high to losing connected and transitional to disconnected when creek flow ceased for extended periods (Figure 18) and/or river stage declined. The number of days when the creek was locally gaining groundwater decreased from 65 days (15 June to 19 August) in 2022 to 35 days (17 May to 21 June) in 2023, consistent with the changes to freshet duration. Similarly, the number of days when the groundwater elevation was above the streambed decreased from 118 d in 2022 to 79 d in 2023 (Figure 19). Peak to peak translation of hydraulic responses for creek events to C1A occurred within three to five hours of flow events in the creek when flow was likely saturated but increased when the creek had been dry for long periods. Similarly, when saturated flow was likely, the magnitude of groundwater level change was similar to or smaller than stage change in the creek but larger after dry periods in the creek, indicating a process similar to the draining and wetting up observed at C2. As observed at C2, the groundwater level at C1A dropped rapidly when the creek dried up. After an extended dry period in the creek, all groundwater levels in the lower fan stabilised at levels supported by the river stage. Gaining periods were driven by river stage increases. While groundwater EC decreased with creek water EC into freshet, it rose to river concentrations through July 2022, and remained there until 12 September, before returning to creek concentrations in early November (Figure 16). Isotopic data confirmed the switch in source for the shallow groundwater, and the mixing between the sources that occurred in the shallow and deep aquifer (Figure 15). It is assumed that a similar pattern occurred in 2023, but the first sampling event missed the early freshet dilution. Groundwater elevation data from the Mouth streambed piezometer (0.5 m from left/south bank at low flows, underwater at high flows) was generally within measurement error of the shallow groundwater level at C1, indicative of rapid vertical infiltration and lateral spreading through a highly conductive aquifer. The vertical hydraulic gradient from C1A to C1B was generally -0.5 m to -1.5m over 5.8 m, i.e., 0.09 m/m to 0.26 m/m. Chemistry and isotope data confirmed rapid water movement and mixing between the two sources in the early phase of freshet and after dry periods and lowering of the water table (scatter in river-sourced groundwater (C1B) on Figure 15). After peak freshet in 2023 the groundwater level in the streambed was lower than both the creek and C1A. This indicated a flow-through system driven by the timing of the river stage increase, with groundwater flowing from north to south and mixing in the streambed. Chemistry and isotope data confirm the presence of river-sourced water in the streambed (Figure 15; Figure 16).

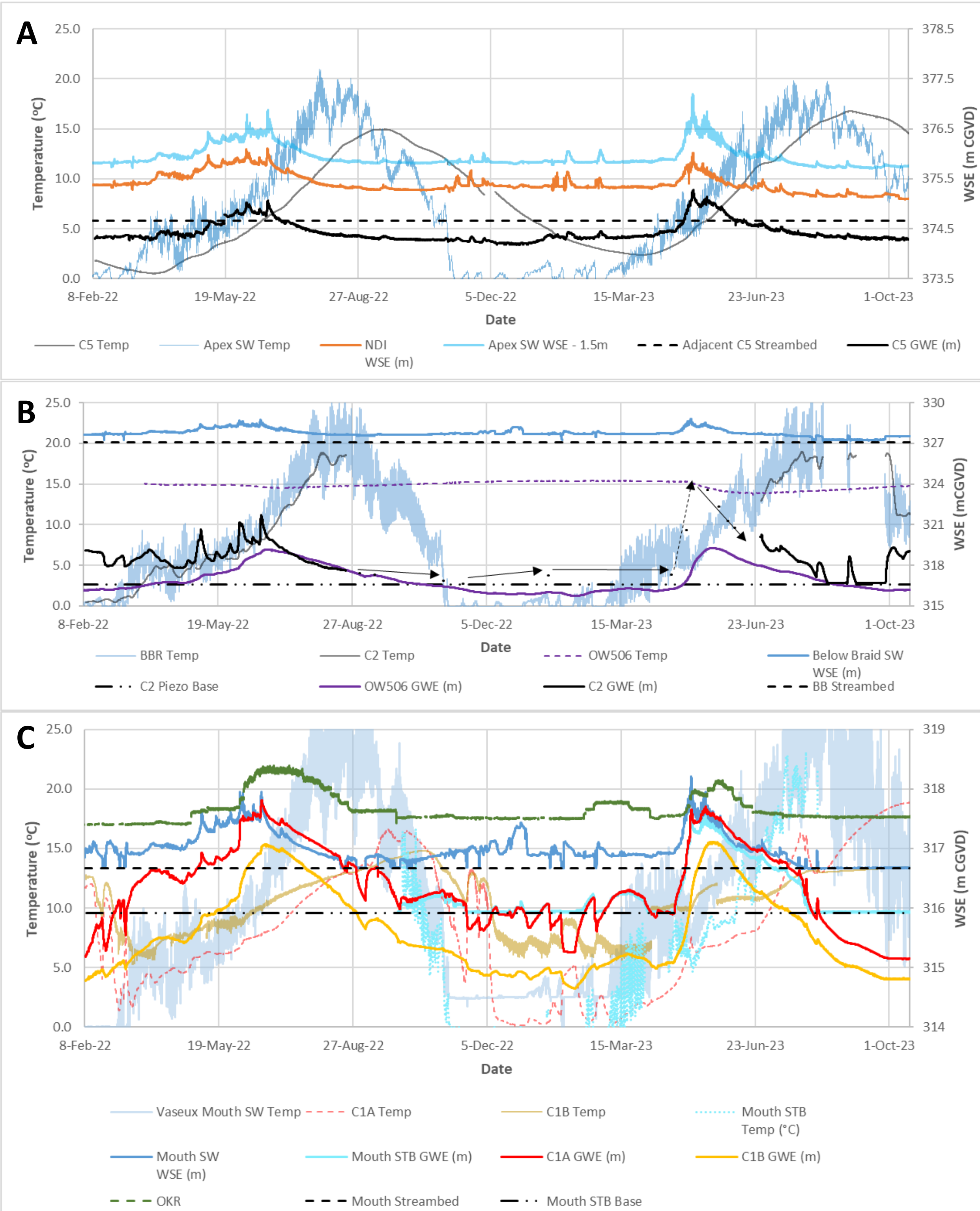

Figure 17: Comparison of groundwater (GWE) and stream water surface (WSE) elevations and temperatures at A) the fan apex, B) the mid fan and C) the lower fan/mouth. Streambed elevations are represented by blacked dashed lines.

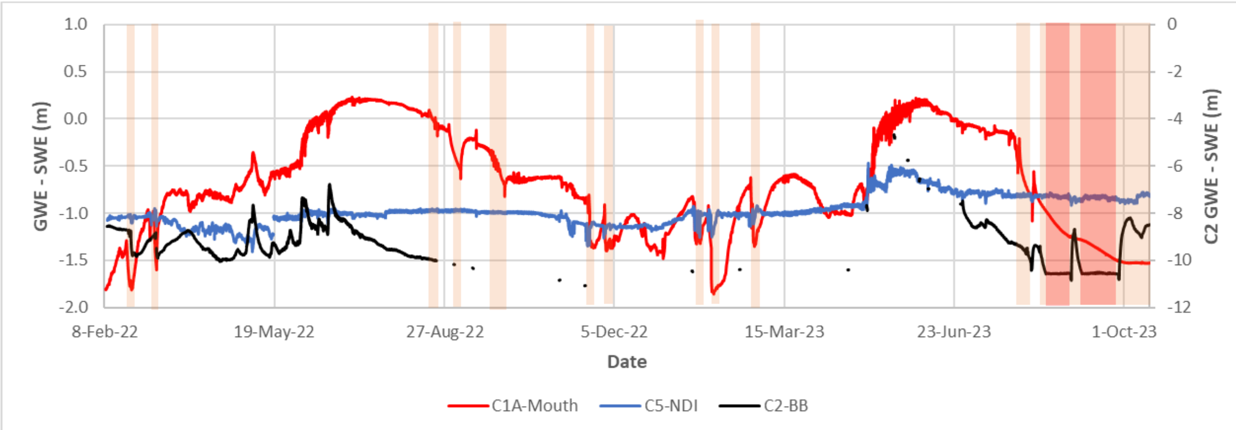

Figure 18: Direction of exchange flux at co-located stations. The mid fan (C2/BB) is presented on the second y-axis (note scale difference). Positive values indicate gaining conditions; negative values losing conditions. Light (mouth) and dark (BB) orange shading indicates periods when the creek dried up at those locations.

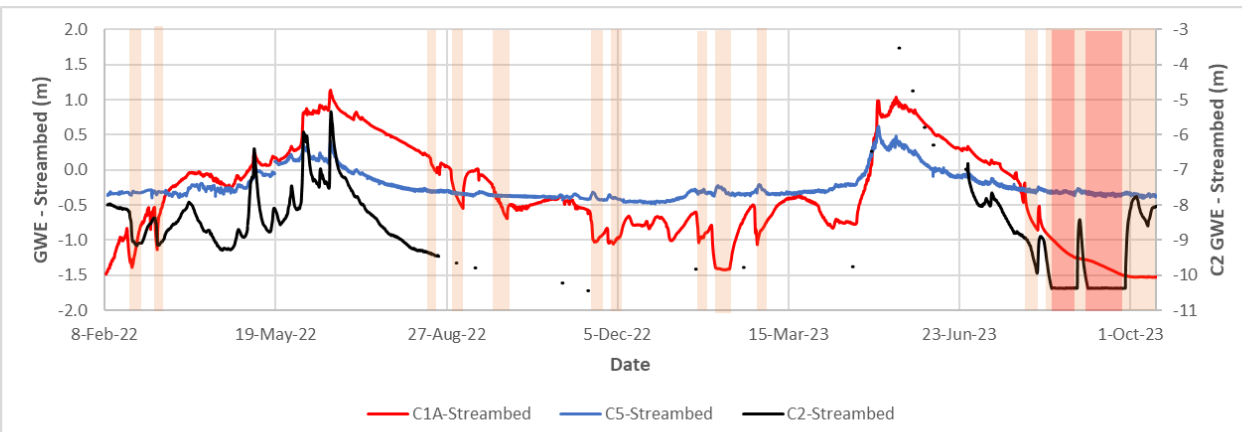

Figure 19: Hydraulic connectivity potential at co-located stations. A value of 0 indicates that the groundwater is at the streambed and hence connected; positive values also connected; negative values indicate groundwater is below the streambed and either transitional or disconnected. Orange shading as per Figure 18.

4.7 Reach-scale Exchange Flux

Overall, snʕax̌əlqaxʷiyaʔ (Vaseux Creek) consistently lost water to the underlying aquifer over the monitoring period (Table 6, longitudinal surveys; Figure 20, hydrometric data). The stream loss (or negative exchange flux) was significant, that is, the bounds of uncertainty did not overlap with zero. Temporally (Figure 20), stream losses tended to increase with discharge and were largest on the rising and falling limbs of the hydrograph each year. Winter exchange fluxes were higher in 2021/2022 after a very dry summer than observed in 2022/2023, but generally lower than summer values. Mean daily whole fan exchange varied from -0.1 m^3/s over winter to -0.6 m^3/s around freshet. Stream loss varied from <10% to 100% of discharge at the fan apex (Figure 21). Surface water diversions also constitute a negative flux (loss) from the creek water budget. Mean daily diversion loss was generally -0.05 m^3/s to -0.1 m^3/s outside of freshet. The proportion of water lost to diversions was greatest in August and September (up to 50% Q at apex in 2022 and 30% Q at apex in 2023) and sometimes April (2023 only) when discharge is lowest.

Table 6: Vaseux Creek exchange flux by reach (m^3/s) calculated from discharge measurements during longitudinal stream surveys. Errors are in italics. Bold text indicates that the exchange flux is significant.

Date	Q @ Apex (m^3/s)	Apex - Braid		Braided Central		Below Braid - Mouth		Northern Diversion		Overall Exchange		Natural (no diversion losses)	
		1		2		3		4					
16-Mar-22	0.278	**0.039**	*0.019*	**-0.125**	*0.011*	**-0.083**	*0.005*	**-0.036**	*0.007*	**-0.215**	*0.016*	**-0.169**	*0.018*
30-Jun-22	3.122	0.205	*0.225*	-0.321	*0.673*	0.036	*0.658*	**-0.092**	*0.046*	**-0.186**	*0.173*	-0.080	*0.179*
11-Jul-22	1.758	**0.207**	*0.122*	**-0.278**	*0.112*	**-0.191**	*0.097*	**-0.037**	*0.012*	**-0.340**	*0.107*	**-0.262**	*0.108*
8-Aug-22	0.273	0.026	*0.036*	**-0.149**	*0.022*	**-0.054**	*0.004*	**-0.044**	*0.007*	**-0.241**	*0.028*	**-0.176**	*0.029*
12-Sep-22	0.142	0.005	*0.023*	**-0.064**	*0.014*	**0.006**	*0.003*	**-0.037**	*0.009*	**-0.109**	*0.016*	**-0.053**	*0.019*
2-Nov-22	0.212	-0.006	*0.028*	**-0.075**	*0.019*	**-0.054**	*0.005*	0.009	*0.010*	**-0.155**	*0.018*	**-0.135**	*0.021*
7-Jun-23	1.718	**-0.400***	*0.103*	0.050	*0.126*	0.011	*0.108*	**-0.050**	*0.005*	**-0.402**	*0.080*	**-0.339**	*0.080*
28-Aug-23	0.154	**-0.039***	*0.014*	**-0.094**	*0.008*	**Dry**	-	**-0.020**	*0.002*	**-0.154**	*0.012*	**-0.133**	*0.012*
									Max	-0.402		-0.339	
									Min	-0.109		-0.053	

*In 2023, the start of the braided section moved upstream. This loss includes water moving through the secondary braid (Figure 6).

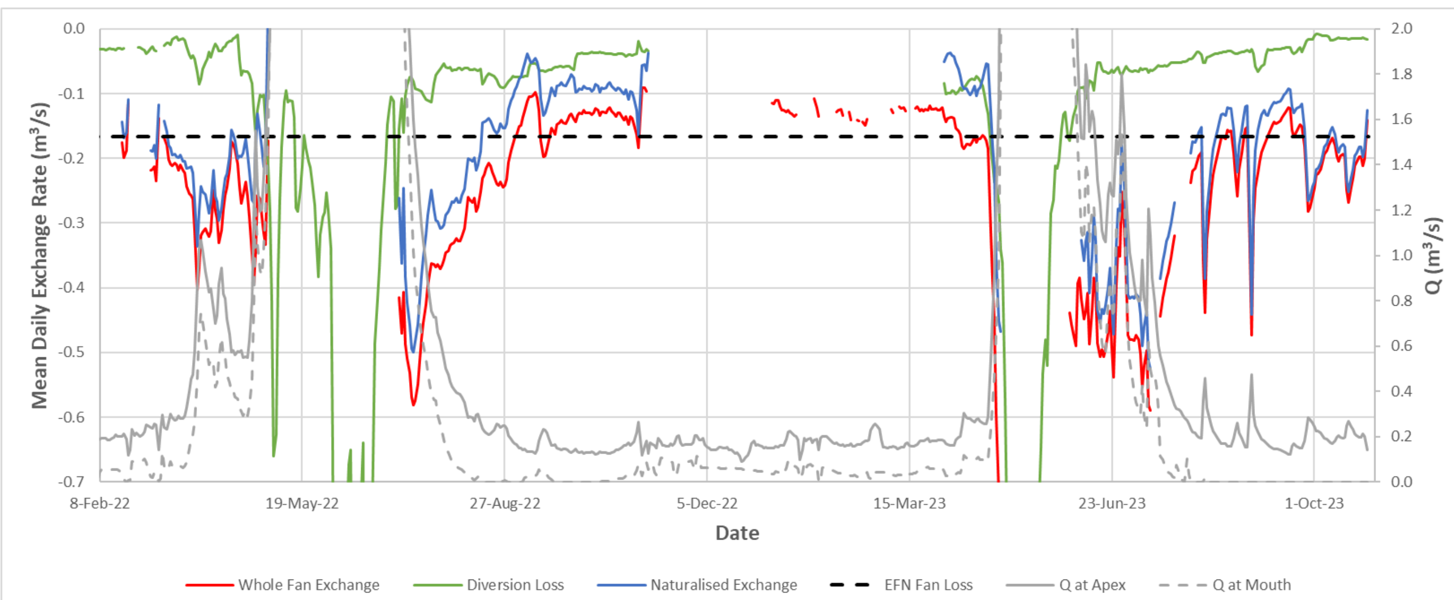

Figure 20: Mean daily exchange rate for the whole fan and the combined diversions. Discharge at the apex and mouth are plotted for reference.

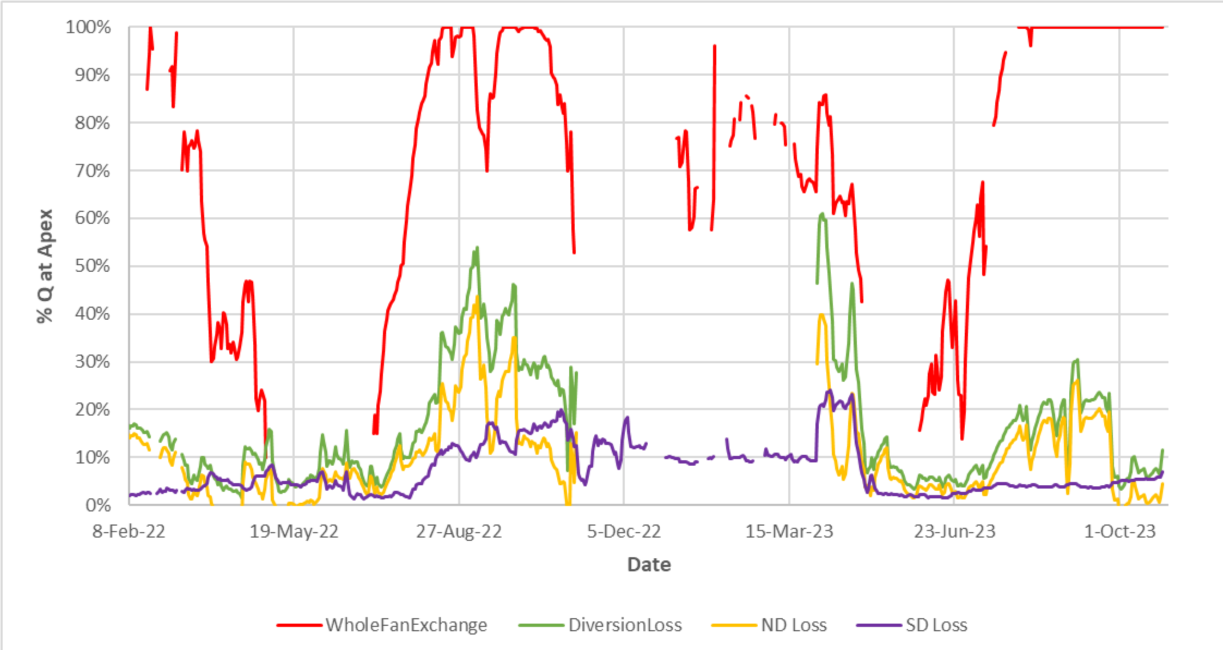

Figure 21: Exchange rates as a percentage of discharge at the apex. Ice covered channel periods and other low quality data were removed.

On a reach basis (Figure 22; Figure 24), and excluding the effect of diversions:

- Reach 1 (apex to above the braided section): Neutral to gaining. In 2022 and up to freshet 2023, hydrometric data indicated that this reach gained water or had minimal net exchange. The lack of change in water chemistry suggested that the reported gains may be due to non-steady state flow over the day of measurement (longitudinal surveys), accumulated errors (continuous data), or an inflow that is chemically similar to creek water. This reach lost water in 2023 post-freshet due to channel changes upstream that directed water into the northern braid.
- Reach 2 (braided section): Loss. Consistent throughout seasons. The flow at Above the Braid was always higher than the flow at Below the Braid and the difference was greater than the uncertainty. The secondary, northern braid dried up during the summers of 2022 and 2023.
- Reach 3 (below braided section to mouth): Loss and gain. Hydrometric data generally indicated that this reach lost water, except around freshet (small gains) and when dry. This reach partially dried up for periods from August onwards in 2022 and was dry in August and September 2023. Chemistry and isotopic analyses confirmed that gross gains occurred in this reach, initially previously infiltrated creek water and subsequently river-sourced groundwater. The location of groundwater inflow appeared to move upstream as the groundwater level at C1 reduced and were often outweighed by downstream infiltration.

Although Reach 2 dominated the exchange flux due to its length, infiltration through Reach 3 occurred at similar or higher rates when not gaining and inflow from upstream was sufficient (Figure 23). For example, the zero fluxes in August and September 2023 were because this reach was dry. The rate of flux through Reach 2 is underestimated when portions of the creek dry up.

Figure 22: Median monthly exchange flux by reach in A) 2022 and B) 2023.

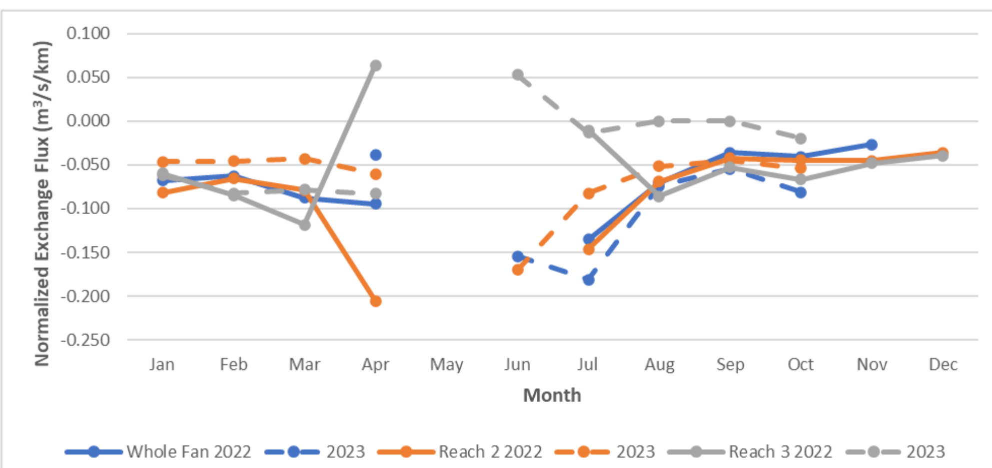

Figure 23: Inter-annual comparison of normalized exchange flux ($m^3/s/km$).

As noted above, the surface water diversions also constitute loss from Vaseux Creek. The proportion of creek flow diverted was generally higher during low flows. Diversion losses varied between seasons. In the northern braid, this appeared largely to be a function of channel configuration changes in August 2022 that directed a greater proportion of flow towards NDR1, returning it to Vaseux Creek. This reduced the quantity of water returned to the secondary braid (via NDR2), all of which was effectively lost from Vaseux Creek when this braid ceased to flow in mid August 2022 and late August 2023.

Although loss through the northern diversion did not cease outside the irrigation season, hydrometric data indicates that gate closure at the diversion structure reduced loss outside the licensed period. There were no indications of regulation in the southern diversion other than channel excavation after freshet.

5. DISCUSSION

5.1 Diversion Assessment

The annual volume of water diverted from snʕax̌əlqaxʷiyaʔ (Vaseux Creek) was 1.5 million m^3 to 1.9 million m^3, or 5.7 (2022) and 4.5 (2023) times the licensed volume (Table 7). The quantity of water removed by operation of the southern diversion was consistently an order of magnitude (10 times) higher than the licensed volume, whereas the quantity of water removed by operation of the northern diversion was 4.4 (2022) and 2.9 (2023) times the licensed volume. These values are conservative estimates of the volumes diverted based on median monthly daily discharges. The reduction in 2023 was primarily attributable to decreased loss through the northern diversion, at least partially due to changes in the configuration of the northern diversion returns in August 2022.

Table 7: Measured diversion fluxes and quantities compared to licensed.

Metric	Northern Diversion		Southern Diversion	
	2022	2023	2022	2023
Winter Median Q (m^3/s)	0.025	0.01	0.004	0.016
Apr - Sep Median Q (m^3/s)	0.04-0.06	0.025-0.055	0.02-0.04	0.006-0.06
Licensed volume (m^3)	268,020		60,037	
Diverted (m^3)	1,182,107	767,831	678,388	696,194
Total Licensed	328,057			
Total Diverted 2022	1,860,495			
Total Diverted 2023	1,464,025			

5.2 Summary of Exchange and Connectivity

In summary, as snʕax̌əlqaxʷiyaʔ (Vaseux Creek) flowed across the fan it lost water to shallow groundwater and gained groundwater on the lower fan during the latter part of freshet and when the river stage was high. Groundwater inflow in the lower fan consisted of a short period of infiltrated creek water followed by sq̓awsitkʷ (Okanagan River) water that travelled through the aquifer from the west.

With respect to the wider aquifer, Vaseux Creek recharged the aquifer immediately beneath it along the length of the fan. From the apex, this recharge moved out radially into the aquifer, before turning south where it intersected and mixed with aquifer recharge from the mountain block in the central fan and the river in the mid – lower fan. During freshet, a wedge of groundwater recharged from Vaseux Creek flowed over the river contributions in the lower fan and penetrated the deeper portion of the aquifer. As Vaseux Creek discharge reduced, the leading edge of this wedge shrank upstream towards the canyon, reaching C2 in 2023 when creek conditions were dry. Presumably there is a zone in the northern portion of the fan where mountain block recharge and river-sourced recharge mix in AQ255; however, this was not possible to determine with the available observation wells.

The annual volume of water that infiltrated from Vaseux Creek towards AQ255 was approximately 5.5 million m^3 over the monitoring period. This provides an upper bound for the quantity of creek water that recharged the aquifer due to evapotranspiration and transit through the unsaturated zone. The volume is one order of magnitude lower than the volume estimated in the Okanagan Basin Water Supply and Demand Study Phase 2 (40.1 million m^3), which was considered an overestimate (Golder and Summit, 2009).

Groundwater – surface water connectivity and exchange are summarised by reach in Table 8 and on Figure 24.

Table 8: Summary of estimates of exchange and connectivity.

Reach	Name	Average gradient (%)	Reach-scale exchange	Point-scale exchange	Groundwater Source
1	Upper fan	3.64	Neutral to gaining; loss to diversions	Losing connected	Creek, hyporheic exchange?
2	Central fan	2.81	Loss	Losing disconnected, connected after peak freshet with transitional phases Periodically dry	Shallow: creek (C2) Deep: river (OW056) Distal: creek/mountain block
3	Lower fan	1.69	Loss and gain; generally net loss	Gaining, losing connected to transitional and potentially disconnected Periodically dry	Shallow: creek, river Deep: river, creek in freshet
	Overall	2.65	Loss	n/a	

Vaseux Creek is a steep stream that flows across a highly conductive aquifer. The creek and groundwater are tightly coupled, even where transitional or disconnected states are inferred in the central and lower fan. The likely development of a saturated connection at C2 during freshet and subsequently an inverted water table below the creek extends the period of bi-directional hydraulic feedback between the creek and groundwater and hence the transition from connected to disconnected status (Xian et al., 2017). (Note that while bi-directional hydraulic feedback is inferred, water flow is consistently unidirectional from the creek to the groundwater). Recent theoretical research suggests that hydraulic feedback is likely to occur under ephemeral systems up to a creek – groundwater distance of 10 m (Quichimbo et al., 2020). In practice, it is generally impractical to determine the presence of an unsaturated zone beneath an entire streambed, and hence, it is challenging to identify completely disconnected systems. Preliminary analysis of isotopic data at Vaseux Creek indicates that connection occurs even when a groundwater well 1 m from the stream shows a water level 3 m below (Montgomery, in prep). Consequently, the period over which groundwater levels affect the exchange flux from the creek directly in this central reach are longer than suggested by a comparison of stream stage and groundwater elevation. Longitudinally, the infiltration flux from the creek also remains susceptible to groundwater level change in this reach because it is connected both up- and downstream (e.g., Fox and Durnford, 2003; Brunner et al., 2010). Unlike other fan systems where streamflow recharges groundwater at the apex of the fan, flows laterally, and then returns to the stream in the distal fan (e.g., Blackburn, 2021), the north-south hydraulic gradient of AQ255 and resulting direction of flow perpendicular to the axis of the fan appears to direct creek-sourced recharge from the apex and central fan south before reaching the distal fan.

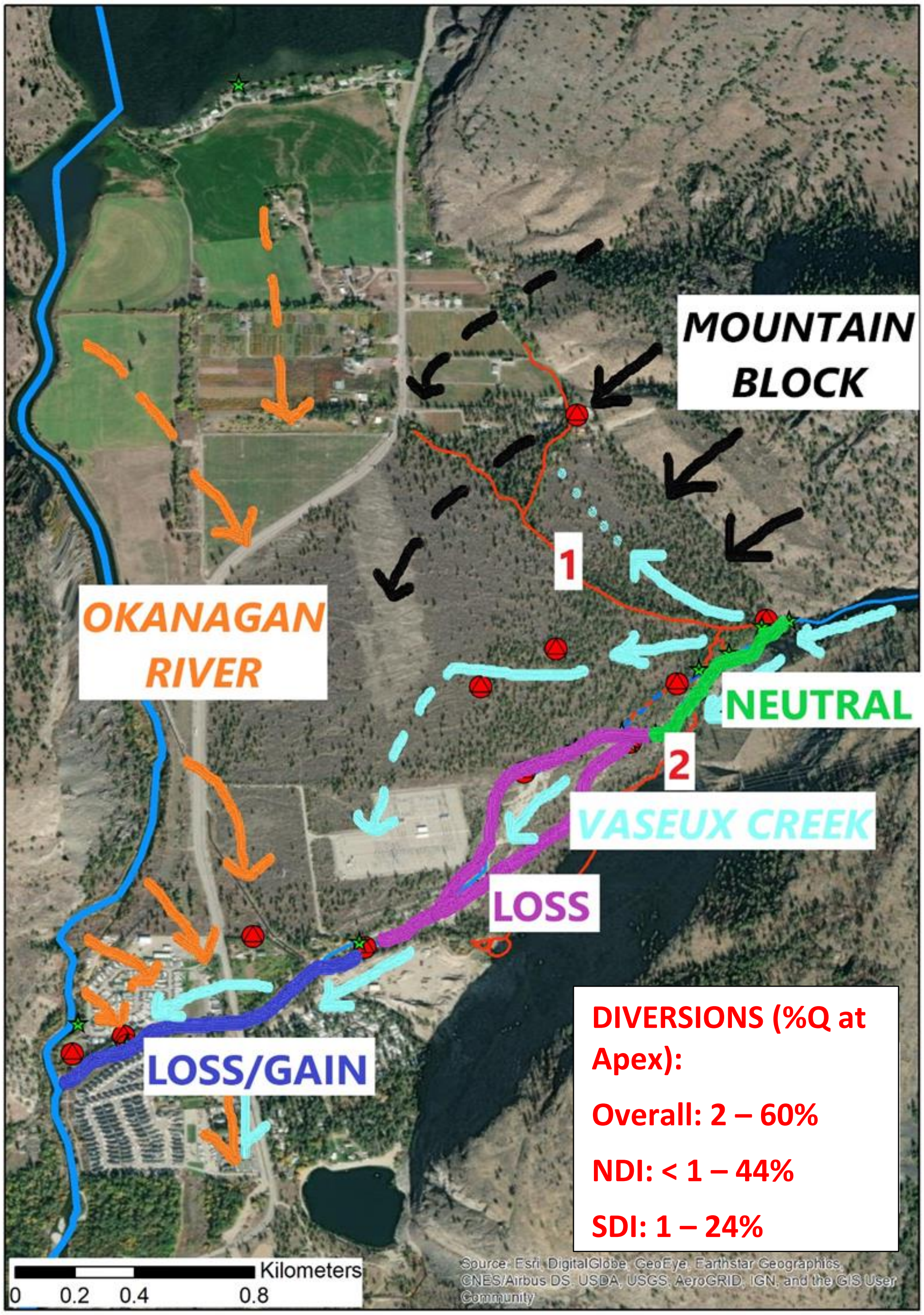

Figure 24: Schematic of surface and groundwater flow across the fan. Arrows indicate flow direction. Red sections of creek are diversions (1 – NDI; 2 – SDI). Reach 1 – neutral (green), Reach 2 – loss (consistent, purple), and Reach 3 – loss/gain (blue). Groundwater flow paths are indicated by solid arrows colour-coded by source; assumed groundwater flow paths by dashed lines.

5.3 Temporal Variability in Exchange

Temporal variability in exchange flux was assessed primarily at the whole fan scale. The raw daily exchange flux was first calculated as the difference between discharge at the apex and mouth. The naturalized exchange flux was then calculated by subtracting the measured daily loss to surface water diversions from the raw exchange. All periods of low data quality were then removed from the dataset. These periods included all data when the discharge at the apex was greater than 2 m^3, when ice cover was observed at either of the stations, over much of winter 2023 due to rating curve issues at NDI, and when continuous flow did not extend all the way through from the canyon to the mouth. Based on the two years of data for which diversion monitoring is available and hence the exchange flux can be naturalised, temporal variability in exchange flux across the snʕax̌əlqaxʷiyaʔ (Vaseux Creek) alluvial fan occurred as follows (Figure 25):

- Winter negative exchange flux (stream loss) increased when more dry days were reported in the creek in the preceding summer.
- Loss rate increased as discharge at the apex increased, likely due to increased head gradient and/or wetted area.
- Loss rate on the rising limb was smaller in 2023 after a winter in which the creek experienced one dry day compared to 2022 when there were 9 dry days.
- Greater loss rates on falling limbs for the same discharges indicated that freshet disturbed the streambed sufficiently to increase vertical hydraulic conductivity.
- Exchange on the recession limb appeared to stabilize at a relatively constant value if wetted area was considered:
  - 2022: -0.3 m^3/s
  - 2023: -0.4 m^3/s (measured, yellow points) reduced to -0.3 m^3/s when the measured flow into the north braid was removed (orange points). This difference in rate was assumed to represent the loss through the additional wetted area of creek added when the 2023 freshet realigned the braids.
- Loss rate reduced as discharge reduced on the falling limb through to fall, likely due to reduced head gradient/wetted area and decrease in vertical hydraulic conductivity over time due to a combination of fine particle deposition at low flows, filling of interstitial voids, and promotion of clogging by the downward vertical flux. Decreases in vertical hydraulic conductivity are known to reduce by half to up to orders of magnitude due to these processes (Rosenberry et al., 2021).
- Loss rate further reduced over winter to April, likely due to in-reach movement of fines and potentially lower water temperatures (Rosenberry et al., 2021).
- Dry antecedent conditions increased infiltration flux, and each stage increase resulted in a period of higher infiltration (Batlle-Aguilar and Cook, 2012). For example, discharge events in August 2023 that occurred after the creek had initially dried up had higher loss rates for the same discharge than July 2023.
- Gaining conditions at the mouth also reduced the overall exchange flux (purple cluster at Q = 0.13 m^3/s September 2022; June 2023 (not shown)).

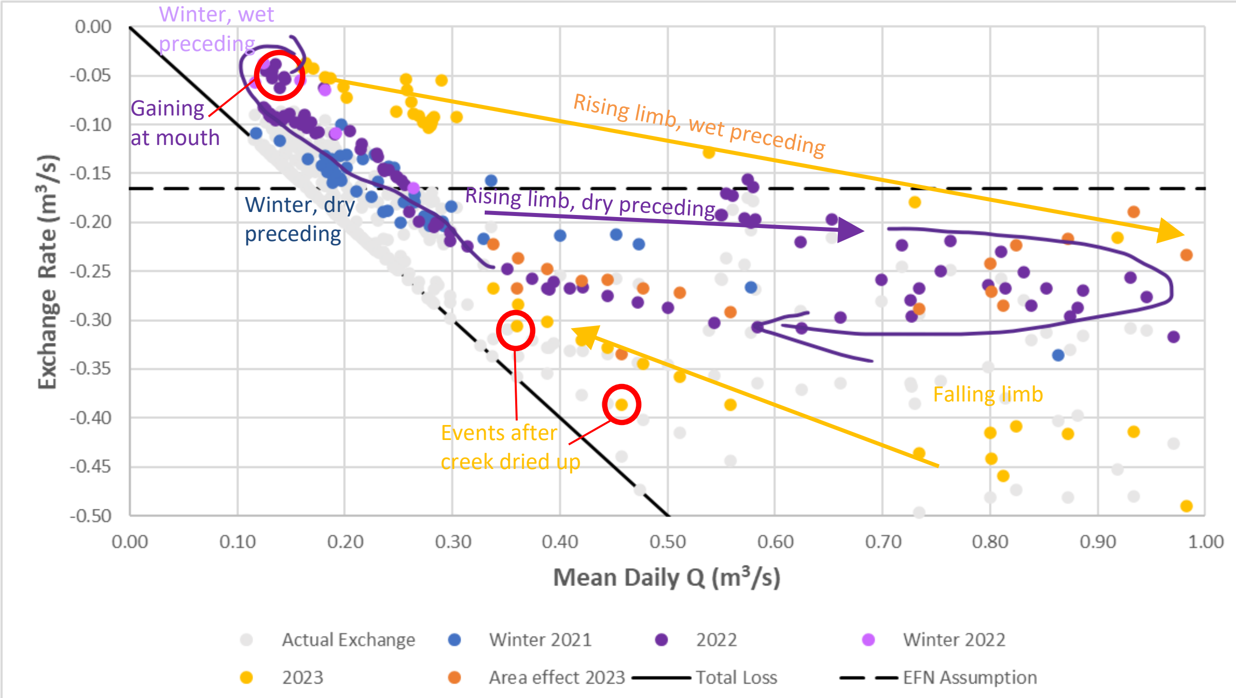

Figure 25: Vaseux Creek mean daily exchange rate vs discharge (Q) at the apex. Actual exchange values are plotted in grey. All colour points are naturalized exchange (i.e., surface diversion loss removed), with winter values plotted separately.

In summary, temporal variability in exchange flux at Vaseux Creek is a function of multiple non-linear processes:

- Discharge at the apex. Loss rate (negative exchange flux) generally increases with discharge.
- Antecedent moisture conditions. Dry antecedent moisture conditions increase loss rates (Batlle-Aguilar and Cook, 2012). When the subsurface dries out, infiltrating water must first fill storage. The increased storage is reflected in responsive shallow groundwater levels. Rapid reductions in shallow groundwater level when surface water inputs cease reflect the tight coupling of surface water infiltration and shallow groundwater levels in the mid and lower fan.
- Position in the hydrologic year. Loss rates pre-freshet are lower than post-freshet due to cyclical changes in streambed hydraulic conductivity (Rosenberry et al., 2021).
- Wetted area. This is related positively to change in flow; step changes also occur in response to freshet.
- Gaining conditions in Reach 3/at the mouth. This reduces the overall loss rate (by water balance).

5.4 Drivers of Exchange

The factors clearly driving groundwater – surface water exchange and connectivity on the snʕax̌əlqaxʷiyaʔ (Vaseux Creek) alluvial fan are mountain block discharge, sq̓awsitkʷ (Okanagan River) mainstem water levels, Vaseux Creek discharge and diversion losses. There is also some evidence that groundwater extraction in Reach 3, from Gallagher Lake to the confluence with Okanagan River, is affecting the regional groundwater level and, under specific conditions, groundwater discharge into Vaseux Creek.

Vaseux Creek will flow continuously across the fan whenever the water supply from the upper catchment exceeds the infiltration capacity of the creekbed. Hence, understanding precipitation in the upper catchment, rather than on the valley bottom, is critical to managing flow across the fan. Diversion losses reduce the available water supply, and hence contribute to increased frequency and duration of dry periods.

Near the apex, the infiltration capacity is reduced by the shallow bedrock that holds up the shallow groundwater table. Although it may be a contributing factor to the lower infiltration flux through Reach 1, its steep decline likely controls the steep hydraulic gradient at the fan apex and relatively flat water table throughout the remainder of the fan distant from the creek. Mountain block discharge recharges AQ255 along the eastern boundary, but its role in maintaining fan groundwater levels could not be separated from the Okanagan River mainstem and creek with the available observation wells.

Groundwater flow in the northern portion of the fan is assumed to be to the south based on the hydraulic gradient, however, the presence of groundwater extraction wells raises the possibility of a local recirculation system that reduces the flow of groundwater to the south from akspaqmix (Vaseux Lake). Similarly, the effect of mountain block discharge in this portion of the fan and where it intersects with mainstem contributions remains unknown.

Groundwater levels across the southern portion of the fan, and hence hydraulic gradient and flow, are a combined function of river level and creek level. A delay between Vaseux Creek freshet and freshet in the Okanagan River mainstem above Vaseux Creek extends the period when gaining conditions are observed on the lower fan, as in 2022. The potential for gaining conditions can be approximately determined by comparing the regional water level in OW506 to the elevation of the streambed.

5.5 Stream Discharge, Water Use and EFNs

EFNs and CEFTs were developed for snʕax̌əlqaxʷiyaʔ (Vaseux Creek) following the methods developed collaboratively as part of the Okanagan EFN Project (ONA, 2020). For Vaseux Creek specifically, this consisted of:

- scaling discharge data from WSC 08NM171 Vaseux Creek above Solco Creek to the catchment area at the fan apex,
- subtracting the estimated natural loss rate across the fan (0.16 m^3/s) to estimate the naturalised flow at the mouth, and
- further subtracting the estimated diversion losses to estimate the residual flow at the mouth. As no metered information was available, the diversion losses were assumed to occur within the license periods at the licensed rates.

This information was combined with in-stream habitat measurements to determine both the EFN and the CEFT. When the EFN otherwise would have resulted in conditions unsuitable for aquatic health, it was set to equal the CEFT due to highly degraded stream morphology and consequent loss of discharge to channel width relationships.

During the monitoring period of this project, the discharge at the fan apex was generally at or above the EFN and CEFT, whereas the discharge at the mouth (equivalent to EFN Residual) was consistently below the EFN, CEFT, and estimated residual discharge except over winter (Figure 26). The results of this project provide some clarification as to why these discrepancies occurred here and may occur in other locations.

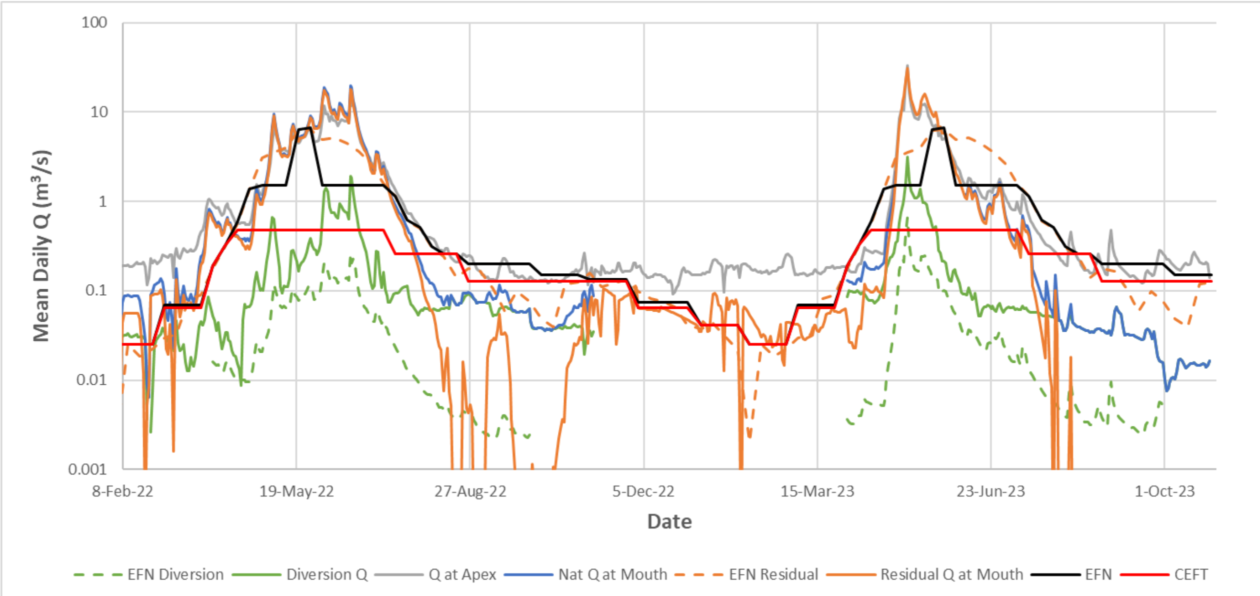

Figure 26: Measured discharge and EFN assumptions, EFN and CEFT.

Firstly, the exchange rate (loss rate) across the fan is not consistent throughout the year (Section 5.3). It is a function of multiple non-linear processes but may be generalized as higher after dry conditions and freshet and during higher discharges, and lower over winter relative to the assumed value. Secondly, the loss to diversions was five to six times higher than licensed (Table 7), increased as a proportion of flow over the critical summer/fall period when discharge decreased, and continued throughout winter (Section 4.7). In contrast, the diversions were assumed to be withdrawn as a proportion of discharge and only during the licensed period during EFN/CEFT development. Together, these factors resulted in discharge at the mouth below the EFN and CEFT over the critical summer/fall period.

Clearly, Vaseux Creek has a conductive streambed over a conductive aquifer. It is also a very dynamic creek with a naturally varying wetted area. Hence, maintaining flow across the fan requires sufficient inputs at the apex to offset natural losses across the fan. Diverting streamflow for consumptive use reduces the amount of water in the creek, the effect of which is magnified by transient infiltration rates exacerbated by dry antecedent conditions. Figure 25 provides one way of estimating if removing the diversions would have led to continuous flow to the mouth. Taking September 2022 as an example, the naturalised rate of loss was approximately -0.1 m^3/s for a discharge of approximately 0.15 m^3/s at the apex (Figure 25). Diversion losses were -0.05 m^3/s to -0.08 m^3/s, sufficient to reduce the amount of water in the creek below the threshold required for continuous flow to the mouth. Supporting evidence is provided by the return to continuous flow after the reduction in water diverted into the northern diversion on October 1. In 2023, continuous flow to the mouth ceased when discharge at apex was below 0.3 m^3/s and diversion losses were approximately 0.05 m^3/s, suggesting that the creek would have dried up regardless of the diversions when apex discharge reduced below 0.2 m^3/s to 0.25 m^3/s, which occurred for short periods throughout summer and fall. However, the duration of dry creek would have been substantially reduced, which would reduce desaturation and hence increase the rate of return to continuous flow. Interestingly, lines of best fit through points immediately preceding the loss of continuous flow intersect the Total Loss line on Figure 25 at -0.1 m^3/s and -0.2 m^3/s, indicating that these may be the minimum loss rates for the given conditions. Further years of data are required to confirm this.

In summary, surface water diversions from Vaseux Creek are increasing the frequency and duration of periods when creek flow is not continuous to the mouth. Hence, removing the diversions would help return the creek to the state identified by Syilx TEKK, that is, sometimes drying up, rather than always. Consistent supply of moisture would also facilitate the re-establishment of a healthy riparian corridor, which would further reduce water temperature. The impact of groundwater extraction on creek flow remains an open question.

5.6 Limitations

Comparison of exchange calculated from longitudinal stream discharge surveys and continuous discharge estimated from rating curves indicated that the direction of exchange flux was consistent between methods. However, the assumption of quasi-steady state conditions during stream surveys in a single day was not regularly met due to diurnal fluctuations likely resulting from evapotranspiration throughout the catchment. The induced error varied based on the magnitude of discharge variability during the day relative to the magnitude of the exchange flux. At snʕax̌əlqaxʷiyaʔ (Vaseux Creek) the daily variability was often of a similar order of magnitude to the exchange flux (up to 0.2 m^3/s). Hence, continuous hydrometric data is invaluable in calculating exchange rates at the reach-scale.

Diversion losses were measured as the water lost from the creek. Due to likely losses from open, unlined diversion channels, this amount may be considered an upper estimate of the actual water use.

Groundwater use is not quantified and therefore the effects of pumping on groundwater level and potential stream interactions are unknown. September 2022 data indicated that groundwater pumping may be sufficient to affect streamflow, and September 2023 data also suggests that groundwater activities are impacting local groundwater levels.

Regional flow direction in AQ255 is assumed. There is insufficient data to determine the relative volumes of water sourced from akspaqmix (Vaseux Lake), sq̓awsitkʷ (Okanagan River), and mountain block recharge that recharge AQ255. The junction where mountain block and mainstem contributions mix in the northern portion of the fan remains unknown, as are flow directions immediately adjacent to Vaseux Lake. Hydraulic gradients south of Vaseux Creek are also unknown, as is the influence of the connection between groundwater sources and Gallagher Lake. There is also insufficient data to assess the primary drivers of groundwater level change on the central fan.

6. CONCLUSIONS

Groundwater – surface water interactions on the snʕax̌əlqaxʷiyaʔ (Vaseux Creek) alluvial fan are complex and vary through time and space. Key findings:

- The water in Vaseux Creek is primarily sourced from the catchment uplands, although the sq̓awsitkʷ (Okanagan River) also contributes via groundwater flow in the lower fan under specific combinations of creek and river stages.
- There are three sources of groundwater recharge: mountain block recharge, the Okanagan River mainstem, and Vaseux Creek. Creek recharge spreads radially out from the fan apex and appeared to travel up to 800 m northwest. Elsewhere, vertical infiltration dominated. A wedge of creek water appears to sit over river- and/or mountain block recharge-sourced water in the central and lower fan. This wedge retreats upstream as creek discharge declines.
- Overall, Vaseux Creek loses water between the apex and the mouth. The loss is significantly different to zero and is concentrated in Reach 2 in the central braided section of the fan. Although the system is closely coupled, the creek is perched metres above the groundwater in

this reach. Normalized loss rates in Reach 3 downstream can be as high as in Reach 2 depending on the position of the groundwater table.

- The drivers of connection vary spatially across the fan: at the apex, the creek and groundwater are connected due to the shallow depth to bedrock; in the central fan, connection occurs due to high creek discharge (freshet); and in the lower fan, connection occurs due to a combination of high creek discharge and river stage. Transitional and potentially disconnected states are otherwise present on the central and lower fan.
- Discharge at the mouth was consistently lower in 2022 and 2023 than residual discharge estimated in the EFN setting process. This was a function of the large temporal variation in exchange flux compared to the fixed value assumed and diversion losses and discrepancies between licensed and actual diversion losses.
- The naturalised rate of stream loss is a function of creek stage, wetted area, time since freshet, continuity of creek flow (antecedent moisture conditions when events occur), and groundwater level due to river stage rise.
- The actual loss of water from the creek is greater due to surface water diversions. The diversions result in stream losses on average five times greater than licensed volumes each year.
- The quantity of water lost from the creek due to diversion operations was sufficient to reduce the amount of water in the creek below the threshold required for continuous flow to the mouth in 2022; analysis indicates that without this loss the creek would likely not have dried up. In 2023, hydroclimatic conditions were such that dry periods were likely to occur regardless of diversion operation, but that the frequency and duration of dry periods would have been reduced without this additional loss.
- Reductions in the duration, frequency, and extent of periods over which the creek bed is dry are required to support the thriving riparian vegetation and fishing asserted by Syilx TEKK.
- Groundwater use is potentially affecting streamflow on the lower fan. Groundwater extraction volumes, timing and locations and groundwater level monitoring on the south side of the creek are required to further investigate the magnitude of impact.

Recommendations to further refine the understanding of groundwater-surface water interactions across the Vaseux alluvial fan include:

- Continue monitoring creek and groundwater levels and temperature at co-located stations over multiple years to assess long-term trends.
- Collect and analyse groundwater water level and environmental tracer data in the northern portion of the fan to assess groundwater flow direction and sources in this area.
- Continue monitoring all points of diversion and diversion return to 1) monitor volumes lost from the creek and 2) more accurately determine naturalised discharge estimates.
- Develop a methodology for including time-varying natural loss rates into residual flows for EFNs.
- Estimate the quantities of mountain block and river-sourced recharge to AQ255 on the fan.
- Monitor groundwater extraction volumes and timing at all locations on the fan.
- Monitor groundwater level on the south side of Vaseux Creek to assess the impact of groundwater extraction on the connectivity of the creek and groundwater in this area.
- Assess the relationship between Gallagher Lake, groundwater levels in AQ255 and creek discharge.

As stated in the Syilx siwɬkʷ Declaration (ONA, 2014):

iʔ‿siwłkʷ yʕat taʔkín k̓l̓‿kscxʷl̓xʷal̓ts iʔ‿tm̓xʷúlaʔxʷ uł k̓l̓‿tmixʷ.

Water comes in many forms and all are needed for the health of land and for the animals.

iʔ‿siwłkʷ cxʷuy tl̓‿tm̓xʷúlaʔxʷ tl̓ wist uł lut kscwsn̓cuts tl̓‿stim.

Water comes from the sky and the highest place yet it never wilfully rises above anything.

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APPENDIX A. WATER USE AND LICENSING

Appendix A - Groundwater/Surface Water Use and Licencing - Vaseux Fan Area

	WELL TAG NUMBER	AQUIFER ID	NEAREST SURFACE WATER	LICENCE STATUS	LICENCE NUMBER	POD NUMBER	PRIORITY DATE	SOURCE NAME	PURPOSE USE	QTY m^3/day	QTY/year m^3	Max Rate (m^3/sec)	Use Year/Term	REMARKS
SOUTH			vaseux_creek	Licensed	C069839	PD54211	1887-01-06	vaseux_creek	03B - Irrigation: Private		29,443.17		Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C037630	PD54211	1887-01-06	vaseux_creek	03B - Irrigation: Private		22,646.69		Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C037638	PD54211	1936-01-25	vaseux_creek	03B - Irrigation: Private		13,074.89		Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C110435	PD54211	1936-01-25	vaseux_creek	03B - Irrigation: Private		9,867.84	0.809	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C069841	PD54211	1887-01-06	vaseux_creek	03B - Irrigation: Private		29,603.52	2.428	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	F050550	PD54211	1906-05-07	vaseux_creek	03B - Irrigation: Private		2,466.96	0.202	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C126685	PD54211	1887-01-06	vaseux_creek	03B - Irrigation: Private		19,735.68	1.56	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C037635	PD54211	1887-01-06	vaseux_creek	03B - Irrigation: Private		1,134.80	0.093	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C037637	PD54211	1887-01-06	vaseux_creek	03B - Irrigation: Private		30,096.91	2.469	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C037637	PD54211	1887-01-06	vaseux_creek	Domestic	2.273	829.65		Jan 1 - Dec 31	Vaseux Creek WUC
			vaseux_creek	Licensed	C047638	PD54211	1975-01-22	vaseux_creek	03B - Irrigation: Private		14,801.76	1.214	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C110439	PD54211	1975-11-20	vaseux_creek	03B - Irrigation: Private		59,207.04	4.856	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C110477	PD54211	1977-02-10	vaseux_creek	02I31 - Livestock & Animal: Stockwatering	2.273	829.65		Jan 1 - Dec 31	Vaseux Creek WUC
			vaseux_creek	Licensed	C049226	PD54211	1887-04-19	vaseux_creek	03B - Irrigation: Private		325,145.33	26.669	Apr 1 - Sept 30	Vaseux Creek WUC (intended to sum individual licences from PD54211)
			vaseux_creek	Licensed	C069842	PD54211	1887-01-06	vaseux_creek	03B - Irrigation: Private		13,161.23	1.081	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C069840	PD54211	1887-01-06	vaseux_creek	03B - Irrigation: Private		4,255.51	0.348	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C069840	PD54211	1887-01-06	vaseux_creek	Domestic	2.273	829.66		Jan 1 - Dec 31	Vaseux Creek WUC
			vaseux_creek	Licensed	C110436	PD54211	1936-01-25	vaseux_creek	03B - Irrigation: Private		16,035.24	1.315	Apr 1 - Sept 30	Vaseux Creek WUC
			vaseux_creek	Licensed	C111065	PD54210	1959-11-02	vaseux_creek	03B - Irrigation: Private		59,207.04		Apr 1 - Sept 30	
			vaseux_creek	Licensed	C111065	PD54210	1959-11-02	vaseux_creek	Domestic	2.273	829.66		Jan 1 - Dec 31	
	58653	255	vaseux_creek	Unlicensed										
	46682	255	vaseux_creek	Unlicensed										
	39192	255	vaseux_creek	Unlicensed										
	16717	255	vaseux_creek	Unlicensed										
	39184	255	vaseux_creek	Unlicensed										
	18457	255	vaseux_creek	Unlicensed										
	19571	255	vaseux_creek	Unlicensed										
	125206	255	vaseux_creek	Unlicensed					Monitoring					Provincial observation well #506
	none	255	vaseux_creek	Unlicensed										Identifed as domestic use purpose during an inspection
	89174	255	vaseux_creek	Licensed	501945	PW198839	1978-01-01	255	WSA03 - Commercial Enterprise	95	34,675.00	0.0011	Jan 1 - Dec 31	Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	38805	255	vaseux_creek	Licensed	501945	PW198838	1978-01-01	255	WSA03 - Commercial Enterprise					Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	20414	255	gallagher_lake	Licensed	501945	PW198840	1978-01-01	255	WSA03 - Commercial Enterprise					Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	5220	255	gallagher_lake	Unlicensed										
	13500	255	gallagher_lake	Unlicensed										
	23583	255	gallagher_lake	Unlicensed										
	44010	255	gallagher_lake	Unlicensed										
	25665	255	gallagher_lake	Unlicensed										
	105385	255	gallagher_lake	Unlicensed										
	49935	255	gallagher_lake	Unlicensed										
	87393	255	gallagher_lake	Unlicensed										
	84708	255	gallagher_lake	Unlicensed										
	37794	255	gallagher_lake	Unlicensed										
	47552	255	gallagher_lake	Unlicensed										
	17716	255	gallagher_lake	Licensed	501901	PW198792	1994-01-01	255	WSA03 - Commercial Enterprise	25	9,125.00		Jan 1 - Dec 31	Total demand for purpose, one POD.
	21130	255	gallagher_lake	Unlicensed										
	3177	255	gallagher_lake	Unlicensed										
	95116	255	gallagher_lake	Unlicensed										
	44467	255	gallagher_lake	Licensed	503277	PW202218	1980-02-27	255	WSA03 - Commercial Enterprise	5	1,825.00		Jan 1 - Dec 31	Total demand for purpose, one POD.
	21129	255	gallagher_lake	Unlicensed										
	34636	255	gallagher_lake	Unlicensed										
	17224	255	gallagher_lake	Unlicensed										
	61073	255	gallagher_lake	Unlicensed										
NORTH CENTRAL	116737		okanagan_river	Unlicensed										
	28275	255	okanagan_river	Unlicensed										
	28246	255	okanagan_river	Unlicensed										
	54602	255	okanagan_river	Unlicensed										
	82954	255	okanagan_river	Unlicensed										
	110321	255	okanagan_river	Licensed	502337	PW199901	1977-03-15	255	03B - Irrigation: Private		35,376.21	0.0082	Apr 1 - Oct 31	Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	110316	255	okanagan_river	Licensed	502337	PW199902	1977-03-15	255	03B - Irrigation: Private					Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	22180	255	okanagan_river	Unlicensed										
	27217	255	vaseux_lake	Unlicensed										
	35904	255	vaseux_lake	Unlicensed										
	19588	255	vaseux_lake	Unlicensed										
	38592	255	vaseux_lake	Unlicensed										
	125693		vaseux_lake	Unlicensed										
	19583	255	vaseux_lake	Unlicensed										
	19584	255	vaseux_lake	Unlicensed										
	129618	255	vaseux_lake	Unlicensed			2023-04-06		Non Domestic (see remarks)					New well, no water licence associated with well, *water use purpose identified from drilling record

Appendix A - Groundwater/Surface Water Use and Licencing - Vaseux Fan Area

	WELL TAG NUMBER	AQUIFER ID	NEAREST SURFACE WATER	LICENCE STATUS	LICENCE NUMBER	POD NUMBER	PRIORITY DATE	SOURCE NAME	PURPOSE USE	QTY m^3/day	QTY/year m^3	Max Rate (m^3/sec)	Use Year/Term	REMARKS
NORTH CENTRAL	47301	255	vaseux_lake	Unlicensed										
	120970		vaseux_lake	Unlicensed										
	76687	255	vaseux_lake	Unlicensed										
	70007	255	vaseux_lake	Unlicensed										
	82803	255	vaseux_creek	Unlicensed										
	105325	255	vaseux_creek	Unlicensed										
	119654		vaseux_creek	Unlicensed										
	61086	255	vaseux_creek	Unlicensed										
	19307	255	vaseux_creek	Unlicensed										
WEST			vaseux_lake	Licensed	C107217	PD68330	1993-10-25	vaseux_lake	01A - Domestic	2.27305	367.27		Jan 1 - Dec 31	
			vaseux_lake	Licensed	F039822	PD54209	1963-07-08	vaseux_lake	02F - Lwn, Fairway & Grdn: Watering		444.05		Apr 1 - Sept 30	
			vaseux_lake	Licensed	F039823	PD54209	1963-07-08	vaseux_lake	02F - Lwn, Fairway & Grdn: Watering		1,036.12		Apr 1 - Sept 30	
	39960	255	vaseux_lake	Unlicensed										
	43293	255	vaseux_lake	Unlicensed										
	112256		vaseux_lake	Unlicensed										
	21132	255	vaseux_lake	Unlicensed										
	119903		vaseux_lake	Unlicensed										
	118121	255	vaseux_lake	Licensed	502357	PW199993	2018-06-04	255	WSA03 - Commercial Enterprise	7.22	2,635.30		Jan 1 - Dec 31	Total demand for purpose, one POD.
	22386	255	vaseux_lake	Unlicensed										
	45981	255	vaseux_lake	Unlicensed										
	21131	255	vaseux_lake	Unlicensed										
	123407		vaseux_lake	Unlicensed										
	21125	255	vaseux_lake	Unlicensed										
	18037	255	vaseux_lake	Unlicensed										
	36123	255	vaseux_lake	Unlicensed										
	22500	255	vaseux_lake	Unlicensed										
	50460	255	vaseux_lake	Unlicensed										
	121610		vaseux_lake	Unlicensed										
	112254		vaseux_lake	Unlicensed										
	51509	255	vaseux_lake	Unlicensed										
	54660	255	vaseux_lake	Unlicensed										
	112253		vaseux_lake	Unlicensed										
	118949		vaseux_lake	Unlicensed										
	47551	255	vaseux_lake	Unlicensed										
			okanagan_river	Licensed	C035861	PD54207	1968-04-19	okanagan_river	03B - Irrigation: Private		98,678.40		Apr 1- Sept 30	
					C038164	PD54180	1970-11-13	okanagan_river	03B - Irrigation: Private		473,656.32		Apr 1- Sept 30	
			okanagan_river	Licensed	F047365	PD54206	1965-02-26	okanagan_river	03B - Irrigation: Private		275,312.74		Apr 1- Sept 30	
			okanagan_river	Licensed	502516	PD54204	1908-01-30	okanagan_river	03A - Irrigation: Local Provider		16,845,000		Apr 1 - Oct 31	Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown. Actual volume reported from 2022 = 7404446.33 m3 at POD 54204 on Okanagan River
			okanagan_river	Licensed	503180	PD54181	1970-08-13	okanagan_river	03B - Irrigation: Private		43,740.00	0.005	Apr 1 - Oct 30	
			okanagan_river	Licensed	503181	PD54206	1970-08-13	okanagan_river	03B - Irrigation: Private		47,820.00		Apr 1 - Oct 30	
	117574	255	okanagan_river	Licensed	501346	PW197201	2019-01-28	255	WSA11 - Lawn, Fairway & Garden		454.00		Feb 1 - Nov 3	Total demand for purpose, one POD.
	39471	255	okanagan_river	Unlicensed										
	22914	255	okanagan_river	Unlicensed										
	34383	255	okanagan_river	Unlicensed										
	82375	255	okanagan_river	Unlicensed										
	36120	255	okanagan_river	Unlicensed										
	82374	255	okanagan_river	Unlicensed										
	39185	255	okanagan_river	Unlicensed										
	61069	255	okanagan_river	Unlicensed										
	119497	255	okanagan_river	Licensed	504018	PW203761	1950-09-29	255	03B - Irrigation: Private					Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	119500	255	okanagan_river	Licensed	504018	PW203762	1950-09-29	255	03B - Irrigation: Private					Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	119509	255	okanagan_river	Licensed	504018	PW203765	1950-09-29	255	03B - Irrigation: Private		1,652,863.20	0.292	Apr 1 - Nov 30	Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	119502	255	okanagan_river	Licensed	504018	PW203763	1950-09-29	255	03B - Irrigation: Private					Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	119505	255	okanagan_river	Licensed	504018	PW203764	1950-09-29	255	03B - Irrigation: Private					Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown
	20397	255	okanagan_river	Unlicensed										
	19579	255	okanagan_river	Unlicensed										
	37097	255	okanagan_river	Unlicensed										
	116741		okanagan_river	Unlicensed										
	120635	255	okanagan_river	Licensed	504476	PW205624	2020-04-22	255	WSA07 - Misc Indust	5	1,825.00		Jan 1 - Dec 31	Total demand for purpose, one POD.
	17711	255	okanagan_river	Unlicensed										

Licenced groundwater

Licenced surface water

Data reported August 15, 2023 Updated June 20, 2024

APPENDIX B. WELL CONSTRUCTION DETAILS

WELL CONSTRUCTION LOG

BOREHOLE: C1A (Shallow) & C1B (Deep)

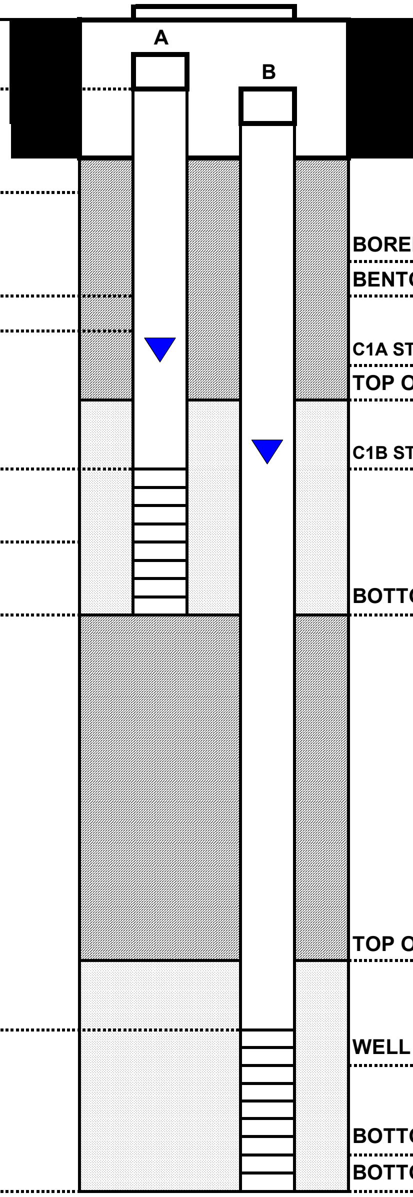
TOC elevation:

C1A 319.585 masl

C1B 319.53 masl

FLUSHMOUNT ROADBOX

GROUND 319.66 masl



SURFACE COMPLETION: CONCRETE

CAP TYPE: J-PLUG

STICKUP C1A: 7.5 cm (3.0") bgs

STICKUP C1B: 13 cm (5.1") bgs

TOP OF BENTONITE: 0.3 m (1 ft)

BOREHOLE DIAMETER: 18 cm (7")

WELL DIAMETER: 5 cm (2")

BENTONITE: COARSE CHIPS

SOLID PIPE: PVC SCH40

C1A STATIC WATER LEVEL: 4.337 m btoc (February 9, 2022)

TOP OF FILTER PACK: 4.42 m (14.5 ft)

TOP OF SCREEN: 4.6 m (15 ft)

C1B STATIC WATER LEVEL: 4.729 m btoc (February 9, 2022)

FILTER PACK: 10/20 FRAC SAND

BOTTOM OF SCREEN: 6.2 m (20 ft)

BOTTOM OF FILTER PACK: 6.2 m (20 ft)

TOP OF FILTER PACK: 9.95 m (32.7 ft)

TOP OF SCREEN: 10.4 m (34 ft)

WELL SCREEN, SCH40 PVC, 10-SLOT (0.010")

BOTTOM OF FILTER PACK: 12 m (39 ft)

BOTTOM OF SCREEN: 12 m (39 ft)

BOTTOM OF HOLE: 12 m (39 ft)

MONITORING WELL COMPLETION COMMENTS:

MONITORING WELL DEVELOPED: Yes

DATE OF DEVELOPMENT: February 8, 2022

VOLUME OF WATER REMOVED:

C1A 170 L

C1B 700L

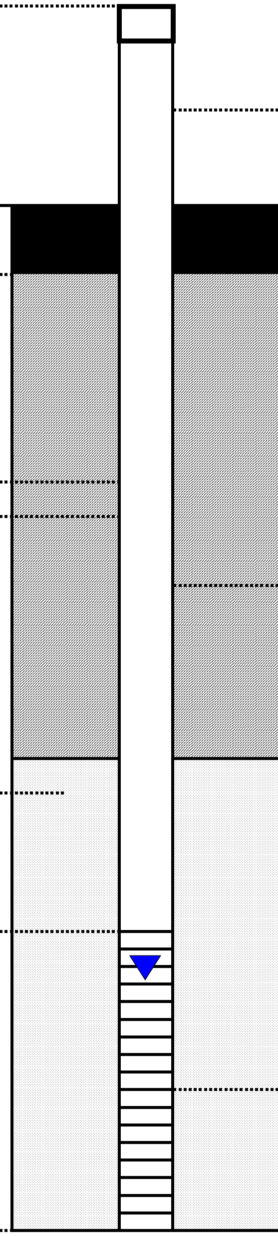
DEVELOPMENT NOTES:

WELL CONSTRUCTION LOG

BOREHOLE: C2

TOC elevation: 329.29 masl

CAP TYPE: J-PLUG



STICKUP: 68 cm (27")

GROUND 328.61 masl

SURFACE COMPLETION: CONCRETE

TOP OF BENTONITE: 0.76 m (2.5 ft)

BOREHOLE DIAMETER: 15 cm (6")

WELL DIAMETER: 5 cm (2")

SOLID PIPE: PVC SCH40

BENTONITE: COARSE CHIPS

TOP OF FILTER PACK: 10.2 m (33.5 ft)

FILTER PACK: 10/20 FRAC SAND

TOP OF SCREEN: 10.5 m (34.5 ft)

STATIC WATER LEVEL: 10.71 m btoc (February 8, 2022)

WELL SCREEN, SCH40 PVC, 10-SLOT (0.010")

BOTTOM OF SCREEN: 12.025 m (39.5 ft)

BOTTOM OF FILTER PACK: 12.025 m (39.5 ft) btoc

BOTTOM OF HOLE: 12.025 m (39.5 ft)

MONITORING WELL COMPLETION COMMENTS:

MONITORING WELL DEVELOPED: Yes

DATE OF DEVELOPMENT: February 8, 2022

VOLUME OF WATER REMOVED: 300 L

DEVELOPMENT NOTES: Surge block used

WELL CONSTRUCTION LOG

BOREHOLE: C4

TOC elevation: 365.57 masl

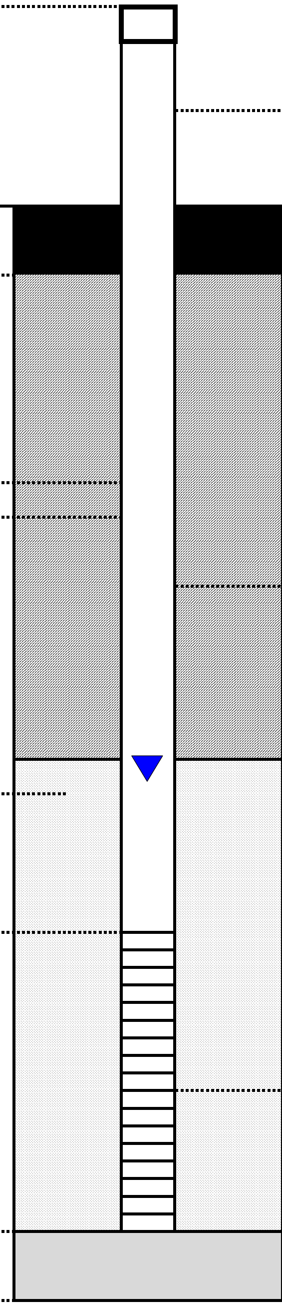
CAP TYPE: J-PLUG

STICKUP: 58 cm (23")

GROUND 364.99 masl

SURFACE COMPLETION: CONCRETE

TOP OF BENTONITE: 0.3 m (1 ft)



BOREHOLE DIAMETER: 15 cm (6")

WELL DIAMETER: 5 cm (2")

SOLID PIPE: PVC SCH40

BENTONITE: COARSE CHIPS

TOP OF FILTER PACK: 10 m (33 ft)

FILTER PACK: 10/20 FRAC SAND

STATIC WATER LEVEL: 10.57 m btoc (January 21, 2022)

TOP OF SCREEN: 10.63 m (34.9 ft)

WELL SCREEN, SCH40 PVC, 10-SLOT (0.010")

BOTTOM OF SCREEN: 12.15 m (39.9 ft)

BOTTOM OF FILTER PACK: 12.15 m (39.9 ft)

BOTTOM OF HOLE: 12.2 m (40 ft)

BACKFILL MATERIAL: SLOUGH

MONITORING WELL COMPLETION COMMENTS:

MONITORING WELL DEVELOPED: No

DATE OF DEVELOPMENT:

VOLUME OF WATER REMOVED:

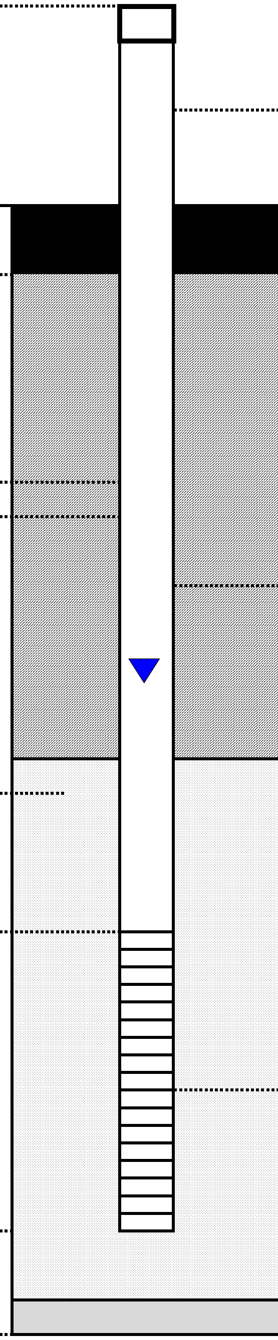
DEVELOPMENT NOTES: Well went dry shortly after install

WELL CONSTRUCTION LOG

BOREHOLE: C5

TOC elevation: 381.23 masl

CAP TYPE: J-PLUG



STICKUP: 67 cm (26")

GROUND 380.56 masl

SURFACE COMPLETION: CONCRETE

TOP OF BENTONITE: 0.46 m (1.5 ft)

BOREHOLE DIAMETER: 15 cm (6")

WELL DIAMETER: 5 cm (2")

SOLID PIPE: PVC SCH40

BENTONITE: COARSE CHIPS

STATIC WATER LEVEL: 6.930 m btoc (February 9, 2022)

TOP OF FILTER PACK: 7.3 m (23.9 ft)

FILTER PACK: 10/20 FRAC SAND

TOP OF SCREEN: 7.6 m (25 ft)

WELL SCREEN, SCH40 PVC, 10-SLOT (0.010")

BOTTOM OF SCREEN: 9.11 m (30 ft)

BOTTOM OF FILTER PACK: 10.1 m (33 ft)

BOTTOM OF HOLE: 10.7 m (35 ft)

BACKFILL MATERIAL: BENTONITE CHIPS

MONITORING WELL COMPLETION COMMENTS:

MONITORING WELL DEVELOPED: Yes

DATE OF DEVELOPMENT: February 9, 2022

VOLUME OF WATER REMOVED: 500 L

DEVELOPMENT NOTES: Surge block used

WELL CONSTRUCTION LOG

BOREHOLE: F2

TOC elevation: 353.07 masl

CAP TYPE: J-PLUG

STICKUP: 50 cm (20")

GROUND 352.57 masl

SURFACE COMPLETION: CONCRETE

TOP OF BENTONITE: 0.3 m (1 ft)

BOREHOLE DIAMETER: 15 cm (6")

WELL DIAMETER: 5 cm (2")

SOLID PIPE: PVC SCH40

STATIC WATER LEVEL: 30.61 m btoc (February 9, 2022)

BENTONITE: COARSE CHIPS

TOP OF FILTER PACK: 34.8 m (114.3 ft)

FILTER PACK: 10/20 FRAC SAND

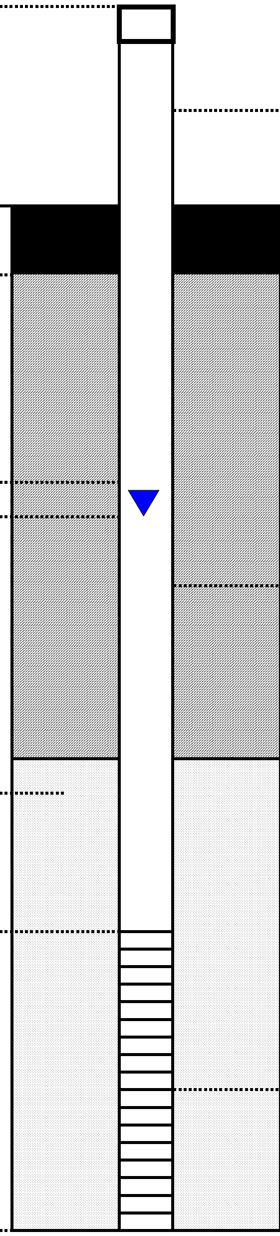
TOP OF SCREEN: 35.1 m (115.3 ft)

WELL SCREEN, SCH40 PVC, 10-SLOT (0.010")

BOTTOM OF SCREEN: 36.67 m (120.3 ft)

BOTTOM OF FILTER PACK: 36.67 m (120.3 ft)

BOTTOM OF HOLE: 36.67 m (120.3 ft)



MONITORING WELL COMPLETION COMMENTS:

MONITORING WELL DEVELOPED:

DATE OF DEVELOPMENT: , 2022

VOLUME OF WATER REMOVED: L

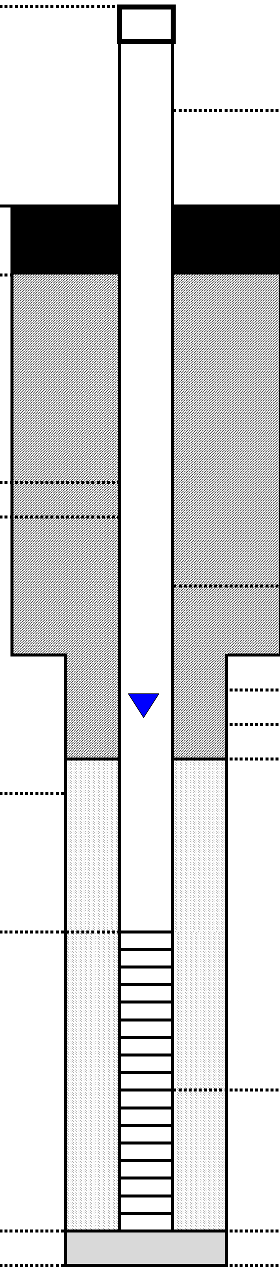
DEVELOPMENT NOTES:

WELL CONSTRUCTION LOG

BOREHOLE: F3

TOC elevation: 360.49 masl

CAP TYPE: J-PLUG



STICKUP: 37 cm (14.6")

GROUND 360.12 masl

SURFACE COMPLETION: CONCRETE

TOP OF BENTONITE: 0.3 m (1 ft)

BOREHOLE DIAMETER: 18 cm (7") (from 0 to 60 ft bgl)

WELL DIAMETER: 5 cm (2")

SOLID PIPE: PVC SCH40

BENTONITE: COARSE CHIPS

BOREHOLE DIAMETER: 15 cm (6") (to EOH)

STATIC WATER LEVEL: 37.631 m btoc (February 9, 2022)

TOP OF FILTER PACK: 37.98 m (124.59 ft)

FILTER PACK: 10/20 FRAC SAND

TOP OF SCREEN: 38.28 m (125.59 ft)

WELL SCREEN, SCH40 PVC, 10-SLOT (0.010")

BOTTOM OF SCREEN: 39.805 m (130.59 ft)

BOTTOM OF FILTER PACK: 39.805 m (130.59 ft)

BOTTOM OF HOLE: 40 m (131 ft)

BACKFILL MATERIAL: BENTONITE CHIPS

MONITORING WELL COMPLETION COMMENTS:

MONITORING WELL DEVELOPED: Yes

DATE OF DEVELOPMENT: , 2022

VOLUME OF WATER REMOVED: L

DEVELOPMENT NOTES: Surge block used

APPENDIX C. WELL LITHOLOGY

Vaseux GW-SW Interactions Study

Well: C1

Depth/Interval (below ground surface): feet 0, 4, 8, 12, 16, 20, 24; metres 0, 1, 2, 3, 4, 5, 6, 7

Lithology	Description
COBBLES	COBBLES - moist, brown, little fine Sand and little fine Gravel
SAND	SAND - dry, brown, little fine to coarse Gravel and little Cobbles
GRAVEL	GRAVEL - dry, brown, fine to coarse Gravel with some fine to medium Sand and little Cobbles
BOULDER	BOULDER - dry, grey Boulder
NO RETURNS	NO RETURNS
BOULDER	BOULDER - dry, grey Boulder
GRAVEL	GRAVEL - dry, brown, fine to coarse Gravel with little fine to coarse Sand and little Cobbles
BOULDER	BOULDER - dry, grey Boulder
COBBLES	COBBLES - moist to wet, grey Cobbles with little brown medium to coarse Sand and little fine to coarse Gravel
SAND	SAND - wet, brown, medium to coarse Sand with little fine to coarse Gravel and some Cobbles
COBBLES	COBBLES - wet, brown, few coarse Sand, some fine to coarse Gravel
NO RETURNS	NO RETURNS

WELL CONSTRUCTION DETAILS

Drilling company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 19, 2022
Screened interval: C1A (Shallow) 4.6 – 6.2 m, C1B (Deep) 10.4 – 12 m
Static water level: C1A (Shallow) 4.337 mbgs, C1B (Deep) 4.729 mbgs (February 9, 2022)
Ground surface elevation: 319.7 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: C1

Depth/Interval (below ground surface)

feet: 28, 32, 36, 40, 44

metres: 8, 9, 10, 11, 12, 13

Log	Description
NO RETURNS	NO RETURNS
GRAVEL	GRAVEL - wet, brown, fine Gravel with some medium Sand and little Cobbles
SAND	SAND - wet, brown with red staining, fine Sand
CLAY	CLAY - wet, grey Clay with fine Silt. Wood sample collected for dating.
SAND	SAND - wet, grey, medium Sand with fine Silt lenses.
SILT	SILT - wet, grey Silt
SAND	SAND - wet, grey with orange staining, fine Sand

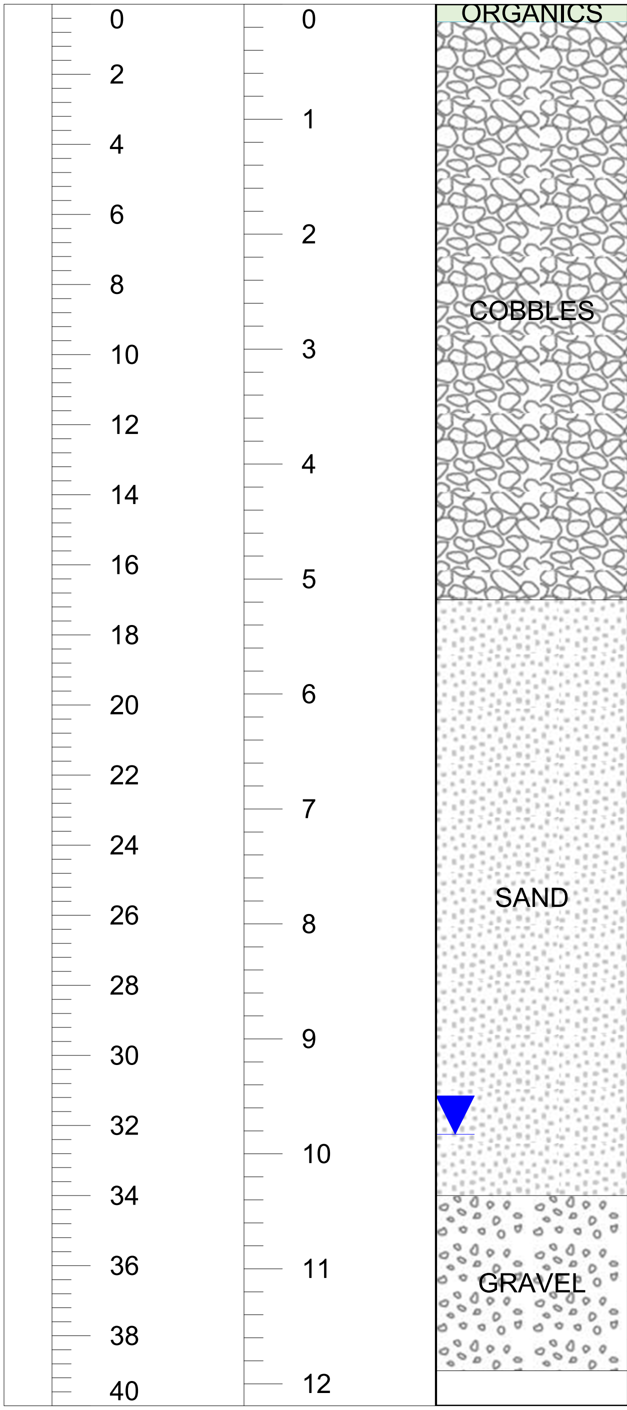
WELL CONSTRUCTION DETAILS

Drilling company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 19, 2022
Screened interval: C1A (Shallow) 4.6 – 6.2 m, C1B (Deep) 10.4 – 12 m
Static water level: C1A (Shallow) 4.337 mbgs, C1B (Deep) 4.729 mbgs (February 9, 2022)
Ground surface elevation: 319.7 masl

Vaseux GW-SW Interactions Study

Well: C2

Depth/Interval (below ground surface) feet / metres	Description



ORGANICS - moist, brown Organics with little Gravel

COBBLES - dry, grey and brown Cobbles with little fine to coarse Sand and few fine to coarse Gravel

SAND - moist to wet, brown, fine to coarse Sand with little fine Gravel and little Cobbles

GRAVEL - wet, brown, fine to coarse Gravel with little some to coarse Sand and few Cobbles

WELL CONSTRUCTION DETAILS

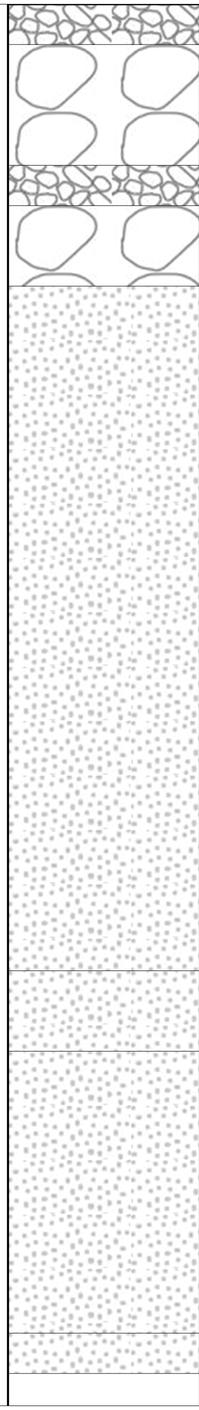
Drilling company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 17, 2022
Screened interval: 10.5 – 12.0 m
Static water level: 10.03 mbgs (February 8, 2022)
Ground surface elevation: 328.6 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: C3

Depth/Interval (below ground surface) feet / metres	Description



COBBLES - moist, brown cobbles with some fine Sand

BOULDER - dry, grey Boulder

COBBLES - dry, grey Cobbles with some fine to medium Sand

BOULDER - dry, grey Boulder with little fine Sand

SAND - moist, brown fine Sand with few fine Gravel

SAND - moist, brown fine Sand with clumps of coarse Sand and Silt

SAND - moist, brown fine Sand with trace fine Gravel

SAND - moist, brown, fine to coarse Sand with trace Silt and trace fine Gravel

Feet scale: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85

Metres scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26

WELL CONSTRUCTION DETAILS

Drilling company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: March 7, 2022*
Ground surface elevation: 347.8 masl

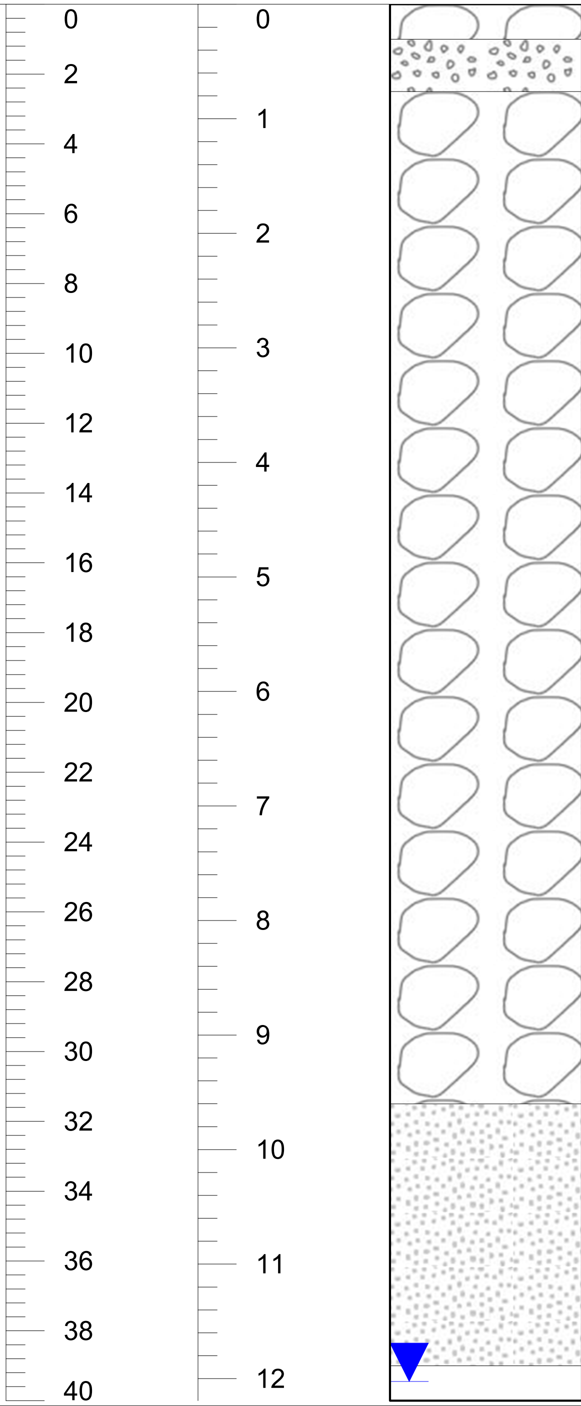
*Note: Well not completed due to hole collapse. Did not reach the water table.

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: C4

Depth/Interval (below ground surface) feet / metres	Description
	BOULDER - dry, brown Boulder with some fine Sand
	GRAVEL - dry, brown fine to coarse Gravel with some fine to medium Sand, little Cobbles and trace Organics
	BOULDER - wet*, grey Boulder with some brown, fine to medium Sand
	SAND - wet*, fine to coarse, brown, some fine to coarse Gravel



WELL CONSTRUCTION DETAILS

Drilling company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 21, 2022
Screened interval: 10.6 – 12.2 m
Static water level:12.025 mbgs (February 9, 2022)
Ground surface elevation: 365.0 masl

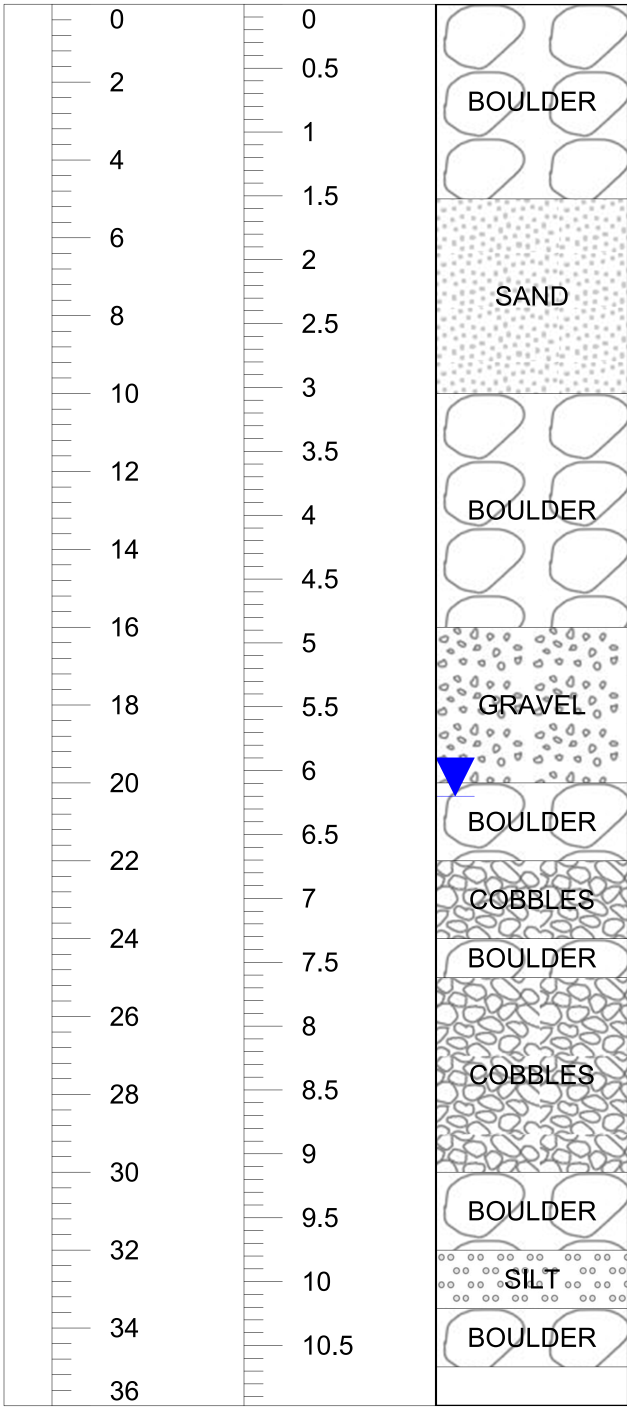
*Note: substantial drilling water added from 4.3 m to bottom of hole.

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: C5

Depth/Interval (below ground surface) feet / metres	Description



BOULDER - dry, grey Boulder with little fine to coarse Gravel and little Cobbles

SAND - dry, grey, fine to coarse Sand with little fine to coarse Gravel, little Cobbles

BOULDER - dry, grey Boulder

GRAVEL - dry, brown, fine to coarse Gravel with some fine Sand

BOULDER - dry, grey Boulder

COBBLES - wet, grey Cobbles with little fine Gravel and few fine to coarse Sand

BOULDER - wet, grey Boulder with little fine Gravel and few fine to coarse Sand

COBBLES - wet, grey Cobbles with some fine Gravel and few coarse Sand

BOULDER - wet, grey Boulder

SILT - wet, grey silt with some fine to coarse Sand

BOULDER - wet, grey Boulder

<u>WELL CONSTRUCTION DETAILS</u>

Drilling company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 18, 2022
Screened interval: 7.6 – 9.1 m
Static water level: 6.260 mbgs (February 9, 2022)
Ground surface elevation: 380.6 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: F2

Depth/Interval (below ground surface) feet	metres		Description
0	0	COBBLES	COBBLES - dry, brown Cobbles with Organics and some fine Sand
		BOULDER	BOULDER - dry, light brown Boulder with some fine Sand
	2	COBBLES	COBBLES - wet*, grey and brown Cobbles with some fine Gravel and little medium to coarse Sand
10		BOULDER	BOULDER - wet*, grey and brown Boulder with little medium to coarse Sand and little fine to coarse Gravel
		COBBLES	COBBLES - wet*, brown Cobbles
	4	BOULDER	BOULDER - dry, grey Boulder
		COBBLES	COBBLES - wet*, grey Cobbles with some medium Sand
		BOULDER	BOULDER - wet*, grey Boulder
		GRAVEL	GRAVEL - wet*, grey and brown, fine to coarse Gravel with some fine to coarse Sand
20	6	BOULDER	BOULDER - dry, grey Boulder with some fine to medium Sand and little fine Gravel
		GRAVEL	GRAVEL - moist*, brown, fine to coarse Gravel with little fine to medium Sand
	8	BOULDER	BOULDER - dry, grey Boulder
		GRAVEL	GRAVEL - dry, grey, fine and coarse Gravel with little fine to medium Sand
30		BOULDER	BOULDER - dry, grey Boulder

WELL CONSTRUCTION DETAILS

Drilling company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 20, 2022
Screened interval: 35.1 – 36.7 m
Static water level: 30.110 mbgs (February 9, 2022)
Ground surface elevation: 352.6 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: F2

Depth/Interval (below ground surface) feet	metres	Description	
	10	BOULDER	BOULDER - dry, grey Boulder
		COBBLES	COBBLES - wet*, brown Cobbles with some fine Sand and few fine Gravel
		COBBLES	COBBLES - dry, brown Cobbles with little fine Sand
		BOULDER	BOULDER - wet*, grey Boulder with some fine Sand
		GRAVEL	GRAVEL - moist*, grey and brown, fine Gravel with some fine Sand and few coarse Gravel
		BOULDER	BOULDER - dry, grey Boulder with some fine Sand
		GRAVEL	GRAVEL - wet*, grey and brown, fine to coarse Gravel with little fine to coarse Sand
		SAND	SAND - wet*, brown, fine to medium Sand with few Silt and few fine Gravel
40	12	GRAVEL	GRAVEL - wet*, brown, fine to coarse Gravel with some coarse Sand
		BOULDER	BOULDER - dry, brown Boulder with little fine Sand and trace fine Gravel
		COBBLES	COBBLES - dry, brown Cobbles with little fine Sand and trace fine Gravel
50	14, 16, 18	SAND	SAND - moist to wet*, brown, fine to medium Sand with little Silt, few fine Gravel and few Boulders
60			

WELL CONSTRUCTION DETAILS

Drilling company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 20, 2022
Screened interval: 35.1 – 36.7 m
Static water level: 30.110 mbgs (February 9, 2022)
Ground surface elevation: 352.6 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: F2

Depth/Interval (below ground surface)		Description
feet	metres	

Depth scale — feet: 70, 80, 90; metres: 20, 22, 24, 26

Lithology	Description
SAND	SAND - moist to wet*, brown, fine to medium Sand with little Silt, few fine Gravel and few Boulders
SAND	SAND - moist*, brown, fine Sand with some Silt**
SILT	SILT - dry, grey, lightly cemented Silt with little fine Sand
SAND	SAND - dry, brown, fine to medium, cemented Sand with little Silt
SILT	SILT - dry, grey Silt
SAND	SAND - dry, brown, lightly cemented Sand
SAND	SAND - wet*, brown, fine to medium Sand with trace fine Gravel

<u>WELL CONSTRUCTION DETAILS</u>

- Drilling company: Mud Bay Drilling
- Drilling method: Sonic
- Date of completion: January 20, 2022
- Screened interval: 35.1 – 36.7 m
- Static water level: 30.110 mbgs (February 9, 2022)
- Ground surface elevation: 352.6 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: F2

Depth/Interval (below ground surface) feet / metres		Description
	SAND	SAND - wet*, brown, fine to medium Sand with trace fine Gravel
	SAND	SAND - dry, brown, fine to medium Sand with little Silt and lightly cemented layers
	SAND	SAND - wet, brown, fine to medium Sand with few Silt and trace fine Gravel

WELL CONSTRUCTION DETAILS

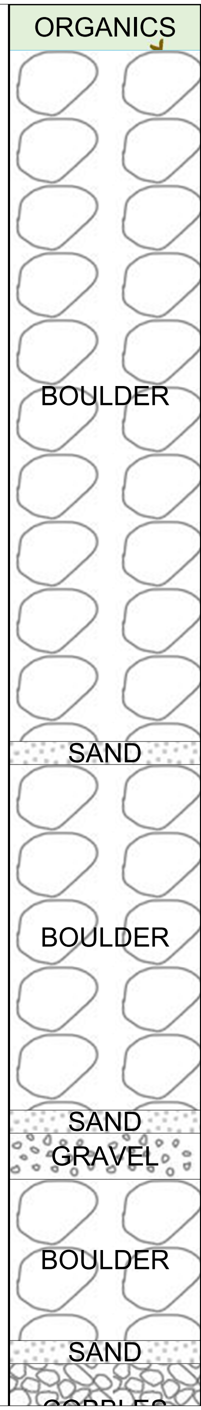
Drilling company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 20, 2022
Screened interval: 35.1 – 36.7 m
Static water level: 30.110 mbgs (February 9, 2022)
Ground surface elevation: 352.6 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: F3

Depth/Interval (below ground surface) feet	metres	Description
0	0	ORGANICS - dry, brown Organics
	2	BOULDER - dry, brown Boulder with some fine Sand and trace fine to coarse Gravel
10	4	
		SAND - dry, brown, find Sand with little Silt and few fine Gravel
20	6	BOULDER - dry, brownish grey Boulder with little Silt, little fine Sand and trace fine Gravel
		SAND - wet*, brown, medium Sand with little fine Gravel
		GRAVEL - wet*, brown, fine to coarse Gravel with some Cobbles and little coarse Sand
	8	BOULDER - dry, grey Boulder
		SAND - dry, brown, fine Sand with trace Silt
30		



WELL CONSTRUCTION DETAILS

Drilling Company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 22, 2022
Screened interval: 38.3 – 39.8 m
Static water level: 37.261 mbgs (February 9, 2022)
Ground surface elevation: 360.1 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: F3

Depth/Interval (below ground surface) feet	metres		Description
		COBBLES	COBBLES - dry, brown Cobbles with little fine Sand and few fine Gravel
	10	BOULDER	BOULDER - dry, grey Boulder
		GRAVEL	GRAVEL - dry, light brown, fine Gravel with little Boulder and little fine to coarse Sand
40	12	SAND	SAND - wet*, brown, fine Sand with trace Silt
	14	SILT	SILT - dry, grey Silt with some interbedded orangish brown, fine Sand, cemented
		NO RETURNS	NO RETURNS
50	16	SAND	SAND - dry, brown, fine to medium Sand with few Silt and trace fine Gravel, lightly cemented
		SILT	SILT - dry, grey Silt with some interbedded brown, fine Sand, lightly cemented
60	18	SAND	SAND - moist*, brown, fine to medium Sand with trace Silt

WELL CONSTRUCTION DETAILS

Drilling Company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 22, 2022
Screened interval: 38.3 – 39.8 m
Static water level: 37.261 mbgs (February 9, 2022)
Ground surface elevation: 360.1 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: F3

Depth/Interval (below ground surface) feet	metres		Description
	20	SAND	SAND - moist*, brown, fine to medium Sand with trace Silt
70	22		
		SAND	SAND - moist*, grey, fine Sand, with few Silt, cemented
		SILT	SILT - dry, brown Silt with little fine Sand, cemented
		SAND	SAND - dry, brown, fine Sand with little interbedded grey Silt, lightly cemented
80	24	SAND	SAND - moist*, brown, fine to coarse Sand with few Silt
	26	SAND	SAND - moist*, blackish brown, fine Sand with little Silt, cemented
90		SAND	SAND - moist*, brown, fine Sand with little Silt

WELL CONSTRUCTION DETAILS

Drilling Company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 22, 2022
Screened interval: 38.3 – 39.8 m
Static water level: 37.261 mbgs (February 9, 2022)
Ground surface elevation: 360.1 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: F3

Depth/Interval (below ground surface) feet	metres		Description
	28	SAND	SAND - moist*, brown, fine Sand with little Silt
	30	SILT	SILT - dry, grey Silt with some interbedded brown, fine Sand, cemented
100		SAND	SAND - moist*, brown, fine Sand with little Silt
		SAND	SAND - moist*, brown, fine Sand with some Silt, cemented
		SILT	SILT - dry, light brown Silt with some fine Sand, cemented
	32	SAND	SAND - dry, brown, fine Sand, clumping
		SAND	SAND - dry, light brown, fine Sand with some Silt, cemented
		SILT	SILT - dry, grey Silt with some fine Sand
		SAND	SAND - dry, brown, fine Sand with little Silt, clumping
		SAND	SAND - dry, light brown, fine Sand with some Silt, cemented
		SAND	SAND - dry, brown, fine Sand with few Silt, cemented
		SAND	SAND - wet*, brown, fine Sand
110	34	SAND	SAND - dry, brown, fine to coarse Sand with little fine Gravel and few Silt
	36	SAND	SAND - dry, brown, fine to medium Sand with little Silt and few Gravel
120		SAND	SAND - wet, brown, fine to coarse Sand with some Gravel and few Silt

WELL CONSTRUCTION DETAILS

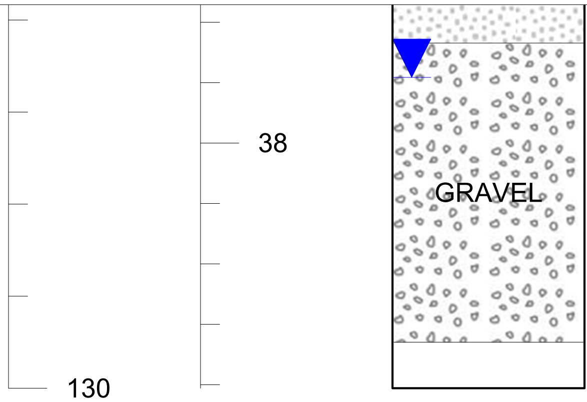
Drilling Company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 22, 2022
Screened interval: 38.3 – 39.8 m
Static water level: 37.261 mbgs (February 9, 2022)
Ground surface elevation: 360.1 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: F3

Depth/Interval (below ground surface) feet / metres	Description
	GRAVEL - wet, brown, fine to coarse Gravel with some fine to coarse Sand with trace Silt



WELL CONSTRUCTION DETAILS

Drilling Company: Mud Bay Drilling
Drilling method: Sonic
Date of completion: January 22, 2022
Screened interval: 38.3 – 39.8 m
Static water level: 37.261 mbgs (February 9, 2022)
Ground surface elevation: 360.1 masl

BRITISH COLUMBIA

Vaseux GW-SW Interactions Study

Well: OW506

Depth/Interval (below ground surface): feet 0–100; metres 0–30

Lithology	Description
SAND	SAND - moist, brown, fine with trace Silt and Organics
COBBLES	COBBLES - dry, grey, some fine to coarse Sand and Gravel
SAND	SAND - dry, brown, medium Sand with little fine Gravel
SAND	SAND - dry, grey, fine Sand with some fine to coarse Gravel
GRAVEL	GRAVEL- dry, grey, fine to coarse Gravel with some fine Sand and trace coarse Sand
SAND	SAND - moist to wet, brown, fine to medium Sand with few Silt and trace fine Gravel
GRAVEL	GRAVEL - wet, brown, fine Gravel with little medium Sand and trace Silt
SAND	SAND - wet, brown, fine Sand with little Silt and trace fine Gravel
GRAVEL	GRAVEL - wet, brown, fine and coarse Gravel with little Silt
SILT	SILT - wet, brown Silt with little to trace fine Sand and trace fine Gravel
SAND	SAND - wet, brown, fine Sand with trace Silt
SILT	SILT - wet, brown Silt with little fine Sand and trace coarse Gravel
SAND	SAND - wet, brown, medium to coarse Sand with trace Gravel
SAND	SAND - wet, grey, medium Sand. Coarsening with depth.

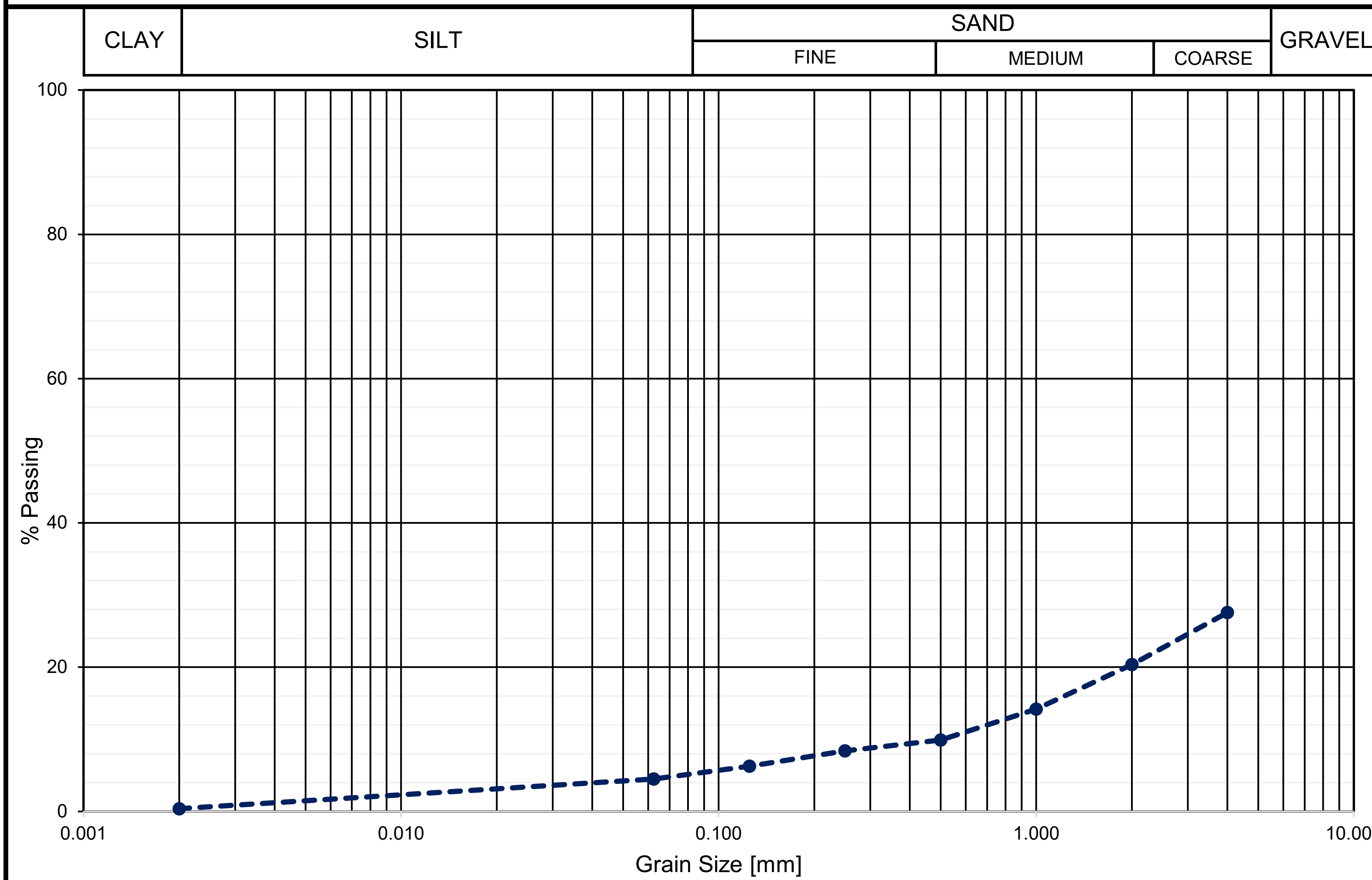
WELL CONSTRUCTION DETAILS

Drilling company: Robbins Drilling and Pump Ltd.
Drilling method: Air rotary
Date of completion: November 18, 2021
Screened interval: 28.4 – 29.6 m
Static water level: 9.702 mbgs (November 18, 2021)
Ground surface elevation: 326.2 masl

BRITISH COLUMBIA

APPENDIX D. GRAIN SIZE ANALYSIS

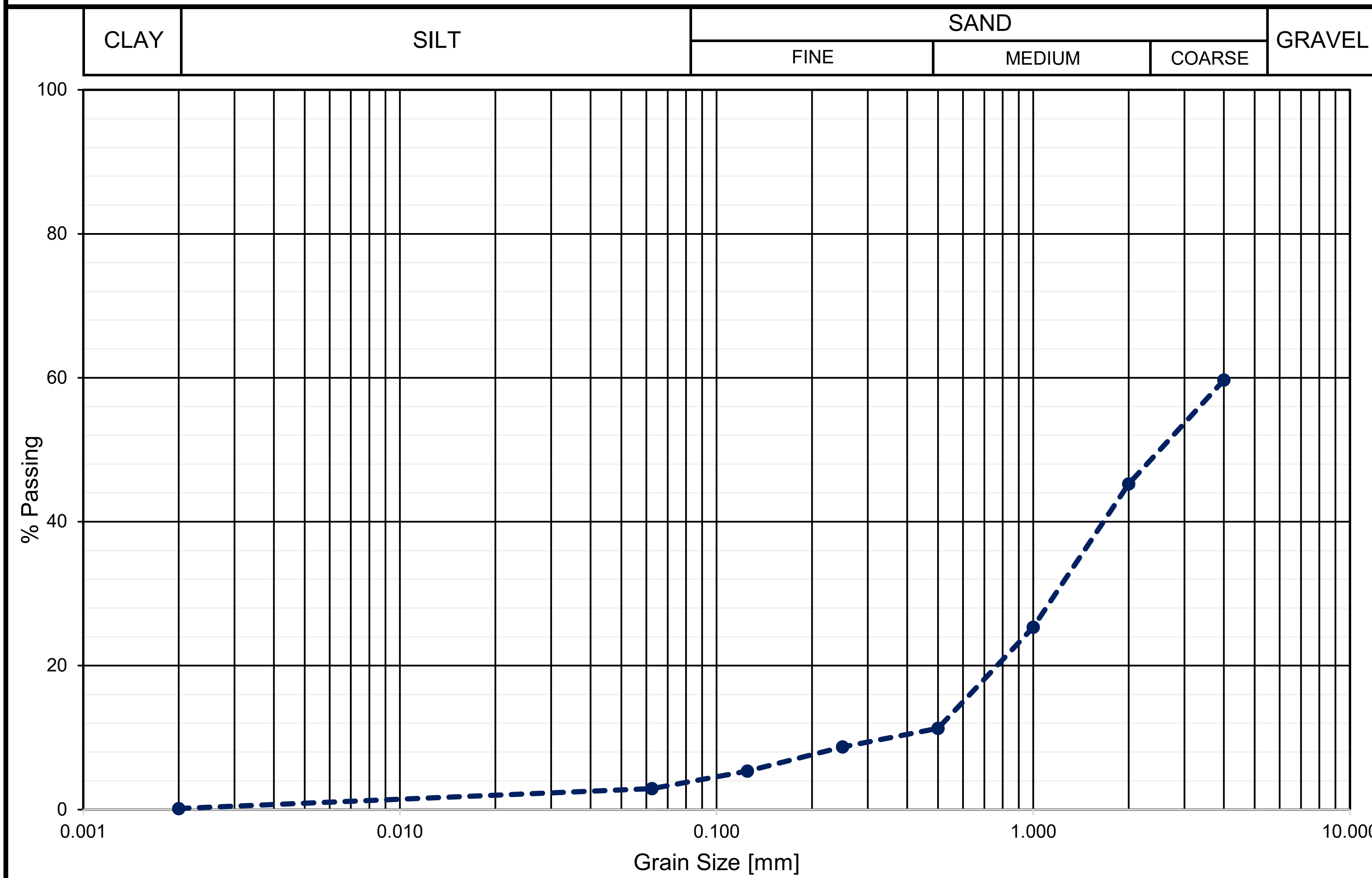
Borehole No.	**C1**	**Sample ID**	**C1 10-13**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	3.51	Sample Elevation [masl]	316.15
Drill Date:	January 19, 2022	Depth [ft]	11.5		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	C1	Sample ID	C1 22-23	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	6.86	Sample Elevation [masl]	312.80
Drill Date:	January 19, 2022	Depth [ft]	22.50		

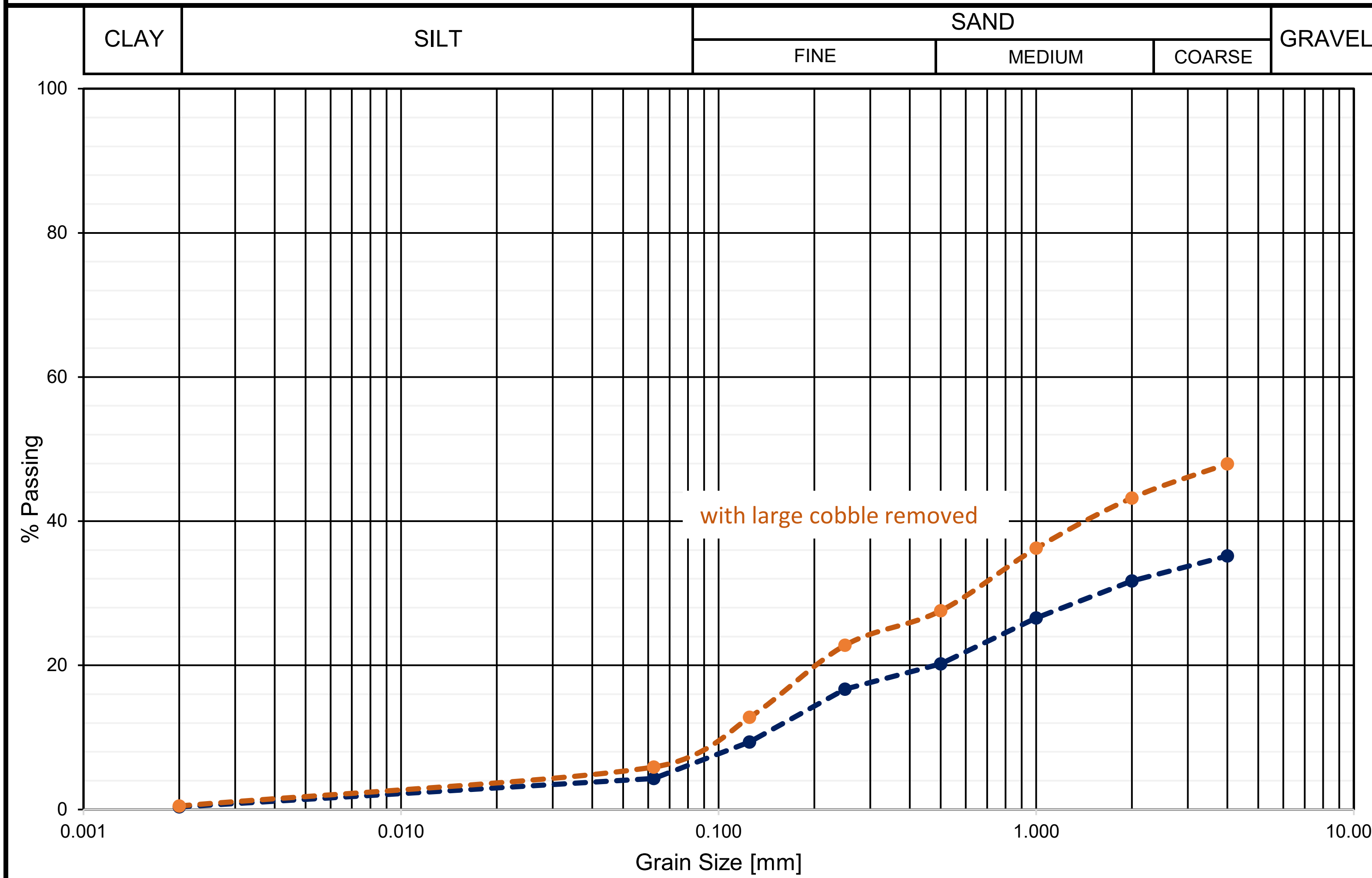


Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. C1	Sample ID C1 38	GRAIN SIZE ANALYSIS

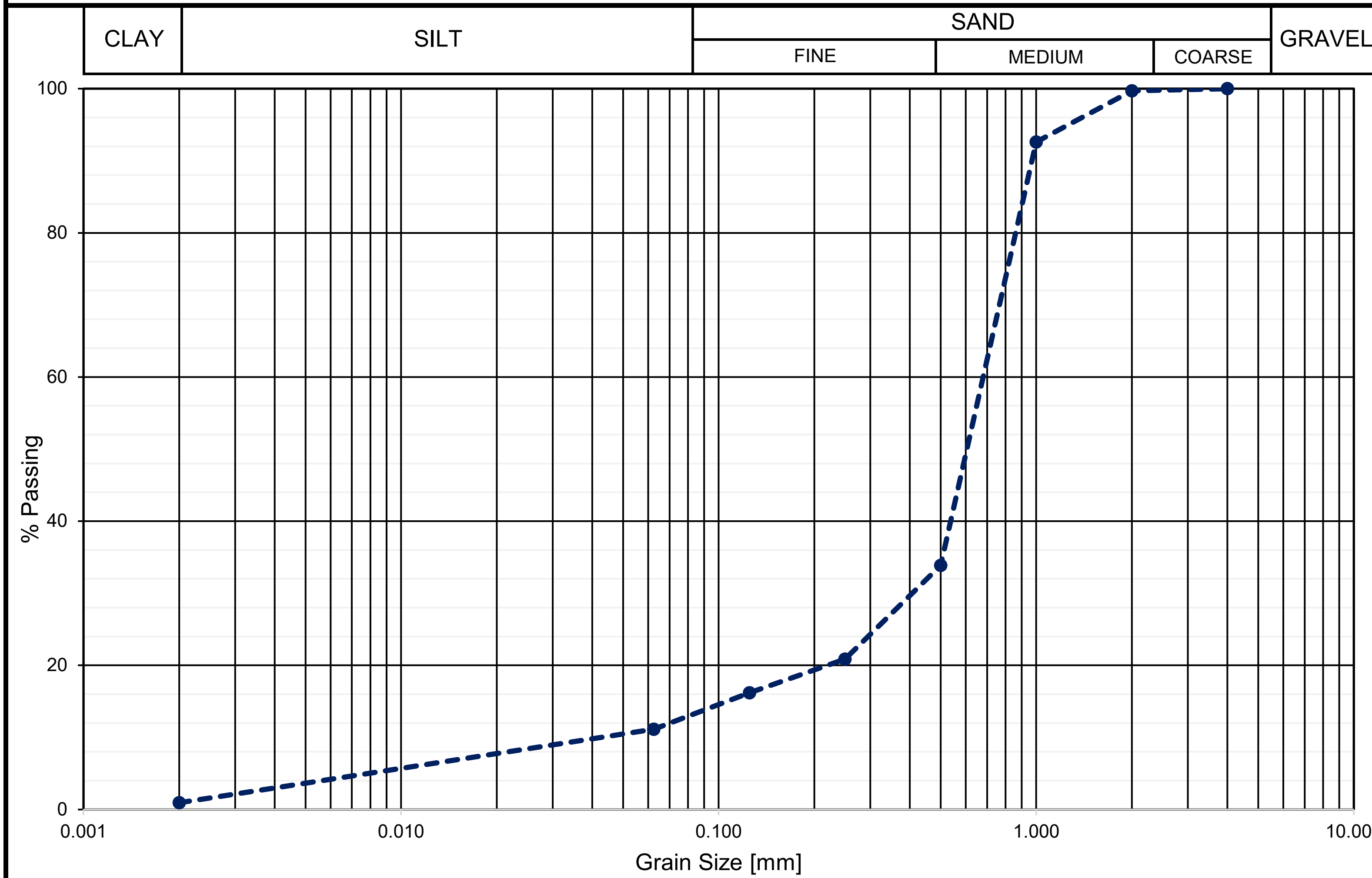
Project:	Vaseux GW-SW Interaction Study	Depth [m]	11.58	Sample Elevation [masl]	308.08
Drill Date:	January 19, 2022	Depth [ft]	38.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

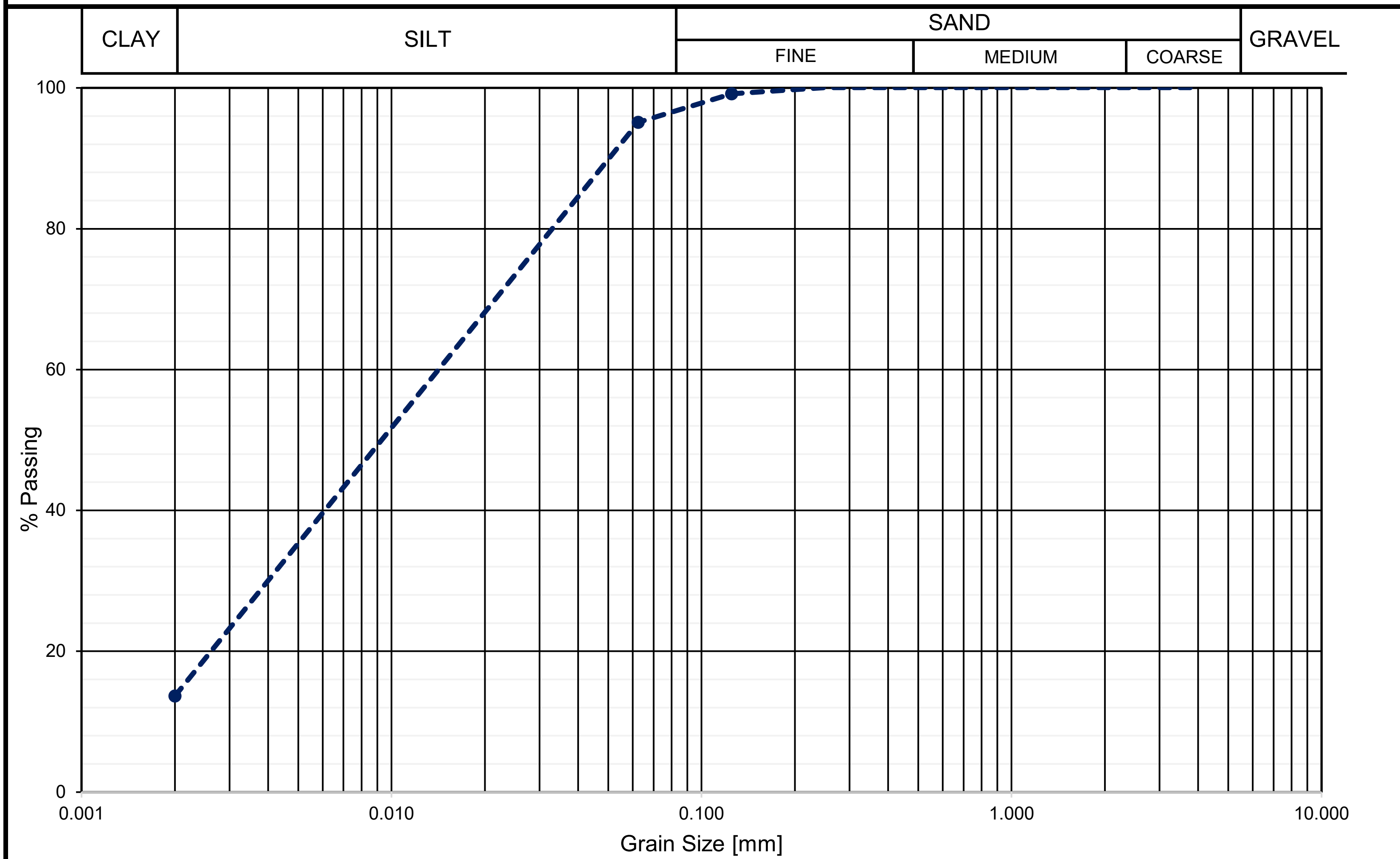
Borehole No.	C1	Sample ID	C1 41.5	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	12.65	Sample Elevation [masl]	307.01
Drill Date:	January 19, 2022	Depth [ft]	41.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	**C1**	**Sample ID**	**C1 42.5**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	12.95	Sample Elevation [masl]	306.71
Drill Date:	January 19, 2022	Depth [ft]	42.50		

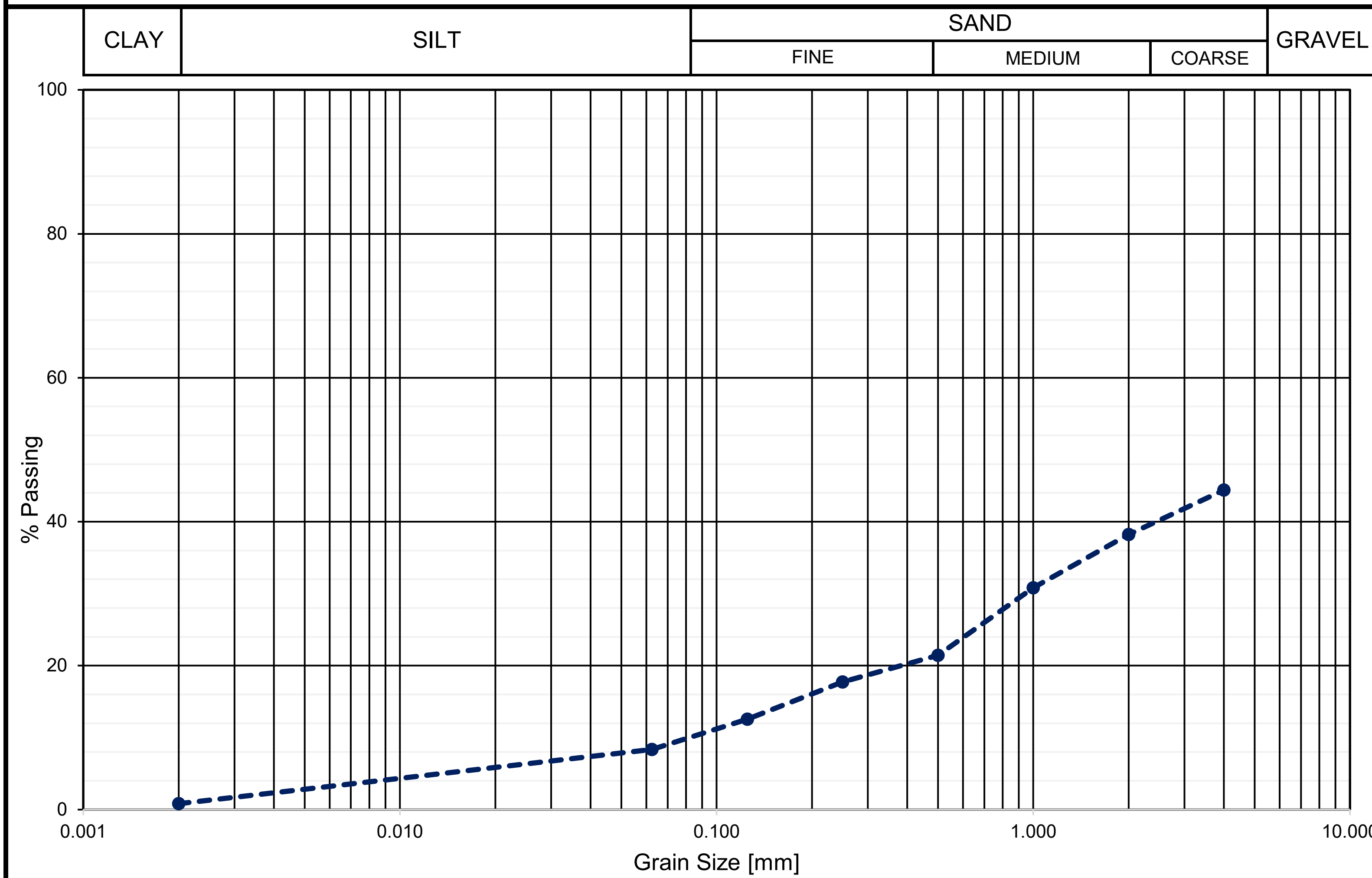


Note: Unified Soil Classification System (USCS) used for soil divisions

Not sieved

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

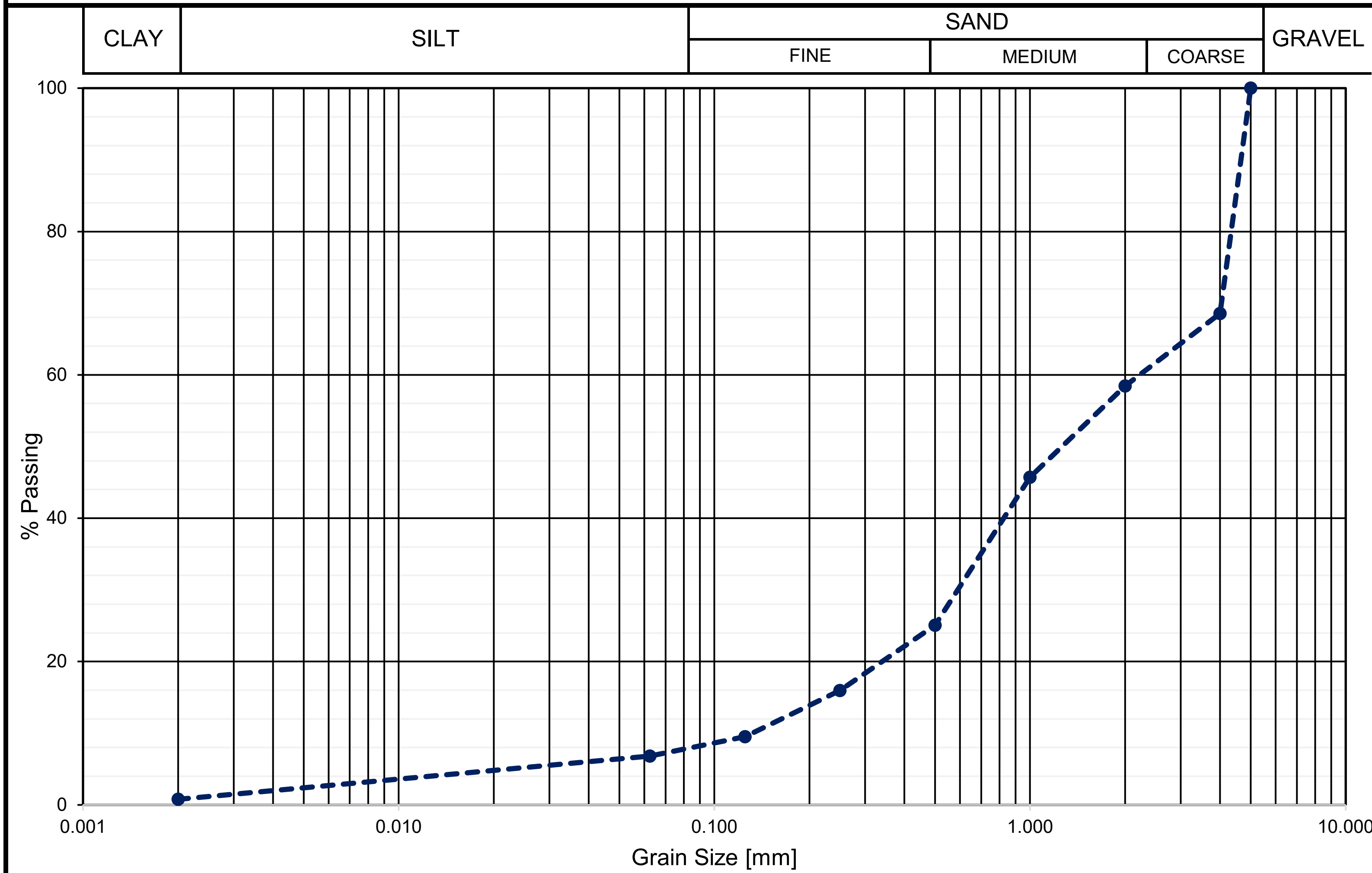
Borehole No.	**C2**	**Sample ID**	**C2 18**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	5.49	Sample Elevation [masl]	323.12
Drill Date:	January 17, 2022	Depth [ft]	18.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	**C2**	**Sample ID**	**C2 25**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	7.62	Sample Elevation [masl]	320.99
Drill Date:	January 17, 2022	Depth [ft]	25.00		

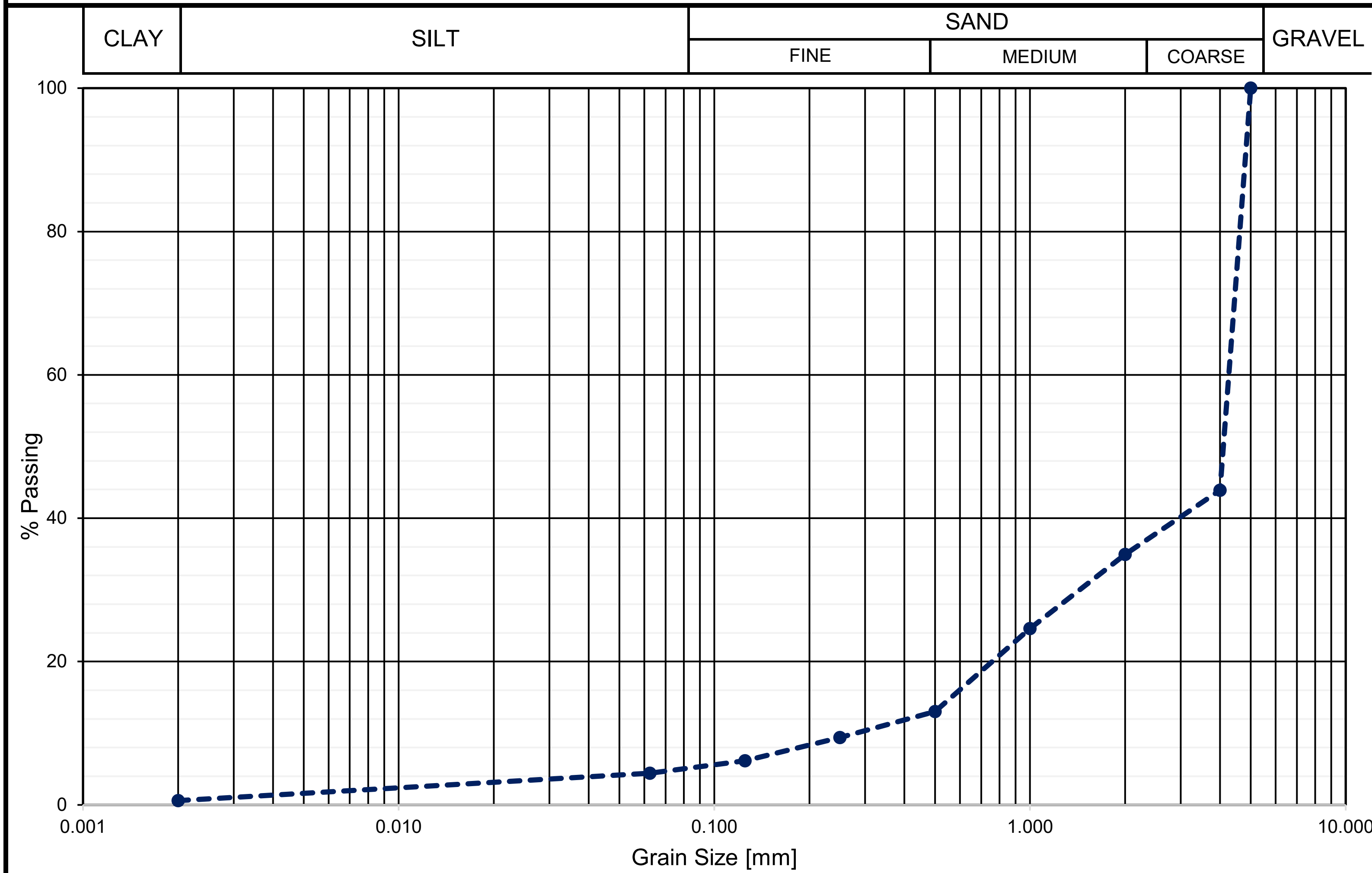


Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. C2	Sample ID C2 27-29	GRAIN SIZE ANALYSIS

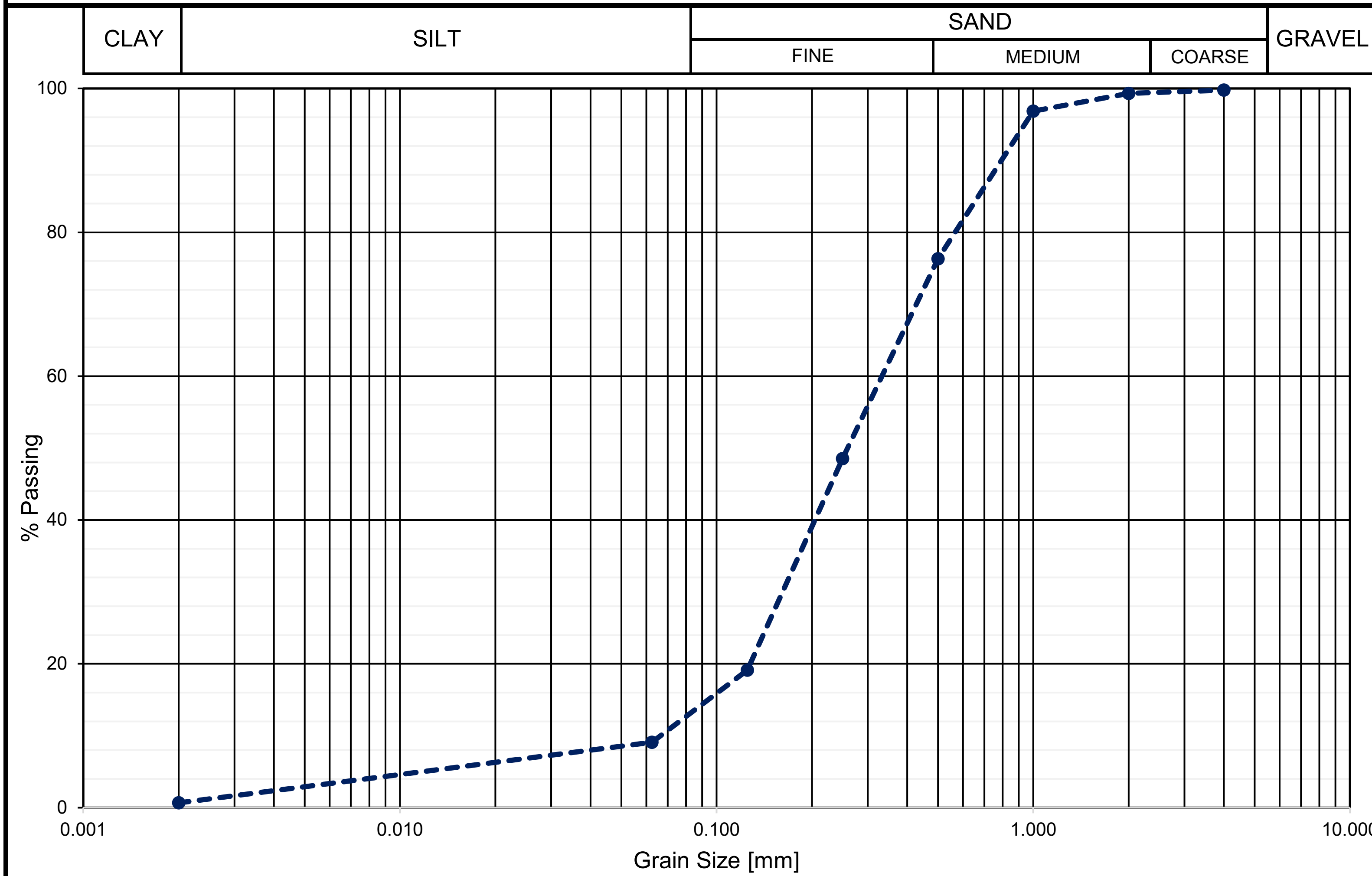
Project:	Vaseux GW-SW Interaction Study	Depth [m]	8.53	Sample Elevation [masl]	320.08
Drill Date:	January 17, 2022	Depth [ft]	28.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	**C2**	**Sample ID**	**C2 32**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	9.75	Sample Elevation [masl]	318.86
Drill Date:	January 17, 2022	Depth [ft]	32.00		

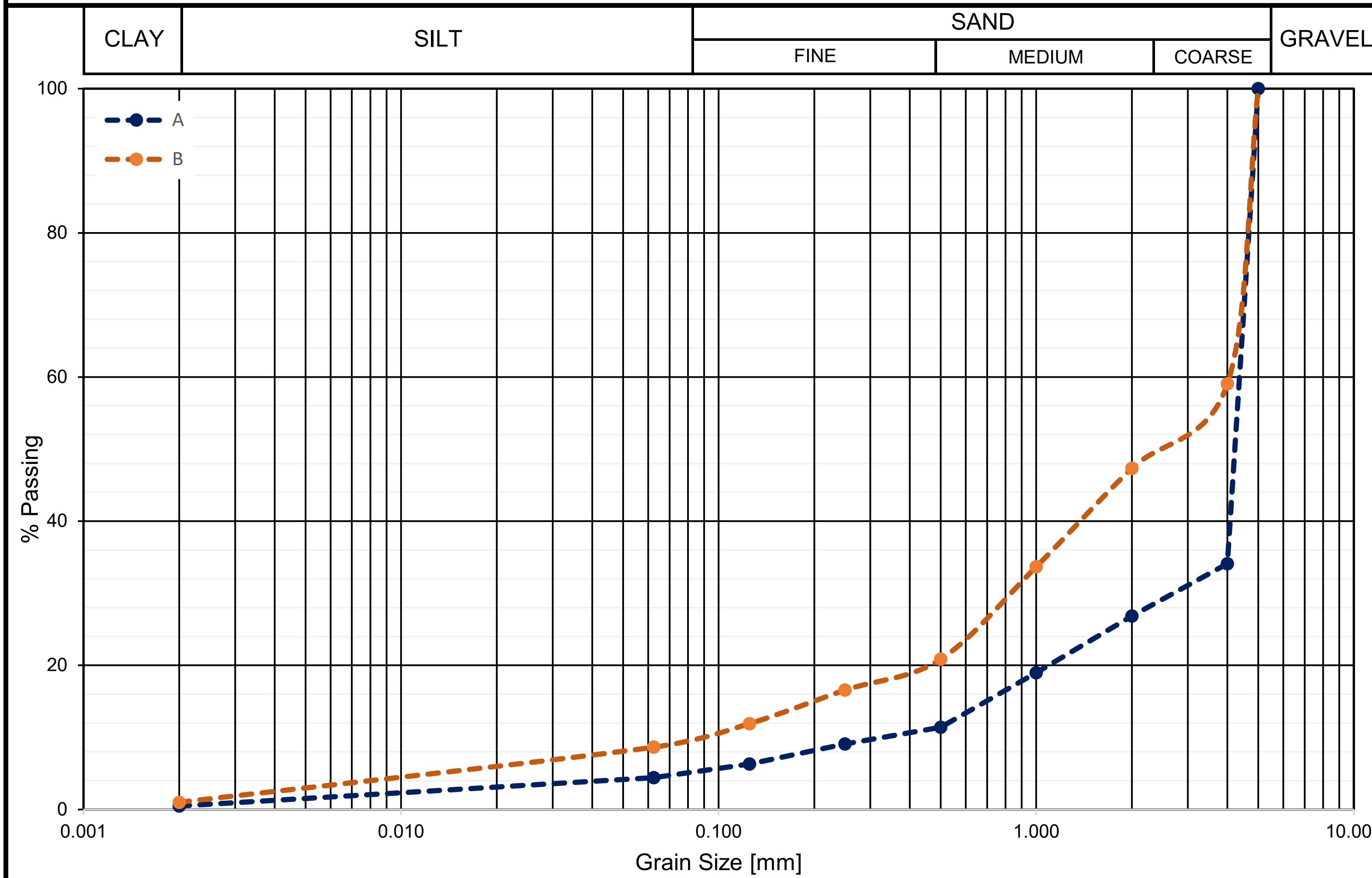


Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. **C2**	**Sample ID** **C2 35-39**	**GRAIN SIZE ANALYSIS**

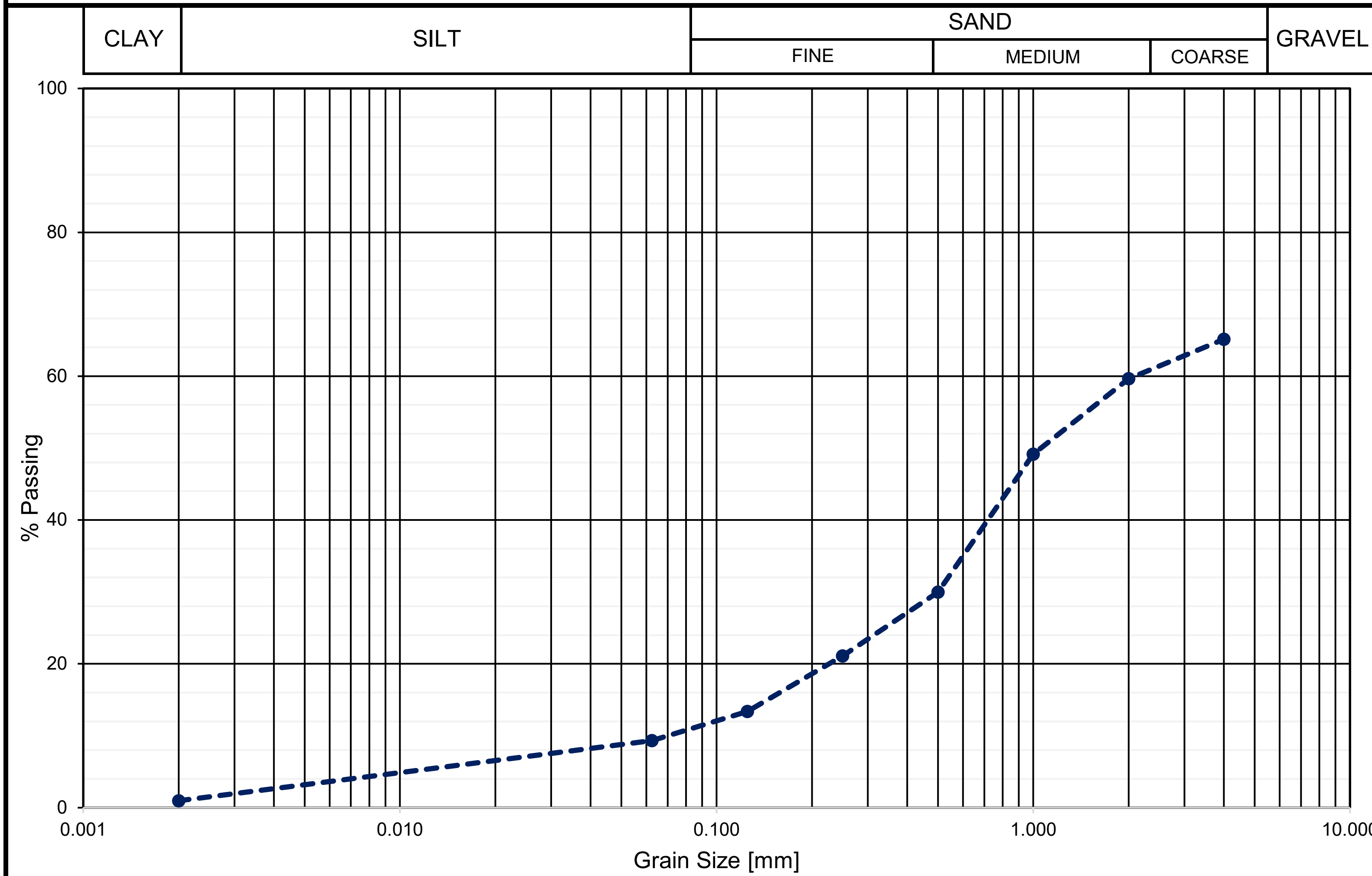
Project:	Vaseux GW-SW Interaction Study	Depth [m]	11.28	Sample Elevation [masl]	317.33
Drill Date:	January 17, 2022	Depth [ft]	37.00		



Note: Unified Soil Classification System (USCS) used for soil divisions
*C2 35-39 A and B had uneven split of >4mm material; 35-39A and B matrix results are consistent

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	C5	Sample ID	C5 9	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	2.74	Sample Elevation [masl]	377.82
Drill Date:	January 18, 2022	Depth [ft]	9.00		

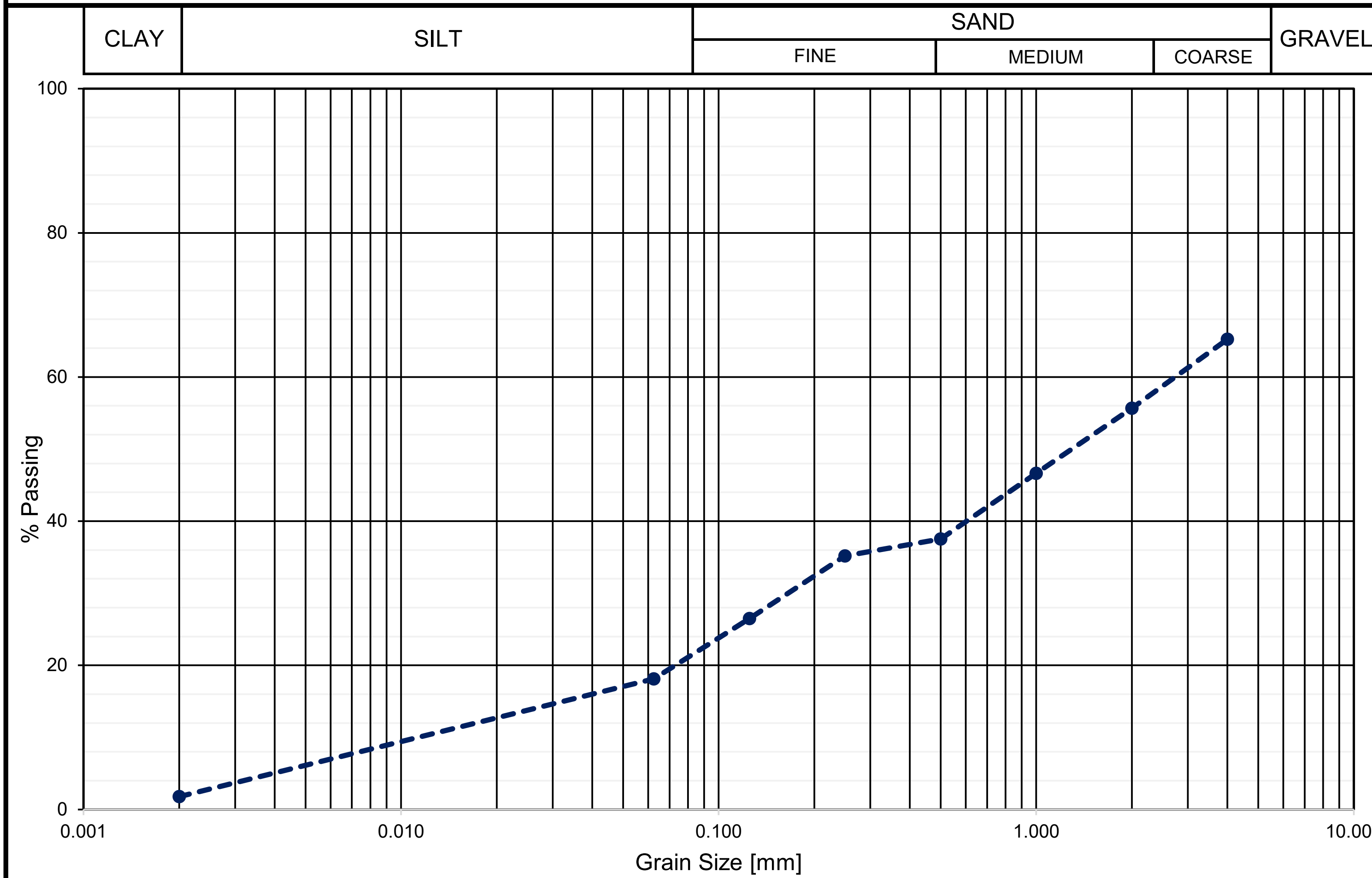


Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. C5	Sample ID C5 18	GRAIN SIZE ANALYSIS

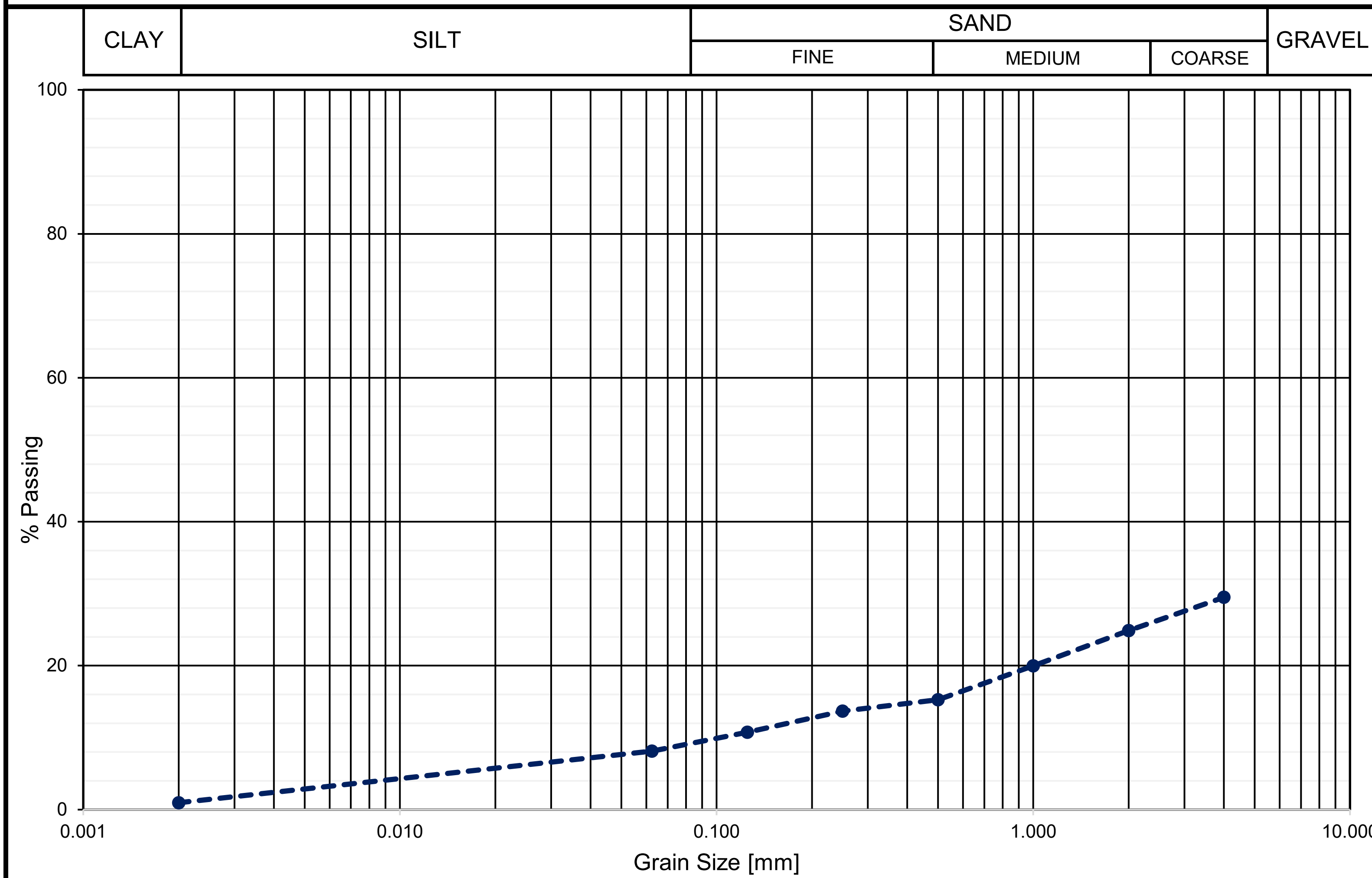
Project:	Vaseux GW-SW Interaction Study	Depth [m]	5.49	Sample Elevation [masl]	375.07
Drill Date:	January 18, 2022	Depth [ft]	18.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

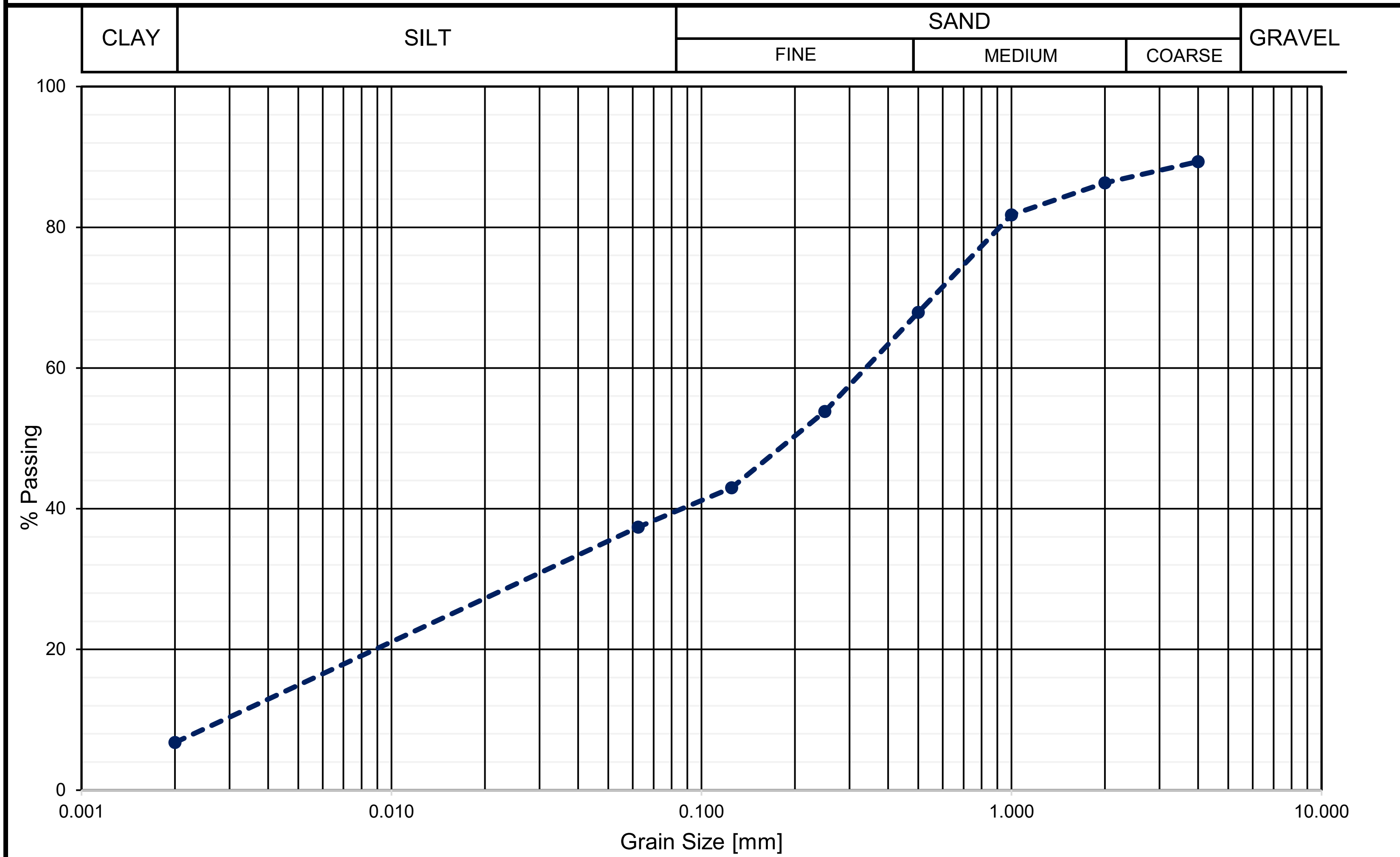
Borehole No.	C5	Sample ID	C5 23	GRAIN SIZE ANALYSIS
Project:	Vaseux GW-SW Interaction Study	Depth [m]	7.01	Sample Elevation [masl] 373.55
Drill Date:	January 18, 2022	Depth [ft]	23.00	



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	**C5**	**Sample ID**	**C5 32-33**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	9.91	Sample Elevation [masl]	370.65
Drill Date:	January 18, 2022	Depth [ft]	32.50		

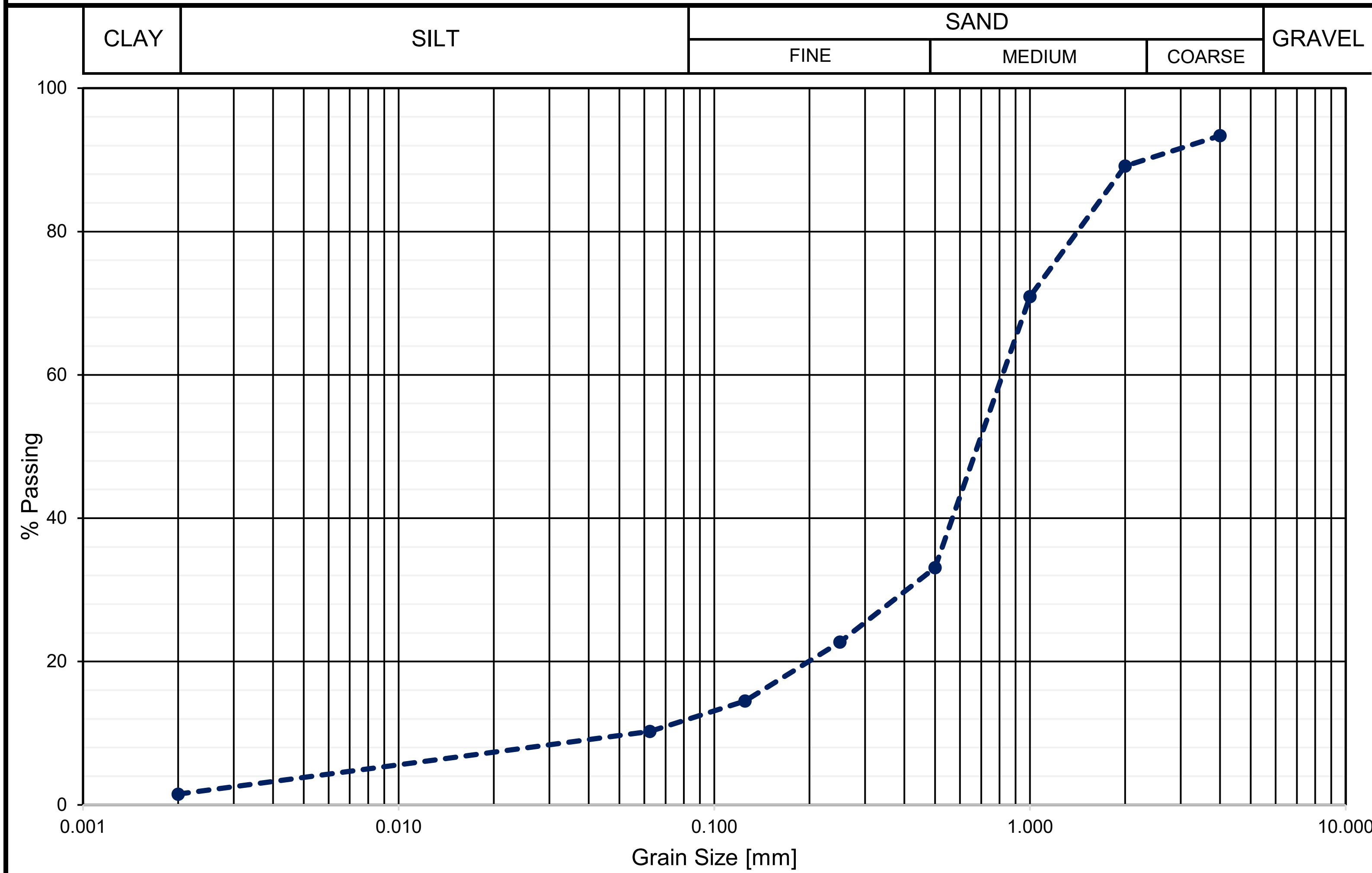


Note: Unified Soil Classification System (USCS) used for soil divisions
Median results of 3 analyses

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. F2	Sample ID F2 38.5	GRAIN SIZE ANALYSIS

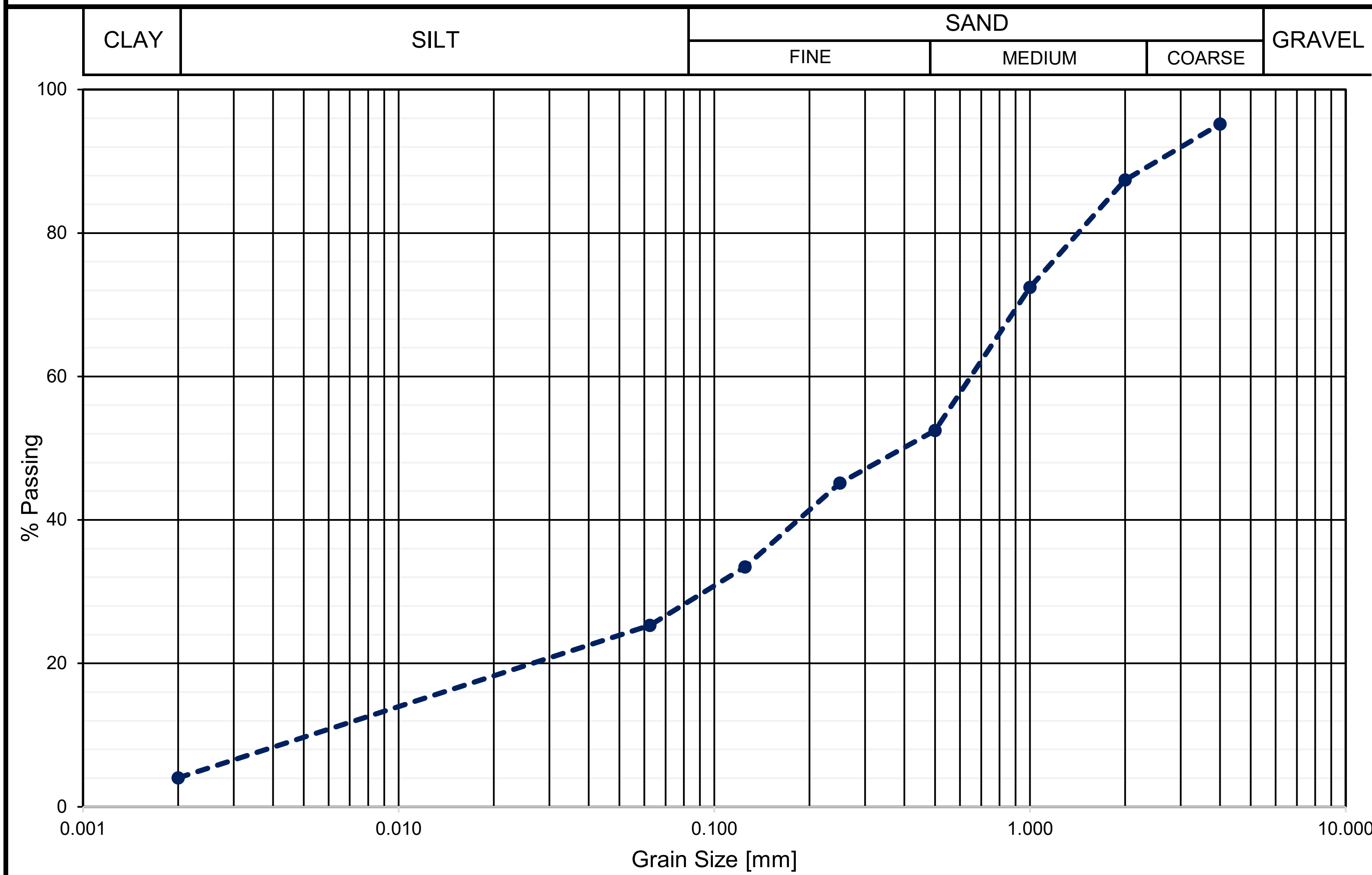
Project:	Vaseux GW-SW Interaction Study	Depth [m]	11.73	Sample Elevation [masl]	340.84
Drill Date:	January 19, 2022	Depth [ft]	38.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

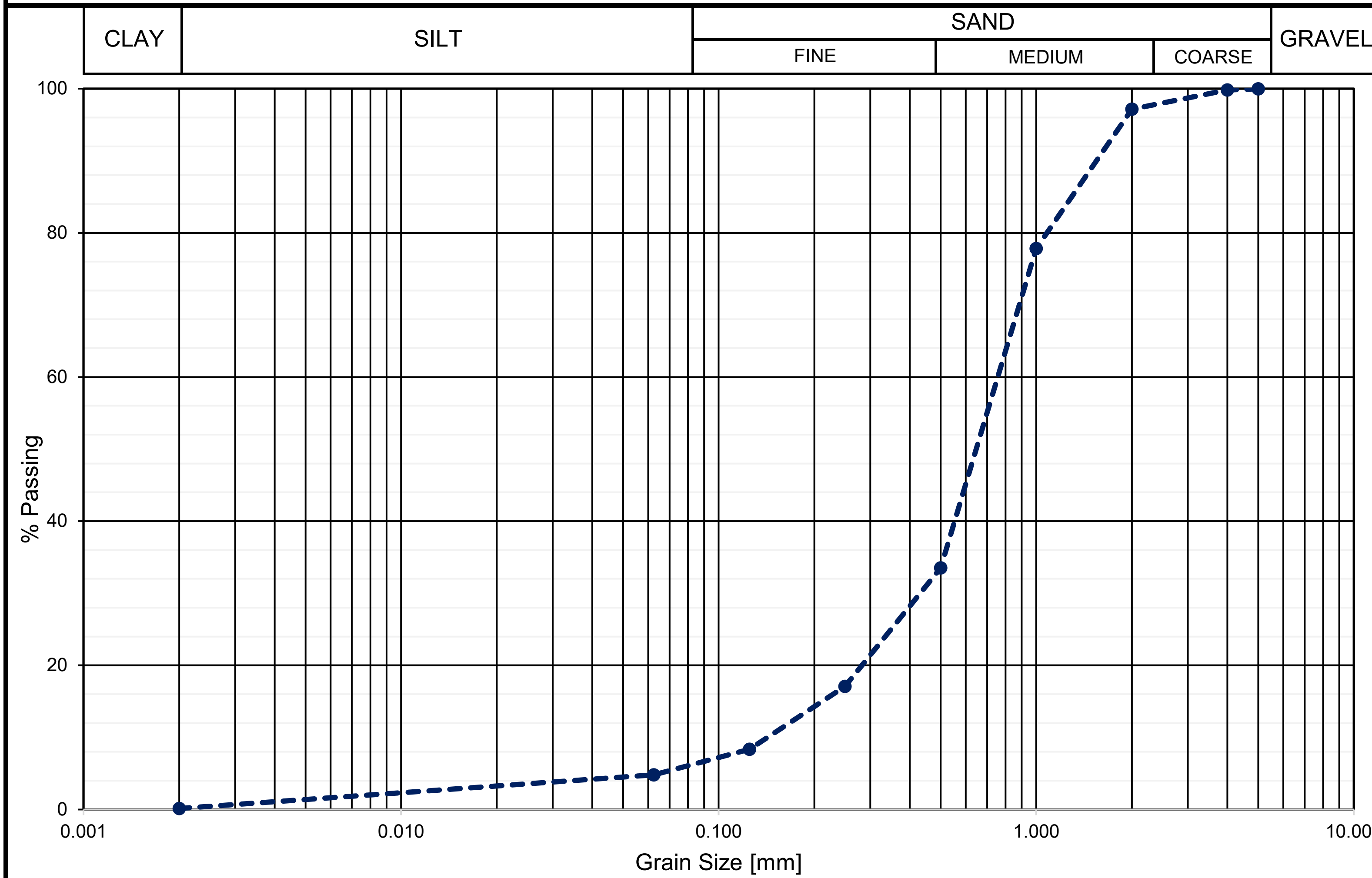
Borehole No.	F2	Sample ID	F2 43.5	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	13.26	Sample Elevation [masl]	339.31
Drill Date:	January 19, 2022	Depth [ft]	43.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

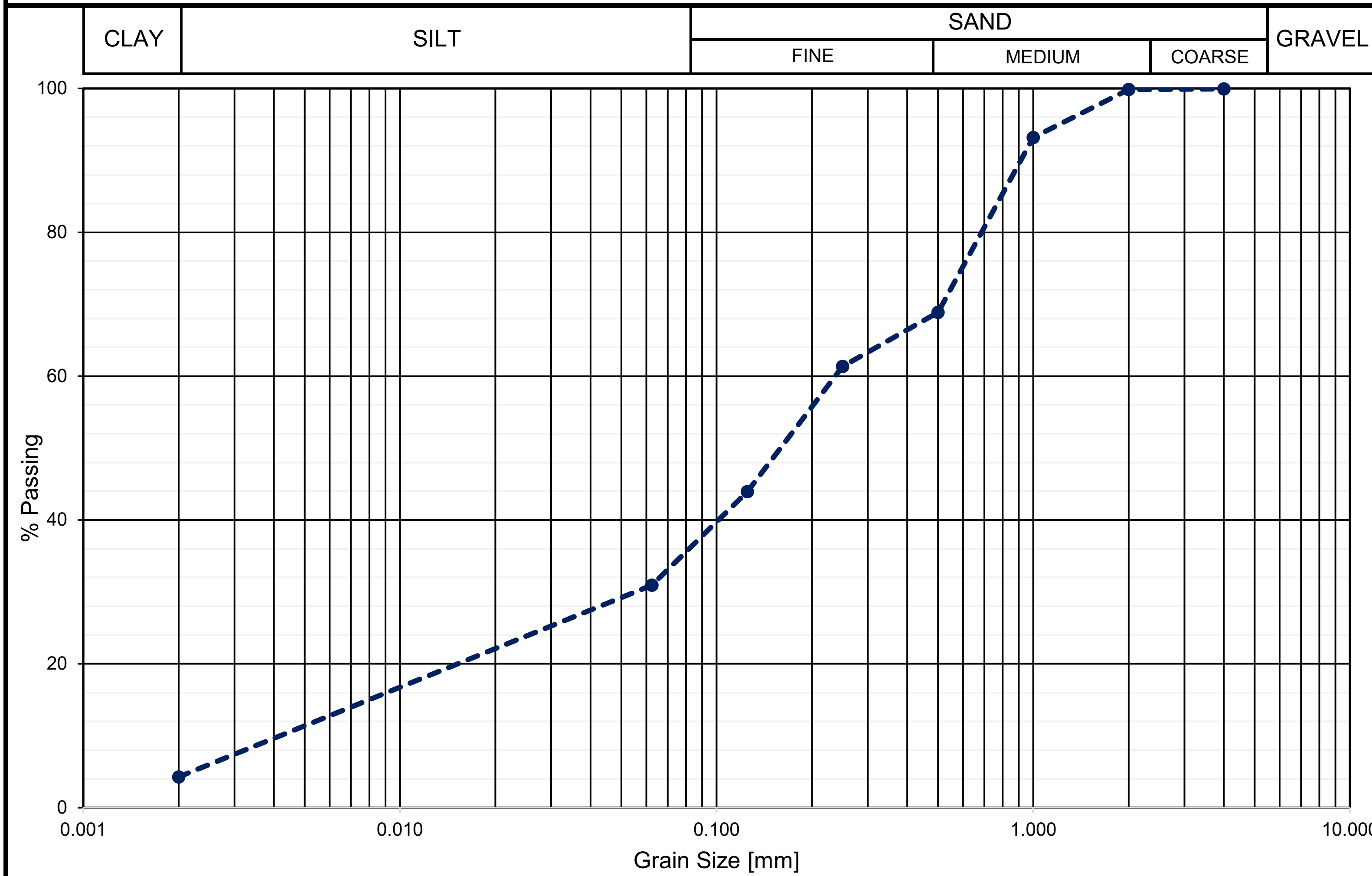
Borehole No. F2		Sample ID	F2 53-55	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	16.46	Sample Elevation [masl]	336.11
Drill Date:	January 19, 2022	Depth [ft]	54.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

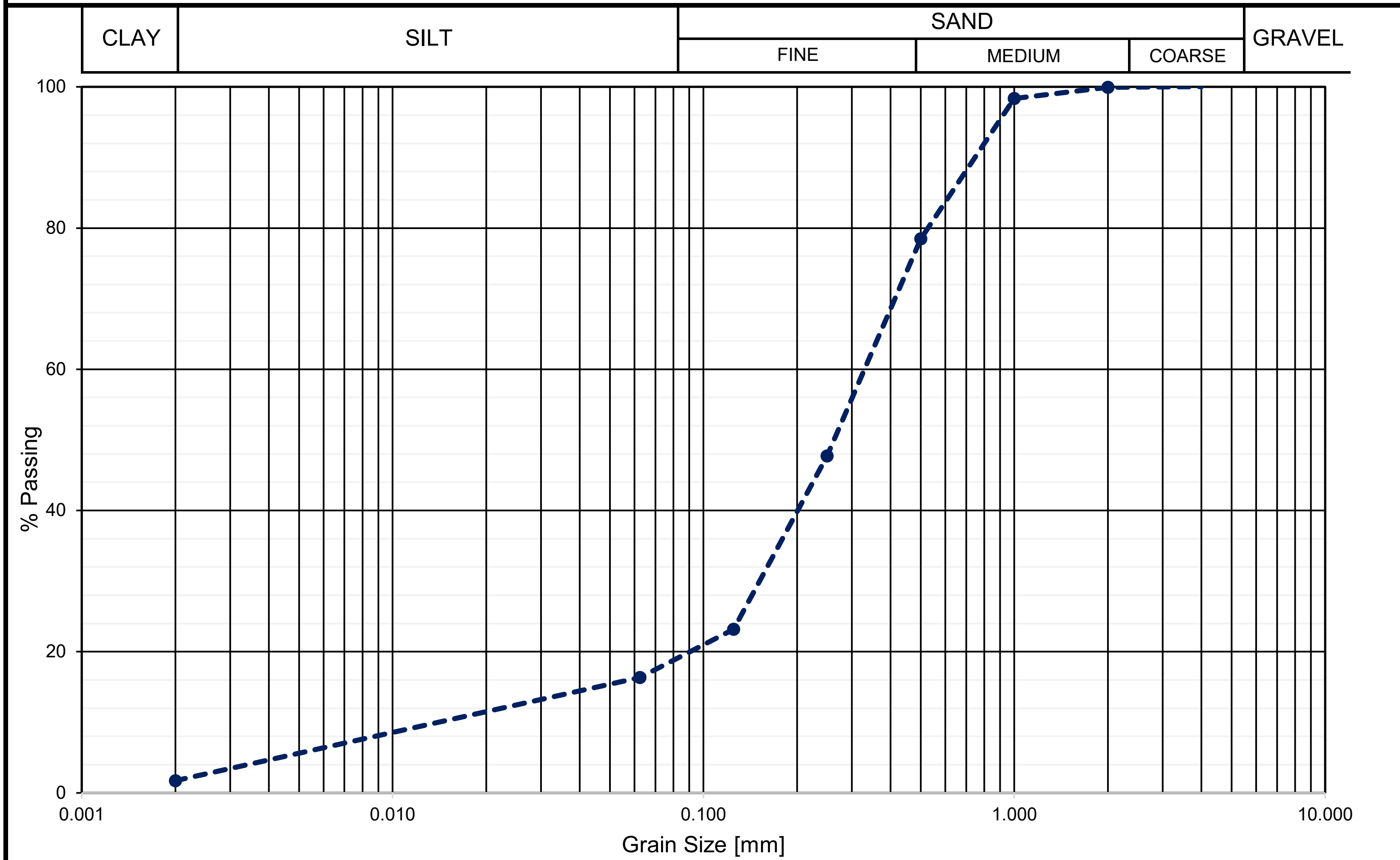
Borehole No.	F2	Sample ID	F2 57	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	17.37	Sample Elevation [masl]	335.20
Drill Date:	January 19, 2022	Depth [ft]	57.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	**F2**	**Sample ID**	**F2 63**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	19.20	Sample Elevation [masl]	333.37
Drill Date:	January 19, 2022	Depth [ft]	63.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. F2	Sample ID F2 69.5-72.5	GRAIN SIZE ANALYSIS

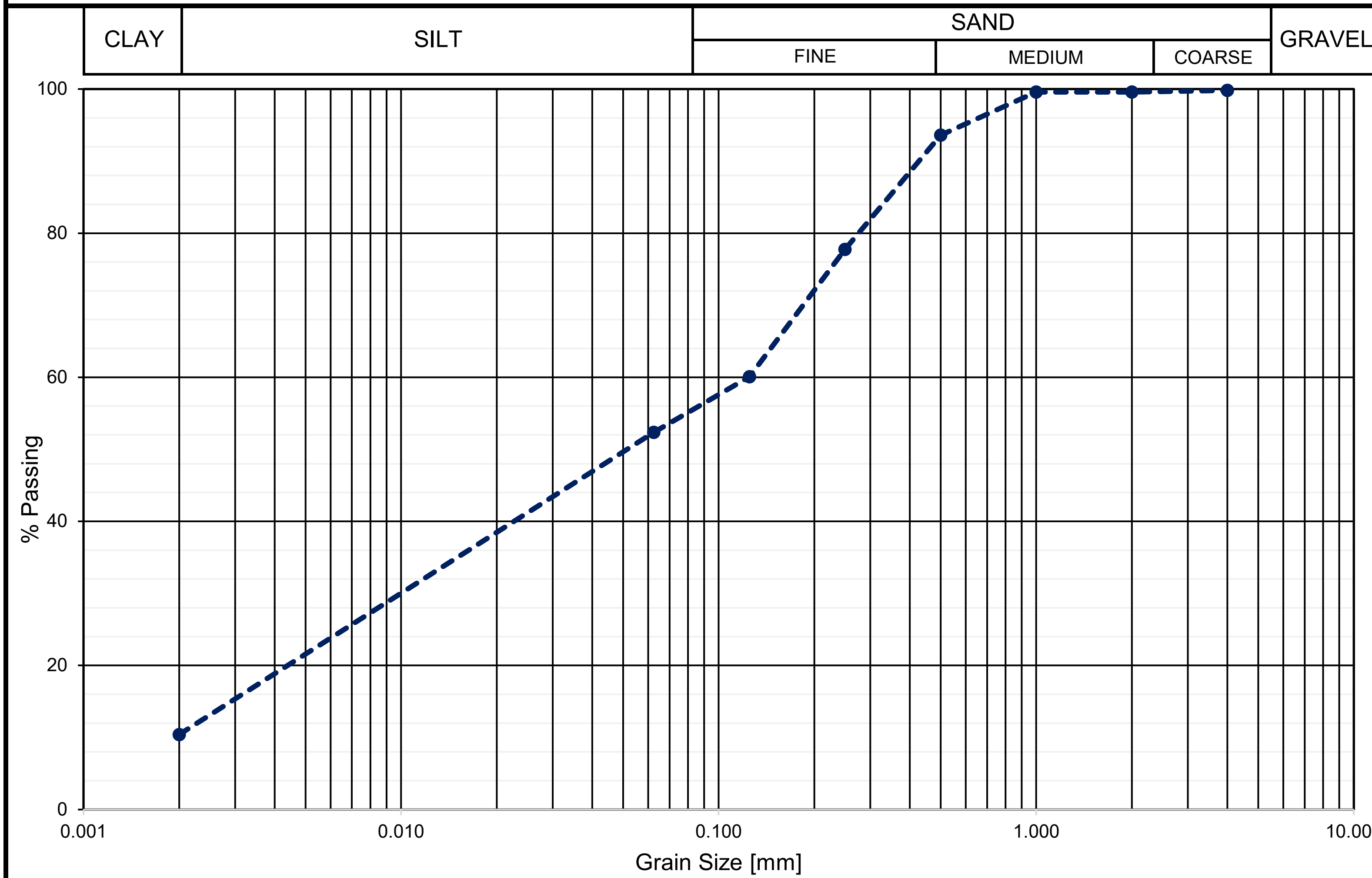
Project: Vaseux GW-SW Interaction Study

Depth [m] 21.64

Sample Elevation [masl] 330.93

Drill Date: January 19, 2022

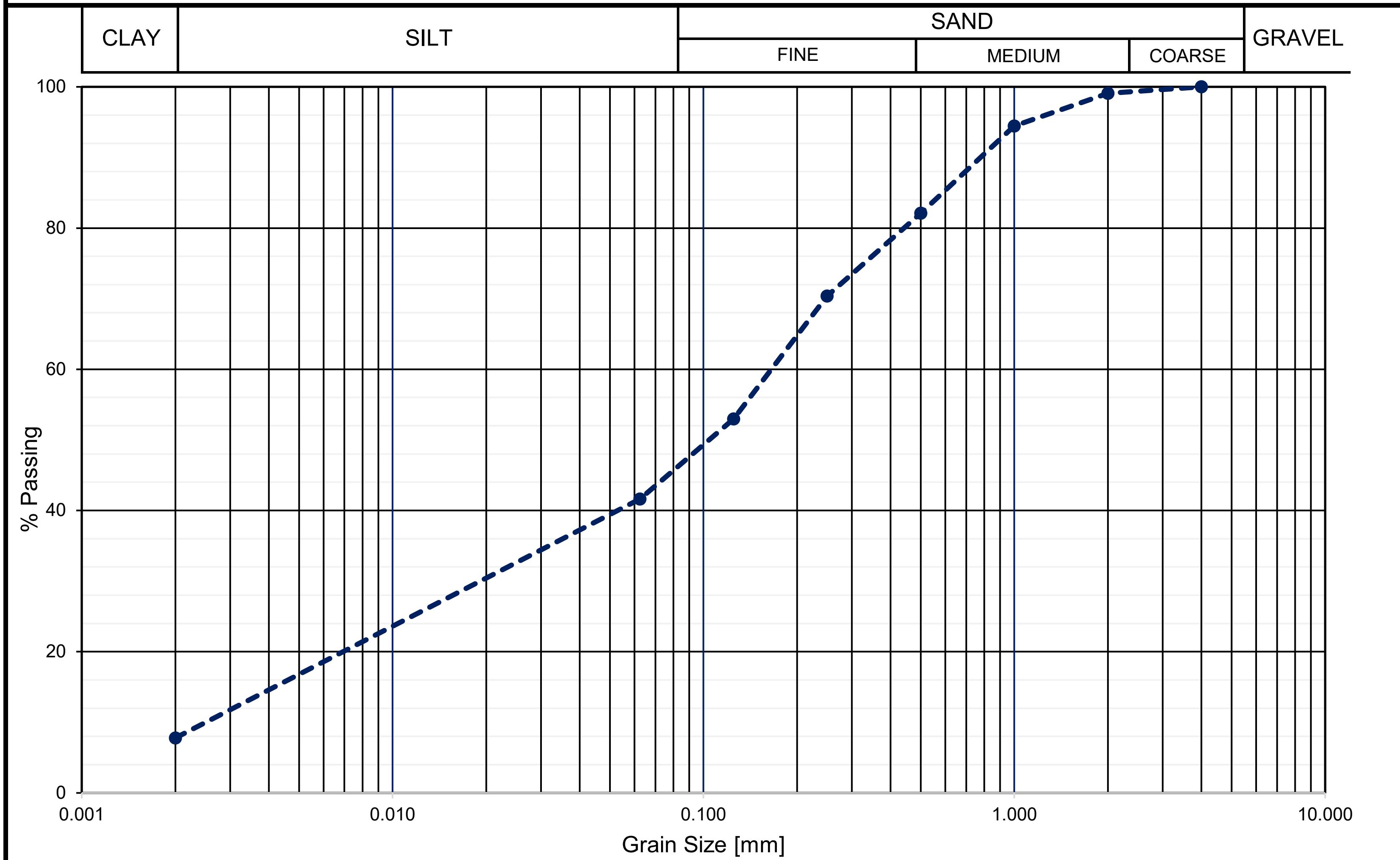
Depth [ft] 71.00



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

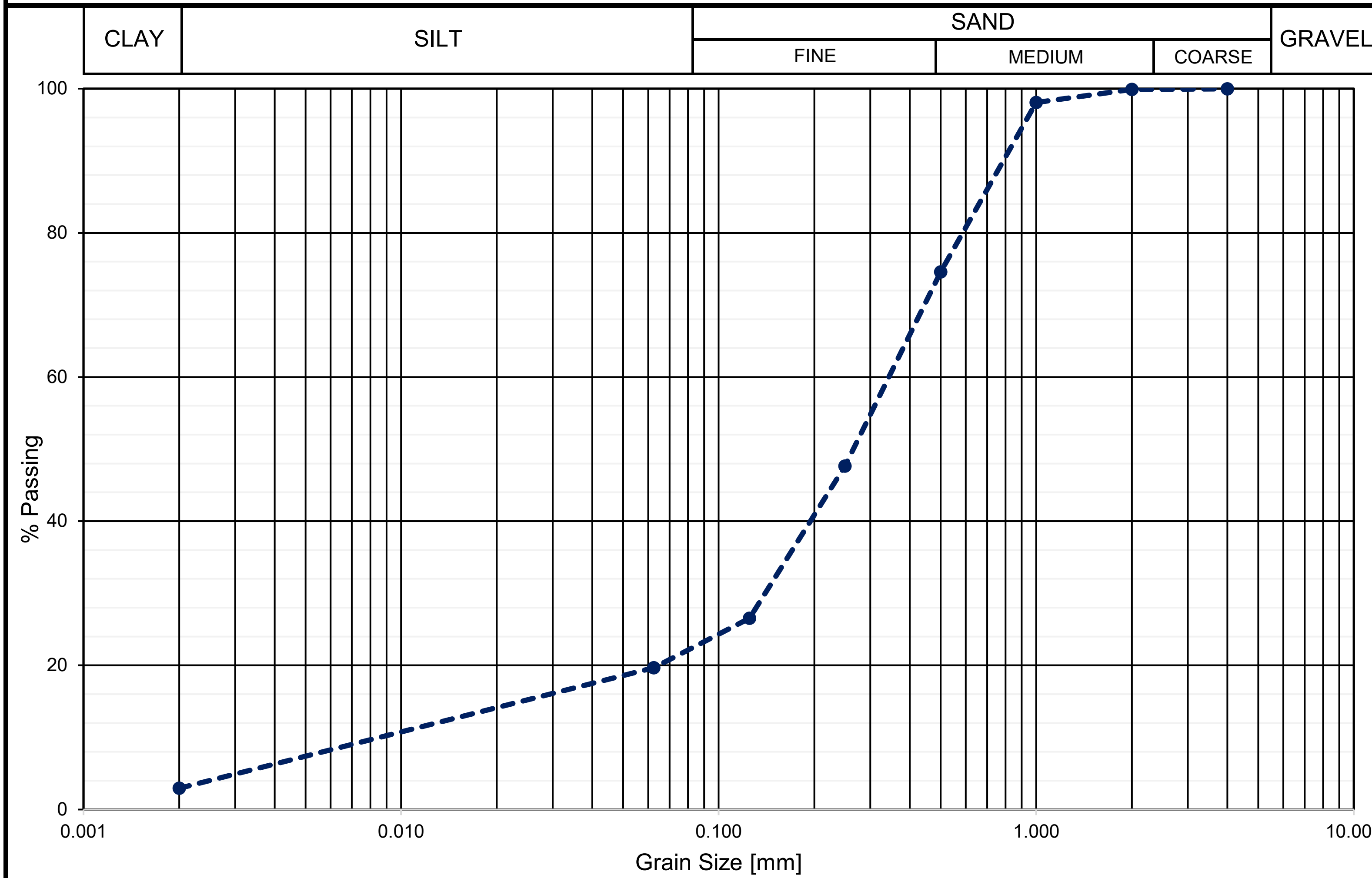
Borehole No.	**F2**	**Sample ID**	**F2 73**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	22.25	Sample Elevation [masl]	330.32
Drill Date:	January 19, 2022	Depth [ft]	73.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

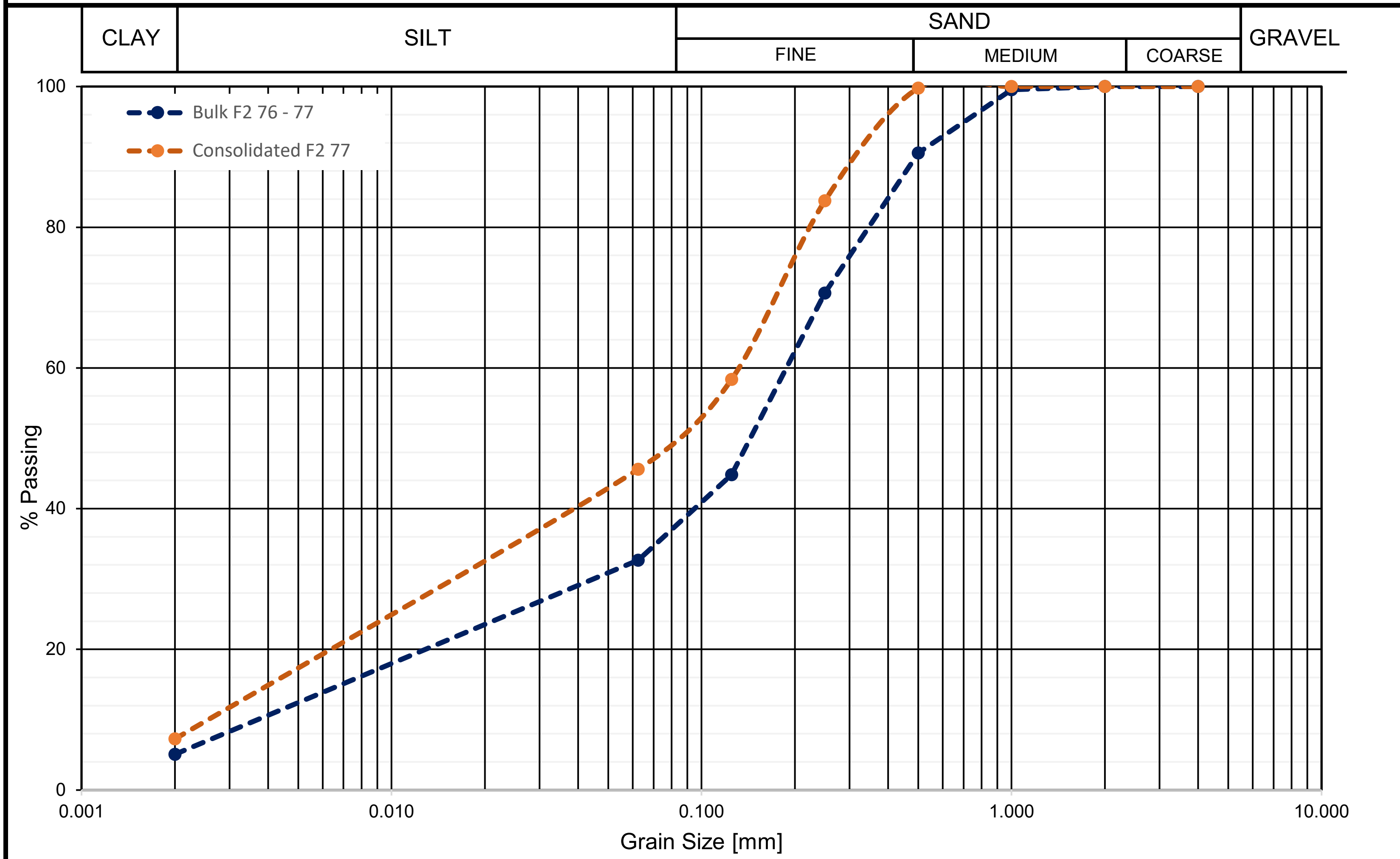
Borehole No.	F2	Sample ID	F2 75	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	22.86	Sample Elevation [masl]	329.71
Drill Date:	January 19, 2022	Depth [ft]	75.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

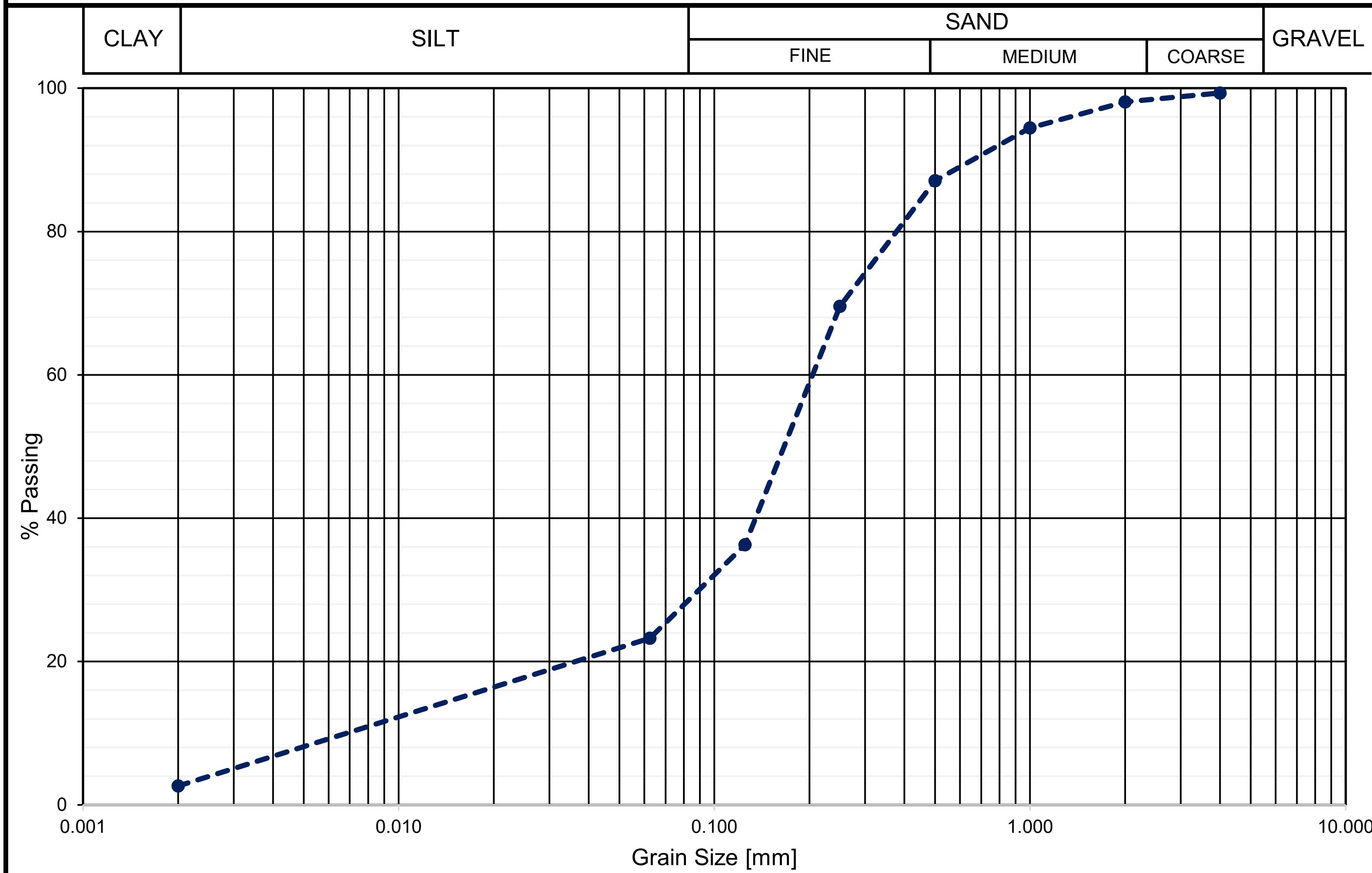
Borehole No.	F2	Sample ID	F2 76-77	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	23.47	Sample Elevation [masl]	329.10
Drill Date:	January 19, 2022	Depth [ft]	77.00		



Note: Unified Soil Classification System (USCS) used for soil divisions
Consolidated unit is about 1" thick. Bulk sample was collected across a 1' thick unit.

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

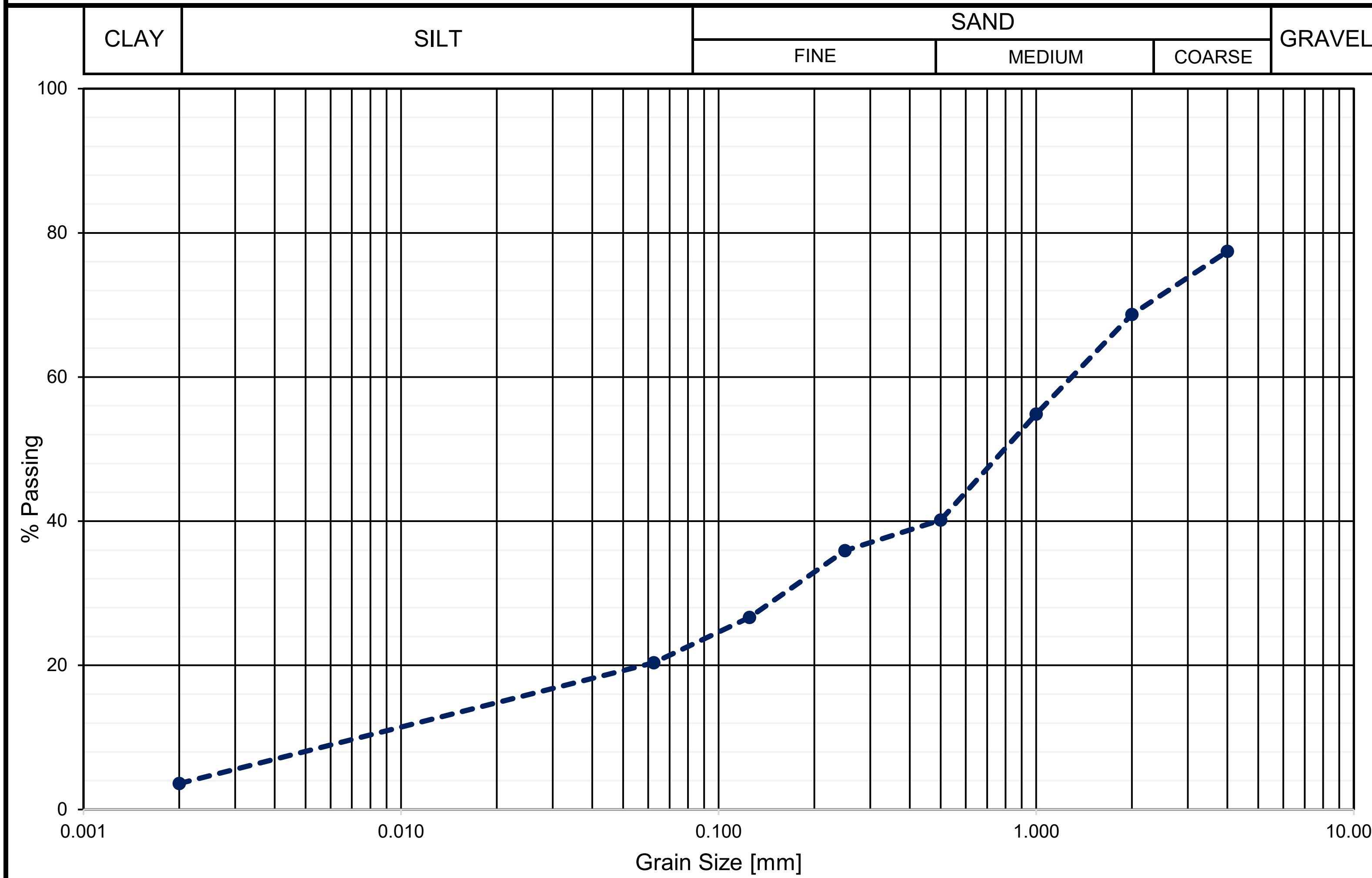
Borehole No.	**F2**	**Sample ID**	**F2 79-83**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	24.69	Sample Elevation [masl]	327.88
Drill Date:	January 19, 2022	Depth [ft]	81.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

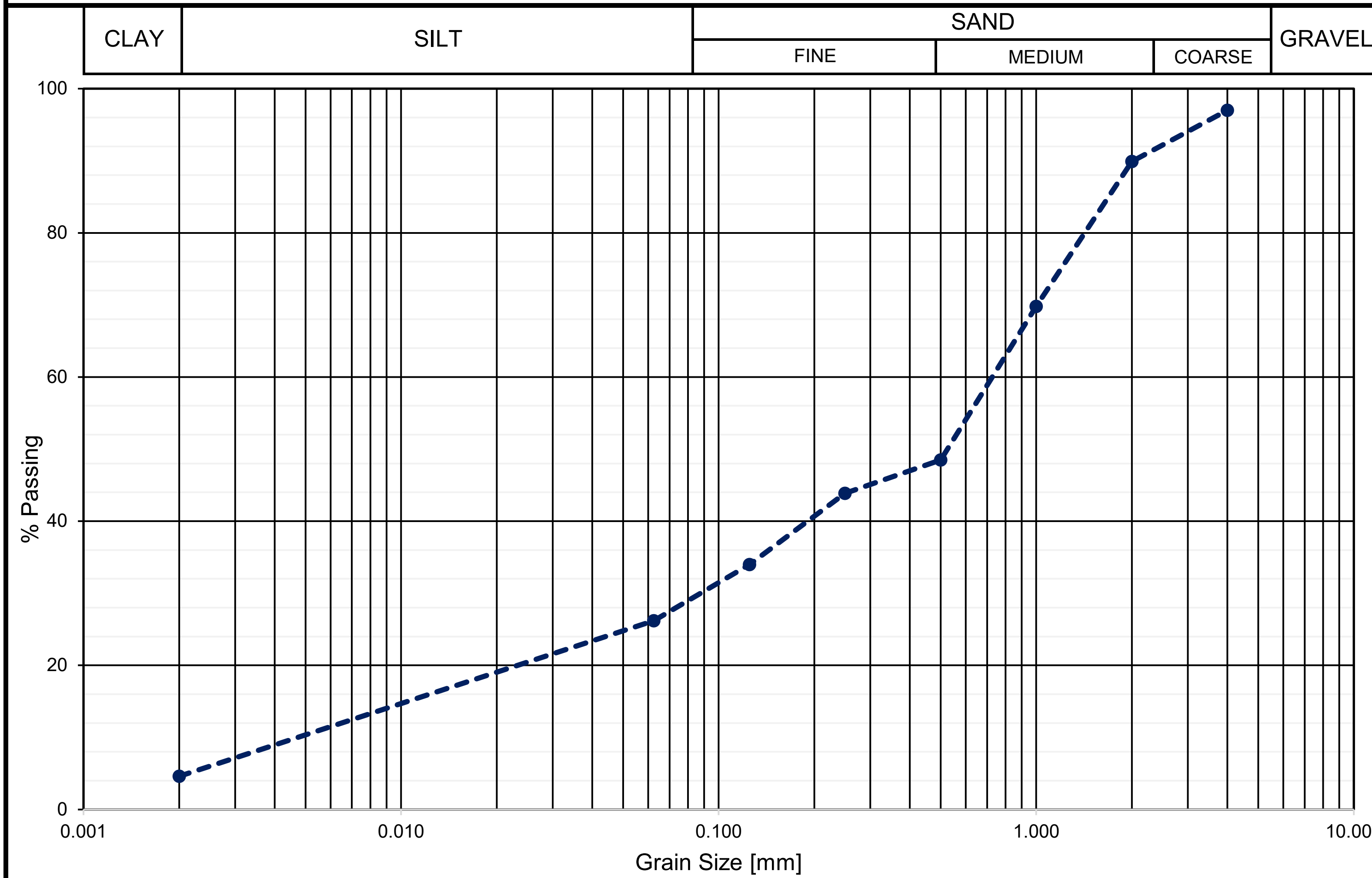
Borehole No.	F2	Sample ID	F2 84.5-85	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	25.91	Sample Elevation [masl]	326.66
Drill Date:	January 19, 2022	Depth [ft]	85.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

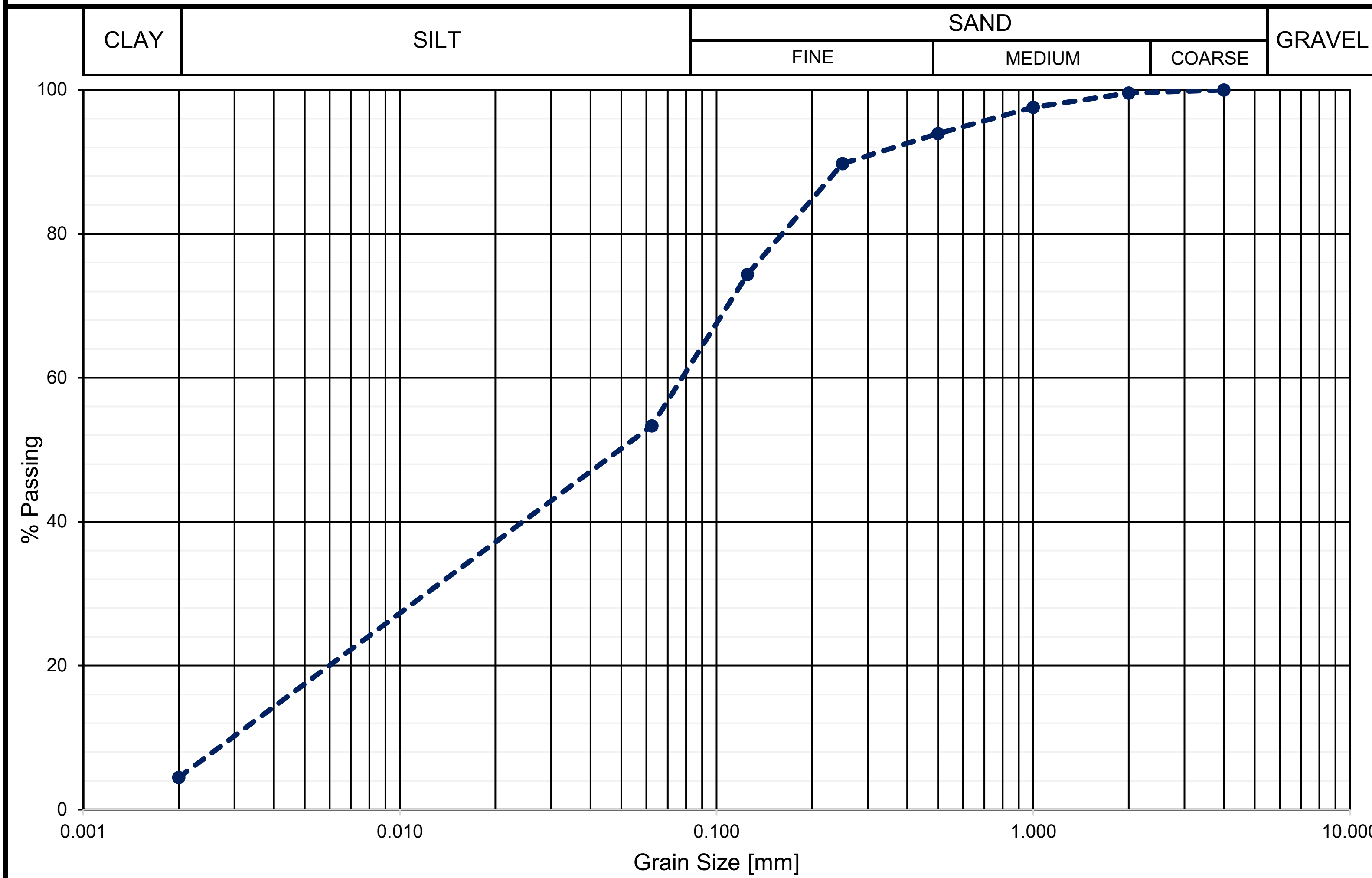
Borehole No.	F2	Sample ID	F2 95-99	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	29.26	Sample Elevation [masl]	323.31
Drill Date:	January 19, 2022	Depth [ft]	96.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

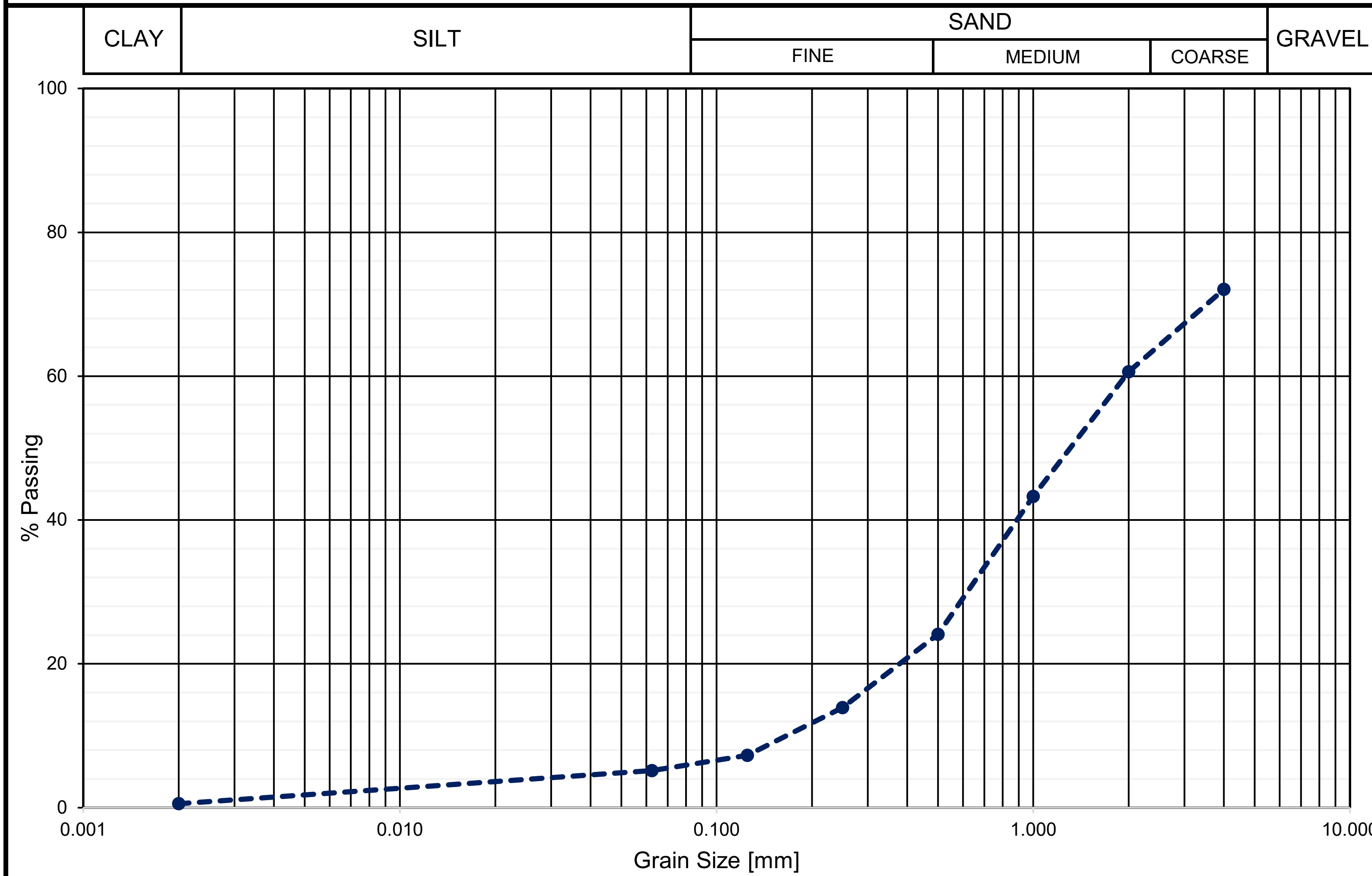
Borehole No.	F2	Sample ID	F2 101	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	30.78	Sample Elevation [masl]	321.79
Drill Date:	January 19, 2022	Depth [ft]	101.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	F2	Sample ID	F2 105	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	32.00	Sample Elevation [masl]	320.57
Drill Date:	January 19, 2022	Depth [ft]	105.00		

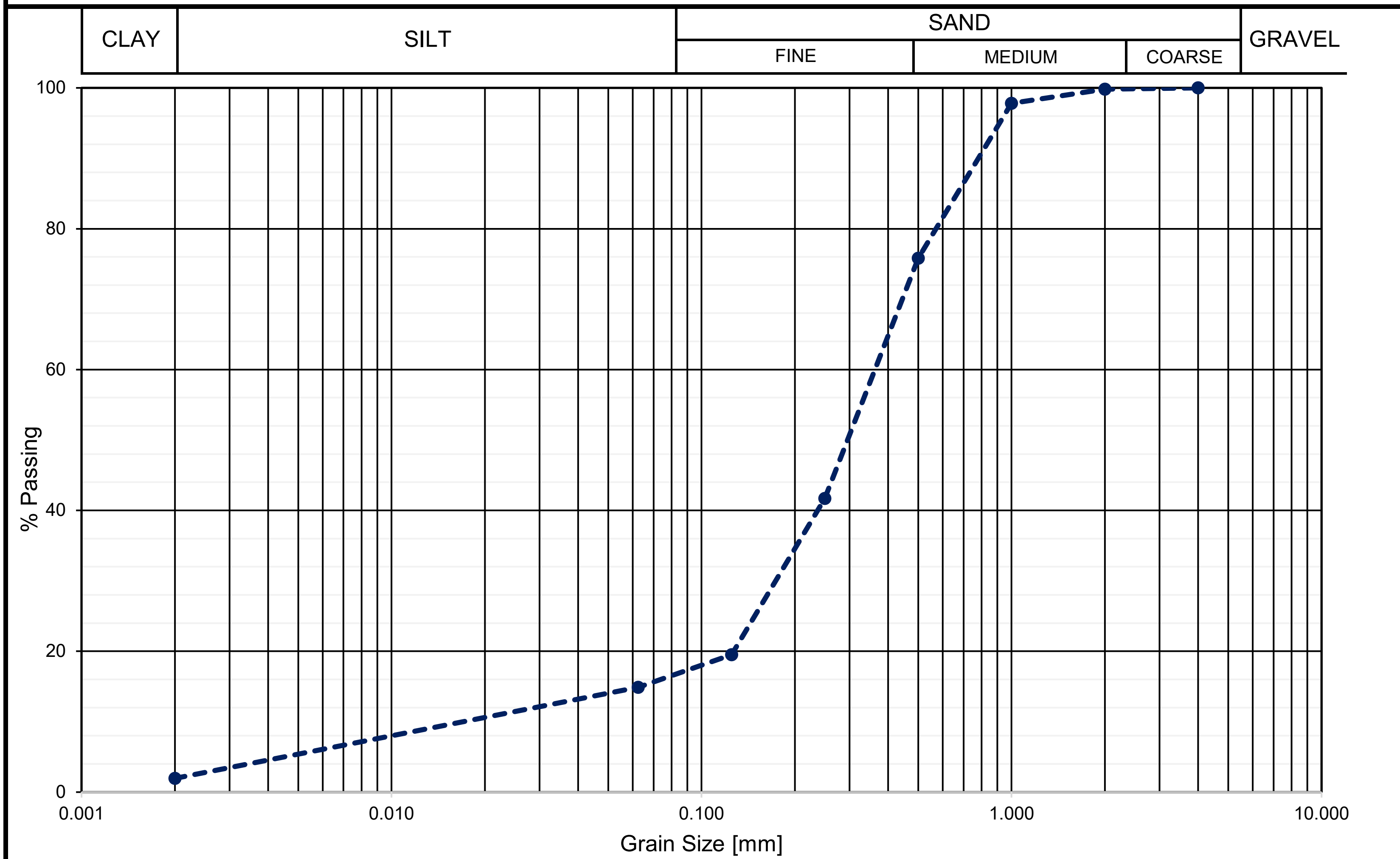


Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. F2	Sample ID F2 106-109	GRAIN SIZE ANALYSIS

Project:	Vaseux GW-SW Interaction Study	Depth [m]	32.77	Sample Elevation [masl]	319.80
Drill Date:	January 19, 2022	Depth [ft]	107.50		

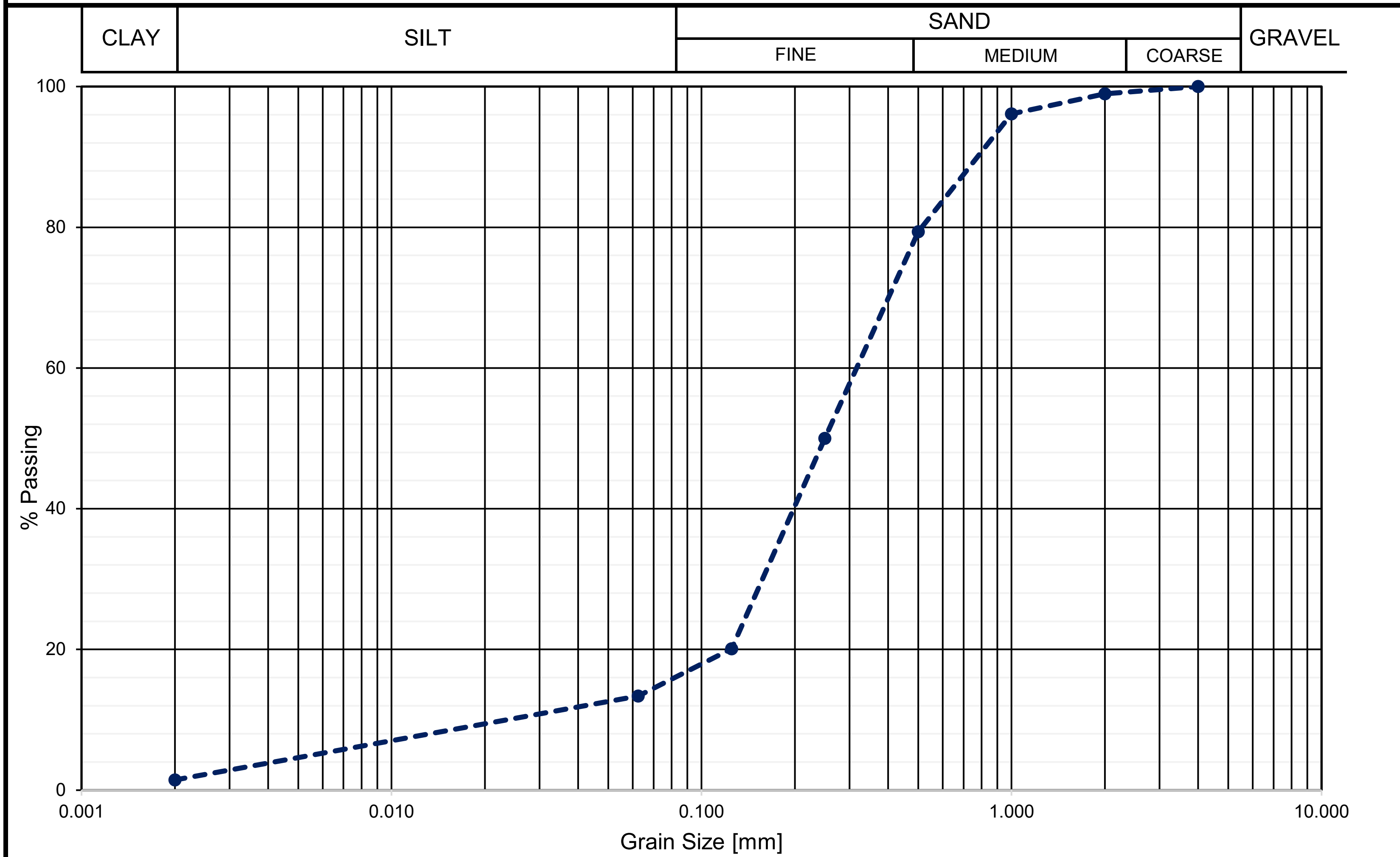


Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. F2	Sample ID F2 109-114	GRAIN SIZE ANALYSIS

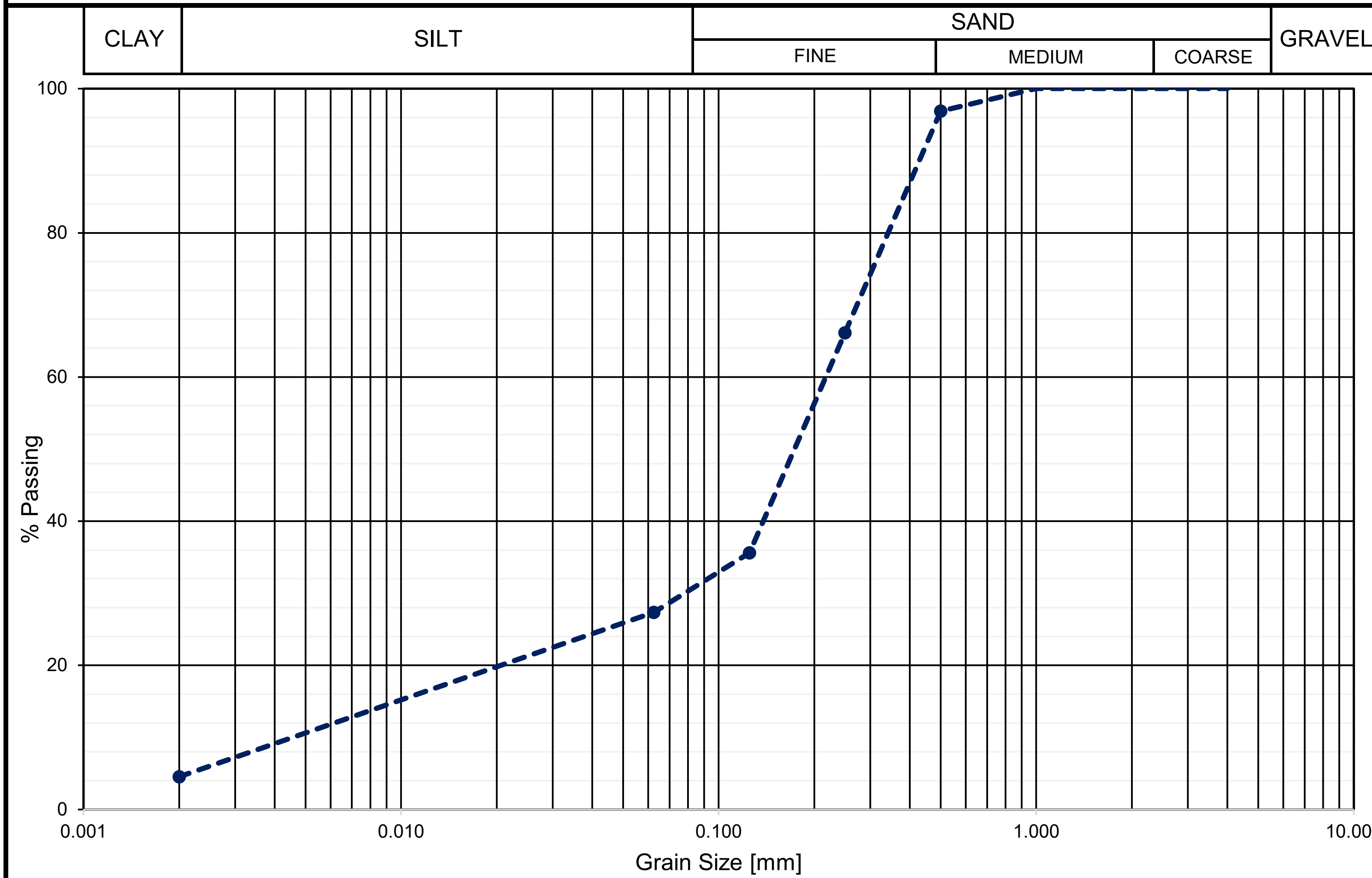
Project:	Vaseux GW-SW Interaction Study	Depth [m]	33.99	Sample Elevation [masl]	318.58
Drill Date:	January 19, 2022	Depth [ft]	111.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

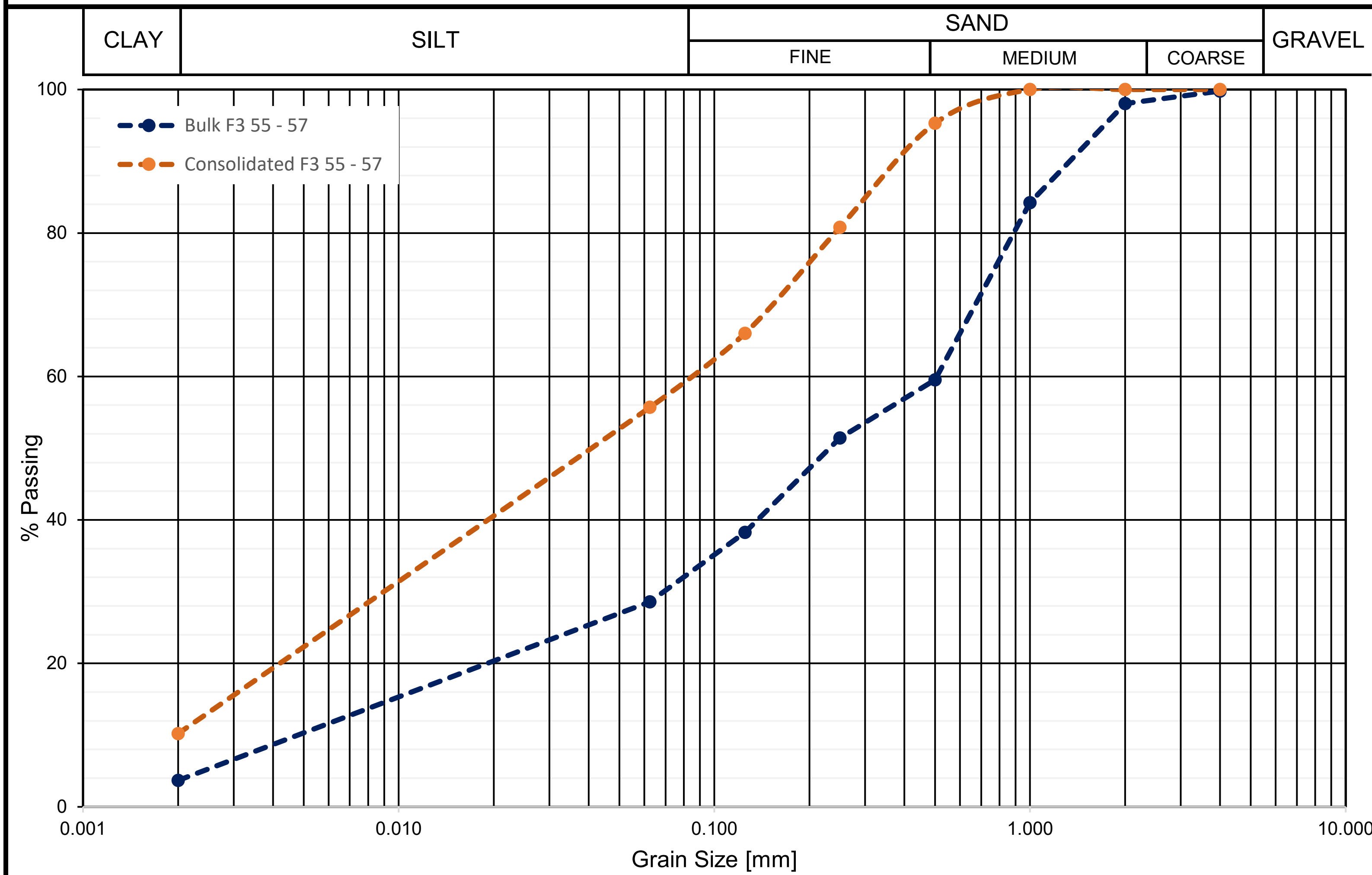
Borehole No.	F2	Sample ID	F2 114-118	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	35.36	Sample Elevation [masl]	317.21
Drill Date:	January 19, 2022	Depth [ft]	116.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	F3	Sample ID	F3 55-57	GRAIN SIZE ANALYSIS
Project:	Vaseux GW-SW Interaction Study	Depth [m]	16.76 - 17.37	Sample Elevation [masl] 342.75 - 343.36
Drill Date:	January 21, 2023	Depth [ft]	55.00 - 57.00	

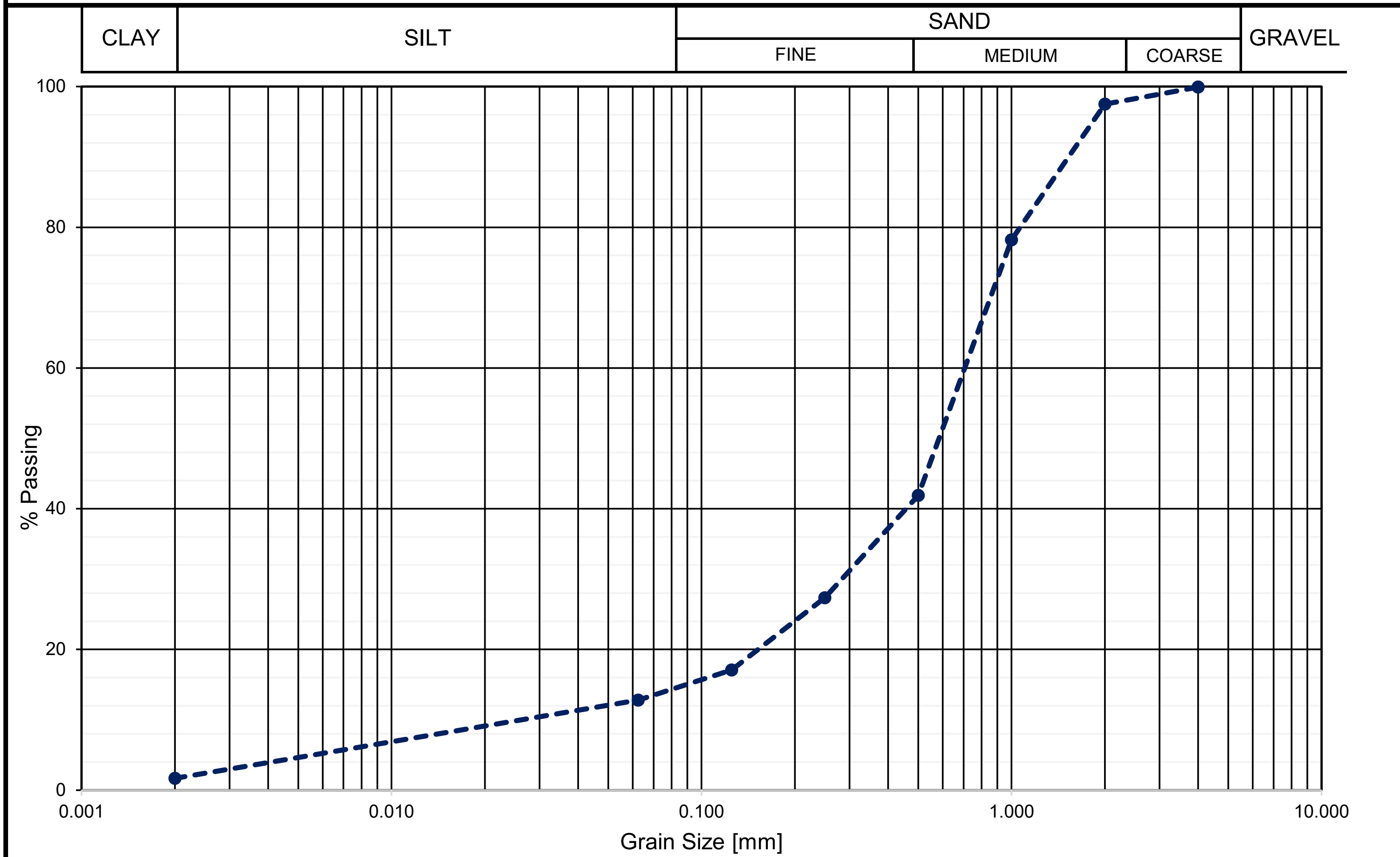


Note: Unified Soil Classification System (USCS) used for soil divisions
Consolidated unit is about 1-2" thick, collected somewhere across a 2' thick unit. Sample was frozen so specific depth not known. Bulk sample was collected across a 2' thick unit.

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. F3	Sample ID F3 59-61	GRAIN SIZE ANALYSIS

Project:	Vaseux GW-SW Interaction Study	Depth [m]	18.29	Sample Elevation [masl]	341.83
Drill Date:	January 21, 2023	Depth [ft]	60.00		



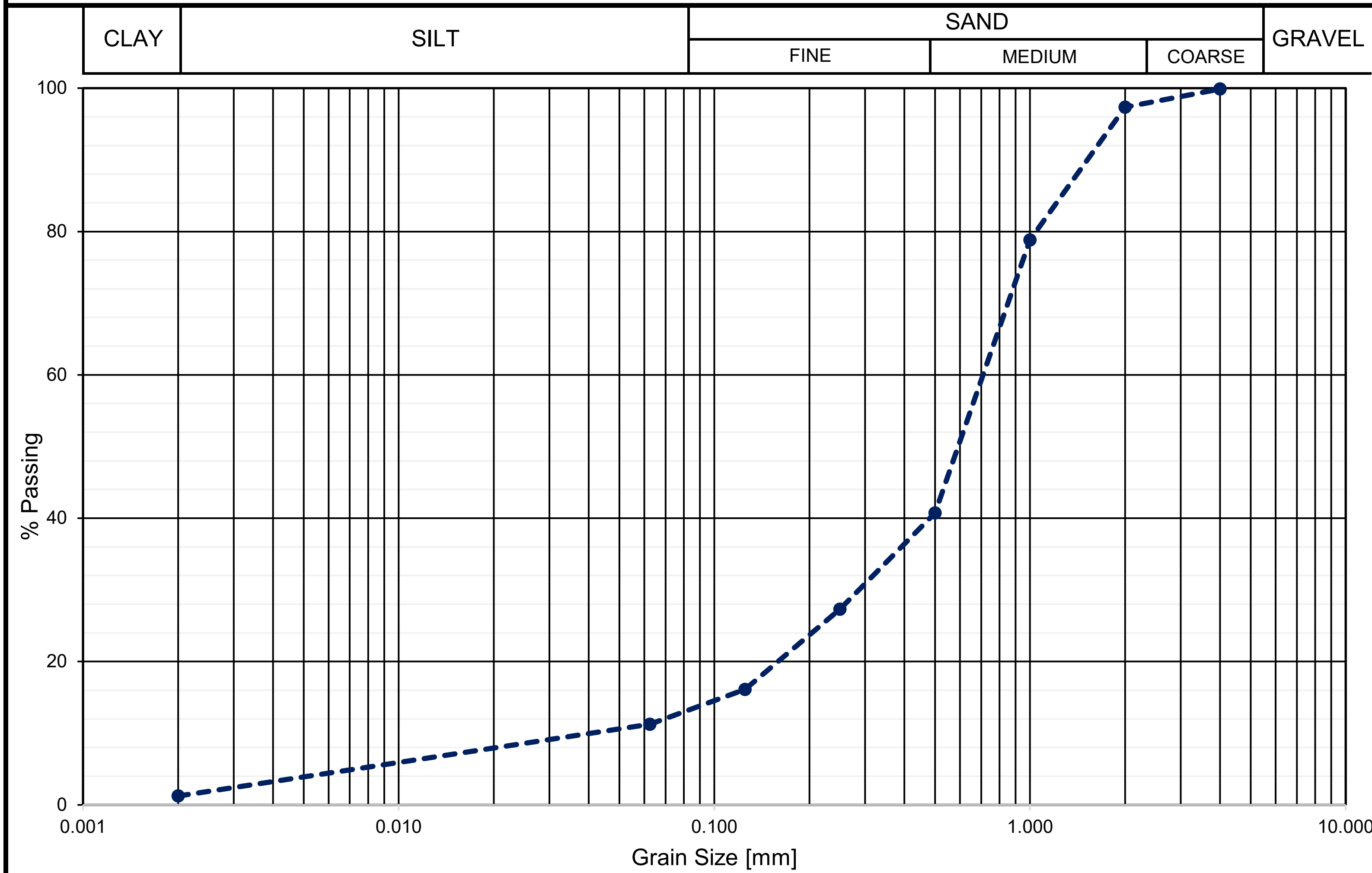
Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	**F3**	**Sample ID**	**F3 63**

GRAIN SIZE ANALYSIS

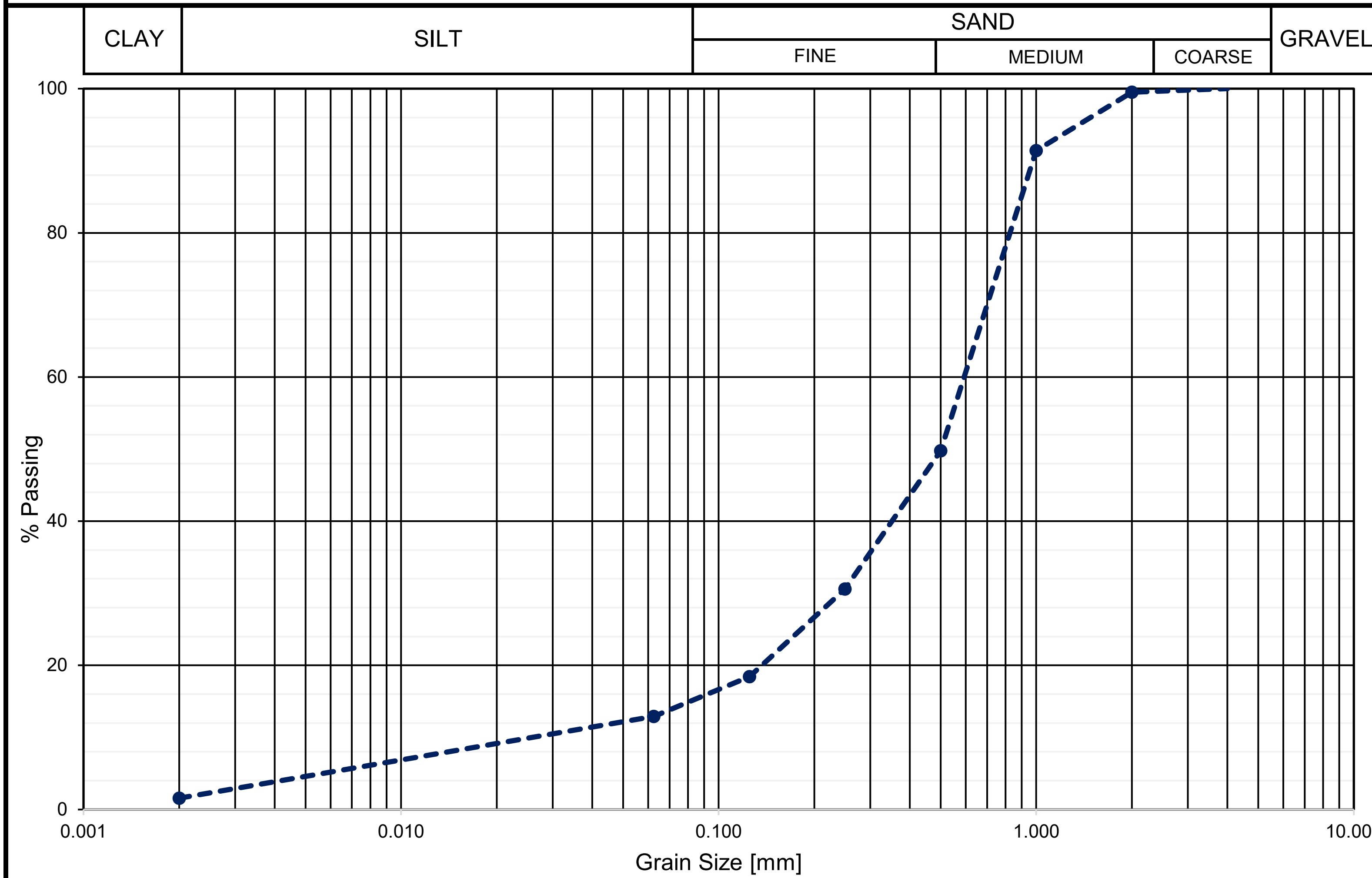
Project:	Vaseux GW-SW Interaction Study	Depth [m]	19.20	Sample Elevation [masl]	340.92
Drill Date:	January 21, 2023	Depth [ft]	63.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

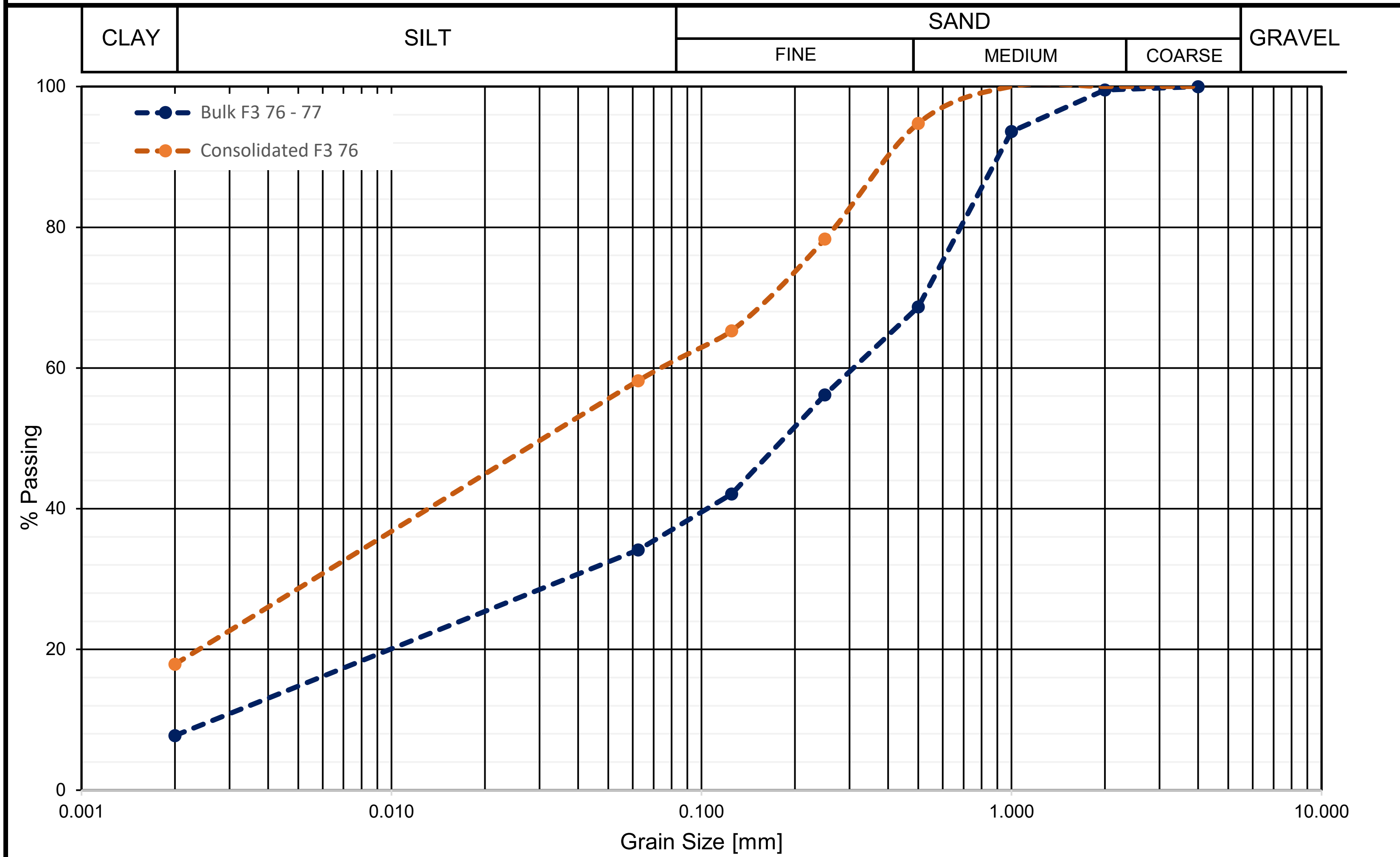
Borehole No.	F3	Sample ID	F3 74.5	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	22.71	Sample Elevation [masl]	337.41
Drill Date:	January 21, 2023	Depth [ft]	74.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	F3	Sample ID	F3 76	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	23.16	Sample Elevation [masl]	336.96
Drill Date:	January 21, 2023	Depth [ft]	76.00		

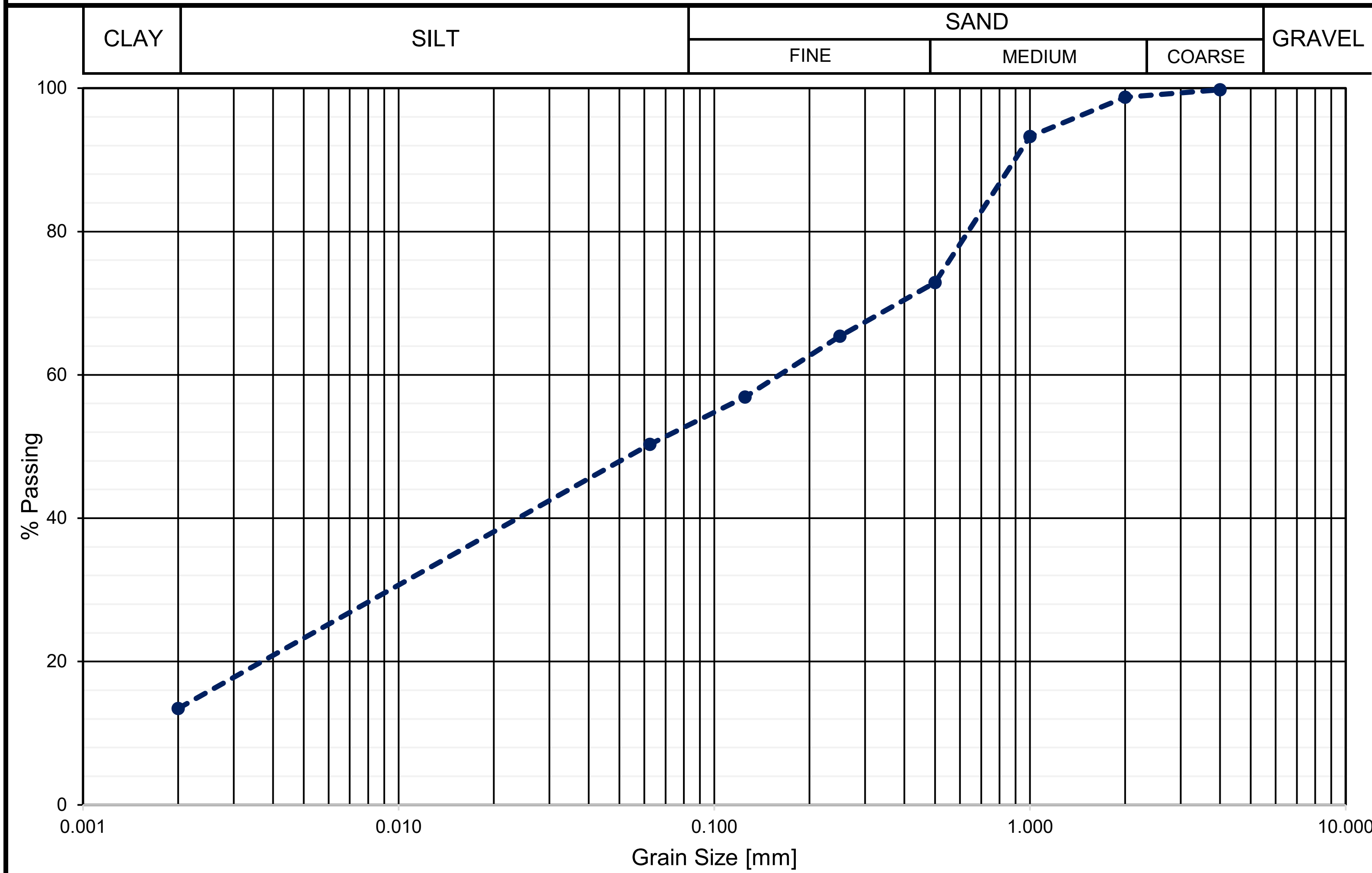


Note: Unified Soil Classification System (USCS) used for soil divisions
Consolidated unit is about 1" thick. Bulk sample was collected across a 1' thick unit.

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. F3	Sample ID F3 76.5	GRAIN SIZE ANALYSIS

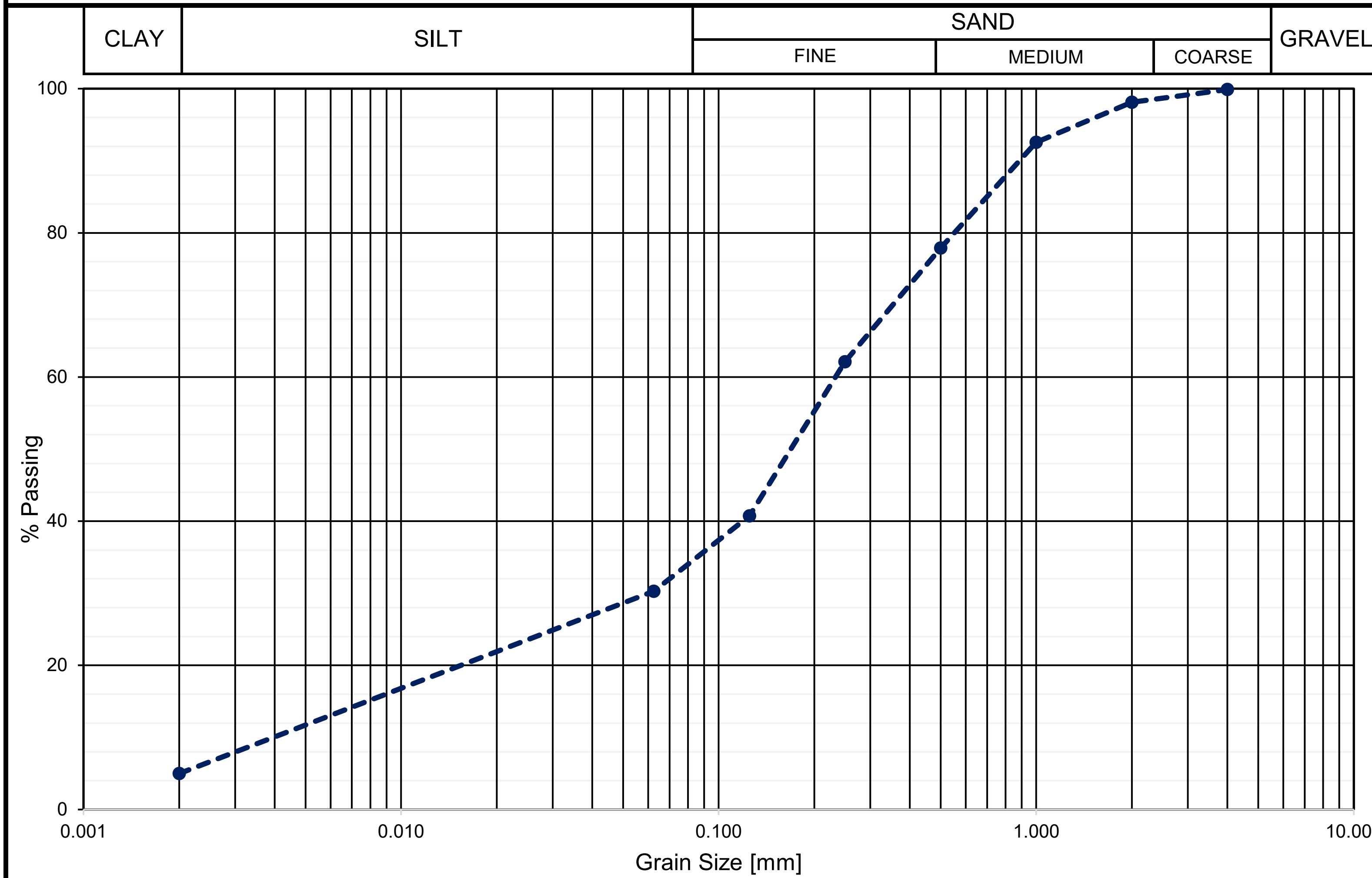
Project:	Vaseux GW-SW Interaction Study	Depth [m]	23.32	Sample Elevation [masl]	336.80
Drill Date:	January 21, 2023	Depth [ft]	76.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	F3	Sample ID	F3 77.5	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	23.62	Sample Elevation [masl]	336.50
Drill Date:	January 21, 2023	Depth [ft]	77.50		

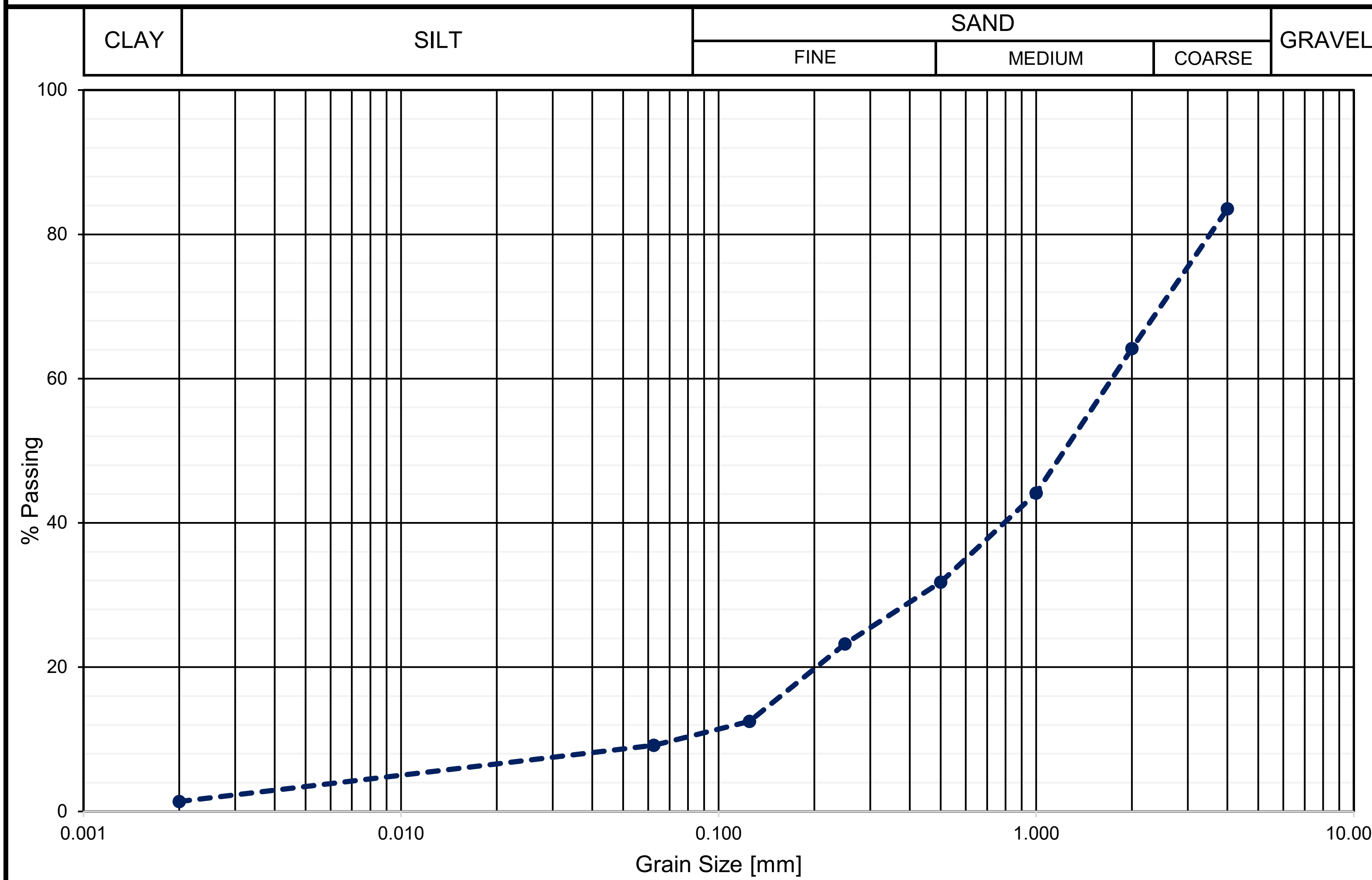


Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. F3	Sample ID F3 85	GRAIN SIZE ANALYSIS

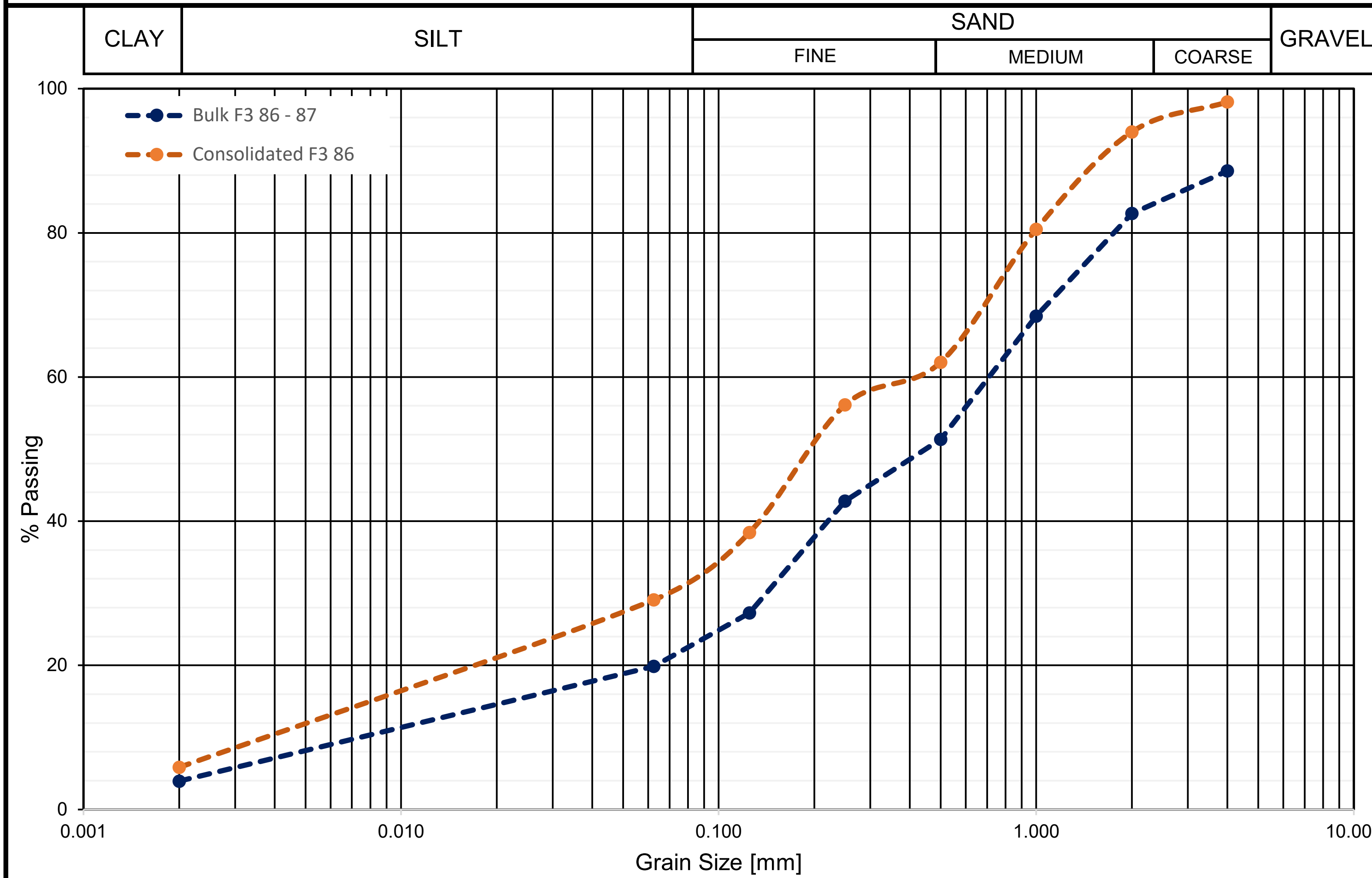
Project:	Vaseux GW-SW Interaction Study	Depth [m]	25.91	Sample Elevation [masl]	334.21
Drill Date:	January 21, 2023	Depth [ft]	85.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

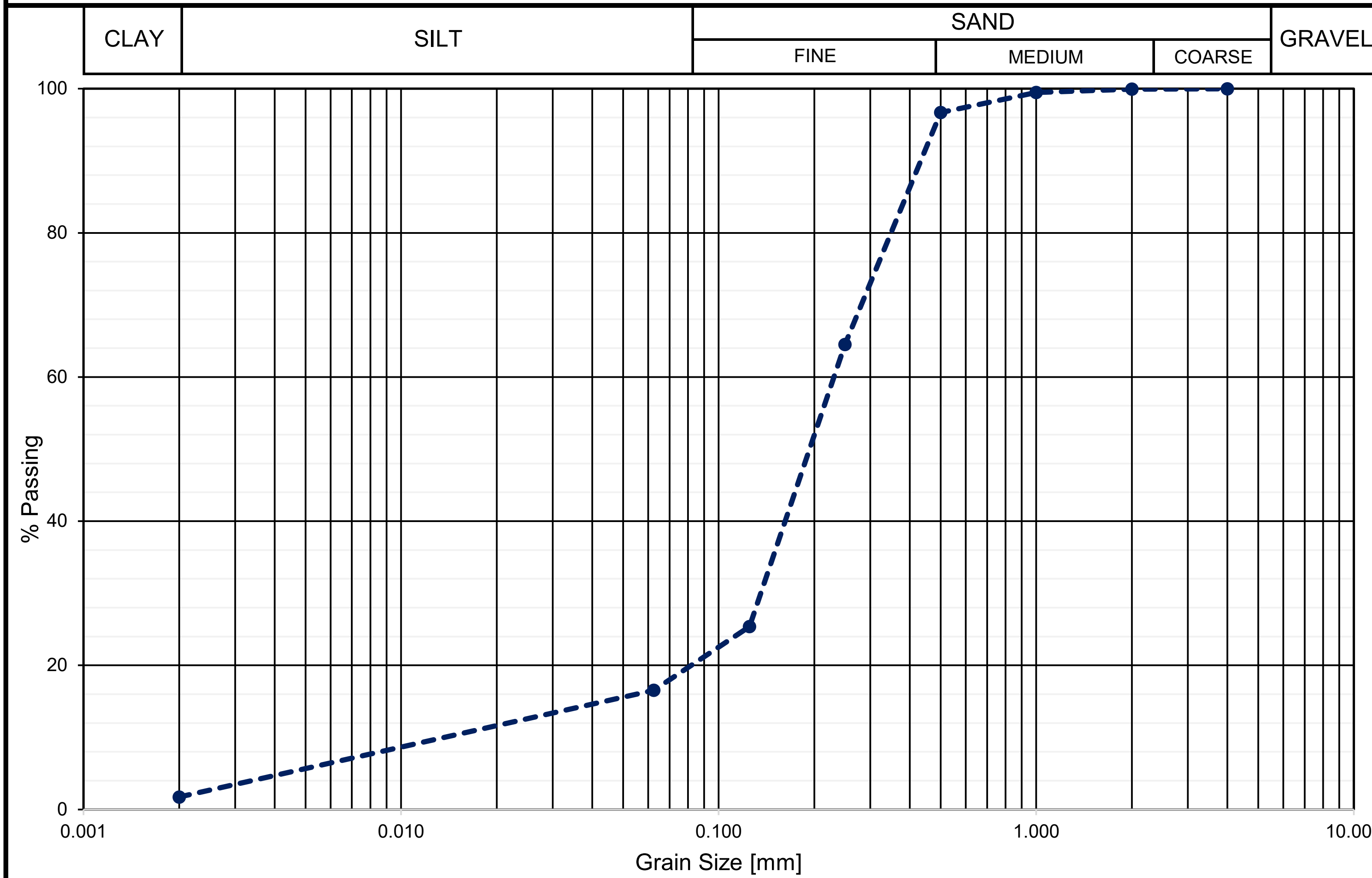
Borehole No.	**F3**	**Sample ID**	**F3 86**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	26.21	Sample Elevation [masl]	333.91
Drill Date:	January 21, 2023	Depth [ft]	86.00		



Note: Unified Soil Classification System (USCS) used for soil divisions
Consolidated unit is about 1" thick. Bulk sample was collected across a 1' thick unit.

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

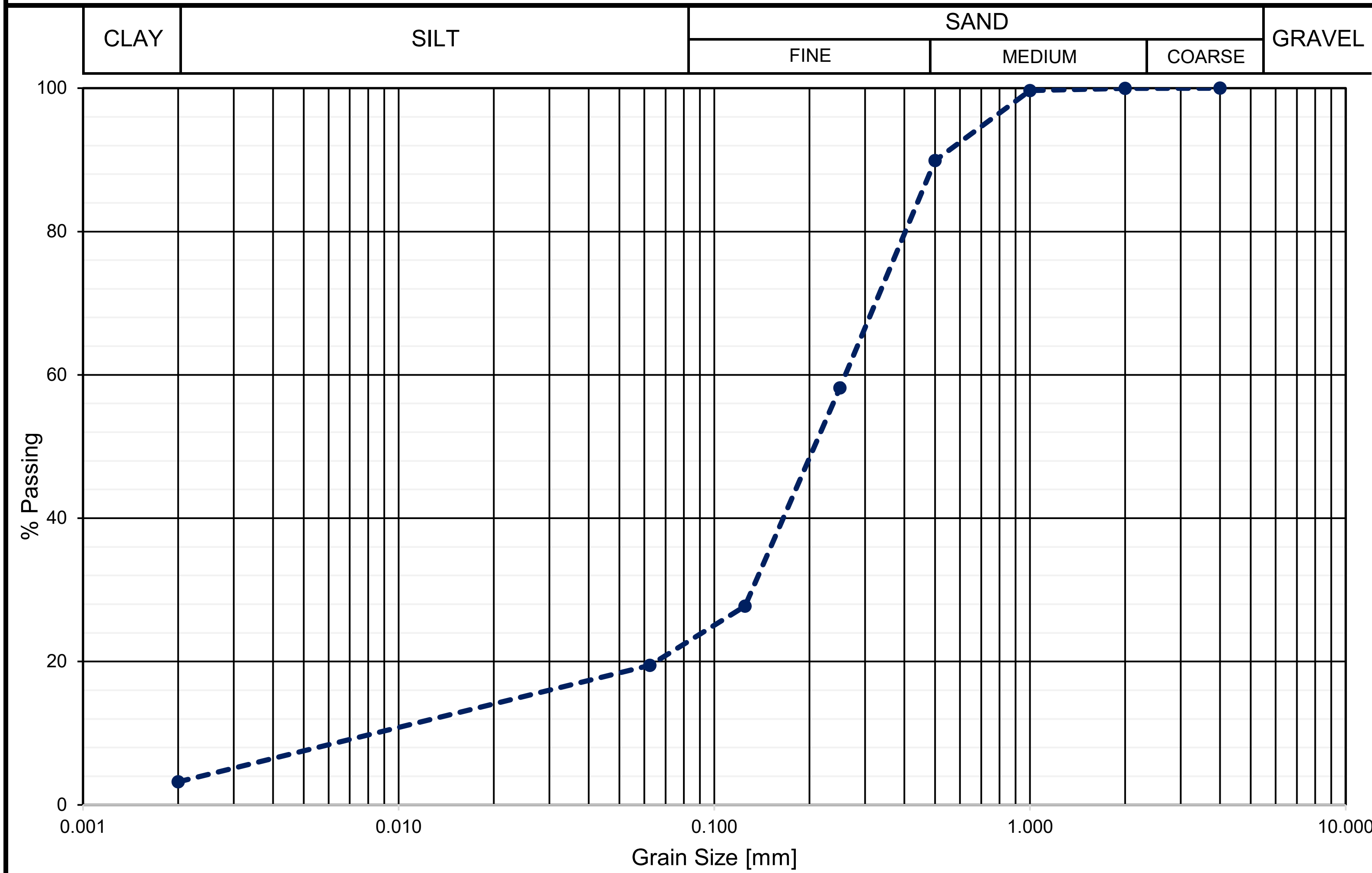
Borehole No.	F3	Sample ID	F3 87.5	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	26.67	Sample Elevation [masl]	333.45
Drill Date:	January 21, 2023	Depth [ft]	87.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

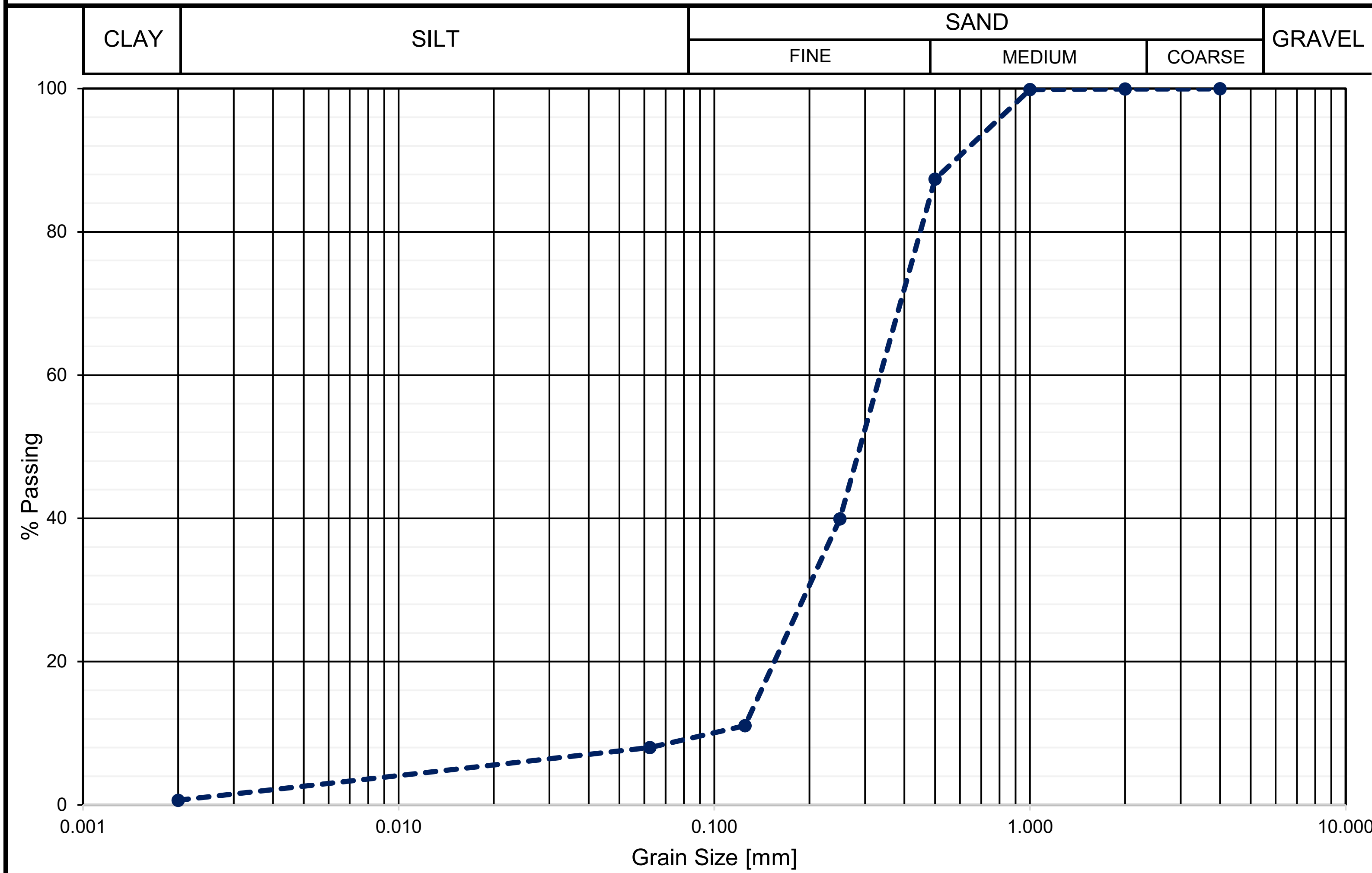
Borehole No.	F3	Sample ID	F3 89-94	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	27.89	Sample Elevation [masl]	332.23
Drill Date:	January 21, 2023	Depth [ft]	91.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

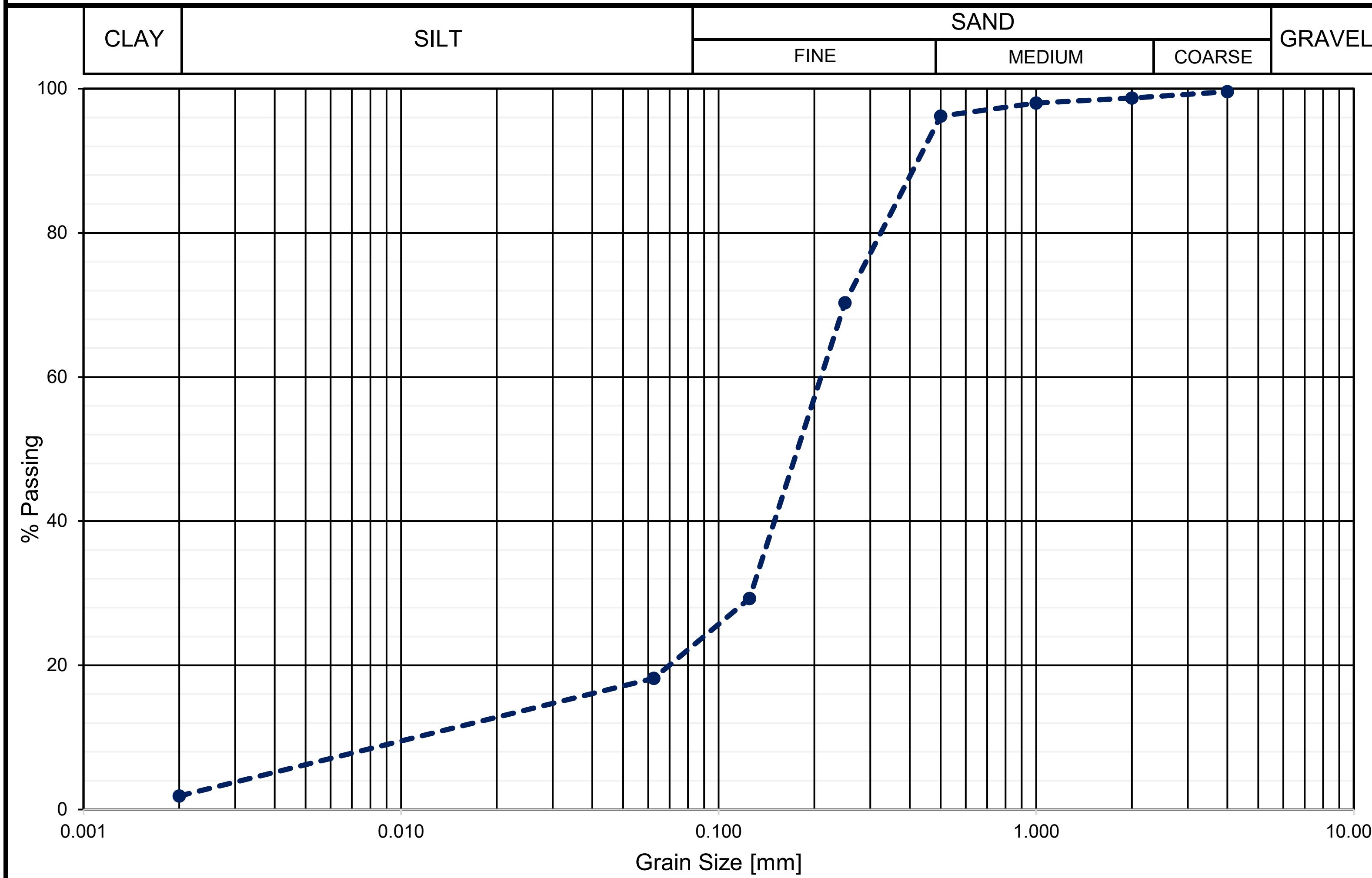
Borehole No.	F3	Sample ID	F3 96.5	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	29.41	Sample Elevation [masl]	330.71
Drill Date:	January 21, 2023	Depth [ft]	96.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

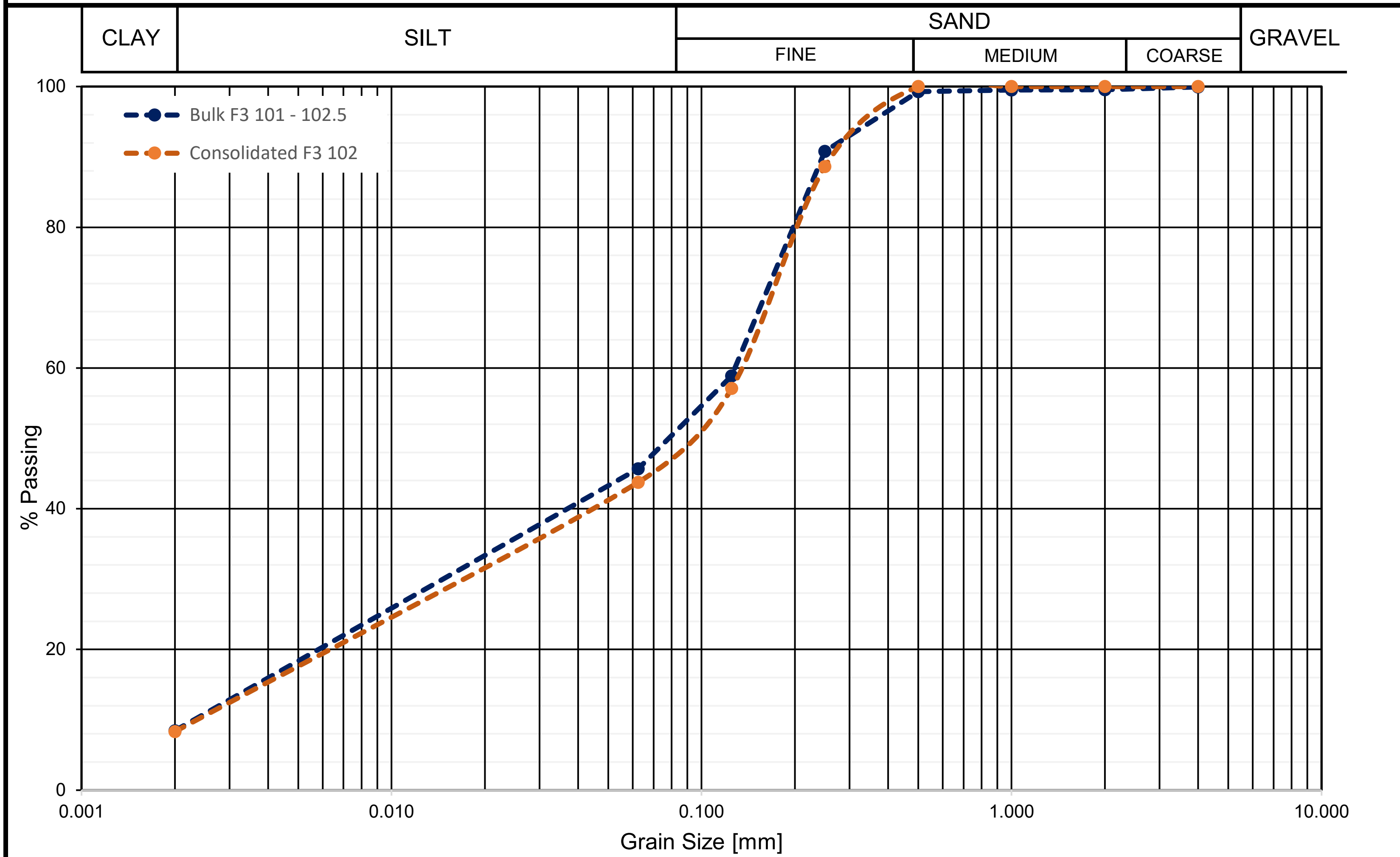
Borehole No.	**F3**	**Sample ID**	**F3 99-101**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	30.48	Sample Elevation [masl]	329.64
Drill Date:	January 21, 2023	Depth [ft]	100.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

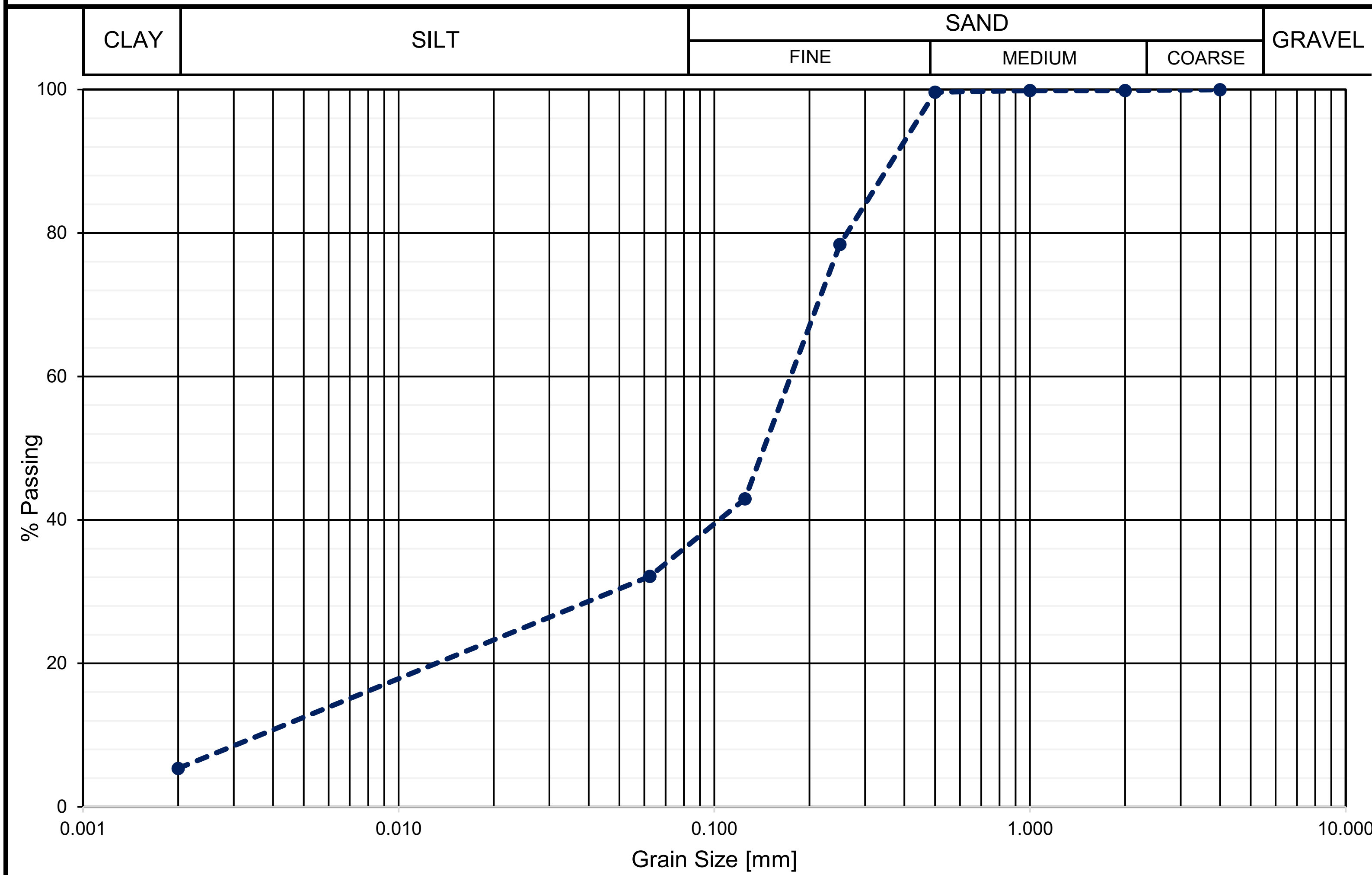
Borehole No. F3	Sample ID F3 101-102.5		**GRAIN SIZE ANALYSIS**
Project: Vaseux GW-SW Interaction Study	Depth [m] 31.09	Sample Elevation [masl]	329.03
Drill Date: January 21, 2023	Depth [ft] 102.00		



Note: Unified Soil Classification System (USCS) used for soil divisions
Consolidated unit is about 1" thick. Bulk sample was collected across a 1.5' thick unit.

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

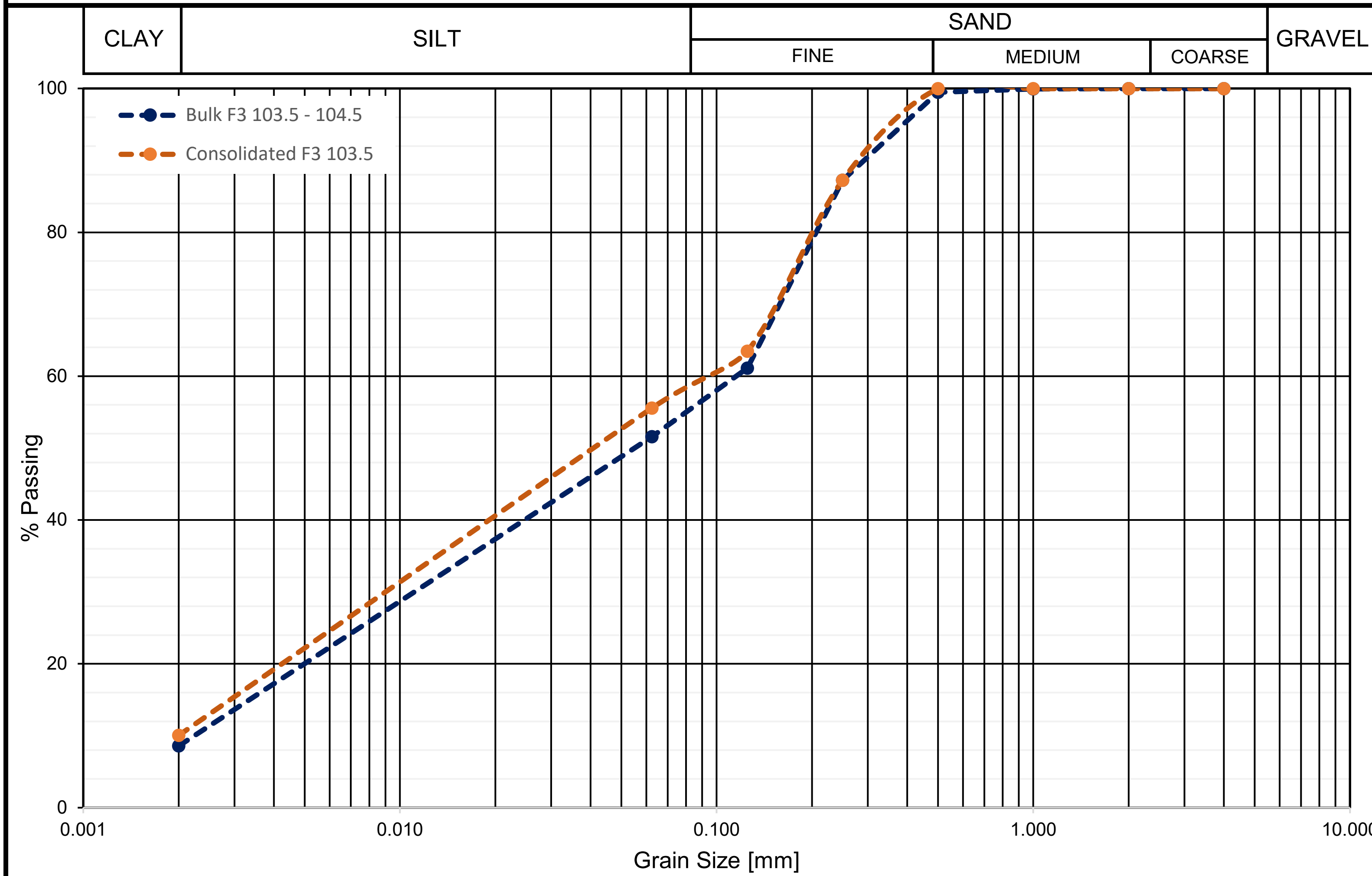
Borehole No.	F3	Sample ID	F3 102.5-103.5	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	31.39	Sample Elevation [masl]	328.73
Drill Date:	January 21, 2023	Depth [ft]	103.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

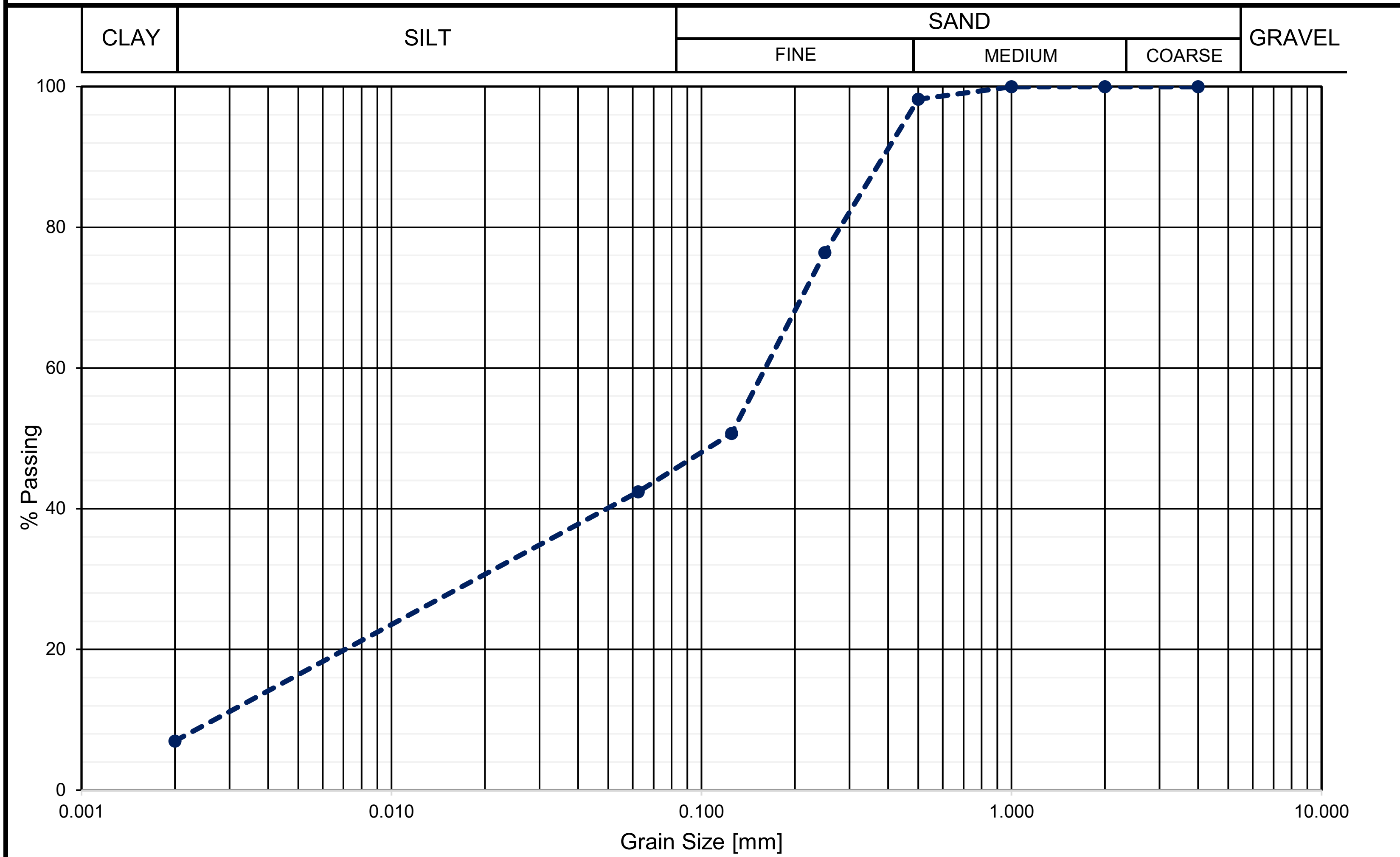
Borehole No. F3	**Sample ID F3 104**		**GRAIN SIZE ANALYSIS**
Project: Vaseux GW-SW Interaction Study	Depth [m] 31.55		Sample Elevation [masl] 328.57
Drill Date: January 21, 2023	Depth [ft] 103.50		



Note: Unified Soil Classification System (USCS) used for soil divisions
Consolidated unit is about 1" thick. Bulk sample was collected across a 1' thick unit.

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

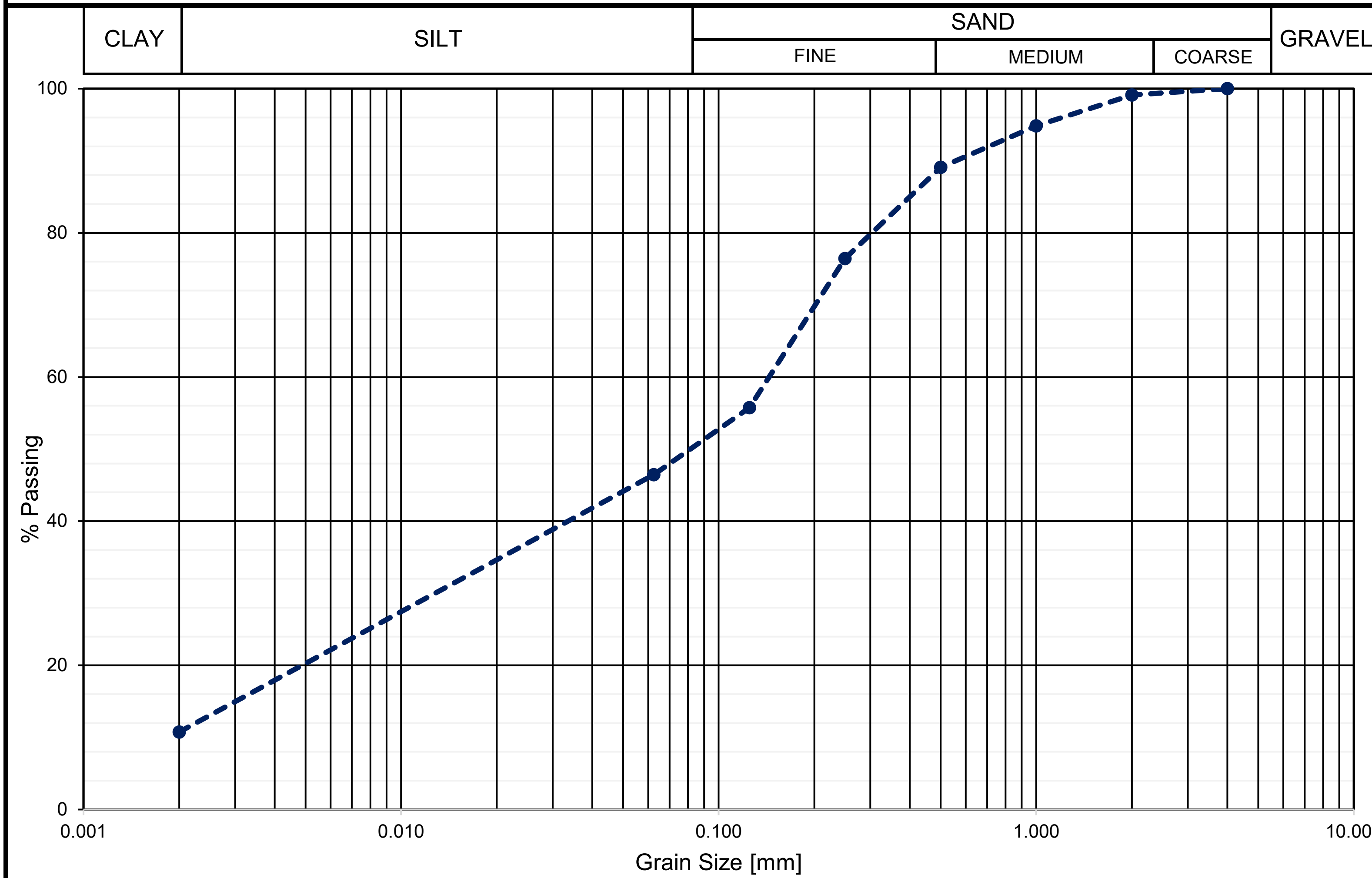
Borehole No. **F3**	**Sample ID** **F3 104.5**	**GRAIN SIZE ANALYSIS**	
Project: Vaseux GW-SW Interaction Study	Depth [m] 31.85	Sample Elevation [masl]	328.27
Drill Date: January 21, 2023	Depth [ft] 104.50		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

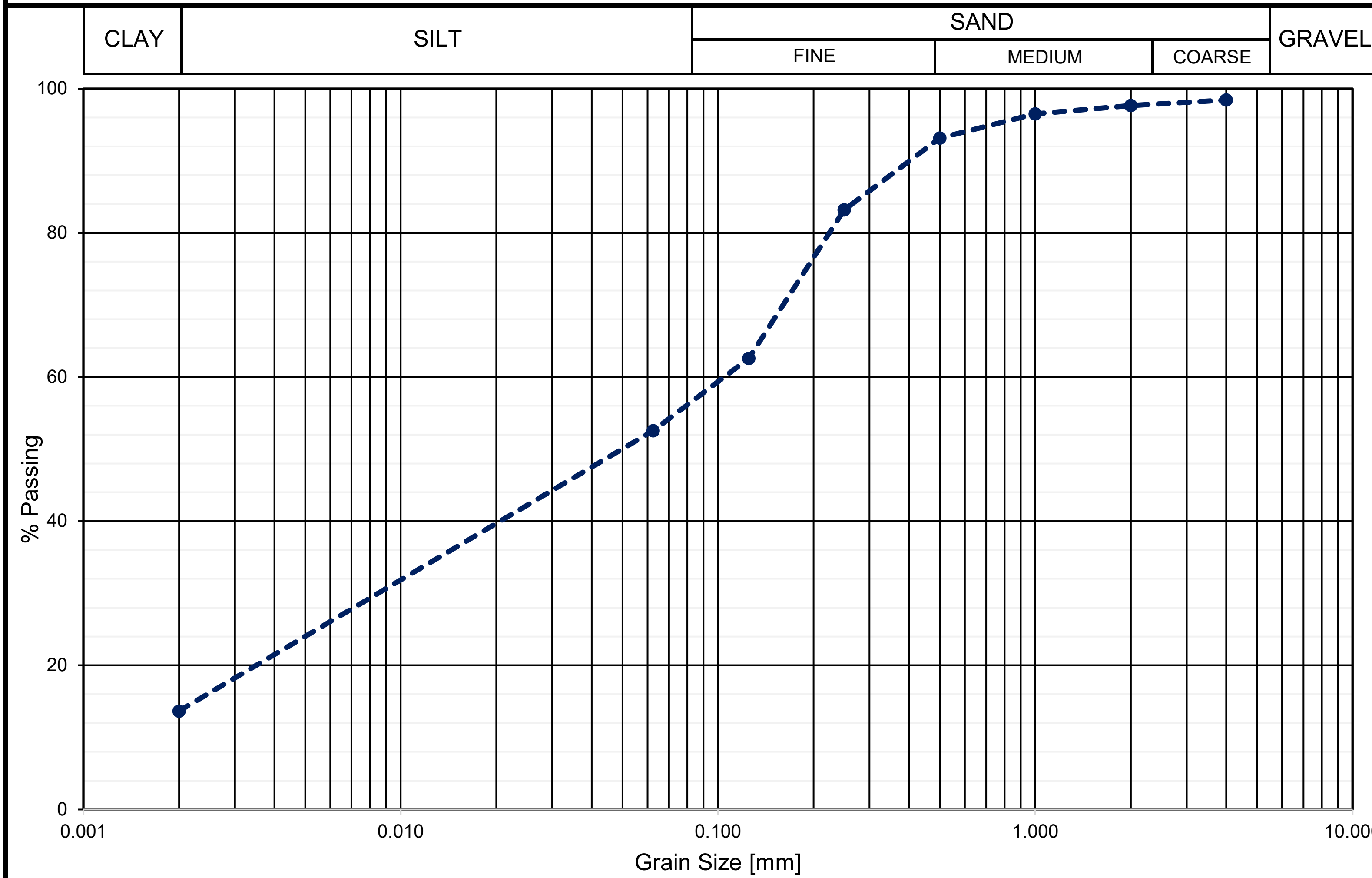
Borehole No.	F3	Sample ID	F3 105-105.5	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	32.00	Sample Elevation [masl]	328.12
Drill Date:	January 21, 2023	Depth [ft]	105.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

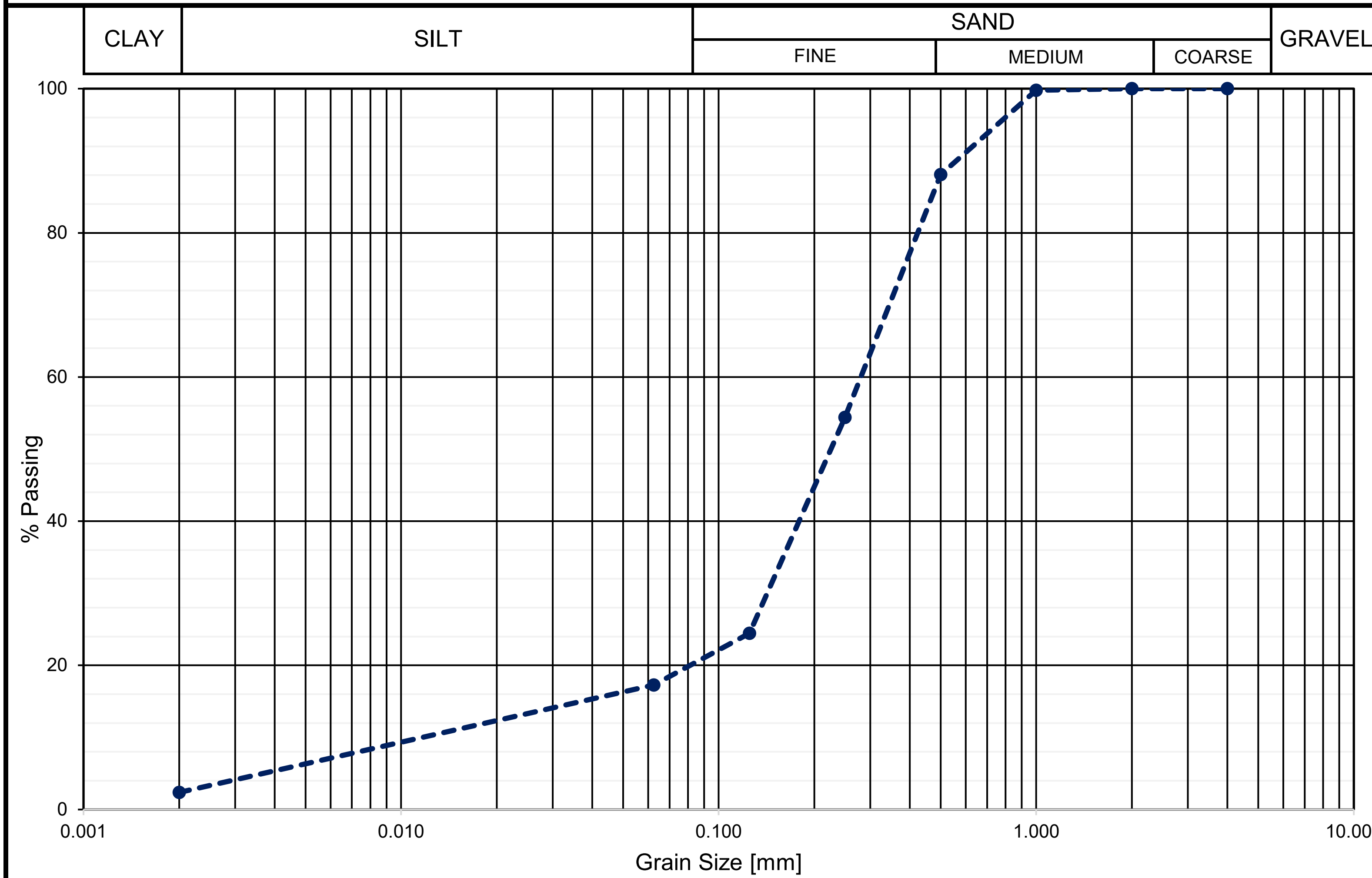
Borehole No.	**F3**	**Sample ID**	**F3 106**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	32.31	Sample Elevation [masl]	327.81
Drill Date:	January 21, 2023	Depth [ft]	106.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

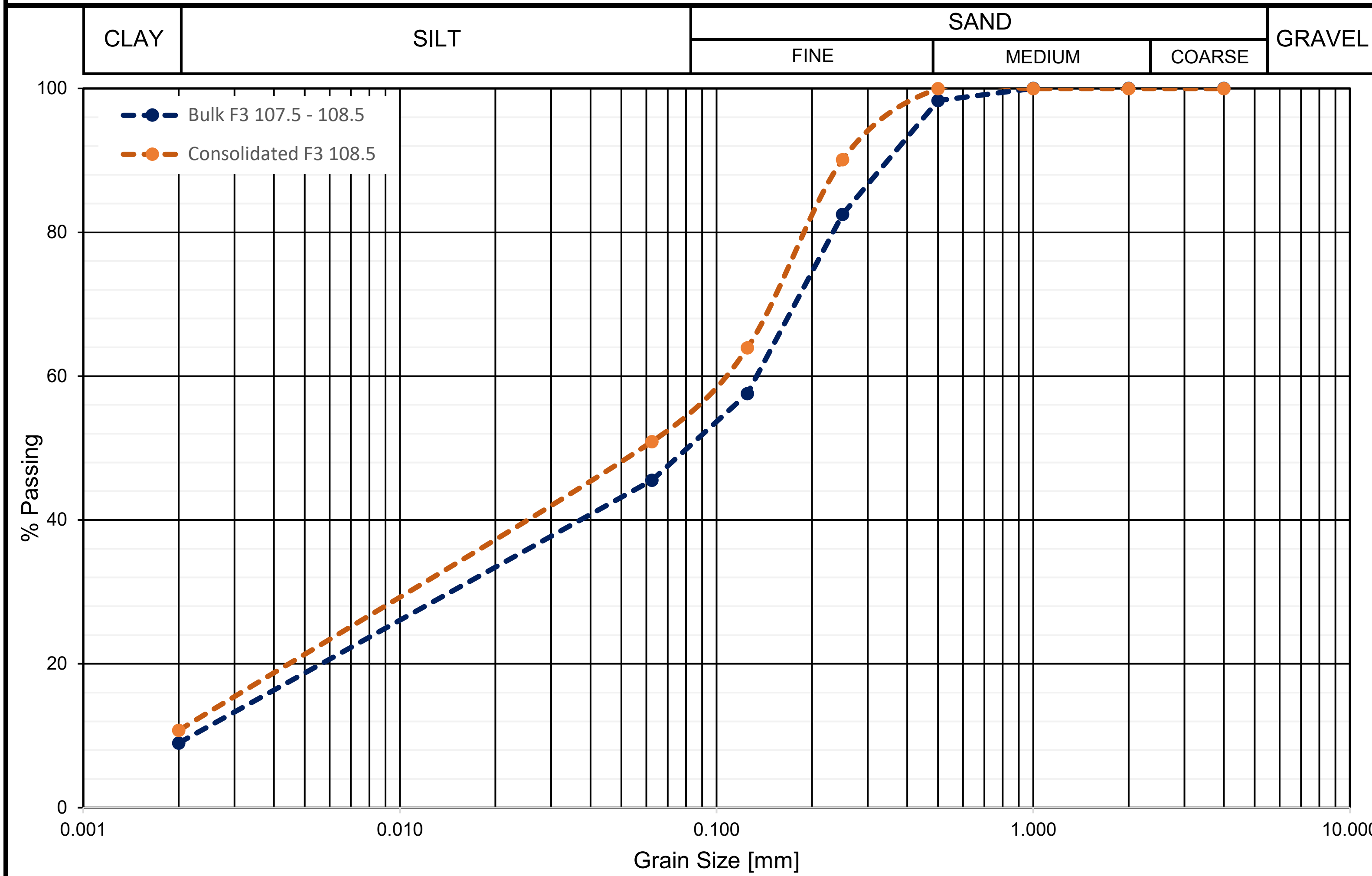
Borehole No.	F3	Sample ID	F3 107	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	32.61	Sample Elevation [masl]	327.51
Drill Date:	January 21, 2023	Depth [ft]	107.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

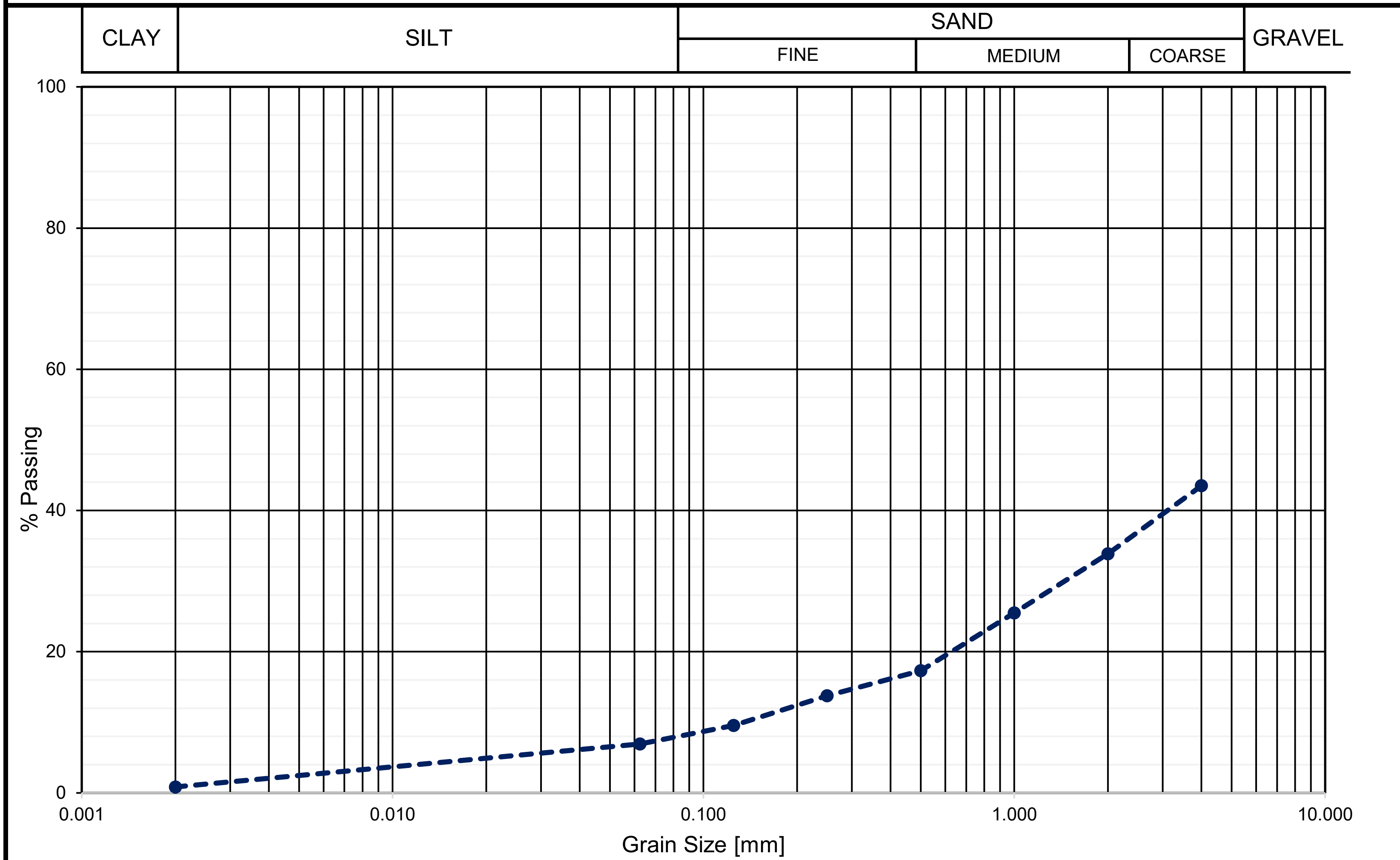
Borehole No. F3	Sample ID F3 107.5-108.5		GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m] 33.07	Sample Elevation [masl]	327.05
Drill Date:	January 21, 2023	Depth [ft] 108.50		



Note: Unified Soil Classification System (USCS) used for soil divisions
Consolidated unit is about 1" thick. Bulk sample was collected across a 1' thick unit.

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

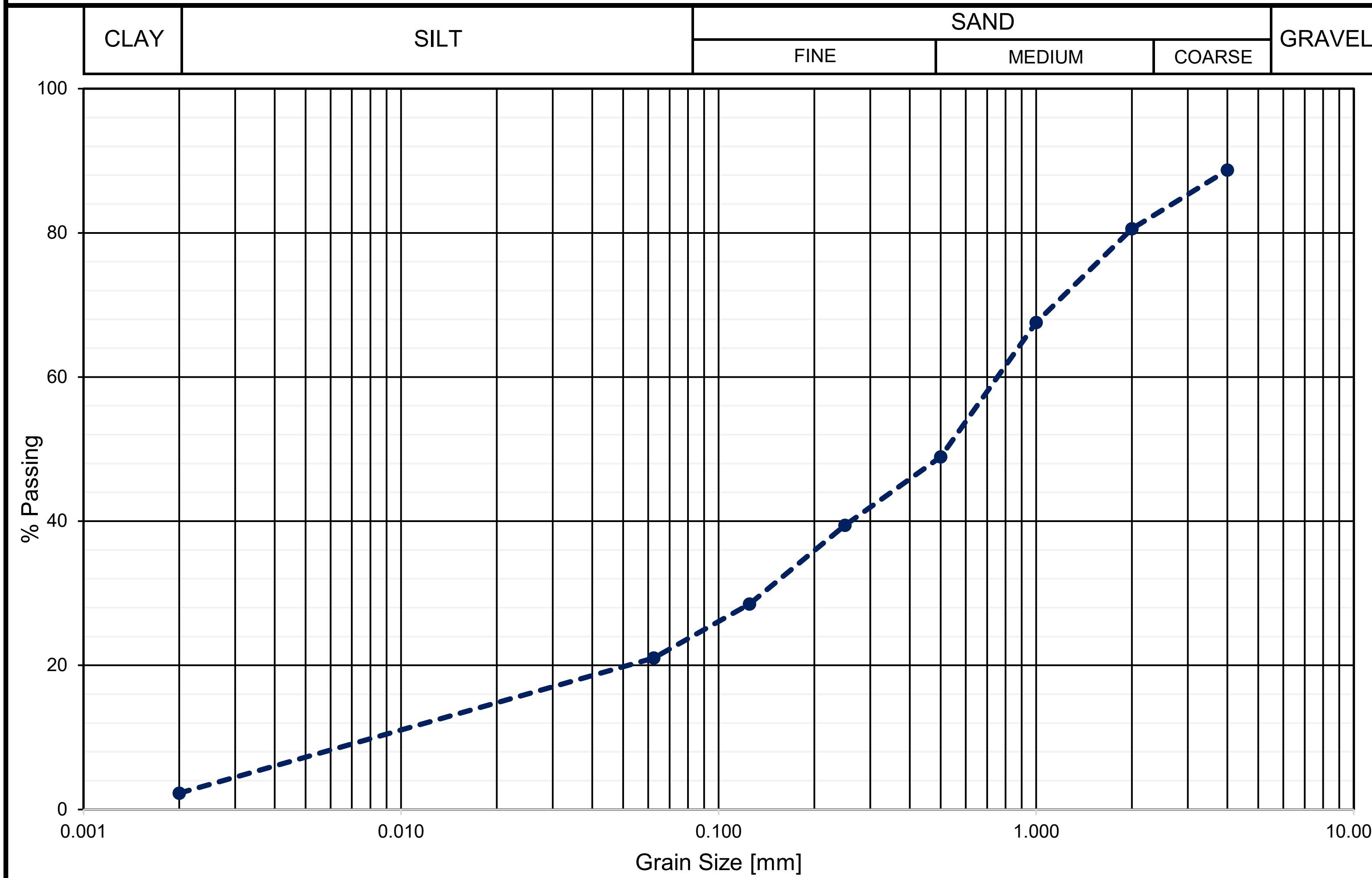
Borehole No.	**F3**	**Sample ID**	**F3 113-115**	**GRAIN SIZE ANALYSIS**	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	34.75	Sample Elevation [masl]	325.37
Drill Date:	January 21, 2023	Depth [ft]	114.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	F3	Sample ID	F3 116-119	GRAIN SIZE ANALYSIS	
Project:	Vaseux GW-SW Interaction Study	Depth [m]	35.81	Sample Elevation [masl]	324.31
Drill Date:	January 21, 2023	Depth [ft]	117.50		



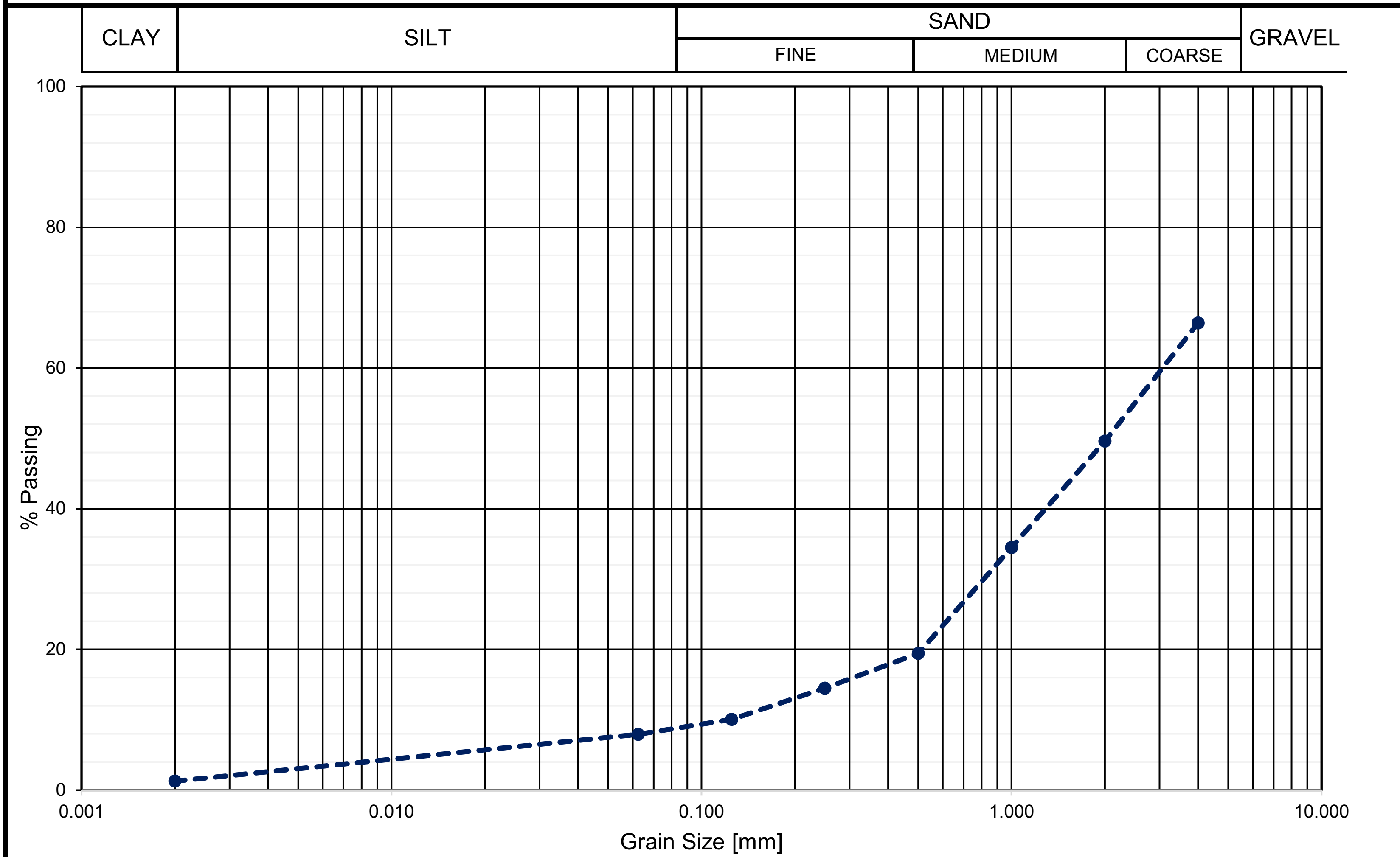
Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No.	**F3**	**Sample ID**	**F3 120-122**

GRAIN SIZE ANALYSIS

Project:	Vaseux GW-SW Interaction Study	Depth [m]	36.88	Sample Elevation [masl]	323.24
Drill Date:	January 21, 2023	Depth [ft]	121.00		

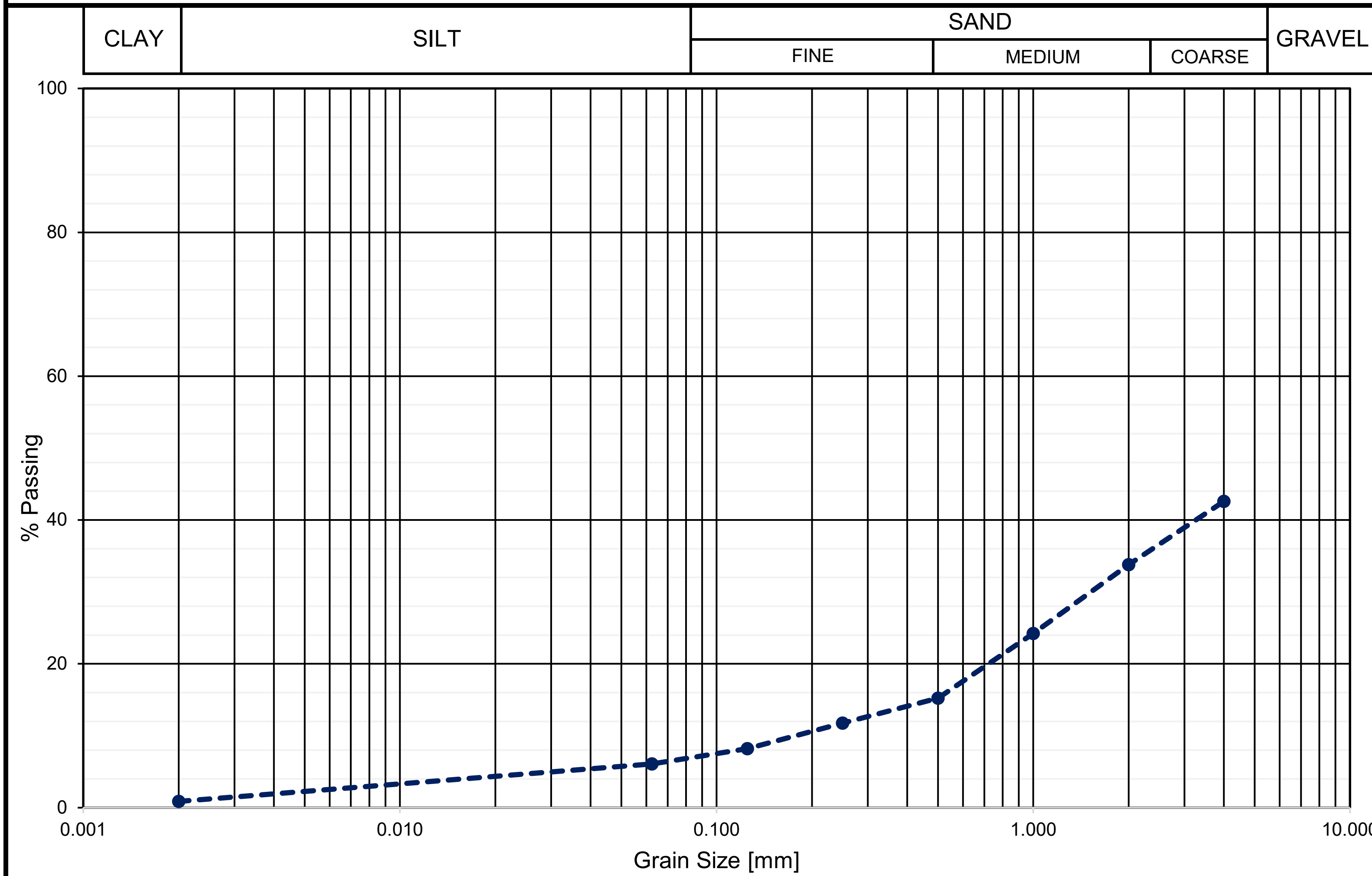


Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

Borehole No. F3	Sample ID F3 127-129	GRAIN SIZE ANALYSIS

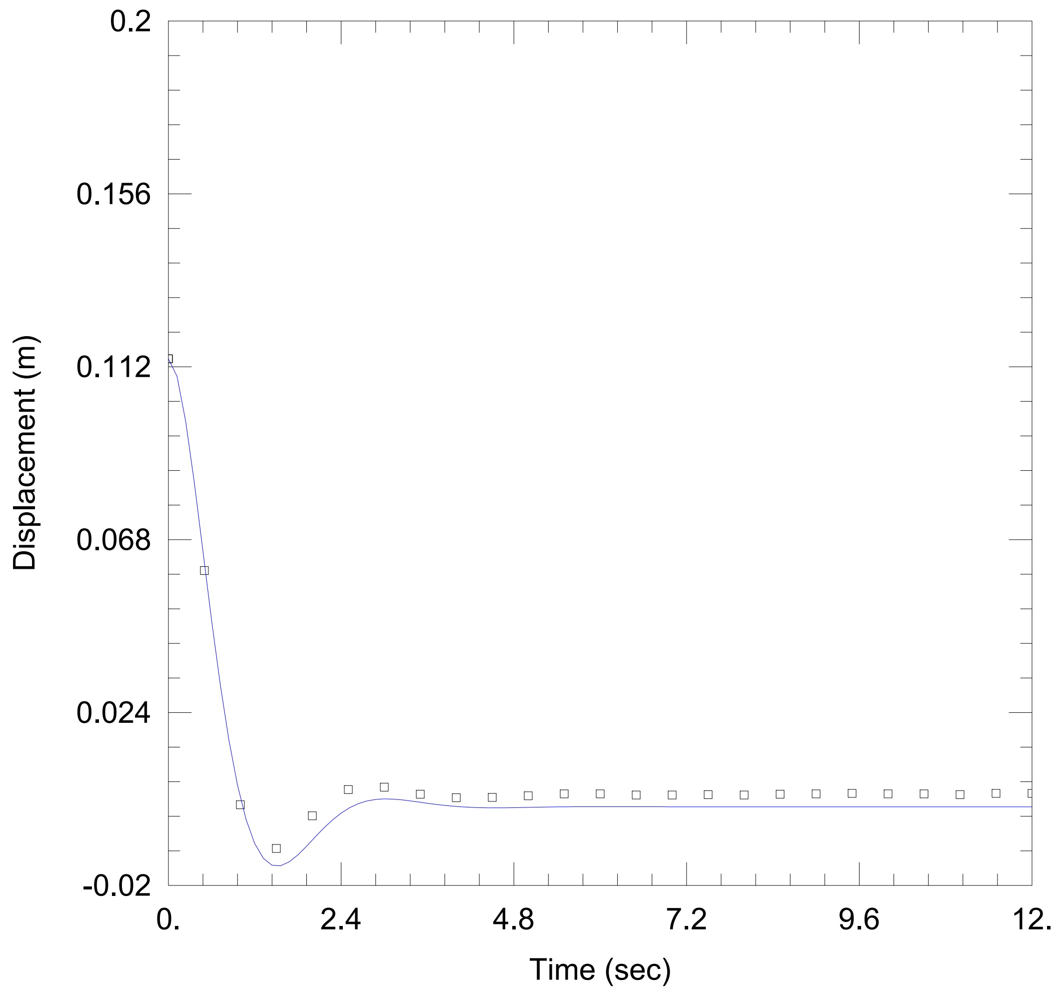
Project:	Vaseux GW-SW Interaction Study	Depth [m]	39.01	Sample Elevation [masl]	321.11
Drill Date:	January 21, 2023	Depth [ft]	128.00		



Note: Unified Soil Classification System (USCS) used for soil divisions

Particle Size Analysis by:
Water Resource Science Laboratory, UBC Okanagan

APPENDIX E. HYDRAULIC CONDUCTIVITY ANALYSIS



WELL TEST ANALYSIS

Data Set: Z:\...\C1A-1 out.aqt
Date: 12/08/23 Time: 14:47:18

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: C1A Test 1 In
Test Date: 6-Apr-2023

AQUIFER DATA

Saturated Thickness: 19.93 m Anisotropy Ratio (Kz/Kr): 0.5

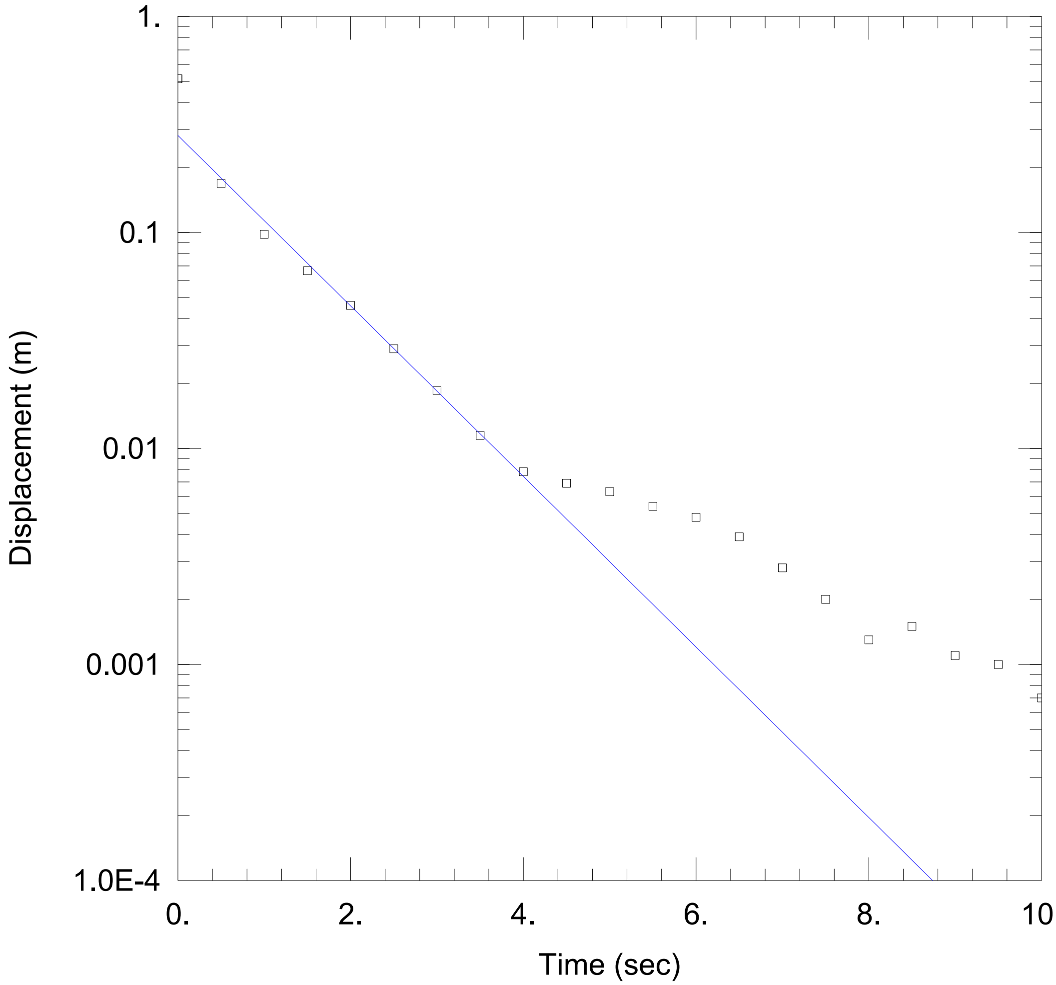
WELL DATA (New Well)

Initial Displacement: 0.114 m
Total Well Penetration Depth: 2.335 m
Casing Radius: 0.0254 m
Static Water Column Height: 2.485 m
Screen Length: 1.424 m
Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Springer-Gelhar

K = 0.001122 m/sec Le = 1.607 m



WELL TEST ANALYSIS

Data Set: Z:\...\C_1B Test 2 231130.aqt
Date: 12/08/23
Time: 15:05:10

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: C1_B Test 1
Test Date: 6-Apr-2023

AQUIFER DATA

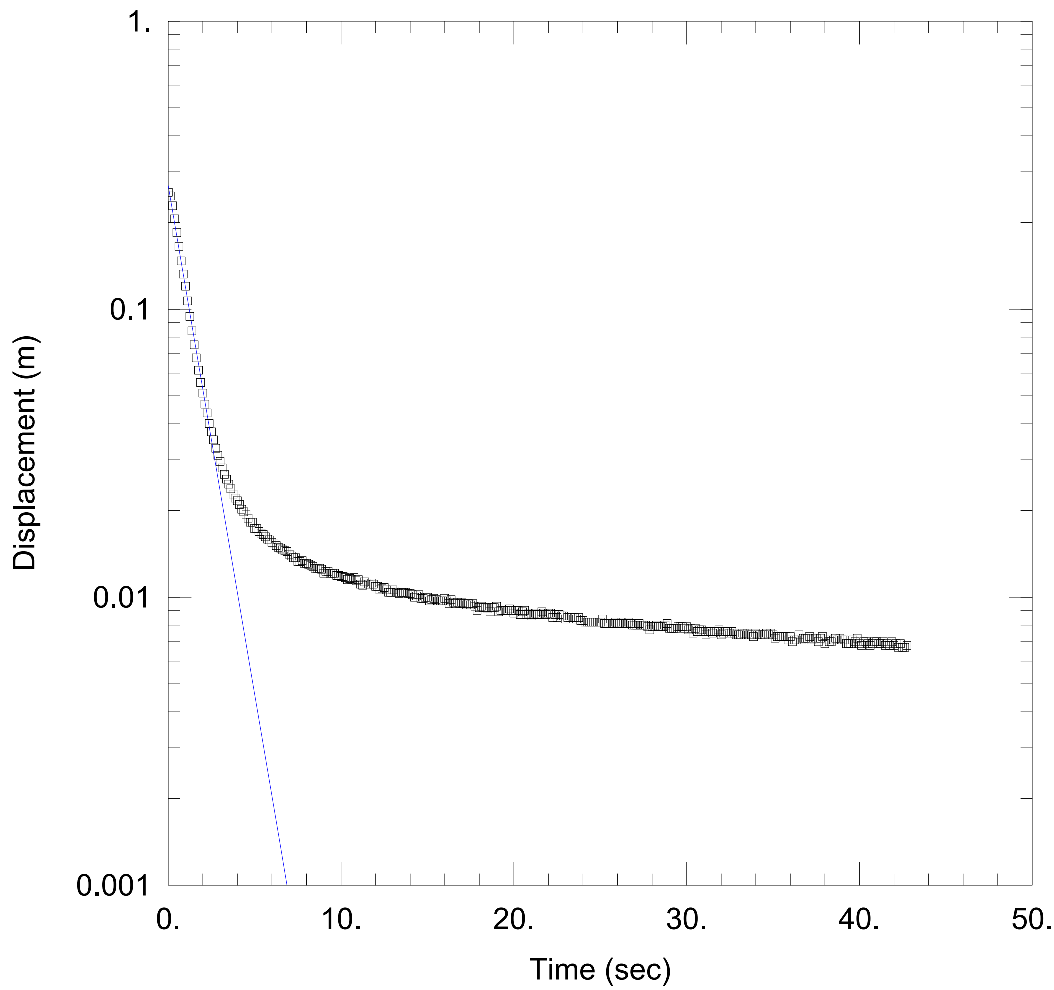
Saturated Thickness: 19.17 m
Anisotropy Ratio (Kz/Kr): 0.5

WELL DATA (C1_B)

Initial Displacement: 0.5149 m
Total Well Penetration Depth: 7.42 m
Casing Radius: 0.0254 m
Static Water Column Height: 7.42 m
Screen Length: 1.524 m
Well Radius: 0.03015 m
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.0006647 m/sec
y0 = 0.2812 m



WELL TEST ANALYSIS

Data Set: Z:\...\C2-2out 2023 Nov.aqt
Date: 12/08/23 Time: 15:19:22

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: C2
Test Date: Nov 8, 2023

AQUIFER DATA

Saturated Thickness: 32.61 m Anisotropy Ratio (Kz/Kr): 0.5

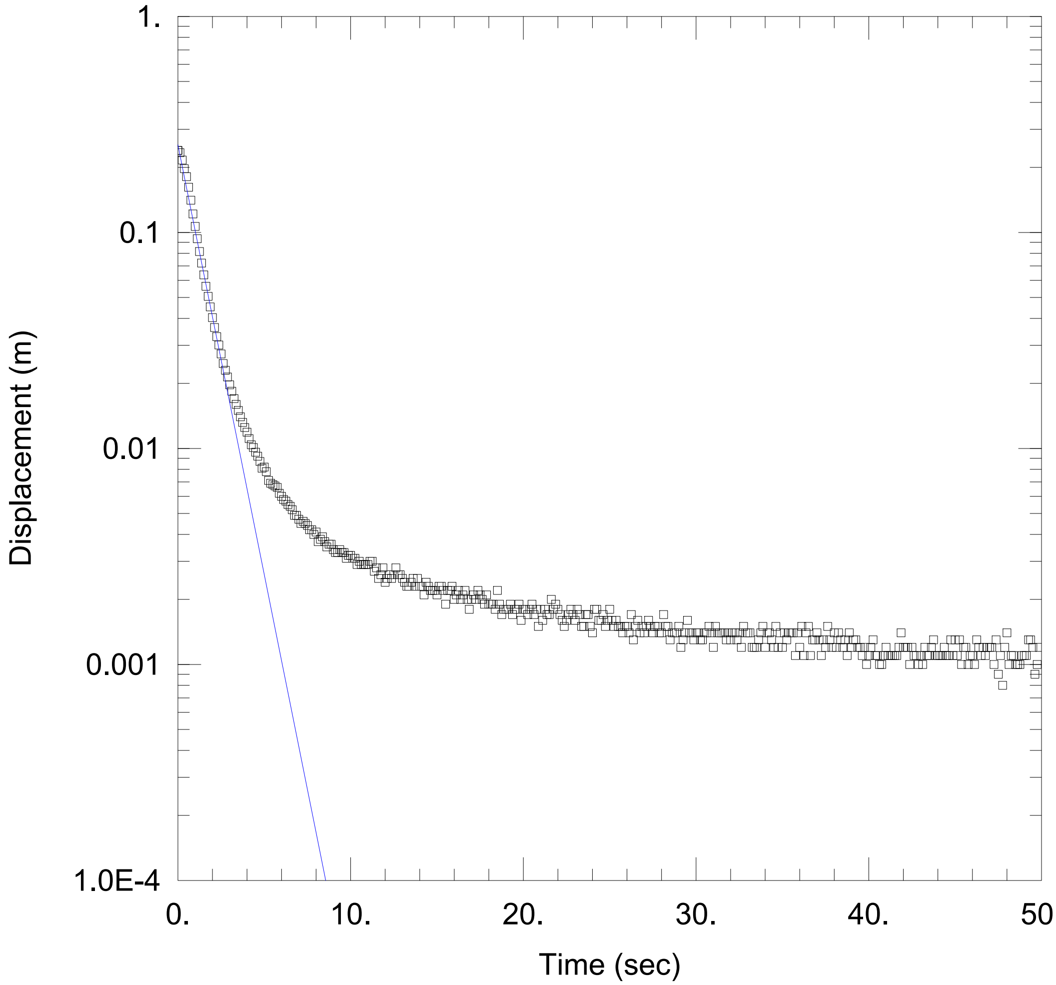
WELL DATA (New Well)

Initial Displacement: 0.2546 m Static Water Column Height: 2.731 m
Total Well Penetration Depth: 2.581 m Screen Length: 1.424 m
Casing Radius: 0.0254 m Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.0004018 m/sec y0 = 0.2681 m



WELL TEST ANALYSIS

Data Set: Z:\...\C2-10out 2023 Nov.aqt
Date: 12/08/23
Time: 15:21:30

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: C2
Test Date: Nov 8, 2023

AQUIFER DATA

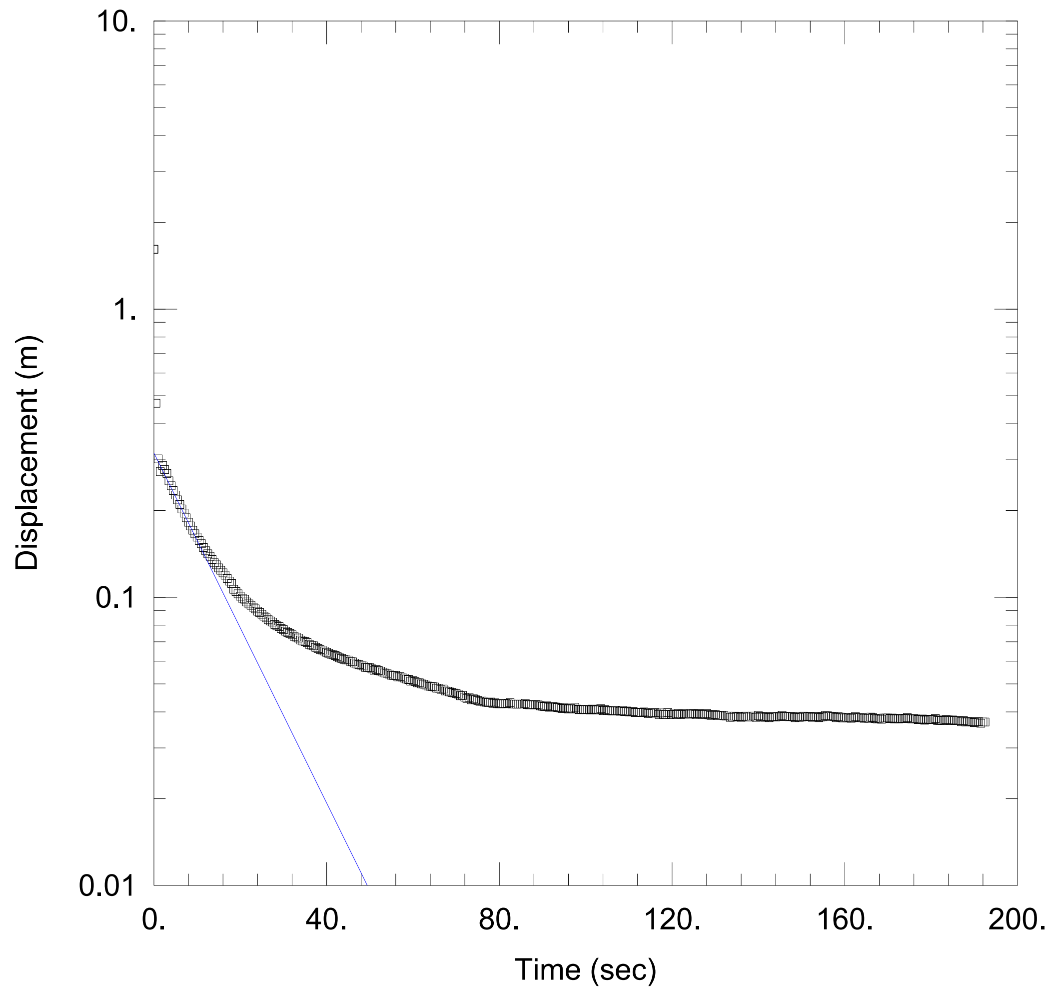
Saturated Thickness: 32.61 m
Anisotropy Ratio (Kz/Kr): 0.5

WELL DATA (New Well)

Initial Displacement: 0.2398 m
Total Well Penetration Depth: 2.59 m
Casing Radius: 0.0254 m
Static Water Column Height: 2.74 m
Screen Length: 1.424 m
Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.0004532 m/sec
y0 = 0.2544 m



WELL TEST ANALYSIS

Data Set: Z:\...\C5-1 in.aqt
Date: 12/08/23
Time: 15:51:50

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: C5 Test 1
Test Date: 16-May-2023

AQUIFER DATA

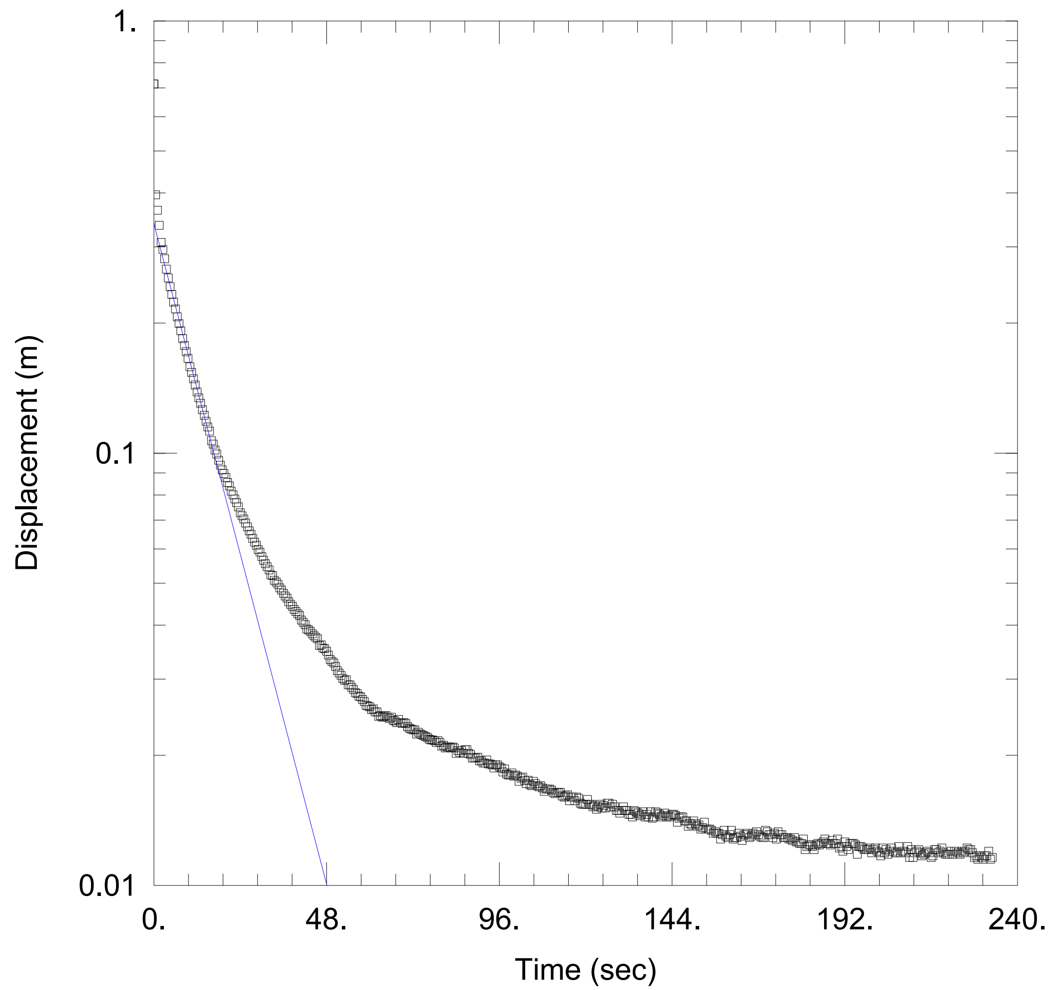
Saturated Thickness: 3.626 m
Anisotropy Ratio (Kz/Kr): 0.5

WELL DATA (C5)

Initial Displacement: 1.612 m
Total Well Penetration Depth: 3.476 m
Casing Radius: 0.0254 m
Static Water Column Height: 3.626 m
Screen Length: 1.424 m
Well Radius: 0.07625 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 4.316E-5 m/sec
y0 = 0.3168 m



WELL TEST ANALYSIS

Data Set: Z:\...\C5-1 out.aqt
Date: 12/08/23 Time: 15:52:58

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: C5 Test 1
Test Date: 16-May-2023

AQUIFER DATA

Saturated Thickness: 3.639 m Anisotropy Ratio (Kz/Kr): 0.5

WELL DATA (C5)

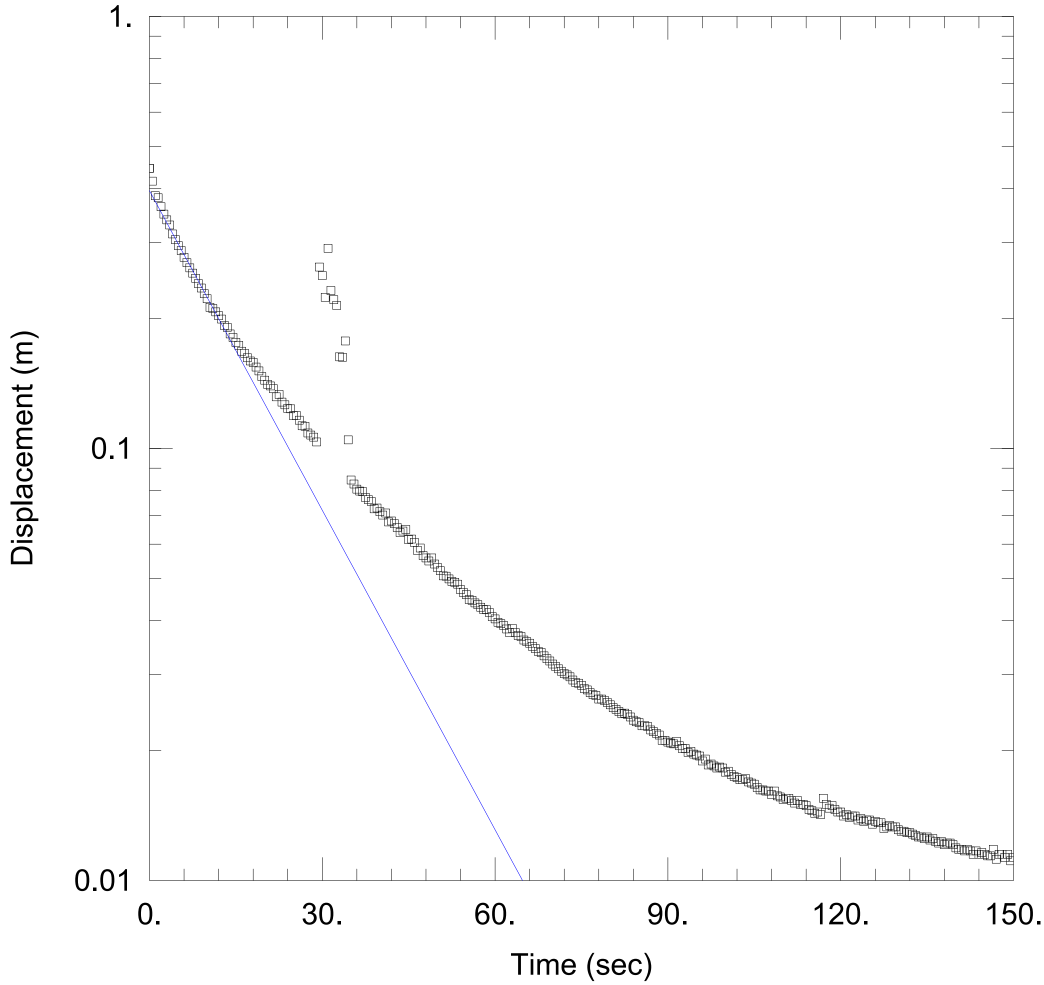
Initial Displacement: 0.7151 m
Total Well Penetration Depth: 3.489 m
Casing Radius: 0.0254 m

Static Water Column Height: 3.639 m
Screen Length: 1.424 m
Well Radius: 0.07625 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 4.528E-5 m/sec y0 = 0.3395 m



WELL TEST ANALYSIS

Data Set: Z:\...\F2-1 out.aqt
Date: 12/08/23
Time: 16:48:51

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: F2 Test 1 out
Test Date: 16-May-2023

AQUIFER DATA

Saturated Thickness: 20. m
Anisotropy Ratio (Kz/Kr): 0.5

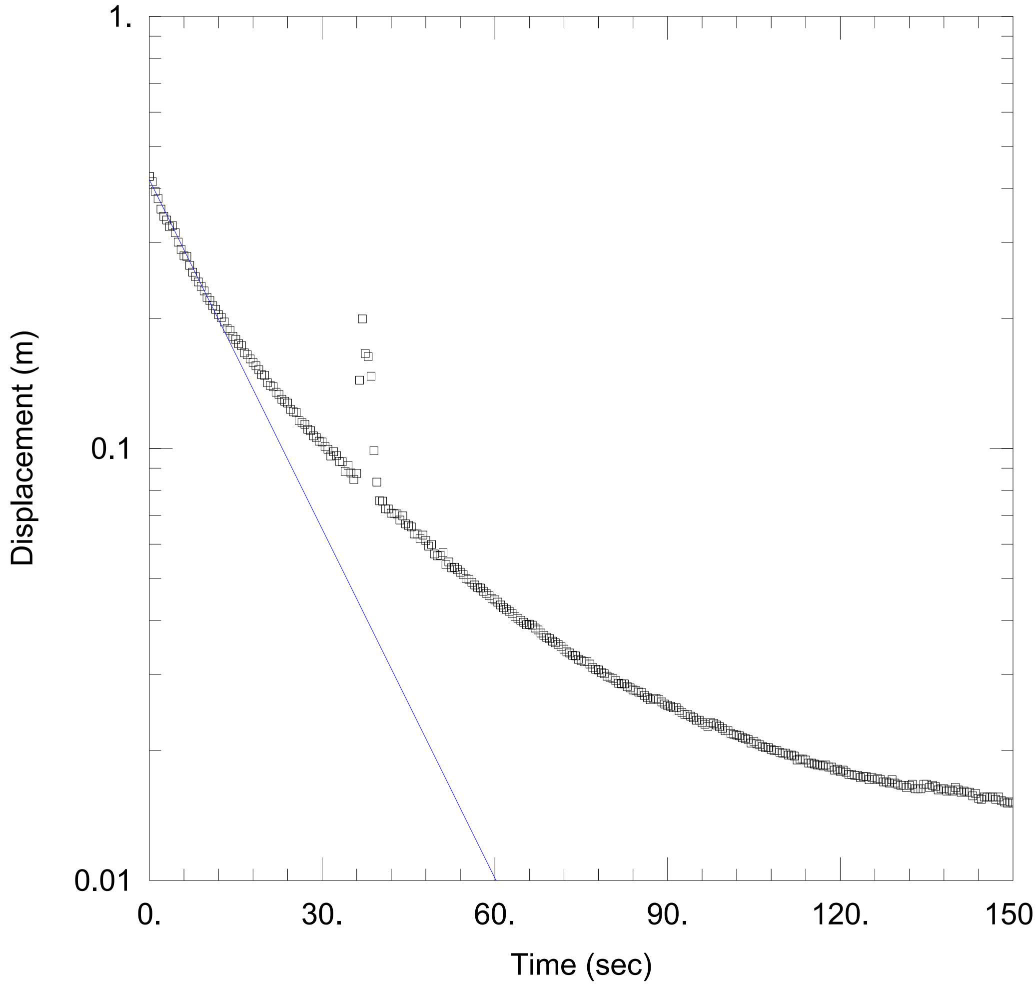
WELL DATA (F2 Test 1 (Out))

Initial Displacement: 0.4448 m
Total Well Penetration Depth: 8.673 m
Casing Radius: 0.254 m
Static Water Column Height: 8.823 m
Screen Length: 1.424 m
Well Radius: 0.07625 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.003372 m/sec
y0 = 0.3948 m



WELL TEST ANALYSIS

Data Set: Z:\...\F2-2 out.aqt
Date: 12/08/23
Time: 16:49:53

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: F2 Test 1 In
Test Date: 16-May-2023

AQUIFER DATA

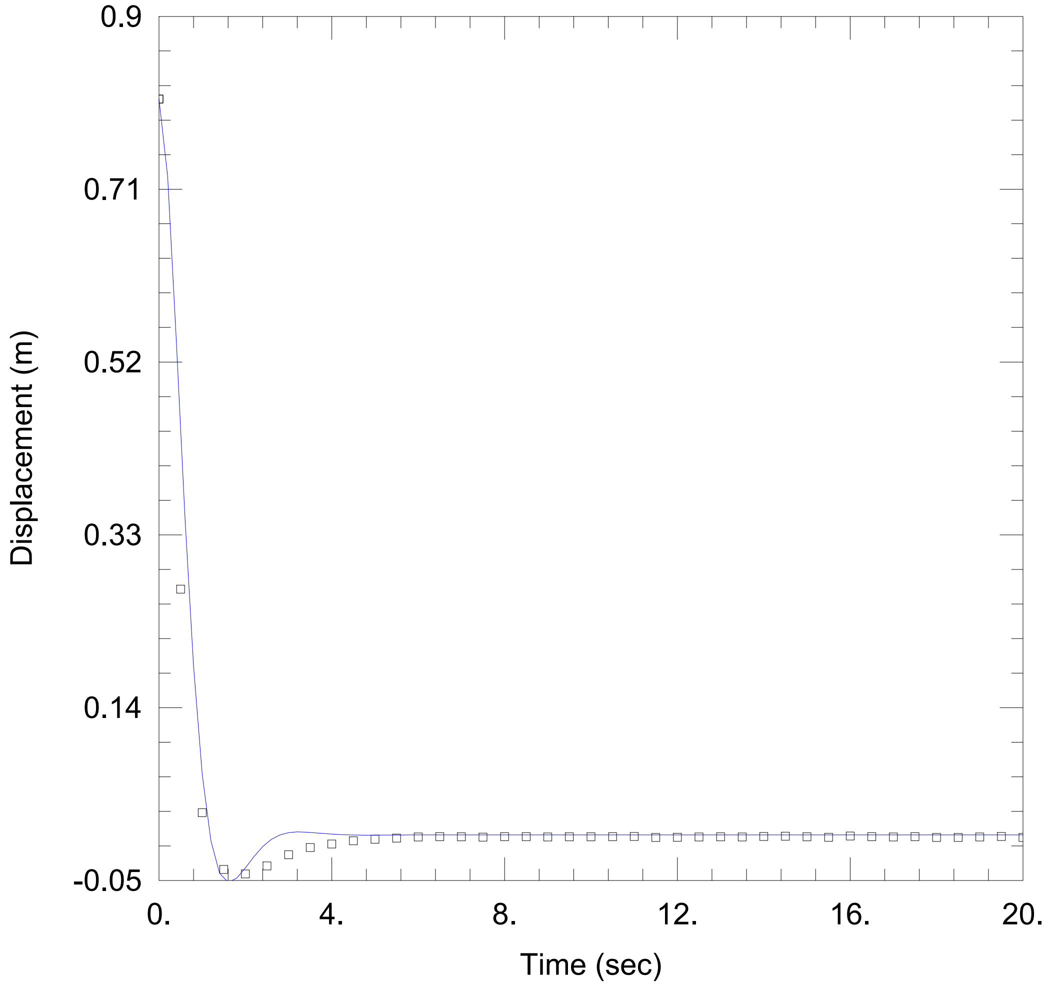
Saturated Thickness: 20. m
Anisotropy Ratio (Kz/Kr): 0.5

WELL DATA (F2 Test 2 (Out))

Initial Displacement: 0.4264 m
Static Water Column Height: 8.823 m
Total Well Penetration Depth: 8.673 m
Screen Length: 1.424 m
Casing Radius: 0.254 m
Well Radius: 0.07625 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.003685 m/sec
y0 = 0.4184 m



WELL TEST ANALYSIS

Data Set: Z:\...\F3-1 out.aqt
Date: 12/08/23
Time: 17:36:01

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: F3 Test 1 Out
Test Date: 18-May-2023

AQUIFER DATA

Saturated Thickness: 20. m
Anisotropy Ratio (Kz/Kr): 1.

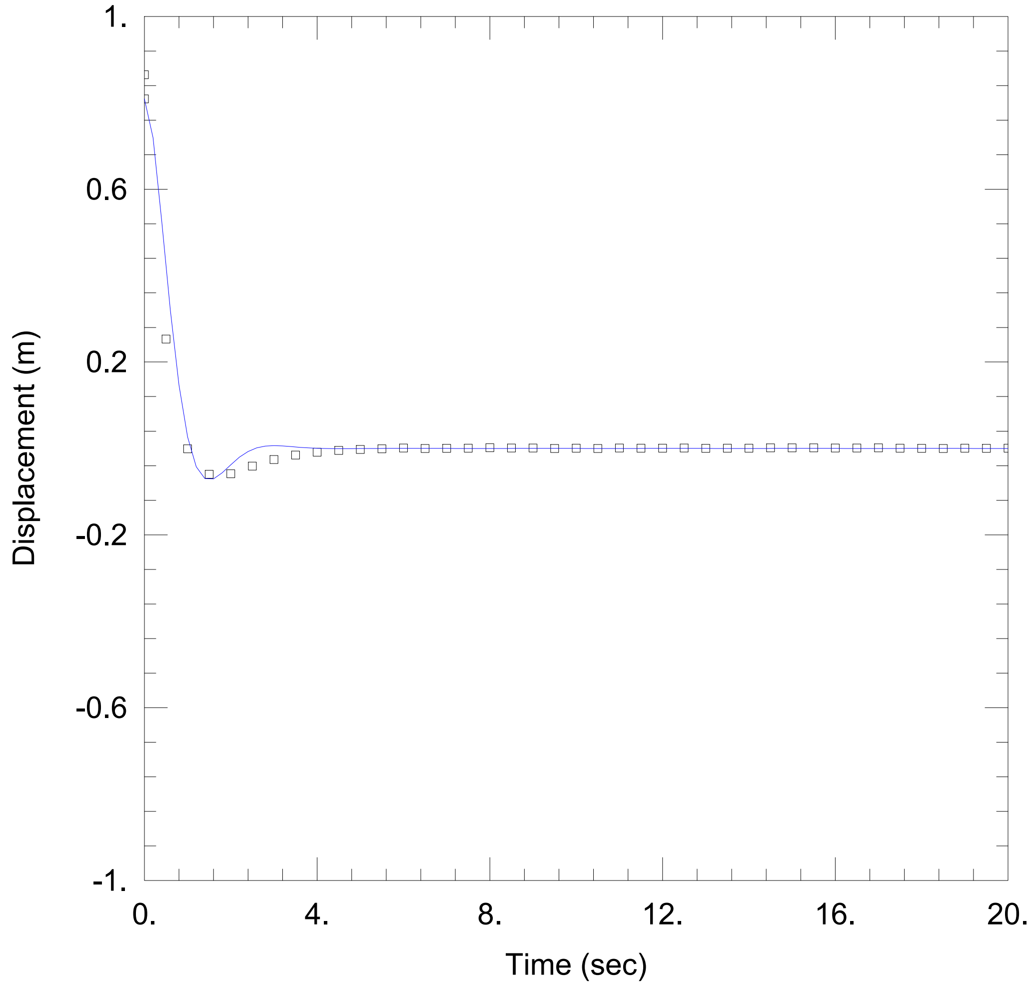
WELL DATA (F3 Test 1 out)

Initial Displacement: 0.8091 m
Total Well Penetration Depth: 5.103 m
Casing Radius: 0.0254 m
Static Water Column Height: 5.253 m
Screen Length: 1.424 m
Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar

K = 0.0009608 m/sec
Le = 1.476 m



WELL TEST ANALYSIS

Data Set: Z:\...\F3-2 out.aqt
Date: 12/08/23 Time: 17:46:26

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: F3 Test 2 Out
Test Date: 18-May-2023

AQUIFER DATA

Saturated Thickness: 5.253 m Anisotropy Ratio (Kz/Kr): 1.

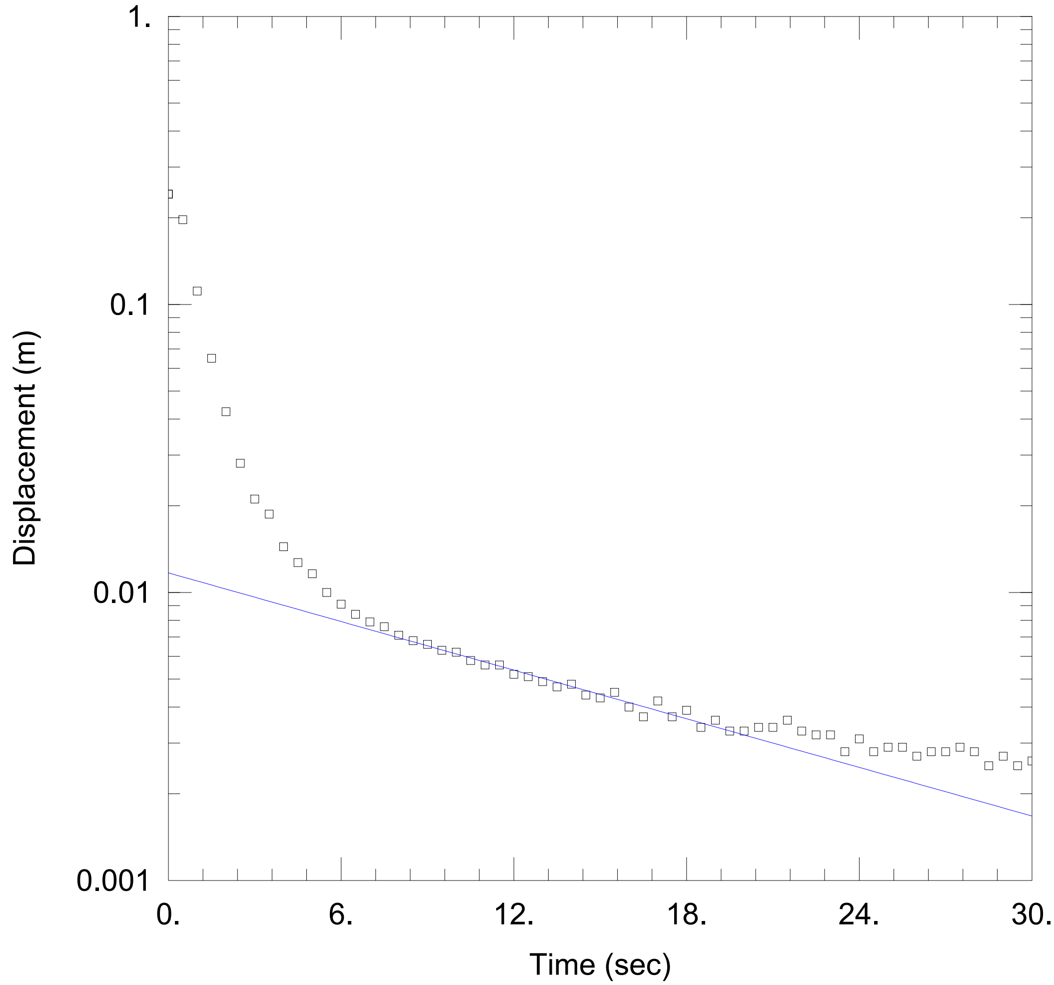
WELL DATA (New Well)

Initial Displacement: 0.8091 m
Total Well Penetration Depth: 5.103 m
Casing Radius: 0.0254 m
Static Water Column Height: 5.253 m
Screen Length: 1.424 m
Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Springer-Gelhar

K = 0.001288 m/sec Le = 1.406 m



WELL TEST ANALYSIS

Data Set: Z:\...\ONA_Deer_Park_1 out.aqt
Date: 12/08/23 Time: 17:49:15

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: ONA Deer Park 1_Out
Test Date: 18-May-2023

AQUIFER DATA

Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 0.5

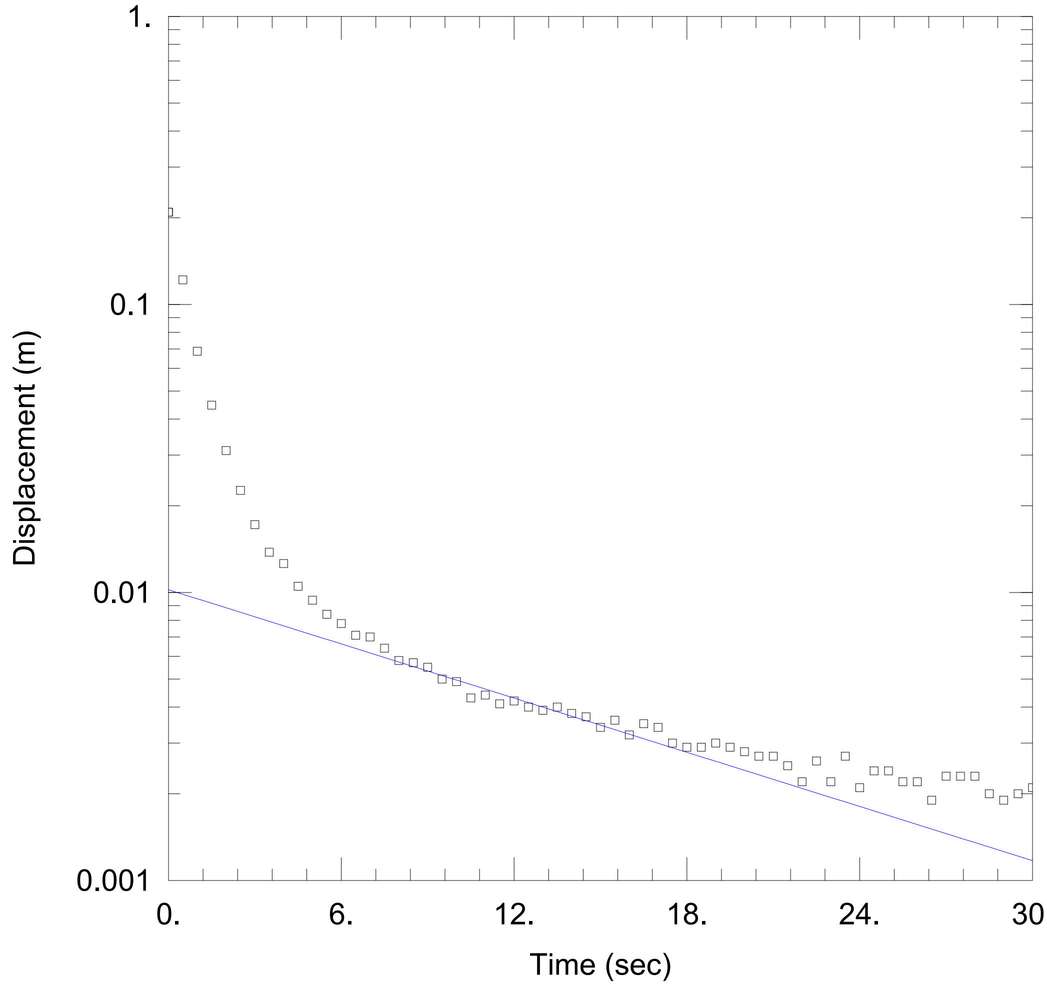
WELL DATA (F2 Test 2 (Out))

Initial Displacement: 0.2417 m Static Water Column Height: 1.638 m
Total Well Penetration Depth: 1.488 m Screen Length: 1.424 m
Casing Radius: 0.254 m Well Radius: 0.07625 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.002916 m/sec y0 = 0.01169 m



WELL TEST ANALYSIS

Data Set: Z:\...\ONA_Deer_Park_2 out.aqt
Date: 12/08/23
Time: 17:51:05

PROJECT INFORMATION

Company: Province of BC
Location: Vaseux
Test Well: ONA Deer Park 2_Out
Test Date: 18-May-2023

AQUIFER DATA

Saturated Thickness: 20. m
Anisotropy Ratio (Kz/Kr): 0.5

WELL DATA (F2 Test 2 (Out))

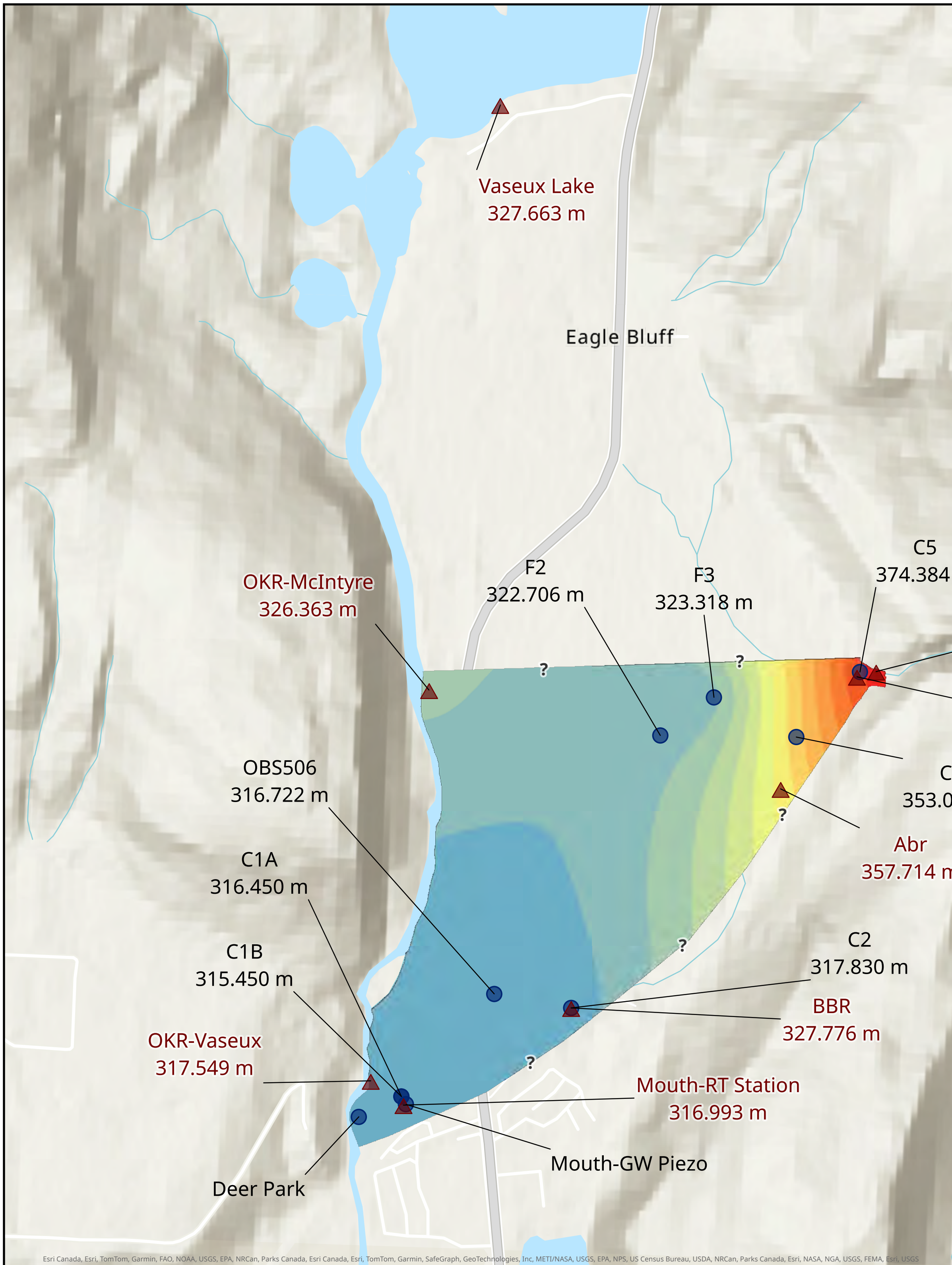
Initial Displacement: 0.2091 m
Total Well Penetration Depth: 1.478 m
Casing Radius: 0.254 m
Static Water Column Height: 1.628 m
Screen Length: 1.424 m
Well Radius: 0.07625 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.003245 m/sec
y0 = 0.01022 m

APPENDIX F. GROUNDWATER ELEVATION CONTOURS



Note:
Water elevation is known with certainty at sample locations. The contours are generated by statistical interpolation methods and should be considered estimates only.

Vaseux Creek Groundwater Levels

Apr 19, 2022

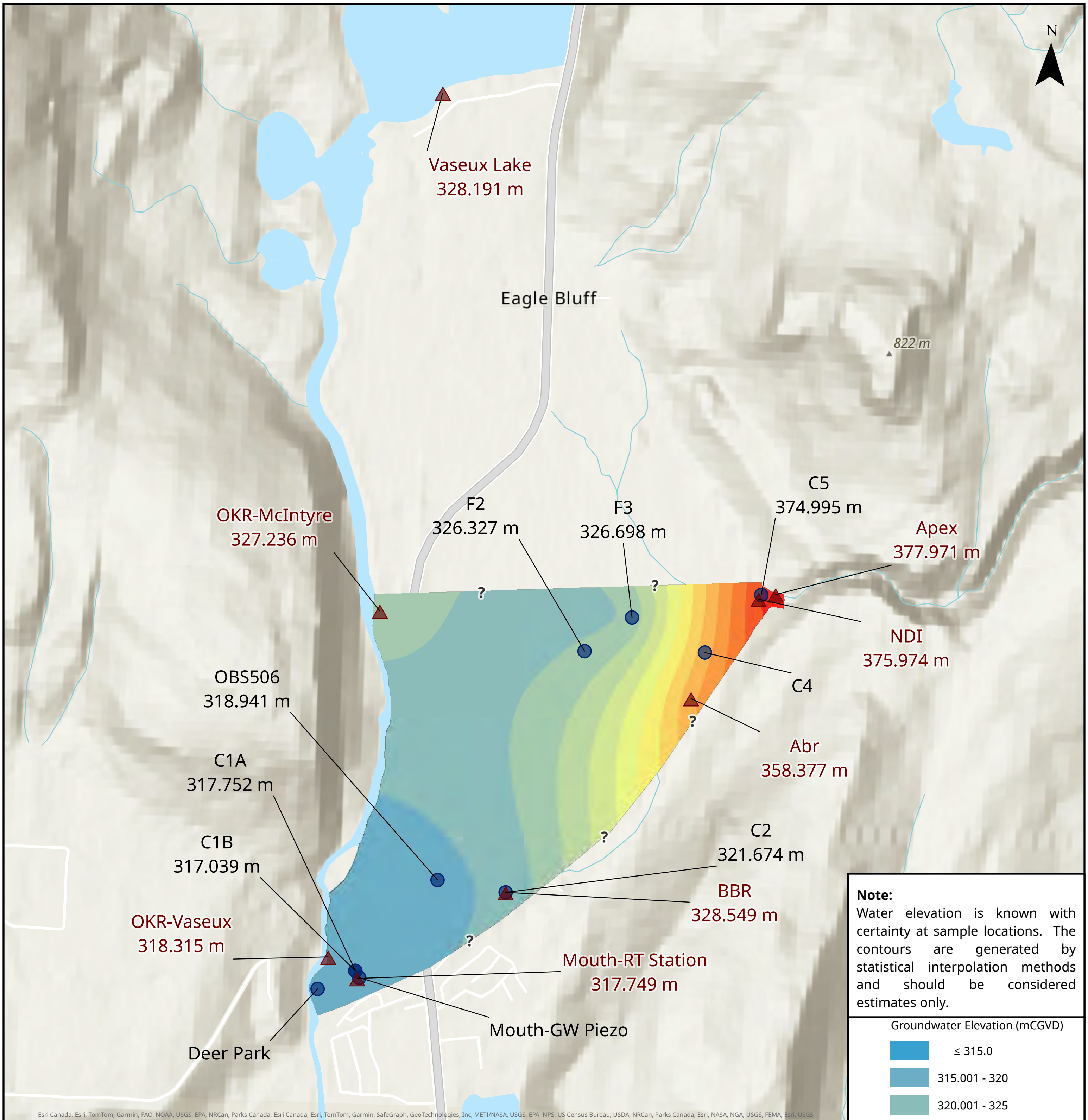
Created by: Water Protection and Sustainability Branch, Ministry of Water, Land, and Resource Stewardship
Datum: North American 1983 CSRS
Projection: Transverse Mercator
Map Date: Mar 5, 2024

1:19,000

0 0.5 1 Kilometers

Sample Locations
- Groundwater
- Surface Water

Groundwater Elevation (mCGVD)
- ≤ 315.0
- 315.001 - 320
- 320.001 - 325
- 325.001 - 330
- 330.001 - 335
- 335.001 - 340
- 340.001 - 345
- 345.001 - 350
- 350.001 - 355
- 355.001 - 360
- 360.001 - 365
- 365.001 - 370
- 370.001 - 375
- 375.001 - 380



Vaseux Creek Groundwater Levels

Jun 20, 2022

Created by: Water Protection and Sustainability Branch, Ministry of Water, Land, and Resource Stewardship
Datum: North American 1983 CSRS
Projection: Transverse Mercator
Map Date: Mar 5, 2024

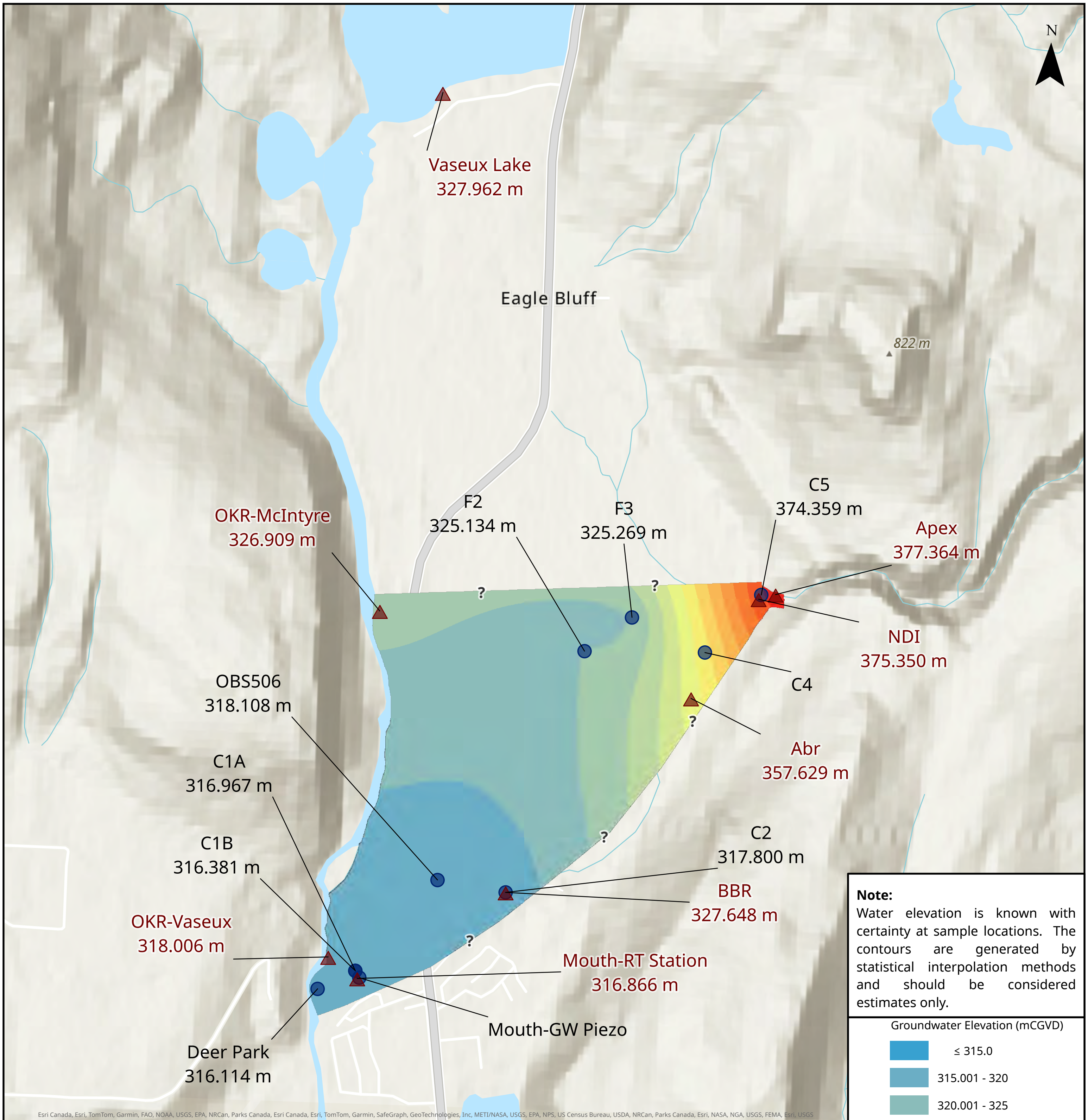
1:19,000

0 — 0.5 — 1 Kilometers

Sample Locations
- Groundwater
- Surface Water

Groundwater Elevation (mCGVD)

- ≤ 315.0
- 315.001 - 320
- 320.001 - 325
- 325.001 - 330
- 330.001 - 335
- 335.001 - 340
- 340.001 - 345
- 345.001 - 350
- 350.001 - 355
- 355.001 - 360
- 360.001 - 365
- 365.001 - 370
- 370.001 - 375
- 375.001 - 380



Vaseux Creek Groundwater Levels

Aug 08, 2022

Created by: Water Protection and Sustainability Branch, Ministry of Water, Land, and Resource Stewardship
Datum: North American 1983 CSRS
Projection: Transverse Mercator
Map Date: Mar 5, 2024

1:19,000

0 0.5 1 Kilometers

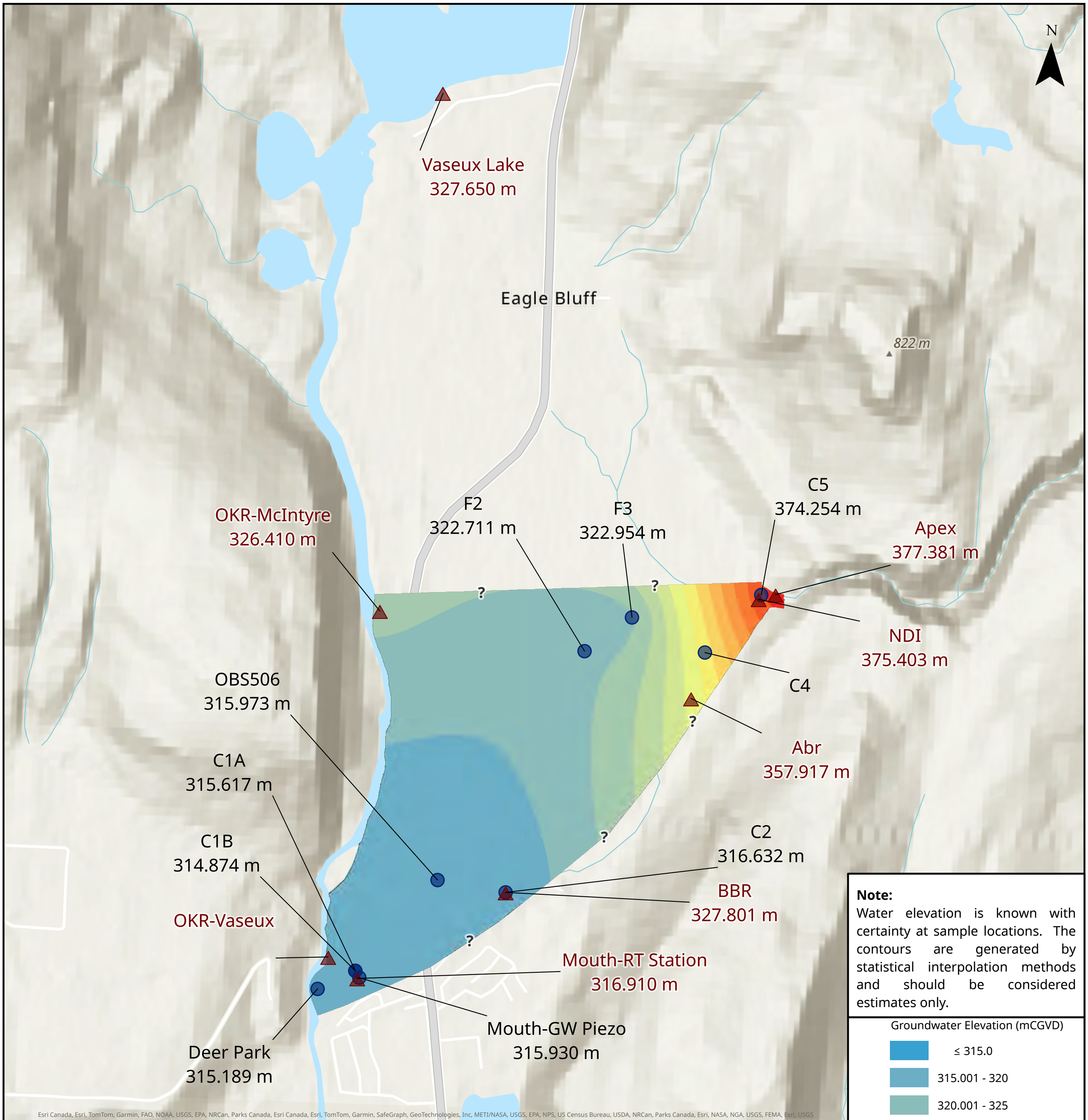
Sample Locations

- Groundwater
- Surface Water

Note:
Water elevation is known with certainty at sample locations. The contours are generated by statistical interpolation methods and should be considered estimates only.

Groundwater Elevation (mCGVD)

- ≤ 315.0
- 315.001 - 320
- 320.001 - 325
- 325.001 - 330
- 330.001 - 335
- 335.001 - 340
- 340.001 - 345
- 345.001 - 350
- 350.001 - 355
- 355.001 - 360
- 360.001 - 365
- 365.001 - 370
- 370.001 - 375
- 375.001 - 380



Note:
Water elevation is known with certainty at sample locations. The contours are generated by statistical interpolation methods and should be considered estimates only.

Vaseux Creek Groundwater Levels

Dec 02, 2022

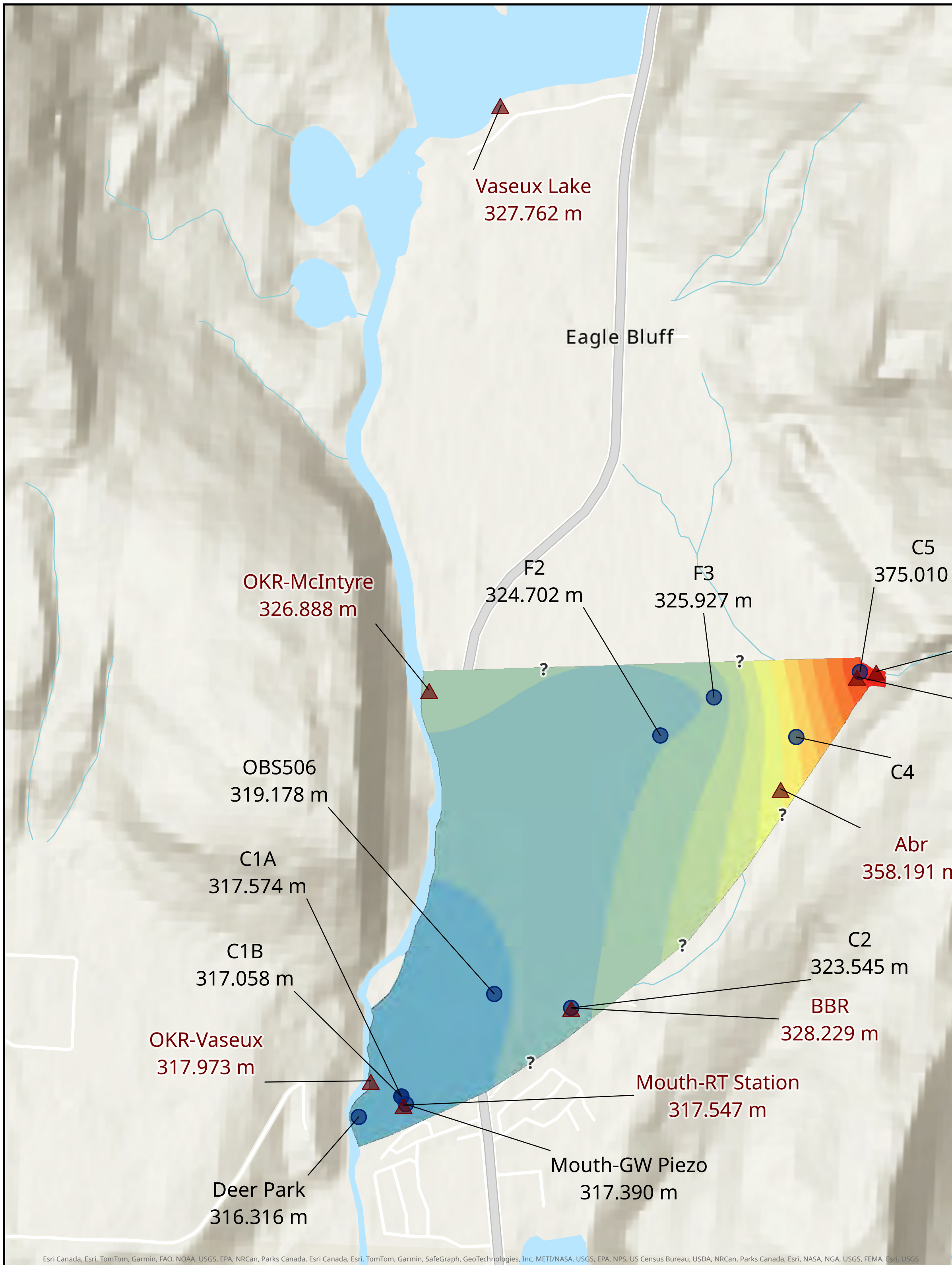
Created by:	Water Protection and Sustainability Branch, Ministry of Water, Land, and Resource Stewardship
Datum:	North American 1983 CSRS
Projection:	Transverse Mercator
Map Date:	Mar 5, 2024

1:19,000

0 0.5 1 Kilometers

Sample Locations
- Groundwater
- Surface Water

Groundwater Elevation (mCGVD)
- ≤ 315.0
- 315.001 - 320
- 320.001 - 325
- 325.001 - 330
- 330.001 - 335
- 335.001 - 340
- 340.001 - 345
- 345.001 - 350
- 350.001 - 355
- 355.001 - 360
- 360.001 - 365
- 365.001 - 370
- 370.001 - 375
- 375.001 - 380



Note:
Water elevation is known with certainty at sample locations. The contours are generated by statistical interpolation methods and should be considered estimates only.

Groundwater Elevation (mCGVD)

- ≤ 315.0
- 315.001 - 320
- 320.001 - 325
- 325.001 - 330
- 330.001 - 335
- 335.001 - 340
- 340.001 - 345
- 345.001 - 350
- 350.001 - 355
- 355.001 - 360
- 360.001 - 365
- 365.001 - 370
- 370.001 - 375
- 375.001 - 380

Vaseux Creek Groundwater Levels

May 18, 2023

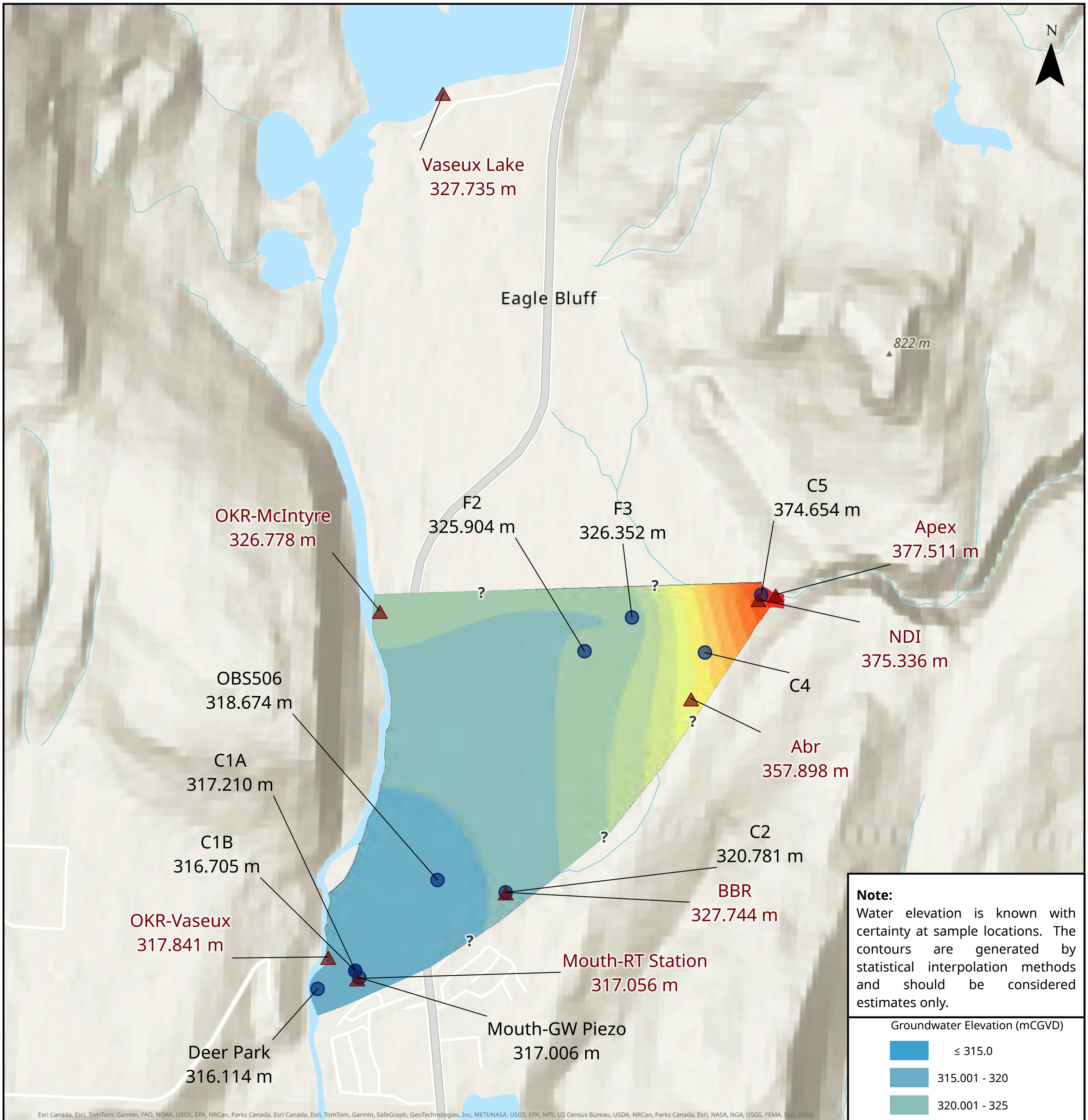
Created by: Water Protection and Sustainability Branch, Ministry of Water, Land, and Resource Stewardship
Datum: North American 1983 CSRS
Projection: Transverse Mercator
Map Date: Mar 5, 2024

1:19,000

0 0.5 1 Kilometers

Sample Locations

- Groundwater
- Surface Water



Note:
Water elevation is known with certainty at sample locations. The contours are generated by statistical interpolation methods and should be considered estimates only.

Vaseux Creek Groundwater Levels

Jun 07, 2023

Created by: Water Protection and Sustainability Branch, Ministry of Water, Land, and Resource Stewardship
Datum: North American 1983 CSRS
Projection: Transverse Mercator
Map Date: Mar 5, 2024

1:19,000

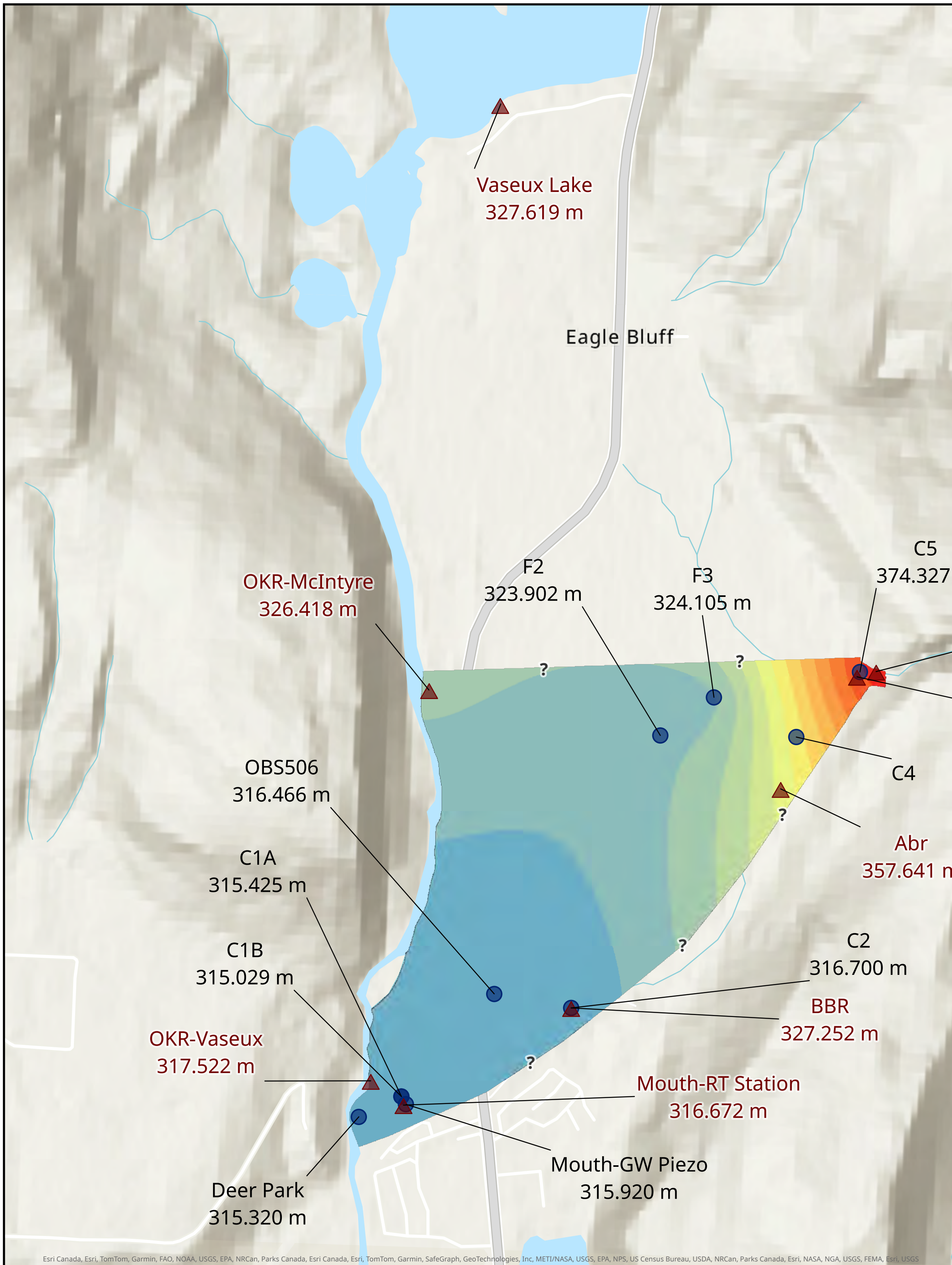
0 — 0.5 — 1 Kilometers

Sample Locations

- Groundwater
- Surface Water

Groundwater Elevation (mCGVD)

- ≤ 315.0
- 315.001 - 320
- 320.001 - 325
- 325.001 - 330
- 330.001 - 335
- 335.001 - 340
- 340.001 - 345
- 345.001 - 350
- 350.001 - 355
- 355.001 - 360
- 360.001 - 365
- 365.001 - 370
- 370.001 - 375
- 375.001 - 380



Note:
Water elevation is known with certainty at sample locations. The contours are generated by statistical interpolation methods and should be considered estimates only.

Vaseux Creek Groundwater Levels

Aug 29, 2023

Created by: Water Protection and Sustainability Branch, Ministry of Water, Land, and Resource Stewardship
Datum: North American 1983 CSRS
Projection: Transverse Mercator
Map Date: Mar 5, 2024

1:19,000

0 0.5 1 Kilometers

Sample Locations
- Groundwater
- Surface Water

Groundwater Elevation (mCGVD)
- ≤ 315.0
- 315.001 - 320
- 320.001 - 325
- 325.001 - 330
- 330.001 - 335
- 335.001 - 340
- 340.001 - 345
- 345.001 - 350
- 350.001 - 355
- 355.001 - 360
- 360.001 - 365
- 365.001 - 370
- 370.001 - 375
- 375.001 - 380

APPENDIX G. WATER CHEMISTRY DATA

UofO Number	Sample ID	^3H (Bq/L)	± 1σ (Bq/L)	Sample Date
UOT-3739	V-SW-AX	< 1.35 *		16/2/2023
UOT-3740	V-GW-C5	< 0.65 **		16/2/2023
UOT-3741	V-GW-C2	< 0.68 **		16/2/2023
UOT-3742	V-GW-C1A	< 0.65 **		16/2/2023
UOT-3743	V-GW-C1B	< 1.41 *		16/2/2023
UOT-3744	V-GW-SRC	< 1.41 *		16/2/2023
UOT-3745	V-GW-DP	< 0.65 **		16/2/2023
UOT-3746	V-GW-MTH	< 1.35 *		16/2/2023
UOT-3750	OBS506	< 1.35 *		22/09/2022
UOT-3751	F2	< 0.65 **		21/09/2022
UOT-3752	F3	< 1.41 *		21/09/2022
UOT-3753	V-GW-DP	< 0.65 **		12/9/2022
UOT-3754	V-GW-C2	< 1.49 *		12/9/2022
UOT-3755	V-GW-C1A	1.5	0.45	12/9/2022
UOT-3756	V-GW-C1B	< 1.35 *		12/9/2022
UOT-3757	V-GW-C5	< 1.41 *		12/9/2022
UOT-3758	SORCO	< 0.68 **		12/9/2022

* Measurement < Minimum Detection Activity. The detection limit below which the analytical process has not statistically led to a quantitative detection in the sample, but some radioactivity is present.

** Measurement < Critical Level Activity. The decision limit below which the analytical process has not detected radioactivity in the sample. Cannot statistically be certain that it is not zero.