REGIONAL HYDROGEOLOGICAL ASSESSMENT FOR GROUNDWATER SUPPLY DEVELOPMENT INCH CREEK HATCHERY
DEWDNEY, BC

Prepared for

FISHERIES AND OCEANS CANADA

October 2024 Project 3333-R1

my notes follow:

1) Piteau Q.E.P. conducted for DFO conducted regular groundwater assessment – a hydrogeologic investigation into aquatic conditions in this area.
2) They installed 7 wells to measure and record water levels at various intervals – establishing a water level measurement station at the Bailey bridge on H.P. Road.
3) Their aim was to see if the wells were affected by Inch creek hatchery's use of water in their operations.
4) The hatchery is located on an alluvial fan deposited by Norrish creek.
5) Inch creek is fed by the flow from upwelling groundwater and overflow from Norrish creek during high water conditions. (Presumably fall).
6) Gravel removal has had an impact: "Following a lowering of the. Water level in Norrish creek caused by the removal of gravel from the Norrish fan, flow from Norrish creek into Inch Creek during high water conditions ceased. …Therefore, groundwater became the primary source of flow in that creek." (Q: any numbers of salmon affected? Any comments by DFO? On record or not)
7) 2.4.4. Barnes Creek: "The creek bed is now mostly dry, except when groundwater levels are high."
8) 2.4.5. Chilqua Slough: (north of Inch hatchery) "No flow or water level monitoring reports for this watercourse have been located by Piteau." (were any done?)
9) 3.3: "In March, 2022, monitoring wells were installed to investigate aquifer thickness and conditions such as water table elevation."
10) 4.5: effects of climate change: "Predicted increases in rainfall may increase ground water recharge into the N. Creek aquifer," but…"prolonged dry spells between spring

and fall, and reduced snow and rapid snowpack melts may not be sufficient to recharge the aquifer's adjacent marshlands and streams."

11) A plan should include continuous monitoring of water level in Norrish creek and the Norrish creek aquifer.
12) Conclusion: re Inch hatchery: "It's possible shallow wells that penetrate the water table may be adversely affected by additional water table drawdowns, especially when water table levels are low."
    Conclusion: "The potential effects to the marshlands adjacent to the slough have not been assessed."
    Conclusion: climate change is expected to magnify effects on marshlands adjacent to Norrish Slough.

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1 INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

In 1983 Fisheries and Oceans Canada (also referred to as Department of Fisheries and Oceans or DFO) commenced operation of the Inch Creek Hatchery (“the hatchery”) in Dewdney BC to produce coho, chum, and steelhead for a number of local tributaries leading to the Fraser River. This involves collecting b

There are presently five production wells supplying groundwater to the facility. Combined pumpage from these wells between 2019 and 2023 averaged about 7.5 million cubic meters per year. After passing through constructed rearing channels the water is discharged into Inch Creek, which flows to Nicomen Slough.

In 2021 the DFO launched the Pacific Salmon Strategic Initiative (PSSI) to support Pacific Salmon populations in BC. One of the pillars of this program is to focus on conservation salmon enhancement programs to help watersheds that are experiencing low returns of adult salmon. The hatchery has been identified as one of two enhancement facilities to receive infrastructure improvements to support this initiative. The main objective of the planned hatchery expansion is to develop a Captive Brood Facility to focus on salmon populations that are experiencing low returns.

00 to 19,000 m3/day ( ). This has included a regional aquifer assessment in the vicinity of the hatchery to fulfill regulatory requirements for groundwater licensing, and an environmental assessment for groundwater extraction, if needed. This work is described in the following report. It has been completed concurrently with construction and testing of three new production wells needed to supply groundwater to the Captive Brood Facility, which is described in a separate report by Piteau (2024).

1.2 SUMMARY OF WORK

1.2.1 Review

Relevant information for the hatchery and surrounding environs was reviewed. This focused on:

- Topography;
- geology and hydrogeology; • climate;

rood stock from local streams and incubating and rearing eggs at the hatchery
using groundwater from wells at the facility. When the eggs have developed into fry or smolts they
are released into their streams of origin, such as the Pitt, Stave, Chilko and Stuart rivers. The hatchery currently releases about 3 million salmon back into various watersheds throughout British
Columbia.

Piteau Associates Engineering Ltd. (Piteau) was retained by DFO to provide hydrogeology

consulting services in support of developing new groundwater supplies at the hatchery at a target

rate of 15,0
170 to 220 L/s

- surface water and drainage;
- land use and infrastructure;
- available groundwater resources, wells, and groundwater utilization;
- groundwater quality;

- past operational data (flow and water level) for the five existing production wells at the hatchery; and
- current and planned future activities at the hatchery.

1.2.2 Hydrogeologic Investigation

A hydrogeologic investigation was conducted to investigate aquifer conditions in the vicinity of the hatchery. This included:

- installing seven monitoring wells to facilitate aquifer monitoring; one well was located on the hatchery property and six were located on surrounding lands at distances up to 900 m from the hatchery. Dataloggers were deployed in the wells on April 1, 2022 to measure and record the level and temperature of water in the monitoring wells at regular intervals;
- establishing a water level measurement station equipped with a datalogger on Norrish Creek at the Hawkins Pickle Road bailey bridge on October 15, 2022; and
- surveying coordinates and elevations for monitoring wells, water wells, the standpipe at the Norrish Creek station, and other selected points; and conducting a regional well survey to collect data on water wells that could be potentially affected by operation of wells at the hatchery.

1.2.3 Construction and Flow Testing with New Production Wells

Three new production wells identified as Wells 6, 7, and 8 were constructed within the hatchery property. Well 6 was constructed in March 2022, and Wells 7 and 8 were constructed between May and August, 2023.

Aquifer flow testing to evaluate the safe yield for each well was completed with Well 6 in October 2022, and with Wells 7 and 8 in September and October of 2023. Samples of groundwater pumped from the wells were collected during the tests for chemical analysis. Additional well development was performed on Well 6 in August, 2023 to increase the safe yield, and a second flow test was completed with this well in March, 2024 to re-evaluate its safe yield.

The well construction and testing program is described in a separate report by Piteau (2024).

1.2.4 Analysis and Interpretation of Data

Data collected during the work described in Sections 1.2.1 through 1.2.3 above was synthesized and analyzed as follows:

• water level monitoring data collected in the monitoring wells and at the Norrish Creek station were converted to equivalent elevations and time-series plots were generated;

- time-series plots of water temperature data collected in the monitoring wells and Norrish Creek were generated;
- water table equipotential maps were created using calculated water elevation data recorded in the monitoring wells on selected dates;
- water level, flow, and temperature data collected by the SCADA system that monitors operations of the five operating production wells at the hatchery was analyzed to assess long-term and seasonal trends; and
- vertical cross sections were generated to integrate topography, geology, and hydrogeologic information in support of developing a conceptual geologic and hydrogeologic model for the region.

1.2.5 Groundwater Flow Modelling

A three-dimensional numerical groundwater flow model was developed to simulate groundwater flow in the vicinity of the hatchery and evaluate the effects of increasing the rate of groundwater extraction at the hatchery by 6.1 million m3/year (192 L/s) via new Wells 6, 7, and 8. After achieving an acceptable match between actual and predicted water levels before, during, and after a 72-hour constant-rate aquifer pumping test with Well 8, the model was further validated by comparing measured and predicted water levels in monitoring wells between October 14, 2022, and October 15, 2023. Predictive simulations were then performed to quantify potential effects of operating the new wells on other groundwater users and on surface water over the same interval.

1.3 REGULATORY CONSIDERATIONS

This report has been prepared in support of an application for a license to use groundwater pursuant to the Water Sustainability Act. It is intended to satisfy information requirements set out in the document entitled “Guidelines for Technical Assessments in Support of an Application for Groundwater Use in British Columbia” (Todd, et. al., 2020). If needed, it may also be used in support of an application for environmental assessment certificate under the BC Assessment Act.

1.4 STUDY LIMITATIONS

The investigations described in this report have been conducted using a standard of care consistent with that expected of scientific and engineering professionals undertaking similar work under similar conditions in BC. No warranty is expressed or implied.

This report is prepared for the sole use of Fisheries and Oceans Canada. Any use, interpretation, or reliance on this information by any third party, is at the sole risk of that party, and Piteau accepts no liability for such unauthorized use.

2 REVIEW OF INFORMATION ON STUDY AREA

2.1 LOCATION, TOPOGRAPHY, AND LAND USE

The hatchery is located at 38620 Bell Road in Dewdney, BC (Figure 1). This is approximately 10 km NNE of Mission, and 3.5 km north of the Fraser River.

As shown on Figure 2, the hatchery is situated within the east side of an irregularly-shaped parcel. This is identified as “Parcel One Section 34 Township 20 New Westminster District Reference Plan 83793”[1]. The southern boundary of the property borders on the Canadian Pacific Railway (CPR) right-of-way and is approximately 592 m long. The triangular western portion is currently unused.

The hatchery, and its environs, are located on an alluvial fan deposited by Norrish Creek, which emerges from a bedrock canyon approximately 1.5 km to the north of the hatchery and slopes gently to the south. Ground elevation within the hatchery parcel averages about 11 m above sea level (m-asl).

The alluvial fan in the vicinity of the hatchery is bordered to the northwest by a steep mountain slope approximately 850 m to the north.

The first documented land use in the area was construction of the CPR track in the 1880s. Hawkins Pickle Road, located parallel to the south side of the rail track, appears on the earliest available aerial photographs for area (1940), and may have been built around the same time as the rail line. This road crosses Norrish Creek via a bailey bridge that is parallel to a rail bridge on the CPR line (Photos 1 and 2).

Land use near the hatchery includes residential, agricultural, gravel extraction, and commercial activities. The marshlands located on the north side of Nicomen Slough are part of a 125 Ha land conservancy owned by Ducks Unlimited. These lands are low-lying and include organic soils hosting grassy vegetation (Photo 3).

The gravel extraction project to the east and north of the hatchery, is operated by CPR and removes gravel from Norrish Creek to mitigate flood risks associated with sediment buildup and the constriction where the creek narrows at the railway and road bridges (Photo 4).

Land use on the east side of Norrish Creek, adjacent to the hatchery, includes agriculture and aggregate extraction.

2.2 CLIMATE

Climate monitoring stations operated by Environment Canada that are within 10 km of hatchery are indicated on Figure 1.

1 Parcel Identifier (PID) code 015-311-317

The Mission West Abbey and Sumas Canal stations have the longest periods of record. The Sumas Canal station is located on the south side of Sumas Mountain and due to local orographic effects is less likely than a more northern station to provide climate data that is representative of conditions in the vicinity the hatchery.

Climate data for the Mission West Abbey station are summarized on Figure 3. Average annual precipitation for the 30 year interval from 1994 to 2023 was about 1,860 mm/year, most of which occurred as rain. At 1,292 mm, the total precipitation recorded in 2023 was the lowest amount on record since this station was established in 1962.

Statistics for monthly precipitation shown on the lower portion of Figure 3 indicate that November, December, and January are typically the wettest months, and that July and August are the driest.

As it is within a mountainous area, average annual precipitation within the catchment area for Norrish Creek can be expected to be greater than at the Mission West Abbey station.

The average annual temperature at the West Abby station is 10.4°C. The minimum and maximum monthly averages for this station are 2.9°C in December and 18.2°C in August.

2.3 SURFICIAL GEOLOGY

A portion of the Geological Survey of Canada surficial geology map (Armstrong, J.E., 1980) that includes the study area is included on Figure 4. This shows that the hatchery is underlain by fan and landslide gravel, sand and rubble ranging to more than 15 m thick (unit SAo), overlying Fraser River Sediments (Unit Fh) that comprise sandy loam to loamy sand. Mountain stream channel gravel and minor sand (Unit SAj), up to 10 m thick, are mapped along Norrish Creek and some of its side channels that drain to Nicomen Slough.

2.4 SURFACE WATER AND DRAINAGE

Mapped creeks, streams, and sloughs, and areas with standing water are depicted on Figure 2.

2.4.1 Norrish Creek

With a gross drainage area of 117 square kilometers, Norrish Creek is the largest watercourse in the vicinity of the hatchery. It supports spawning and rearing of salmon and is a highly valued component of the regional ecosystem. The creek drains multiple sub-basins through steep walled canyons in the Coast Mountains before entering the Fraser River via Nicomen Slough. The creek exits the canyon onto an alluvial fan at a point about 1.5 km north of the hatchery (Photo 5) and deposits large amounts of rock and gravel downstream of the apex. Flow in the creek is provided from snowmelt, precipitation, and groundwater, and creek flow is subject to large fluctuations due to the watershed response characteristics.

The City of Abbotsford has a conditional license to divert flow from Dickson Lake, which is within the Norrish Creek catchment, at a maximum rate of 90,920 m3/day.

Stream maintenance and flood control activities within the alluvial fan have included dike construction to prevent flooding of lands adjacent to the west side of the creek, and gravel extraction within the creek bed to reduce the risk of flood damage to the railway bridge (Cleugh, et. al., 1979).

The Water Survey of Canada (WSC) operated flow gauging station O8MH058 near the apex of the fan (Figures 1 and 2) between August 1959 and May 2007. Figure 5 includes minimum, maximum, and average monthly flows reported during this interval. Average monthly flows ranged from 2.9 m3/s in August to 17.6 m3/s in November. The lowest daily flow (0.45 m3/s) during this interval occurred on September 26, 2005.

A low-flow metering program was completed within the Norrish Creek watershed to quantify creek water losses and gains during the seasonal low-flow period in September and October 1991. Instantaneous discharge measured at WSC Station 08MH058 and the Hawkins Pickle Road bailey bridge between September 9 and October 1, 1991 indicated creek losses of between 0.75 and 2.384 m3/s. Losses reported for the reach between the bailey bridge and the lower fan ranged from -0.119 m3/s (gaining) to 0.339 m3/s. The report for this investigation (Richards, 1992) included the statement “A small part of this loss may be the result of groundwater extraction taking place in the Inches Creek Fish Hatchery located near the CN Railway right-of-way about 1 km west of the Bailey (and CNR) Bridge. The hatchery operates 2 wells each with a rated capacity of 3,500 USGPM (a total of 440 L/s), but which extract a total of about 265 L/s on a continuous basis.”

Figure 5 includes a time-series plot of the measured flows at stations N2 and N3, and the difference between them (equivalent to creek losses), along with the WSC reported flows at Station 08MH058 (N3). The lower plot includes flows at N3 and estimated creek losses between N3 and N2. The apparent trends support the interpretation that the magnitude of creek losses between N3 and N2 is proportional to total flow in the creek.

Piteau monitored water levels on the east bank of the creek at the Hawkins Pickle Road bailey bridge, and has visually observed conditions in the creek on several occasions. On September 13, 2023, portions of the creek channel between apex and Nicomen Slough were observed to be completely dry (i.e., bank to bank), although flow was observed near the apex (Photos 5 to 7). This flow infiltrated through the stream bed to enter the hyporheic zone2 within about 300 m of the apex and some zones with ponded water were observed in the streambed further downstream. These observations are consistent with anecdotal reports indicating that portions of the creek bed have been observed to be dry during previous years, although 2023 is the most extreme example due to record drought conditions. At times of higher flow there are no zones where Norrish creek is dry (Photo 8).

2 Hyporheic zones are the saturated portions of streambeds containing water that originates from a stream and returns to the stream. They are characterized by a mixture of stream water and local and regional groundwater, and usually vary in extent and duration.

2.4.2 Nicomen Slough

Norrish Creek joins with Nicomen Slough about 1.2 km southeast of the Hawkins Pickle Road Bailey bridge (Figure 2). Nicomen Slough is a 22 km long shallow side channel to the Fraser

River that starts about 14 km upstream from the confluence with Norrish Creek, and rejoins the Fraser River about 8 km downstream. In addition to flows from the Fraser River, the slough receives flows from creeks and streams draining steep terrain to the north, and conveys it westward into the Fraser River. Norrish Creek is the largest creek draining into Nicomen Slough.

Monitoring conducted by the WSC in the early 1960s indicates water levels in the slough varied over a range of about 1 m at Dewdney (Station 08MH086 – Figure 1), and over about 0.5 m at Deroche (Station 08MH085 – Figure 1).

2.4.3 Inch Creek

Inch Creek (Figure 2) is a small watercourse that flows southward from the west end of the hatchery. It passes through a box-culvert beneath the CP railway and then flows under a bridge on Hawkin Pickle Road toward Nicomen Slough 0.5 km to the south.

Fedorenko and Bailey (1980) reported that Inch Creek was a minor but consistent producer of coho and chum salmon, and that it was fed by flow from upwelling groundwater and overflow from Norrish Creek during high discharge conditions. The flow was reported to be about 0.3 m^3/s and the mean water temperature was 8°C. Following a lowering of the water level in Norrish Creek caused by removal of gravel from the creek fan, flow from Norrish Creek into Inch Creek during high water conditions ceased. Thereafter, groundwater became the primary source of flow in the creek.

Since operations at the hatchery commenced in 1983, discharge from the incubating and rearing channels at the hatchery has become the primary source of flow in Inch Creek, and if occurring, groundwater upwelling into the creek is no-longer evident. The portion of the Inch Creek channel that is still present is depicted on Figure 2.

2.4.4 Barnes Creek

Barnes Creek is a small watercourse that merges with Inch Creek (Figure 2), and as with Inch Creek, was reported to be a consistent producer of coho and chum salmon (Fedorenko and Bailey, 1980). The creek bed is now mostly dry, except perhaps when groundwater levels are high.

2.4.5 Chilqua Creek

Chilqua Creek is located in the terrace north of the hatchery, and receives flow from three tributaries draining the south slope of Dewdney Peak (elev. 900 m-asl). It flows to Hatzic Lake about 4 km to the west. No flow or water level monitoring reports for this watercourse have been located by Piteau.

Nicomen Slough is a highly valued component of the local and regional ecosystem. Salmon pass through it to reach spawning grounds, and coastal cutthroat trout use the slough as a feeding ground. The adjacent marshlands are inhabited by a rich variety of insects, plants, migratory birds,
and provide nutrients and food for supporting fish.

2.5 HYDROGEOLOGY

2.5.1 Aquifers

Provincial aquifer mapping3 includes two aquifers in the vicinity of the hatchery. Information on these aquifers is summarized below and locations are shown on Figure 4.

The extent of the Norrish Creek Aquifer (13) matches the fan and landslide gravel (Unit SAo) and mountain stream gravel (Unit SAj) described in Section 2.3. The Nicomen Slough Aquifer (12) is within the underlying Fraser River sediments (Unit Fh).

As aquifer mapping is based on existing borehole information available at the time of completion, and reflect the judgement of the individuals doing the mapping, it is subject to reinterpretation and revision.

Groundwater investigations were conducted at the hatchery in 1969 and 1979 in support of water supply development for hatchery operations. These are described in reports by Robinson, Roberts, and Brown (1969) and Campbell (1979) included with Appendix A.

Based on aquifer flow testing conducted with three wells at or near the hatchery, aquifer transmissivity was estimated to range between 1,900,000 to 2,300,000 USgpd/ft (0.27 to 3.3 m2/s), and aquifer storativity values were reported to range from 0.00005 to 0.096. The lower end of this range (0.00005) is discounted based on the small distance between the pumping and observation wells indicated by Robinson, Roberts, and Brown (1969).

Section 4.3 includes information and interpretation on the characteristics of Aquifer 13 based on the results of recent regional investigations, and flow testing with Wells 6, 7, and 8 (Piteau, 2024).

2.5.2 Water Wells

Figure 6 includes locations of provincially registered water wells included in the BC Water Resource Atlas (BCWRA). Locations of unregistered wells identified during a local well survey completed by Piteau (Section 3.8) are also included. In some cases, the locations of registered water wells included in the BCWRA were inaccurate and corrected locations are shown on Figure 6.

3 Available from the BC Water Resource Atlas https://maps.gov.bc.ca/ess/hm/wrbc/

Aquifer Number	Location	Size (km^2)	Geologic Formation	Aquifer Type	Average Depth to Water (m)	Vulner-ability	Produc-tivity	Aquifer Demand	# of Wells	Aquifer Description
12	Nicomen Slough	60.2	Fraser River Sediments - floodplain	Fluvial or glaciofluvial (unconfined)	4.3	High	Moderate	low	116	Predominantly unconfined fluvial or glacio-fluvial sand and gravel aquifers found along major rivers of higher stream order with the potential to be hydraulically influenced by the river.
13	Norrish Creek	2.3	Salish Sediments, alluvial fan	Alluvial fan (unconfined)	6.2	High	High	Moderate	7	Alluvial or colluvial fan sand and gravel aquifers, typically occur at or near the base of mountain slopes, either along the side of valley bottoms, or if formed during the last period of glaciation, raised above the valley bottoms

The five wells currently supplying groundwater to the hatchery draw from Aquifer 13. Information on these wells, and all other wells in the vicinity of the hatchery, are summarized in

Table 1. Well 1 and Well 2 correspond with the Production Wells 1 and 2 described in the Campbell (1979) report included with Appendix A. Logs for Wells 3 and 4 are not available. A 2015 report by Piteau describing construction and testing of Well 5 is included with Appendix B. Information on Well 6 constructed at the hatchery in 2022, and Wells 7 and 8 constructed in 2023, is included in a separate report by Piteau (2024).

Groundwater extraction from the five wells currently operating at the hatchery (Wells 1 to 5) are monitored electronically, and a year-over-year plot of the combined pumping rates between 2019 and 2023 is included as Figure 7. This indicates relatively consistent seasonal patterns with low flows (100 L/s ± 40%) in May-June, and high flows (300 L/s ± 40%) in November and March. Total annual pumpage, and average pumping rate, are summarized on the lower right of the plot. The average combined pumping rate between 2019 to 2023 was about 7.5 million cubic meters per year (240 L/s).

2.5.3 Groundwater Quality

Appendix C includes a summary of chemical analysis results for groundwaters sampled from wells at the hatchery between 1981 and 2019. The specific conductance and total dissolved solids results indicate the water contains extremely low amounts of mineralization, which is indicative of a short residence time for groundwater within the aquifer. With the exception of a few anomalous results for aluminum and lead, all analysis results are within provincial water quality guidelines for freshwater aquatic life (British Columbia Ministry of Environment and Climate Change Strategy. 2024).

3 REGIONAL HYDROGEOLOGICAL INVESTIGATIONS

3.1 OBJECTIVES

Although the hatchery has operated for 40 years, aside from the studies completed in 1969, 1979, and 2015 (Appendices A and B), there have been no detailed hydrogeological investigations to define the characteristics of the Norrish Creek Aquifer. To facilitate assessment of the effects that increasing groundwater withdrawals in support of development of a Captive Brood Facility at the hatchery, and to satisfy regulatory requirements, the objective of the investigations completed by Piteau have included assessments of:

- seasonal variation in ambient water table levels, temperature, and groundwater flow directions;
- surface/groundwater interaction and;
- aquifer recharge and aquifer discharge;
- effects of groundwater extraction from the five wells currently operating at the hatchery; and
- groundwater extraction by others within 1 km of the hatchery.

Tasks completed in support of these objectives are described in the following sections.

3.2 RECONNAISSANCE

Piteau hydrogeologists have reconnoitered the hatchery and surrounding areas to view and map salient hydrogeological features. This has included travelling on public roads, the trail along the west bank of Norrish Creek, and the dike along Nicomen Slough, and Inch Creek.

3.3 INSTALLATION OF MONITORING WELLS

In March 2022 monitoring wells MW22-1 through MW22-7 were installed at eight locations in the vicinity of the hatchery to investigate aquifer thickness and facilitate monitoring of aquifer conditions such as water table elevation. The monitoring well locations are shown on Figure 6. Except for MW22-6, which is located on the hatchery property, and MW22-7 which is on adjacent CPR owned lands (aggregate operation), all monitoring wells were installed within roadway rights-of-way with prior approval from the Ministry of Transport and Highways.

After checking for buried utilities, the boreholes for the monitoring wells were advanced using a rotary sonic drilling rig operated by Downrite Drilling. All boreholes were advanced below the water table. The depth of drilling ranged from 15.2 to 22.9 m below ground (m-bgl).

Monitoring well standpipes comprising of 50 mm PVC piping were installed in each of the boreholes. Silica sand was placed around the slotted screens at the base of the standpipes, and bentonite chips were placed above. The monitoring wells were completed with flush-mount covers.

Three additional boreholes were drilled on the west side of the hatchery property in March 2023 to investigate ground conditions in the vicinity of the planned new production Wells 7 and 8. Monitoring well standpipes were installed using the same methods described above. These monitoring wells are identified as MW23-1, MW23-2, and MW23-3. Their locations are shown on Figure 6.

Logs for all monitoring wells constructed during this investigation are included with Appendix D.

3.4 LONG-TERM MONITORING

SolinstTM Levelogger equipment was deployed in the new monitoring wells, one of the new production wells constructed at the hatchery, and in Norrish Creek. The Levelogger is a self-contained water level datalogger that measures absolute pressure (i.e., water pressure + atmospheric pressure) and temperature. A SolinstTM Barologger, which measures atmospheric pressure and air-temperature, was deployed at an above-ground location to collect data needed to correct the absolute pressure data collected by the Leveloggers for variations in atmospheric pressure, to isolate the water head.

Deployment dates and data intervals for the Leveloggers utilized in this study are summarized below:

	Data Interval		Recording	
Location	From	To	Interval	Comments

MW22-1
MW22-2 MW22-3 MW22-4
MW22-5 MW22-6 MW22-7
Norrish Creek @ Bailey bridge
1-Apr-22
1-Apr-22 1-Apr-22 1-Apr-22
1-Apr-22 1-Apr-22 1-Apr-22
15-Oct-22
Feb 7, 2024
Feb 7, 2024 Feb 7, 2024 Feb 7, 2024
Feb 7, 2024 Feb 7, 2024 18-Oct-23
Feb 7, 2024
15 min
15 min 15 min 15 min
15 min 15 min 15 min
15 min
No data collected April 1 to October 18, 2022 due to deployment error. Barologger at this location.
No data collected April 1 to September 14, 2022 due to equipment error
Deployment terminated due to damaged monitoring well
Levelogger elevation higher than creek invert

Well 6	2-Nov-22	Feb 7, 2024	15 min	Logger removed during well redevelopment (Aug. 24-Sept. 23, 2023) and during aborted flow test (Oct. 12-18, 2023). Logger moved to MW23-1 on Feb. 7, 2024

Data collected by the Leveloggers and the Barologger were downloaded on a quarterly schedule. In the case of monitoring wells and Well 6, an electric tape was used to manually measure the depth to water relative to an established reference point at the top of casing. Similarly, for the standpipe in Norrish Creek the water level was manually measured relative to the top of the standpipe strapped onto the eastern abutment for the Hawkins Pickle Road Bailey bridge.
Analysis and interpretation of water level data is discussed in Section 4.3.

3.5 LOCATION AND ELEVATION SURVEY

The locations and elevations of all production wells, monitoring wells, the standpipe in Norrish Creek, and various water levels along the west bank of Norrish Creek, Nicomen Slough, Inch Creek, and Barns Creek were surveyed by Mathew Barker, Senior Project Technologist and Geomatics Technical Specialist with DFO. This work was completed in stages on January 23, June 26, and August 10, 2023. Locations were surveyed to an accuracy of ±1.9 cm, and elevations with an accuracy of about ±1.3 cm.

3.6 WATER WELL SURVEY

Information on water wells located within in the vicinity of the hatchery was collected and tabulated. This process involved:

- querying the BC Water Resources Atlas for information on all registered water wells within the area of interest;
- reviewing each record to identify obvious spatial errors and verifying or correcting locations;
- reviewing cadastral mapping and determining legal lot descriptions and Parcel ID (PID) numbers for all lots within the area of interest, and identifying landowners by title search;
- soliciting information on registered and unregistered water wells from all landowners by a mailing questionnaires to the addresses indicated on the title searches. In total, 31 questionnaires were mailed. Five responses to the well survey were received; and
- summarizing information on all known registered and unregistered wells within the area of interest.

The extent of the area of interest for the water well survey, and the locations of registered and unregistered wells are indicated on Figure 6. Information on all wells within the area of interest is summarized on Table 1.

3.7 CONSTRUCTION AND TESTING OF WELLS 6, 7, AND 8

three new
the following tasks:
. This work involved
In addition to this regional hydrogeologic study, Piteau has overseen construction and testing of

groundwater supplies to supply the planned Captive Brood Facility

- preparing well specifications and assisted with preparation of tender documents for Well 7 and Well 8 (procurement for Well 6 was by DFO);
- attending on-site meetings to determine location of Wells 7 and 8, and planning drill rig access. Piteau was not involved with selecting the location of Well 6;
- coordinating drilling contractor activities during exploration drilling in the western portion of the hatchery property to confirm suitable ground conditions at the planned locations for production Wells 7 and 8 (Section 3.3);

- monitoring borehole advancement and construction of Well 7 and Well 8;
- completing particle size distribution testing on borehole sediment samples collected from

boreholes for Wells 6, 7 and 8;

- designing screen completions for Wells 6, 7, and 8 and monitoring screen installation and development;
- coordinating pumping test contractor activities and visited well sites to plan the handling of pump discharge, inspected pumping test set-up, monitoring water levels in observation wells, and collecting water samples for chemical, physical, and bacteriological analyses;
- reviewing contractor invoices for completeness and accuracy;
- analyzing pump testing data and assessed aquifer characteristics, water quality, and well

yield; and

- preparing a report describing the well construction and testing program and provided recommendations for safe well yields and well commissioning and operation (Piteau, 2024).

4 ANALYSIS AND INTERPRETATION

4.1 STRATIGRAPHY

Figure 6 includes locations for operating and new production wells at the hatchery, monitoring wells, and provincially registered wells in the vicinity. It also shows the orientation of hydrogeologic cross sections A-A’ and B-B’, which are included as Figures 8 and 9. Section A-A’ extends from southwest to northeast and intercepts a side channel of Nicomen Slough on the left, and Norrish Creek on the right. Trending from the northwest to the south east, Section B-B’ extends from the base of the south facing slope of Dewdney Peak to Nicomen Slough.

Both sections show generally coarse materials comprising sands and gravels (unit SAo), with minor occurrences of silt, are present beneath the region. The transition between these coarse fluvial sediments, and the underlying Fraser River Sediments (Fh) is evident on Section A-A’, and suggests the depth to this interface ranges between about 25 and 30 m-bgl. However, a lateral transition between SAo and Fh sediments, as indicated on surficial geology mapping, is not apparent on the left side of this section, possibly due to lack of borehole data in this area.

Well 6 is the only hole on Section B-B’ that encountered materials consistent with Unit Fh, and this occurred around 35 m-bgl. The material above is SAo. As with the left side of A-A’, the right side of Section B-B’ does not show a lateral transition between SAo and Fh sediments. This is likely due to lack of borehole data in this area.

4.2 AQUIFER PROPERTIES

Table 2 includes a summary of constant-rate aquifer testing results for Wells 6, 7, and 8. The tests data were analyzed during the Cooper-Jacob and Theis-Recovery methods, and data from observation wells were analyzed using these methods and the Neuman method. The Neuman analysis method was selected for the observation well data based on the results of derivative analyses of the data (included with Piteau, 2024), which indicates the “S” shape of the log-log drawdown plots are indicative that vertical drainage at the water table occurred. This is also known as “delayed yield”.

The Neuman method is not suitable for analysis of data from test pumping wells, as this data includes a “well-loss” component caused by localized resistance to groundwater flow as it converges on and passes through well screens. The Cooper-Jacob and Theis-Recovery analyses methods for pumping wells are unaffected by well-loss but are less appropriate at the hatchery as they assume confined aquifer conditions, and instead of fitting a single curve that mathematically accounts for delayed yield to the entire drawdown data-set (as is the case with the Neuman method). As such, the aquifer parameters determined from drawdown at non-pumped observation using this method are judged to be more reliable than results from pumping wells.

Table 2 includes values for the following aquifer parameters:

- transmissivity (T): this is the rate that groundwater would flow through a vertical slice of aquifer one metre wide under a hydraulic gradient of one metre per horizontal metre;
- storativity (S): ratio of the volume of water that will be discharged from an aquifer per unit area per unit reduction in hydraulic head (dimensionless);

• specific yield (Sy): ratio of the amount of water released per unit area of aquifer due to lowering of the water table in an unconfined aquifer (dimensionless); and

• beta (β): coefficient equivalent to ⍰$KKKK$⍰ $* rr2$ where Kz/Kh is the ratio of vertical to horizontal KKh bb2

hydraulic conductivity, r is the distance between the pumping well and observation well, and b is aquifer thickness.

Values of T and S may range over orders of magnitude, and are typically log-normally distributed. The geometric mean (geomean) was therefore used to establish a central value (mean) of all results. These, and the upper and lower quartile values, are presented below:

Transmissivity (T) (m2/s)	Storativity (S)

Lower Quartile 1.0E-01 Upper Quartile 2.8E-01 Median 1.8E-01 Geometric mean 1.7E-01
3.4E-04 3.3E-03 9.7E-04 9.2E-04

Transmissivity (T) is defined as the product of hydraulic conductivity (K) and saturated thickness (b). With an effective aquifer thickness at the hatchery ranging to 30 m, and a depth to the water table of about 5 m, b is equivalent to about 25 m. Accordingly, hydraulic conductivity values are estimated to range between 4 x 10-3 and 1.1 x 10-2 m/s, with a geometric mean of 6.8 x 10-3 m/s.

4.3 WATER TABLE LEVELS, TEMPERATURE, AND FLOW DIRECTIONS

4.3.1 Water Table Levels

A time-series plot of water table levels collected between April 1, 2022 and February 7, 2024 is included as Figure 10. This includes data from all monitoring wells, Well 6, and levels in Norrish Creek at the Hawkins Pickle Road Bailey Bridge. Daily precipitation recorded at the Mission West Abbey climate station is also included.

Water table levels are strongly affected by the water level in Norrish Creek, where water levels may vary rapidly over a range of more than 2 m due to variations in precipitation within the 117 km2 catchment upstream of the fan. Variations of water table levels at the locations monitored follow similar patterns, with a generally decreasing magnitude of fluctuation with increasing distance from Norrish Creek. This is demonstrated by the plot of levels between April 7 and 14, 2023 included as Figure 11. The water table at MW22-7, which is located about 25 m from Norrish Creek, rose by 0.61 m in response to a 0.72 m rise in the creek in the last few hours of April 9, and the water table in MW22-1, which is the next closest monitoring point to the creek (d = 165 m), rose by the lesser

about of 0.27 m. Water levels in more distal monitoring wells (e.g., MW22-5, 1 km from Norrish Creek) also responded at nearly the same time as Norrish Creek, but the magnitude of the rise was significantly attenuated.

Water table levels in some monitoring wells were also influenced by variations in pumping rates of the hatchery wells (e.g., Wells 1 to 5). This is most evident in MW22-6, which is located 27 m from Well 1.

4.3.2 Water Temperature

Water temperatures recorded in Norrish Creek, all monitoring wells, and Well 6 are included on Figure 12. Groundwater temperatures at MW22-7 ranged over about 19°C and aligned closely with temperatures in Norrish Creek4. Temperatures at MW22-6 ranged over about 12°C and lagged temperatures in MW22-7 and Norrish by about two months. At 6 and 10°C, respectively, the range in temperature variations at MW22-1 and Well 6 were less than at MW22-6, and lagged temperatures at MW22-7 by about three months.

Groundwater temperatures at MW22-2, MW22-3, MW22-4, and MW22-5 varied over a much smaller range (~2°C) than at the aforementioned monitoring points. The contrast is attributed to the likelihood that MW22-1, MW22-6, MW22-7, and Well 6 are within the capture zone for the hatchery production wells, which extends towards Norrish Creek. As MW22-2, MW22-3, MW22-4, and MW22-5 are not within this capture zone travel times from Norrish Creek are much greater and temperature variations are significantly attenuated.

4.3.3 Groundwater Flow Directions

Figures 13A and 13B include contour (equipotential) plots for water table levels in the study area for the following dates:

November 15, 2022 December 15, 2022 January 15, 2023 April 15, 2023
May 15, 2023 June 15, 2023 October 2, 2023 October 6, 2023

The first seven plots were selected to evaluate aquifer conditions throughout an annual cycle that takes into account variation in flow in Norrish Creek, groundwater extraction at the hatchery, and precipitation. The October 6, 2023 plot (at 16:00) corresponds to the end of a 72-hour constant- rate test with Well 8.

4 As with water level data, the temperature record for Norrish Creek (at the Hawkings Pickle Road Bailey bridge) is incomplete due to the water level falling below the sensor during periods of low or no flow.

The solid contour lines on each of the plots indicate contours estimated from measured levels using the kriging method, and dashed lines denote inferred contours in the outer periphery of the study area where there are no data points. Interpreted groundwater flow directions are perpendicular to the contour lines.

All of the plots indicate a southwesterly groundwater flow direction between Norrish Creek and the hatchery. There is some convergence of flow towards the hatchery that can be attributed to drawdown caused by pumping of Production Wells 1 through 5. This is least apparent on the plot for June 15, 2023, when the total flow from the wells was about 98 L/s, and more apparent on dates when flows were greater.

Inferred flow directions more distant to the northwest of the hatchery transition from westerly near Norrish Creek to southerly at the base of the steep mountain slope further to the west. In the region south of the CP rail track, and west of Norrish Creek, the inferred flow direction range from westerly to more southwesterly. The inferred direction at the lower portion of the creek transitions to southeasterly and parallel to the creek.

4.4 GROUNDWATER MODEL

4.4.1 Model Development

A three-dimensional numerical flow model was developed to simulate groundwater flow in the vicinity of the hatchery, and to evaluate effects of increasing groundwater extraction on aquifer water levels and surface water flows. As described in the model report included with Appendix E, this process involved:

- reviewing relevant data and surface and groundwater levels, geology, precipitation data, interpretations described in Sections 4.1 through 4.3;

- model calibration by back-simulation of the constant-rate aquifer pumping test with Well 8 (Piteau, 2024) and adjusting aquifer parameters to achieve reasonable agreement between observed and predicted water levels in monitoring wells throughout the region;
- conducting a model sensitivity analysis;
- validating the model by back-simulating water levels between October 2022 and 2023; and
- using the model to predict aquifer response between October 2022 and 2023 with Wells 7 and 8 pumping continuously at a combined rate of 192 L/s.

4.4.2 Predicted Effects

The model was used to predict groundwater water levels after one year's additional groundwater extraction at 192 L/s at the hatchery superimposed on aquifer conditions between October 2022 and October 2023. This interval was chosen for the effects assessment as it the driest period reported for the Mission West-Abbey station between 1964 and 2003. Figures E-7a and E-7b in Appendix E, respectively, indicate predicted water table contours (i.e., equipotentials), and drawdown, at the end of the simulated interval on October 15, 2023. Figure E-7b indicates

drawdown ranging from 1.5 m in the near vicinity of Wells 7 and 8 to 0.1 m about 1.5 km west of the hatchery.

The predicted maximum drawdown interference at locations of neighbouring wells resulting from pumping the new wells at the hatchery are indicated on the right side of Table 1, and range between <0.1 m and 0.62 m in operating wells. In most cases the predicted drawdown is less than 5% of the available drawdown in the well (assumed to be 60% of the available drawdown, which is equivalent to the distance between the top of the screen and the static water level), and the ability of most wells to sustain current demands are therefore unlikely to be impaired. However, it is possible that wells WS-5 and WS-8 identified during the well survey may be adversely affected. Both are shallow "dug" wells that likely penetrate the water table by only a small depth (e.g., <1 m), and may thus be more sensitive to drawdown resulting from pumping of new wells at the hatchery. Well WS-8 is reported to have experienced seasonal water shortages in 2023.

The model predicts that aquifer recharge derived from Norrish Creek east of the hatchery wells will increase by approximately 100 L/s. This will have a negligeable effect on Norrish Creek in wetter months when the entire length of the fan of Norrish Creek has flow present. Under extreme low- water conditions, when there flow in the alluvial fan goes underground, the additional recharge derived from Norrish Creek will be drawn from the hyporheic zone, and the effect on seasonal low flows in Norrish Creek flows at the fan is expected to be negligeable since the river bed is mostly dry.

As Norrish Creek flows into Nicomen Slough, the effects of the reduction flows within Norrish Creek and/or its hyporheic zone, and the reduced groundwater flows to marshlands south of the hatchery and adjacent to the slough, will be limited to the 3 km reach between the confluence with of Norrish Creek and Nicomen Slough, and where the side channel into which Inch Creek (which receives all groundwater extracted by wells at the hatchery after it has passed through the rearing pens) enters the slough. Given the width and depth of Nicomen Slough, this flow reduction is not expected to have a noticeable effect on conditions in the slough at any time of year.

The predicted changes on groundwater flows into Nicomen Slough to the south and southwest of the hatchery over the modelled interval (October 2022 to October 2023) are shown on Figure 14. These were computed for east and west zones, which are shown on the table. Drawing an additional 192 L/s from the aquifer at the hatchery is predicted to alter flows in both zones by nearly constant amounts throughout the year. Groundwater flow towards Nicomen Slough in the west zone is predicted to reduce by an average of 21 L/s, which represents about 4% of the average groundwater flow in this direction. The estimated average change in flow in the east zone is 28 L/s, and is the net of surface water entering the aquifer and the reduced outflow of groundwater into Nicomen Slough.

4.5 EFFECTS OF CLIMATE CHANGE

Climate change modelling performed for the B.C. Ministry of Forests and Range (Pike et. al., 2010) predicts total precipitation in the South Coast region will increase by approximately 6% by 2050, with seasonal changes ranging from -13% in summer to +9% in the fall. These changes can be expected to result in an overall increase in recharge to the Norrish Creek Aquifer due to increased flows in Norrish Creek, and direct infiltration of precipitation. However, prolonged periods with low flow in the Norrish Creek can be expected between spring and fall due to reduced snow pack and accelerated snow melt within the watershed due to rising temperature. As such, the minimum dry-season flow under prolonged drought conditions may not be sufficient to keep the reach below the apex from going dry, as observed in September 2023 when the flowrate for water emerging from the bedrock canyon at the apex of the fan was roughly (visually) estimated to be about 1 m3/s (Photos 5 to 7).

It is possible that under drought conditions more extreme than the 2022-2023 drought recharge to the aquifer from Norrish Creek may be less than the amount observed in September 2023. Depending on the severity of the reduction, pumping an additional 192 L/s from Wells 6, 7, and 8 may cause aquifer water levels to decline below the elevations indicated on Figure E-7a in Appendix E. This could magnify the relative reduction of groundwater flow discharging into Nicomen Slough and the adjacent marshlands, especially in the “east zone” described in Section 4.4. Development of a groundwater management plan to mitigate potential impacts of this nature is therefore recommended. This plan should include continuous monitoring of water levels in Norrish Creek and the Norrish Creek Aquifer, and adjustment of pumping rates at the hatchery if aquifer water levels are observed to be sharply declining towards or below minimal acceptable levels. This is further described in the next section.

5 WELLFIELD MANAGEMENT

5.1 MONITORING

Long-term monitoring will be necessary to continually assess well performance and aquifer conditions and provide information on which to adaptively manage wellfield operations to avoid impacting to the ecosystem and other groundwater users.

5.1.1 Aquifer Water Levels

As with the existing hatchery wells 1 through 5, Wells 6, 7, and 8 should be equipped with water level, flow rate, and temperature sensors. Observations should be logged hourly (or more frequently) and data should be centrally archived.

Water levels in selected observation wells screened in the aquifer should be measured hourly and data should be relayed to a centralized archive. This should include two observation wells within the hatchery (e.g., MW22-6 and MW23-2), and at least one well on the west bank of Norrish Creek (e.g., MW22-7 or replacement). The monitoring system should immediately alert hatchery operators when aquifer levels are below specified alert levels to facilitate appropriate actions to avoid or mitigate potential impacts to other well users and/or the environment.

Water levels in other monitoring wells in the vicinity of the hatchery (e.g., MW22-1, MW22-2, MW22-3, MW22-4, MW22-5, and a recommended new well approximately 400 m north of MW22-7), should be measured and recorded using conventional dataloggers that store data internally. The data should be retrieved on a quarterly basis.

5.1.2 Surface Water

To facilitate monitoring of creek water levels over the full range of variation, the staff gauge on the east bank of Norrish Creek at the bailey bridge should be augmented or replaced by a contactless water level sensor and datalogger attached system to the underside of the Hawkins Pickle Road bailey bridge. Data should be downloaded quarterly. Additionally, water levels in Norrish Creek should be monitored at the apex of the alluvial fan, and flows at this location should be gauged during low water conditions (when the creek downstream from the apex goes dry) to quantify recharge to the hyporheic zone.

5.2 WELLFIELD MANAGEMENT

As described in Section 5.1.1, water levels in selected observation wells screened in the aquifer should be monitored and the measurements should be processed in real-time so that hatchery operators are alerted when aquifer levels drop below specified alert levels and groundwater from Wells 6, 7, and 8 can be reduced to avoid impacts to well users or the environment.

Together with data from other monitoring points, all data should be reviewed annually to compare actual and predicted effects and identify, and where needed, to adapt operation practices to reduce potential impacts. This will need to be detailed in a wellfield management

plan that will also set out requirements for monitoring, assessment, alert levels, and necessary responses.
PITEAU ASSOCIATES

6 CONCLUSIONS AND RECOMMENDATIONS

This report describes a regional aquifer assessment in the vicinity of the Inch Creek Hatchery. This work has included investigation of hydrogeologic conditions, and evaluating potential effects of continuous pumping of groundwater from three new wells (Wells 6, 7, and 8) at a combined rate of 192 L/s (6.1 million m3/year) on other groundwater users and groundwater flows to and from surface water. Together with aquifer flow testing conducted with the three new wells, the investigation has included review of relevant background information, long-term monitoring, and numerical groundwater flow modelling. Key conclusions drawn from this program of work are set out below.

The hatchery is underlain by the highly productive Norrish Creek Aquifer. The primary sources of recharge to the aquifer are infiltration of surface water in the alluvial fan of Norrish Creek, and direct infiltration of precipitation. The groundwater flow direction in the vicinity of the hatchery is southwesterly.

Five existing wells at the hatchery pump groundwater at an average rate of 238 L/s (7.5 million m3/year) to supply water for fish rearing operations. A large proportion of the pumped groundwater is recharged via infiltration from Norrish Creek.

Extraction of an additional 192 L/s (6.1 million m3/year) of groundwater to supply a planned captive brood facility at the hatchery (via new Wells 6, 7, and 8) will represent an 80% increase in the average rate of groundwater extraction at the hatchery. Groundwater flow modelling indicates that approximately 52% of this addition flow (approximately 100 L/s) would be supplied by an increase in infiltration from Norrish Creek, and that the balance of the additional flow will be mostly offset by a reduction of groundwater flow towards Nicomen Slough.

The additional 100 L/s that will be induced to infiltrate into the aquifer from Norrish Creek represents about 1.6% of the average annual flow in the creek, and will be sustainable on a year-over-year basis. During late summer and fall, when flow in the alluvial fan of Norrish may be fully within the hyporheic zone, the additional 100 L/s of infiltration diverted from the creek will represent a larger proportion of total flow. However, as the creek bed is often dry under these conditions and the flow is underground (i.e., in the hyporheic zone), this is not expected to have any discernable impact on the creek ecology.

Continuous extraction of an additional 192 L/s of groundwater at the hatchery is not expected to impair the ability of most water wells within the region to sustain their current demands. However, it is possible that shallow “dug” wells that penetrate the water table by only a small amount (e.g., <1 m) may be adversely affected by additional water table drawdown, especially when water table levels are low. Two shallow wells where these effects may need to be mitigated were identified during this investigation.

The effects of the reduced flow into Nicomen Slough resulting from pumping an additional 192 L/s of groundwater at the hatchery will be limited to the 3 km reach between the confluence with of Norrish Creek and Nicomen Slough the point where the side channel that Inch Creek flows into

enters the slough. Given the width, depth, and flat gradient of Nicomen Slough, the reduction is not expected to have any discernable effect on conditions in the slough at any time of year. The potential effects to the marshlands adjacent to the slough, and the adjacent side channel, have not been assessed.

Climate change is expected to cause prolonged periods with low flow in the Norrish Creek, and it is possible that under extreme drought conditions there may be intervals when recharge to the creek's hyporheic zone may not be sufficient to sustain the planned 192 L/s increase in groundwater extraction at the hatchery. Although this would be expected to occur for relatively short intervals, the reduced availability of recharge from the creek could cause water levels in the aquifer to decline below predicted low levels. This could increase drawdown effects in other water wells beyond the amounts predicted, and magnify potential effects on marshlands adjacent to Nicomen Slough. These risks can be mitigated by implementation of a wellfield management plan that will vary groundwater extraction for the Captive Brood Facility based on real-time monitoring of water table levels in the aquifer.

Respectfully submitted,

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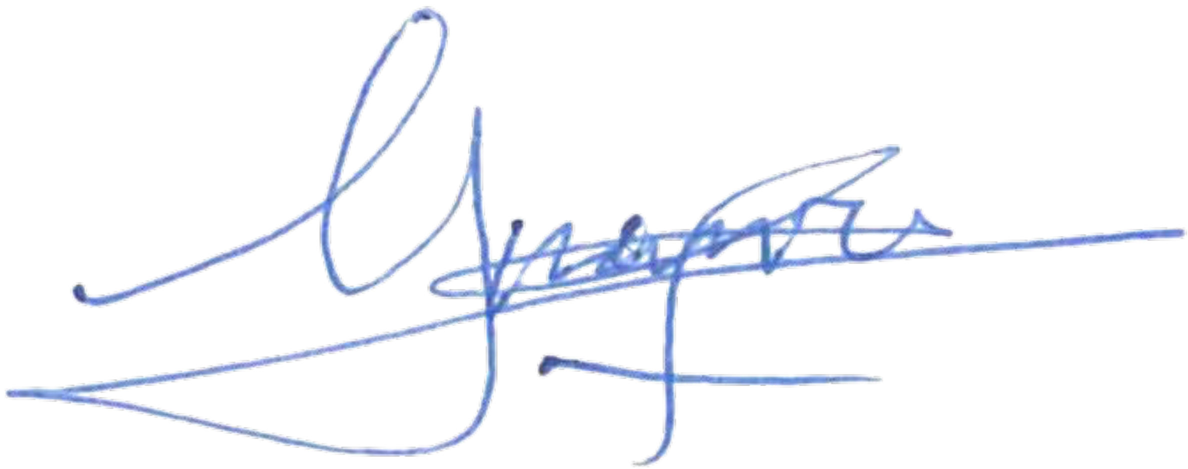

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