P.E.O.P.L.E.

Sub-provincial Population Projections: Methodology and Assumptions

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1. Executive Summary

A modernized methodology

The Population Extrapolation for Organizational Planning with Less Error (P.E.O.P.L.E) model, originally developed in 1999, underwent a modernization process starting in 2022 to incorporate new geographies and data to better reflect current population impacts and trends.

The main enhancements to the P.E.O.P.L.E. model include:

- Incorporating the demographic trends of small areas in the projections.
- Using new data available at the sub-provincial level.
- Projections for all municipalities of B.C.

How the methodology has improved

The new P.E.O.P.L.E. model enhancements incorporate fertility, mortality and migration trends of Community Health Service Areas (CHSA) and municipalities (Census Subdivisions, CSD), the smallest boundaries of the Health and Census regions, respectively, for which annual population estimates are produced. This enables the population projections for these areas to reflect their own demographic trends instead of the trends of more aggregated regions.

This new approach introduces methodological improvements to increase the reliability and accuracy of the population projections for small areas. This will allow BC Stats to produce population projections for even smaller areas across all geographies, such as municipalities, health regions, school districts and electoral partitions of B.C.

Coming soon

For future editions of the P.E.O.P.L.E. model, BC Stats plans to continuously improve this methodology to capture changes in mortality, fertility and migration that originated during and after the pandemic. Similarly, BC Stats will continue to monitor changes in international migration resulting from adjustments to federal immigration policy, modifying the assumptions used in the population projections accordingly.

2. Introduction

2.1. Background

The Population Extrapolation for Organizational Planning with Less Error (P.E.O.P.L.E.) model, introduced in 1999, is a cohort-component demographic model used by BC Stats to produce sub-provincial population projections. The projections are prepared for Local Health Areas (LHAs), Community Health Service Areas (CHSAs), Regional Districts, municipalities (CSDs), school districts, service areas for the Ministry of Children and Family Development (MCFD) and other geographies.

The original P.E.O.P.L.E. model used LHAs as the base geography for sub-provincial population projections. With this model, projections for other sub-provincial geographies are obtained through geographic translation of the base geography projections using relationship tables derived from undercount-adjusted Census population counts; this approach ensures consistent population dynamics across all geographies.

2.2. Overview of the Methodological Changes to the P.E.O.P.L.E. Model

Starting in 2022, BC Stats introduced a new approach to its population projections to improve the projection accuracy for small areas. Integral to the new approach was changing the base geography of the sub-provincial population projections from LHAs to include CHSAs and municipalities. This required a cohort-component approach capable of producing projections for all 231 CHSAs and 751 municipalities instead of only 89 LHAs in previous editions. Table 1 summarizes the methodological differences between the new P.E.O.P.L.E. methodology and previous editions.

Table 1. Methodological Changes in P.E.O.P.L.E.

Feature	P.E.O.P.L.E 2021 and before	New P.E.O.P.L.E methodology
Demographic trends (fertility, mortality and migration)	LHA	CHSA/CSD
Controlling by the provincial-level projection	✓	✓
Projections for all municipalities of B.C.	✗	✓
Controlling for sub-provincial population totals using hierarchical raking[1]	✗	✓
Using sub-provincial forecasts and data	✗	✓

The new P.E.O.P.L.E. methodology preserves several aspects of the previous P.E.O.P.L.E. model, including using the provincial-level projection as a control for the sub-provincial population projections. The incorporation of sub-provincial population projections for CHSAs and municipalities required two major enhancements to the P.E.O.P.L.E. model:

- **A bottom-up approach:** When CHSAs were introduced to the P.E.O.P.L.E. model in 2019, population projections for CHSAs were calculated by converting LHA population projections. The conversion was done using population weights from the 2016 Census and prorated to conform with their corresponding LHA population projections. Therefore, the projections for CHSAs did not reflect the fertility, mortality, and migration trends for these areas. Instead of converting from LHAs, the new P.E.O.P.L.E. methodology follows the methodology proposed by Swanson *et al.* (2010) for small-area population projections to produce projections for each CHSA and municipality directly. The population projections for LHAs, Health

[1] **Raking** is a mathematical technique for adjusting a set of numbers so that they add up to given reference totals along two or more dimensions. In the context of producing population counts, the most common raking dimensions are age, gender, and geographic area. **Hierarchical raking** involves consecutive rounds of raking between levels of a hierarchical geography, i.e. those in which areas at a lower geographic level form a partition of a higher-level area. The application of hierarchical raking for the P.E.O.P.L.E. 2024 model is discussed further in Section 3.2.

Service Delivery Areas and Health Authorities are derived from aggregating the projections at the CHSA level.

- **New methodology for projecting population totals**: Previously, projected population totals of sub-provincial areas were determined by the dynamics of the cohort-component method. This meant that projected population growth trends for each area largely reflected the prevailing fertility, mortality and migration rates at the LHA level. By contrast, in the new P.E.O.P.L.E. methodology, the total population of each region are projected independently, while the age-gender distributions are determined by the cohort-component method, which advances cohort populations through time with births, deaths, and aging as drivers.[2]

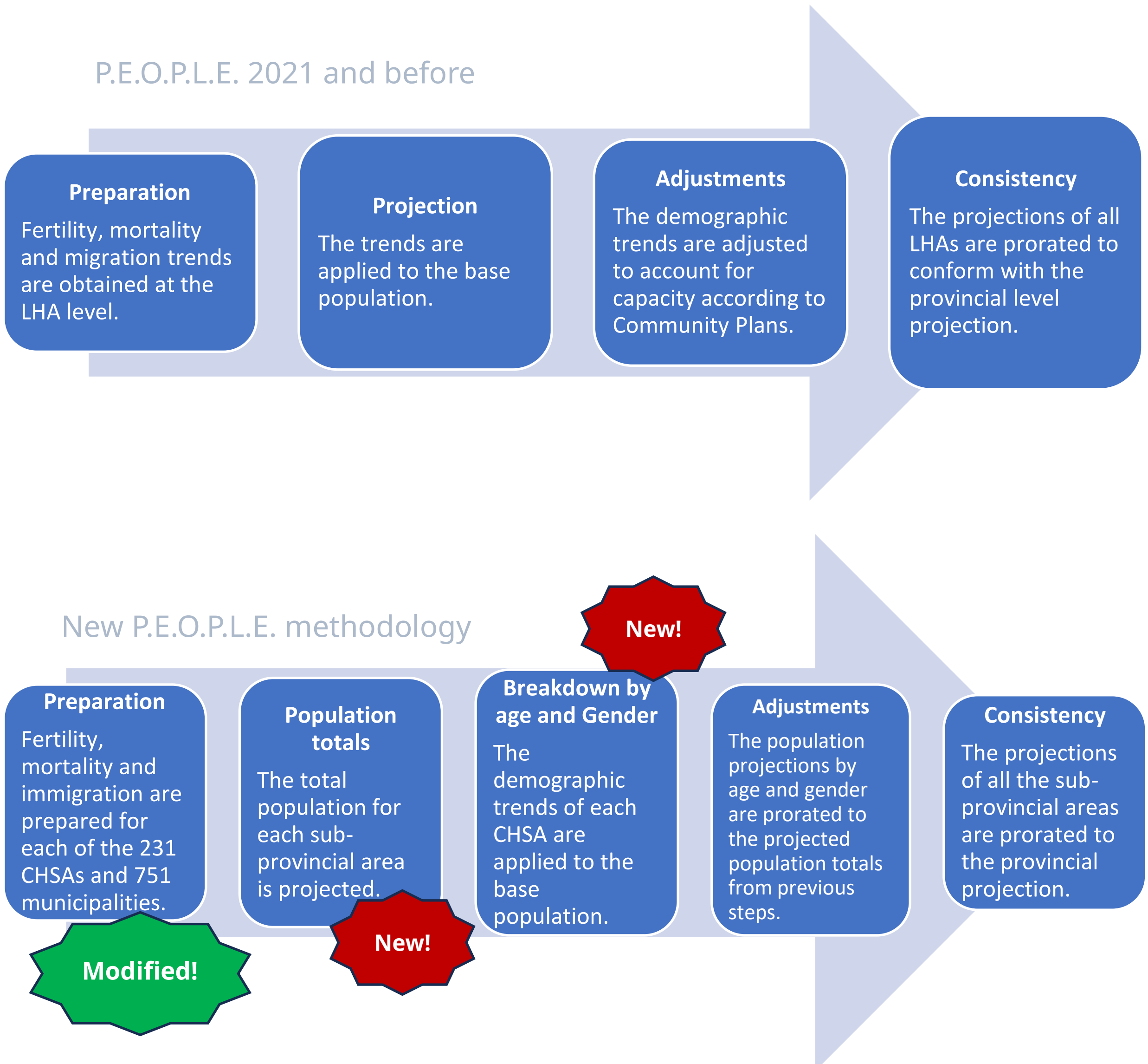
These methodological updates introduced changes to the workflow of the P.E.O.P.L.E. model. The comparison between the previous and new workflows is illustrated in Figure 1. The new methodology introduces two new steps and modifies the first step of the P.E.O.P.L.E. population projections:

- Instead of calculating demographic trends for 89 LHAs, the new procedure requires trends for each of the 231 CHSAs and 751 CSDs of B.C.
- The population totals for each sub-provincial area are prepared independently taking into consideration historic population trends.
- The results of the cohort-component model are prorated to the population totals.

These modifications will be described in more detail in the following sections. However, the final step of the sub-provincial population projections remains largely unchanged, except that this prorating is applied to CHSA and municipalities instead of LHAs.

[2] Cohort-component models tend to overaccentuate trends in small communities undergoing important demographic changes (Wilson; 2016). Wilson (2016), Swanson *et al*. (2010) and others recommend controlling the population of a cohort-component method with an independent projection of the total population. This is the approach followed in the new P.E.O.P.L.E. methodology.

Figure 1: Workflow Comparison of P.E.O.P.L.E. Model Versions



3. Methodology

This section describes the methodology used by BC Stats to produce the new P.E.O.P.L.E. population projections, with a focus on the main methodological changes compared to previous editions. The section is structured as follows:

1. A brief overview of the provincial-level population projection.
2. A description of the methodology used to project the population totals of each sub-provincial area.
3. A review of the approach used to project the population distribution by gender and single year of age.

3.1. The Provincial Population Projection

B.C.'s provincial-level population projection has largely remained unchanged, following the same methodology as in previous editions. This methodology is based on a cohort-component model that requires separate projections of each component of population change at the provincial level: i) fertility, ii) mortality, iii) net international migration and iv) net interprovincial migration.

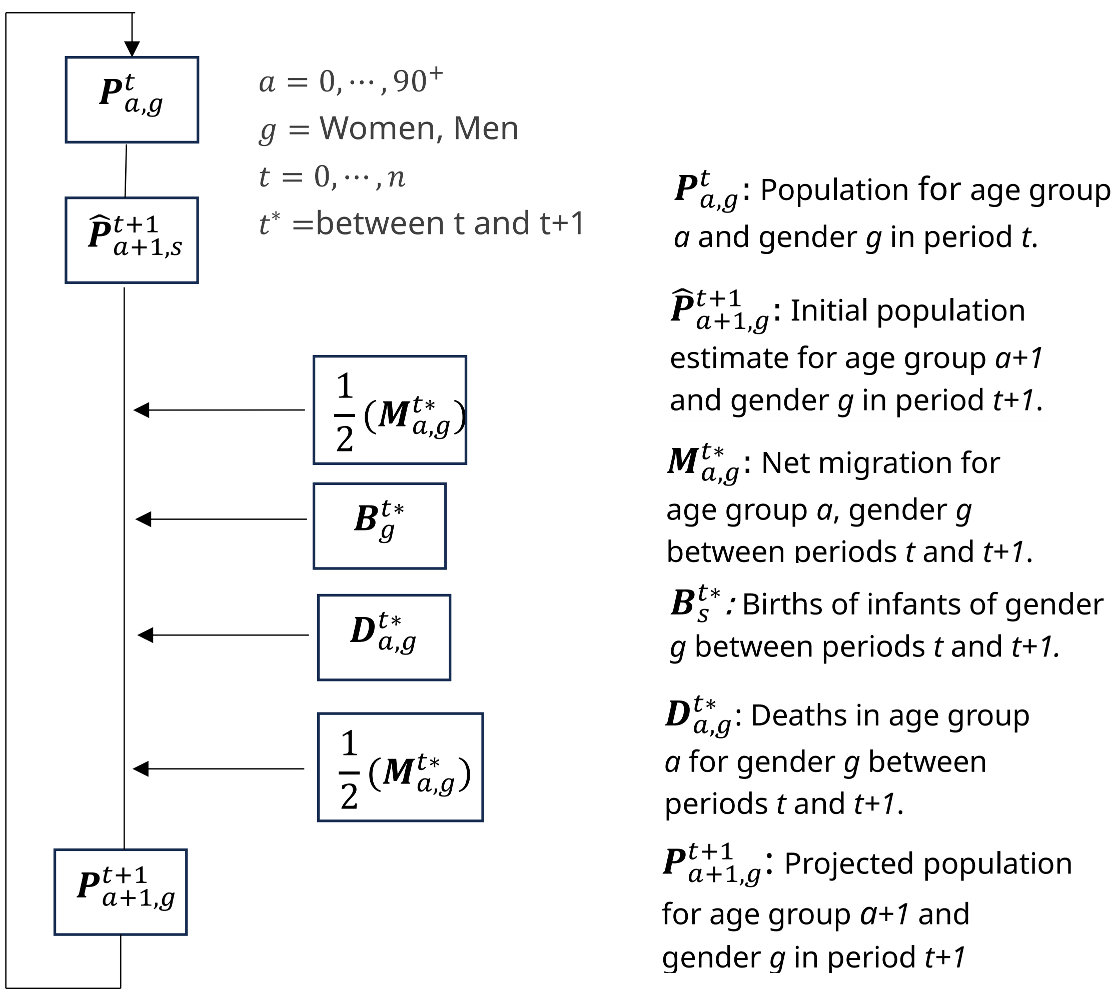
The fertility and mortality rates are projected for each age and gender using the methodology described in section 3.1.1 below. These projections are made using the age-specific fertility and mortality rates computed using vital events data from the Vital Statistics Agency of B.C. International and domestic migration rates are projected using historical trends, current economic conditions and targets set by the federal government.

Using the projected migration, fertility, and mortality rates, and the latest population estimates by age and gender from Statistics Canada,[3] a projection for subsequent years is made by promoting each age group in the preceding year to the next highest age group, while at the same time considering the effects of net migration, deaths, and births.

[3] Statistics Canada. Table 17-10-0005. Population estimates on July 1, by age and gender, annual.

Specifically, beginning from the latest population estimates by single year of age and gender, which are the base year of the projection, each age group *a* in the base year *t* is promoted to the next age group, *a+1*, in period *t+1*. Half of the projected net migration is added in the respective age-gender cohort before applying the respective fertility and mortality rates to incorporate the possible contribution of newcomers to the deaths and births.[4] Finally, the second half of the projected net migration is added to obtain the final population estimate for that age-gender cohort for that period. This process is then repeated for the number of years required. A diagrammatic representation of the process is depicted in Figure 2.

Figure 2: Flow of the Provincial Level Cohort Component Model



[4] Since migration, births and deaths in the area are happening throughout the period, this assumption is made in lieu of a continuous calculation of these components.

3.1.1. Fertility and Mortality Projections

The provincial-level age-specific fertility rates are calculated using birth data from the Vital Statistics Agency of BC by age and gender for women aged 15 to 49 years old. The estimated age-specific fertility rate uses data from 1986 to 2023 after prorating the data from the Vital Statistics Agency with the birth statistics published by Statistics Canada at the provincial level.[5]

The age-specific fertility rates are projected using a Dynamic Factor Model as proposed by Stock and Watson (2010). This approach has been used to project fertility and mortality rates (He *et al*; 2021) and is a generalization of the Lee and Carter (1992) approach.

The steps followed in this approach are summarised below:

1) The age-specific fertility rates are detrended, including corrections for the COVID-19 pandemic using a robust regression suggested by Venables and Ripley (2002).
2) The detrended variables are used to estimate the latent factors using the dynamic factor model approach suggested by Stock and Watson (2010).[6]
3) The latent factors are forecasted using a Vector Autoregressive model.
4) The latent factors are used to forecast the detrended age-specific fertility rates.
5) The age-specific fertility rates are projected using the projection of the detrended variables, controls for the pandemic and other factors, and the trend estimated in previous steps.

The projected Total Fertility Rate (TFR) is shown in Figure 3.[7] While the TFR in B.C. has exhibited a long-term downward trend, this decline has accelerated in recent

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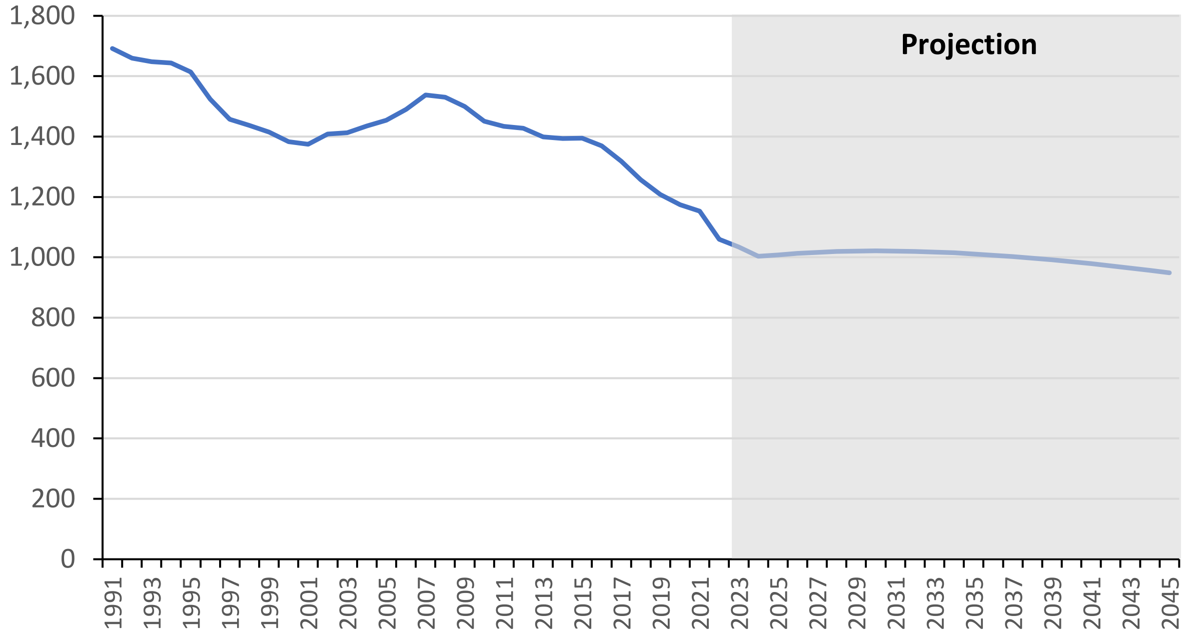
[5] The data from the Vital Statistics Agency of BC has small discrepancies with the data from Statistics Canada due to revisions and differences in the date it is compiled. To keep in line with Statistics Canada, we align the number of births used in the projections with the data published by Statistics Canada. Statistics Canada. Table 17-10-0016-01 Estimates of births, by gender, annual.
[6] The number of factors is selected using the criteria proposed by Bai and Ng (2002). For B.C., there were three latent factors selected.
[7] The TFR is an estimate of the average number of children a woman can be expected to have given the age-specific fertility rates in a given year (Statistics Canada, 2025).

years. Going forward, BC Stats expects the TFR to remain at a level close to one child per woman, which is below the replacement rate of 2.1.[8]

Figure 3: Total Fertility Rate in B.C.
(Live Births per 1,000 Women, 1991 – 2045)



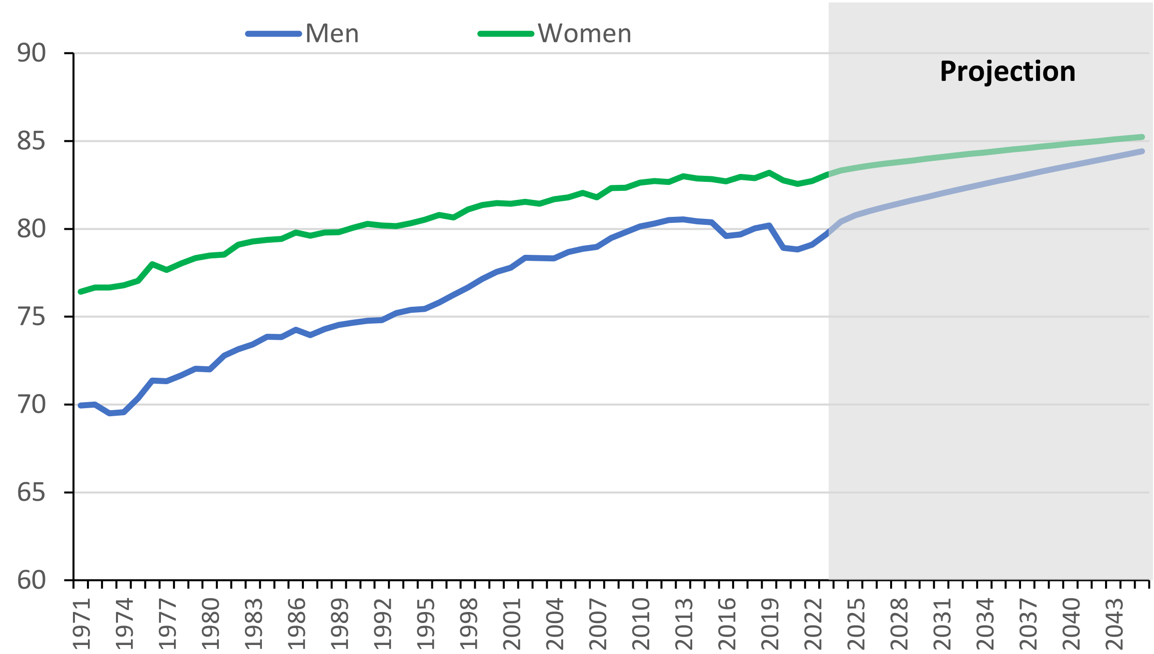
Source: Statistics Canada (2025). Tables 17-10-0005-01, 17-10-0016-01. Projections produced by BC Stats with data and information available up to January 3, 2025.

Mortality rates are calculated for each age and gender using population estimates and mortality data from the Vital Statistics Agency of BC. The projections are made using the Dynamic Factor Model approach proposed by Stock and Watson (2010), as detailed above. The projections of age-specific mortality rates incorporate controls for the COVID-19 pandemic (2020-2022) and the opioid epidemic declared in British Columbia in 2016.

The life expectancy at birth for men and women is shown in Figure 4. The life expectancy at birth is expected to continue its recovery from the COVID-19 pandemic in the coming years. As such, the life expectancy at birth in the province is expected to return to its pre-pandemic trend in the coming years.

[8] As mentioned in UN (2024), a TFR of 2.1 is consistent with a population growth of zero in the long run in countries with low mortality and no migration.

Figure 4: Life Expectancy at Birth in B.C. (1971 – 2045)



Source: Statistics Canada (2025). Tables 17-10-0005-01, 17-10-0006-01. Projections produced by BC Stats with data and information available up to January 3, 2025.

3.1.2. Inter-provincial Migration

The interprovincial migration to B.C. is projected using Statistics Canada's latest estimates as the baseline.[9] The projection is done in three steps:

1) The inflows and outflows of net interprovincial migrants for the current quarter are nowcasted using monthly data from the Child Tax Benefit (CTB).
2) The medium term is forecasted using an econometric model that relates the unemployment rate, the gross domestic product (GDP) and the interprovincial projection.[10]
3) The long-term is estimated using the 15-year average for inflows and outflows of interprovincial migrants to B.C.

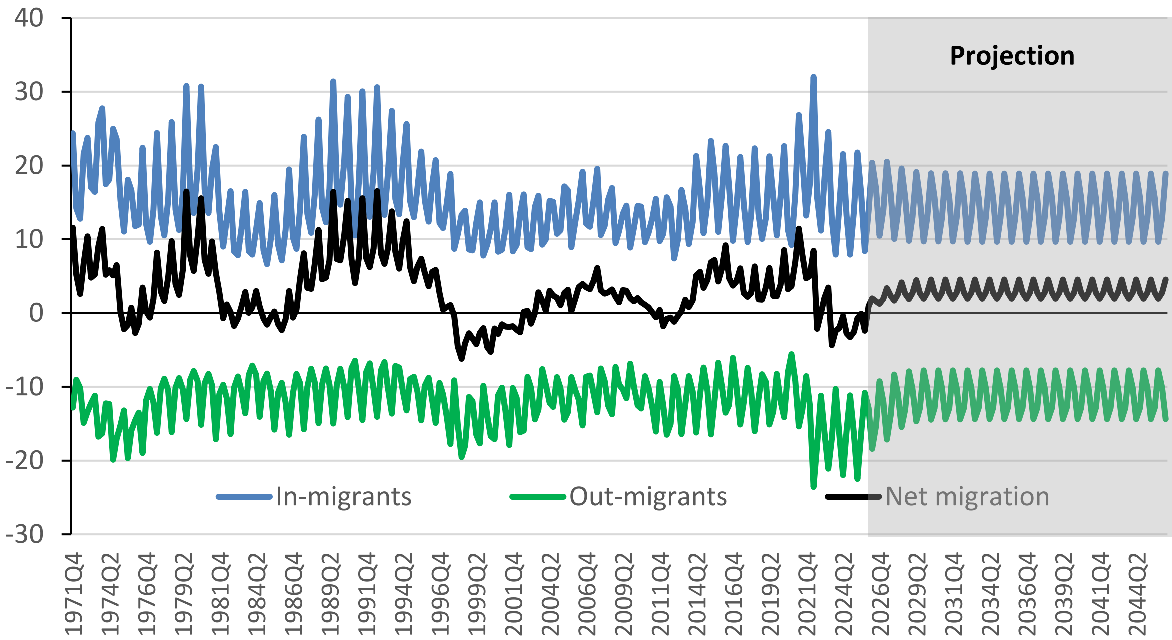
The nowcasting of the current quarter is done by using a bridge equation approach proposed by Schumacher (2016) to estimate an econometric model for

[9] Statistics Canada. Table 17-10-0020-01 Estimates of the components of interprovincial migration, quarterly

[10] Statistics Canada. Table 36-10-0221-01 Gross domestic product, income-based, provincial and territorial, annual (x 1,000,000) and Statistics Canada. Table 14-10-0287-01 Labour force characteristics, monthly, seasonally adjusted and trend-cycle

inflows and outflows of interprovincial migrants, which relates the CTB with these flows using an Autoregressive Distributed Lag (ARDL) model. The medium term is projected using an econometric model that relates the spread in the unemployment rate in B.C. and Alberta, and the GDP of B.C. and the rest of Canada. Figure 5 shows the projections for inflows and outflows of interprovincial migrants for B.C.

Figure 5: Inflows and Outflows of Interprovincial Migrants to B.C. (Thousands, 1971 Q4 – 2046 Q2)



Source: Statistics Canada (2025). Table 17-10-0020-01. Projections produced by BC Stats with data and information available up to January 3, 2025.

3.1.3. International Migration

International migration is projected using population estimates for permanent residents (PRs), emigrants, net non-permanent residents (NPRs), and returning emigrants published by Statistics Canada.[11]

The projection of the components of international migration is done similarly to the interprovincial migration. In particular, the international migration projection

[11] Statistics Canada. Table 17-10-0040-01 Estimates of the components of international migration, quarterly and Statistics Canada. Table 17-10-0015-01 Estimates of the components of interprovincial migration, by age and gender, annual

uses the same nowcasting approach (Schumacher; 2016) to incorporate the monthly permit data published by Immigration, Refugees and Citizenship Canada (IRCC). The projections incorporate information on permits approved for PRs and NPRs, including study and work permits.[12]

For the medium term, the projections use the targets set by the Immigration Levels Plan (ILP) published annually by IRCC.[13] The ILP sets targets for the number of PRs and NPRs expected to be admitted to Canada in the following three years.[14] The projection assumes that the targets set by the federal government will be met. For the fourth year and after, the projection assumes that these components will remain constant as a share of the total population. A similar approach is followed for the emigrants and returning emigrants, where their share is projected assuming that the ratio of these flows to the total population is stationary.

Since the ILP only sets targets for admissions (inflows) of NPRs and not outflows, the NPRs in the projections are modelled by estimating an ARDL model of net inflows of NPRs and the admissions of NPRs reported by IRCC.[15] This model is combined with the targets for NPRs to project the net flows of NPRs arriving in B.C. The age-gender distribution of the net flows of NPRs is projected using a model that relates the net flows of NPRs with their share in each age and gender bin.

Figure 6 below shows the projected components in the P.E.O.P.L.E. 2024 population projection. The net international migration between 2025 and 2027 is expected to decrease significantly in relation to the recent past, driven mainly by large net outflows of NPRs. In the long term, international migration is still expected to be

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[12] In particular, the population projections include IRCC's monthly updates on permits for permanent residents, Study Permits, and International Mobility and Temporary Foreign Worker programs.

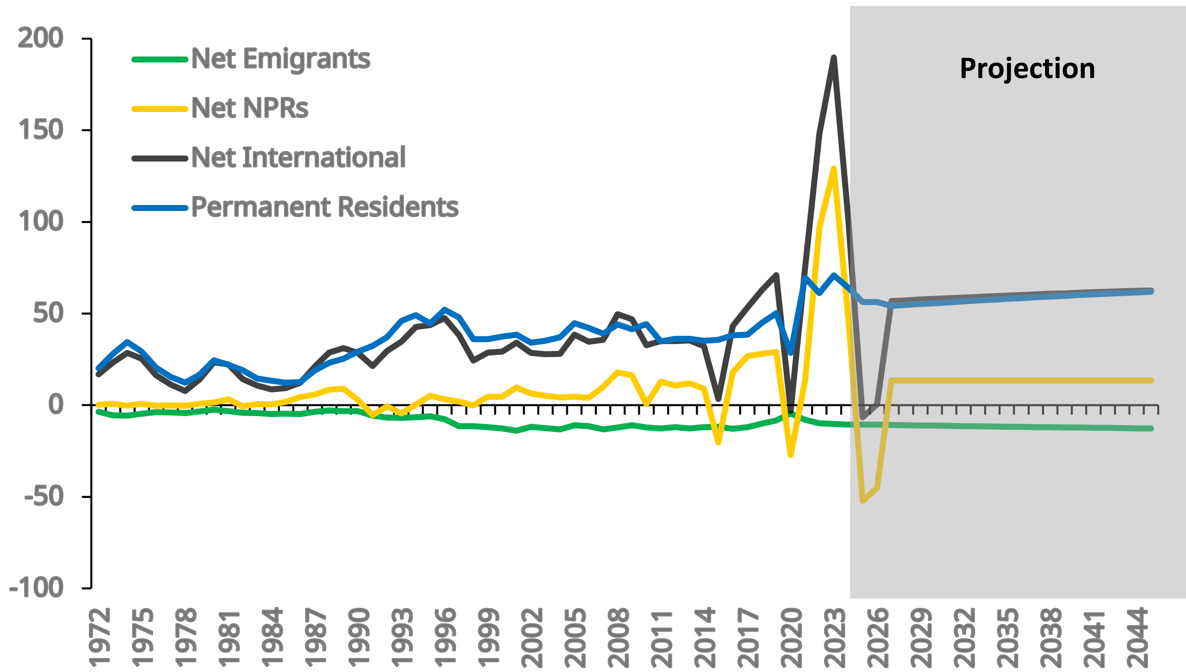
[13] The latest version of this plan was published on October 24, 2024. The 2025 – 2027 Immigration Level Plan can be consulted online.

[14] The ILP has historically only set targets for Permanent Residents; however, the 2025 – 2027 Immigration Levels Plan introduced targets for non-permanent residents for the first time. The targets for PRs and NPRs are expected to be updated annually.

[15] The estimated ARDL uses only lagged values of positive net flows of non-permanent residents. The lagged values of net inflows are used to control for expected net outflows. This modelling approach assumes that net outflows of NPRs should not have later impacts on future net flows of NPRs while large net inflows might produce net outflows in future quarters. This is a similar approach to the asymmetric effects of price changes (Peltzman, 2000).

the primary driver of population change in British Columbia, primarily driven by the inflows of permanent residents (PRS).

Figure 6: Components of International Migration to B.C. (Thousands, 1972 – 2045)



Source: Statistics Canada (2025). Table 17-10-0014-01. Projections produced by BC Stats with data and information available up to January 3, 2025.

3.2. Sub-provincial Population Projections

The sub-provincial projections are produced independently and reflect each geography's fertility, mortality and migration trends. Moreover, given the small population of many of B.C.'s geographies, the approach used for the sub-provincial population projections differs from that used for the provincial projection to account for the added volatility inherent in small populations. However, the P.E.O.P.L.E. sub-provincial population projections are calibrated to the provincial-level population projections using a hierarchical two-way ranking.

The remainder of this section details the methodology used by BC Stats to produce its sub-provincial population projections.

3.2.1. Projection of Population Totals

For the sub-provincial population projections, the new P.E.O.P.L.E. methodology uses the approach suggested by Swanson *et al*. (2010). They recommend projecting the population totals for each region independently of the cohort-component model. This corrects the biases that might happen when applying cohort-component models in small areas, which tend to overaccentuate trends in the projection of the different components of population growth in small areas (Wilson, 2016).[16]

The methodology for projecting the total population for all sub-provincial areas of B.C. is based on the demographic trends for Census Subdivisions (CSD).[17] The total population changes for other sub-provincial areas (i.e. CHSAs, School Districts, Trustee Electoral Areas, etc.) are obtained by translating the total population change of the 751 CSDs of British Columbia to the different geographies of B.C. The translation is done by distributing the population change of each CSD to the corresponding areas with which it intersects using dissemination block (DB) level population counts of the 2021 Census adjusted for net Census undercoverage (NCU).

Figure 7 illustrates a Community Health Service Area (CHSA) that overlaps multiple Census Subdivisions. In particular, CHSA 4123 Langford Highlands nests parts of the following CSDs: i) Highlands District Municipality (CSD 5917049), ii) Langford City (CSD 5917044), and iii) Juan de Fuca (CSD 5917054). Accordingly, the total population of CHSA 4123 Langford Highlands is projected by adding 84.1%, 25.9% and 7.6% of the projected populations of these CSDs, respectively. These weights represent the share of the population of each of these CSDs that intersect CHSA 4123 Langford Highlands, according to NCU dissemination block level population weights of the 2021 Census.

This approach ensures consistency between the population projections of CHSAs and CSDs and follows the same methodology used to produce the population

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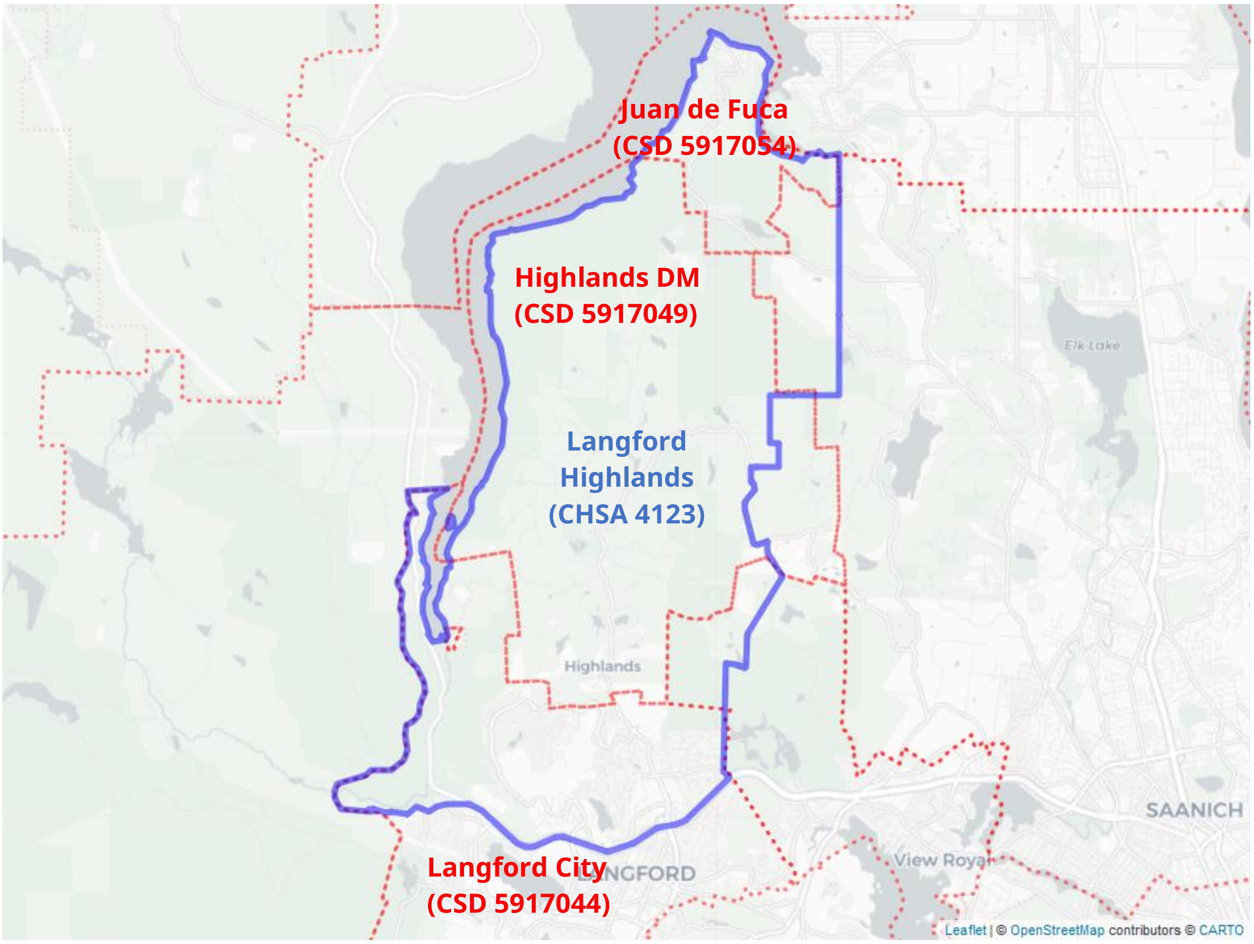
[16] In regions with small populations that are undergoing demographic change due to an increase or decrease of any of the components of population change (births, deaths or migration), CCS models tend to overestimate these trends.

[17] Census Subdivisions (CSDs) are the statistical equivalent of municipalities defined by Statistics Canada every Census. For the 2021 Census, B.C. was divided in 751 CSDs.

estimates for CHSAs. British Columbia is divided into 231 CHSAs, which represent the smallest health geography in the province. By contrast, British Columbia has 751 CSDs using the Standard Geographic Classification (SGC) of the 2021 Census.[18]

Figure 7: CHSA 4123 Langford Highlands and the Census Subdivisions it



The map shows the boundary of the Community Health Service Area of Langford Highlands (CHSA 4123) in blue. The boundaries of Highlands DM (CSD 5917049), Langford City (CSD 5917044) and Juan de Fuca (CSD 5917054) are overlaid (dotted red line).

The total population of the 751 CSDs in British Columbia are also projected independently as recommended by Swanson *et al*. (2010) and Wilson (2010). The

[18] The number of CSDs used for the demographic estimates is updated after the rebasing of each Census according to the changes in municipal boundaries at the time of the Census, which are included in the SGC. While for the 2016 Census there were 737 CSDs in B.C., for the 2021 Census there are 751 CSDs. For more information regarding the SGC of the 2021 Census visit Statistics Canada's website.

projection of the total population for each CSD is projected using the following approach:

1) The total population of each of the eight Development Regions of B.C. are projected using an Autoregressive Fractionally Integrated Moving Average (AFIRMA) model.
2) The total population of the 29 Regional Districts (Census Divisions) of B.C. are projected by forecasting the annual population growth and aligning their total population to aggregate to the projected population of their respective Development Regions.
3) Finally, the total population of the 751 CSDs of B.C. is projected using an AFIRMA model, which is aligned to aggregate to their respective Regional Districts from the previous step using the *plus-minus* method proposed by Judson and Popoff (2004).

This hierarchical approach incorporates regional dynamics in the projection of the total population of each Census Subdivision (CSD). The AFIRMA model was selected after evaluating the performance of the AFIRMA, ARIMA and simple linear trends. The AFIRMA approach showed the smallest root mean squared error in a pseudo-out-of-sample test among these models.

3.2.2. Population Distribution by Gender and Single Year of Age

The approach proposed by Swanson et al. (2010) recommends producing the projection of the total population independently from the projection of the age-gender distribution. As such, to generate population counts by gender and single year of age for CHSAs and CSDs, BC Stats implemented the cohort-component model proposed by Hamilton and Perry (1962) with the modifications suggested by Swanson *et al*. (2010) and Marquez (2021).[19] The new methodology was necessary given the small population size of CHSAs and CSDs. This methodology improves the accuracy of small-area population projections by leveraging two factors:

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[19] The concept of "gender" refers to an individual's personal identity as a man, woman or non-binary person. The demographic estimates are available for the gender category of males and females, which are used in an analogous way to the concept of "men+" and "women+" used by Statistics Canada. For additional details on this concept in the context of the demographic estimates, please refer to the information available at Statistics Canada's website at this link.

- The population projections for each CHSA or CSD depend on their prevailing fertility, mortality and migration trends. This allows the population distribution by age and gender of each CHSA and CSD to evolve according to area-specific demographic trends.
- The combined population of all CHSAs and CSDs are prorated to match the provincial-level population projection using Iterative Proportional Fitting (IPF).[20] This ensures consistency between the provincial and sub-provincial projections.

This approach addresses several shortcomings of applying cohort-component models to produce population projections for small areas. As shown by Baker *et al*. (2020) and Wilson (2016), cohort-component models applied to small area population projections tend to have low accuracy since they overaccentuate their demographic trends. Therefore, the methodology used by BC Stats produces population projections that are consistent with the provincial level population projections but that reflect the demographic trends of each CHSA and CSD. The following sections describe the methodology followed to produce the age-gender distribution for CHSAs and CSDs. Section *3.2.2.1* gives an overview of the original Hamilton and Perry (1962) model while section *3.2.2.2* details the implementation of this model in the P.E.O.P.L.E. population projections.

3.2.2.1. The Hamilton and Perry (1962) Model

The Hamilton and Perry (1962) model is a simplified version of the cohort-component model, which has gained popularity in recent years as a tool for producing population projections for small areas (Swanson, 2021). The main reason for its recent popularity is that this model requires less information than other cohort-component models. In particular, the Hamilton-Perry (HP) model only requires population estimates to produce population projections, allowing it to bypass the need for complete and accurate data on births, deaths and migration.[21]

[20] IPF is a mathematical procedure commonly used in demography and other statistical fields which adjusts population distributions of smaller localities to match an independent projection of their aggregate. For further details see Judson and Popoff (2004).

[21] It is common that birth and death certificates have small errors in their address or postal code. These errors inhibit a correct assignment of these demographic events by geography when the area of analysis is very small (Flotow and Burson; 1996). This phenomenon can affect the accuracy

The HP model requires computing the Cohort Change Ratio (CCR) and the Child-Woman Ratio (CWR) for each area and applying these measures to area-level population estimates to produce population projections for that area. The following equations describe these measures:

$$CCR_{i,g,a}^{t} = \frac{P_{i,g,a+1}^{t+1}}{P_{i,g,a}^{t}} \quad (1)$$

$$CCR_{i,s,(a+)}^{t} = \frac{P_{i,g,(a+)}^{t+1}}{P_{i,g,(a+)}^{t} + P_{i,g,(a+)-1}^{t}} \quad (2)$$

$$CWR_{i}^{t} = \frac{P_{i,f,0}^{t} + P_{i,m,0}^{t}}{\sum_{a=15}^{45} P_{i,f,a}^{t}} \quad (3)$$

$CCR_{i,g,a}^{t}$ in equation (1) is the CCR for region *i*, gender *g* and age *a* during period *t.* It is calculated as the ratio between the population count of gender *g* and age *a+1* in period *t+1* ($P_{i,g,a+1}^{t+1}$) and the number of people of age *a* and gender *g* in the previous period and same region ($P_{i,g,a}^{t}$). As such, the CCR indicates how much the population of a given cohort changes over time for each gender, age and region. For the upper limit of the age range, denoted as (a^{+}), the CCR is computed slightly differently as described by equation (2): it is calculated as the population count of the upper age limit in the next period ($P_{i,g,(a+)}^{t+1}$) divided by the sum of the population of this age group in the current period ($P_{i,g,(a+)}^{t}$) and the cohort that is a year younger ($P_{i,g,(a+)-1}^{t}$). The CWR, defined by equation (3), represents the ratio of infant children of both genders ($P_{i,f,0}^{t} + P_{i,m,0}^{t}$) born in the current period divided by the total population of women between 15 and 45 years old in the area of interest ($\sum_{a=15}^{45} P_{i,f,a}^{t}$). Thus, the CWR represents an aggregate measure of fertility similar to the Total Fertility Rate (TFR).

In the original implementation of the HP model, the CCR and the CWR are held constant during the horizon of the projection and are computed using the two previous data points of population estimates. Thus, $CCR_{i,g,a}^{b}$ and CWR_{i}^{b} represent the Cohort Change Ratio and Child-Woman Ratio, respectively, in the base year, *b*.

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of fertility, mortality and migration rates and the accuracy of cohort-component models that use these rates in their population projections.

Using these measures, the population of age *a+1*, in period *t+1*, gender *g* in area *i* is calculated as follows:

$$P_{i,g,0}^{t+1} = \theta_{i,g}^{b} \cdot CWR_{i}^{b} \cdot \sum_{a=15}^{45} P_{i,f,a}^{t+1} \tag{4}$$

$$P_{i,g,a+1}^{t+1} = CCR_{i,g,a}^{b} \cdot P_{i,g,a}^{t} \tag{5}$$

$$P_{i,g,(a+)}^{t+1} = CCR_{i,g,(a+)}^{b} \cdot (P_{i,g,(a+)}^{t} + P_{i,g,(a+)-1}^{t}) \tag{6}$$

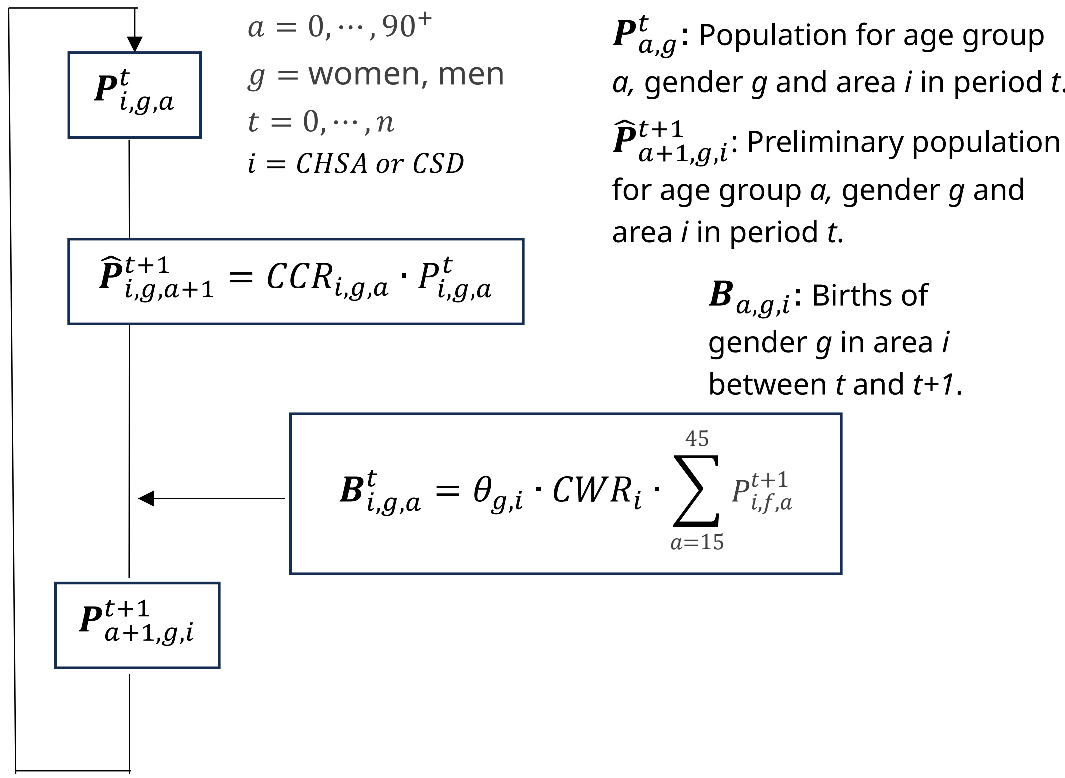
Equation (4) calculates the number of infants of gender *g* born in region *i* during the next period ($P_{i,g,0}^{t+1}$) as the product of three terms:

- The gender split at birth corresponding to that gender, $\theta_{i,s}^{b}$,[22]
- The CWR for region *i*,
- The total population of women aged 15 to 45 years in that region.

The population counts for the other age groups are calculated using the relationships implied by equations (1) and (2), assuming that the corresponding CCRs are constant. The population projections are produced by applying the corresponding CCRs, CWR and splits to the previous year's population (also known as the "launch population"). This is done iteratively until the end of the forecast horizon. This process is summarized in Figure 8.

[22] In the HP model, the gender of infants at birth is modelled as a Bernoulli distribution where the probability of an infant being a women is $\theta_{f,b}$ where $0 \leq \theta_{f,b} \leq 1$, and the probability of being man is $\theta_{m,b} = 1 - \theta_{f,b}$. For more details refer to Smith *et al*. (2013).

Figure 8: Iterative Update Process for the Hamilton-Perry Model



The HP model presents a simple way to produce population projections when there is a lack of reliable fertility, mortality and migration data. Moreover, this model is compatible with the "stable population" theory since the continuous application of the CCR and CWR will eventually take the population projection to a stable population distribution (Smith *et al*; 2013). However, this model also has some important limitations (Baker *et al*.; 2020, Wilson; 2016):

- It tends to overstate/understate population trends for areas experiencing rapid demographic change, like other cohort-component models (Wilson; 2016).
- Using a base year with significant noise in the population estimates to calculate the CCR and CWR might produce unreliable population projections.
- The model does not accommodate expected changes in fertility, mortality and migration trends since the CCR and CWR are held constant during the horizon of the forecast.

Swanson *et al*. (2010), Marquez (2021) and Hauer (2019) have proposed some methodological changes to the HP model to tackle some of these deficiencies. Section 3.2.2.2 details how BC Stats incorporated these changes into the new P.E.O.P.L.E. methodology.

3.2.2.2. The Hamilton-Perry Model on the New P.E.O.P.L.E. Methodology

To correct for the HP model deficiencies mentioned above, Swanson *et al*. (2010) and Marquez (2021) proposed the following modifications to the original HP model:

- The population totals of each region, which are used as controls for the HP model, should be forecasted independently. This will correct the overaccentuating of population trends common in the application of cohort-component models to small areas.
- Since the parameters of the HP model might be prone to outliers, especially in small areas, these authors suggest introducing upper and lower thresholds for the CCR, CWR and gender split at birth. The outliers are replaced with the corresponding parameter of a higher-level geography.
- Instead of using a specific year as a base for the parameters of the HP model that may be susceptible to noisy estimates, the authors suggest taking averages or computing smoothed curves across several years.

BC Stats implemented these recommendations in the updated P.E.O.P.L.E. methodology for its population projections at the CHSA and CSD levels. The projection of the population totals was calculated as described in section 3.2.1, while the population distribution by gender and single year of age was calculated using the modified HP model. The second step of this process is described in Figure 5:

1. **Calculating parameters:** BC Stats calculated the parameters of the HP model for all health geographies in British Columbia between 2016 and 2019 and for all Census regions from 2001 to 2019.[23] This period was selected to cover recent demographic trends but to exclude any changes that may have stemmed from the COVID-19 global pandemic (2020-2022).
2. **Adjusting outliers:** The parameters of the HP model were assigned hierarchically according to the thresholds set for each parameter.

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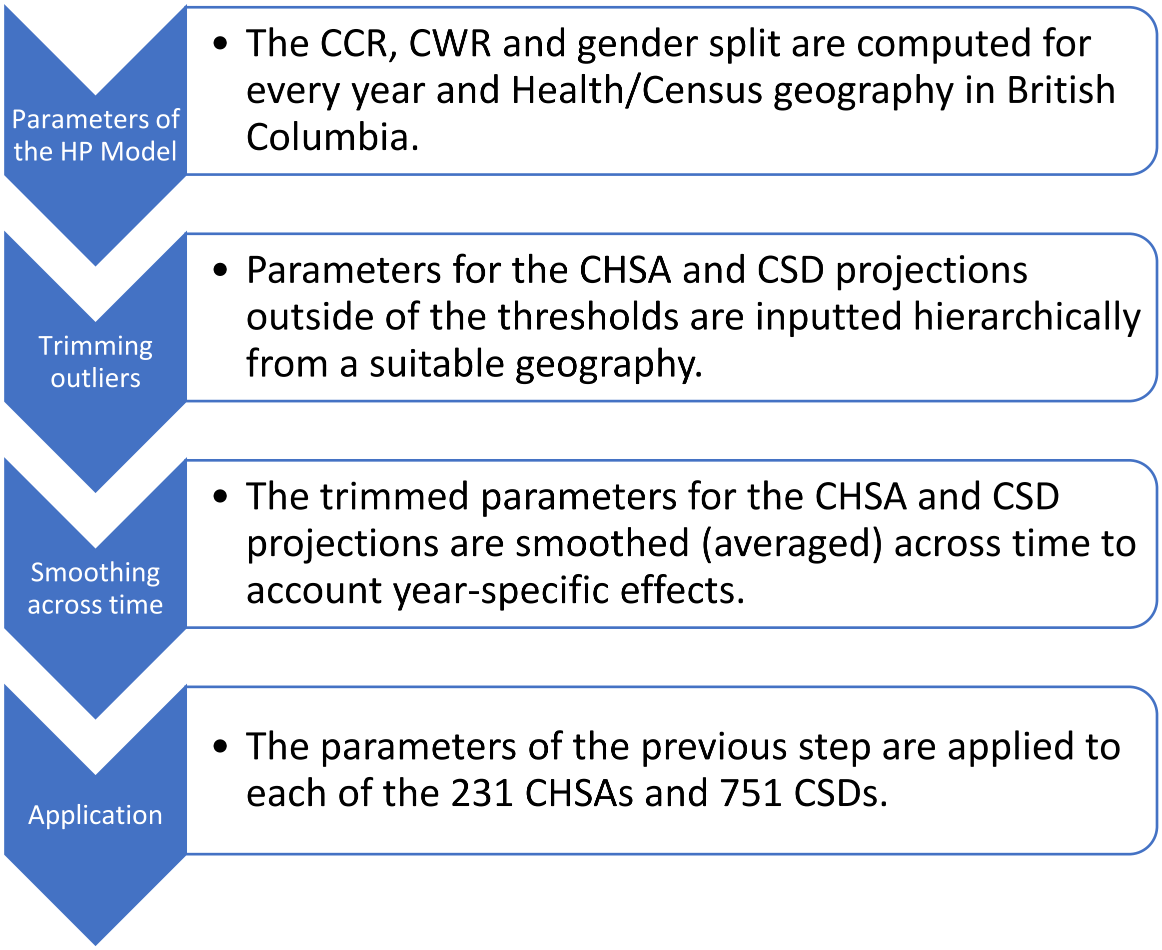
[23] The Census regions included in these calculations were Economic Regions, Census Divisions and Census Subdivisions.

3. **Smoothing across time:** The CCR of each CHSA was smoothed across all years used in the computation using a non-parametric regression to include correlations across ages. The rest of the parameters were averaged across the same period.[24]
4. **Application of the HP model:** The parameters of the HP model from the previous step are applied iteratively to each CHSA and CSD until the end of the projection horizon (2045), following the algorithm depicted in Figure 9.

The first step encompassed estimating the CCR, CWR and the gender split at birth for all 231 CHSAs, 89 LHAs, 16 HSDAs, 5 HAs and at the provincial level in the case of CHSAs. For the CSDs, these parameters were calculated for the 751 CSDs, 29 Census Divisions, 8 Economic Regions and for the province. However, the parameters of this model at the CHSA and CSD levels are subject to significant noise due to the small sample size of some of these regions. For example, the largest value of the CCR was 8, observed in 2016/2017 for females aged 99 years old in CHSA 2321 North Delta. This CHSA had a population of less than three individuals in this age group in 2016, according to BC Stats population estimates.

[24] The CCR is smoother across ages to incorporate the correlation of the CCR across this variable. Other variables, like the CWR and the gender split of the infant, don't present correlation since they are aggregates for the total population, as such this procedure is skipped for these variables,

Figure 9: Overview of the New Methodology used for the Breakdown by Gender and Single Year of Age in P.E.O.P.L.E. for each CHSA and CSD



The parameters of the HP model can exhibit a significant degree of noise in small, sparsely populated areas. To ensure more stability in these parameters, BC Stats followed the methodology proposed in Swanson *et al*. (2010) and established the following thresholds for the CCR, CWR and gender split:

- For the CCR, BC Stats used a lower and an upper threshold of 0.1 and 1.7, respectively. This implies that no cohort will have a reduction exceeding 90% of their population, nor increase by more than 70% year-over-year.
- For the CWR, there was no upper or lower threshold applied. However, the regions with a CWR higher than the provincial average were assumed to converge linearly to the provincial level by the end of the projection.
- For the gender split, a lower and an upper threshold of 0.4 and 0.6 were used. This implies that all regions were assumed to have a share of females in the total number of births between 40% and 60%.

The adjusted parameters for each CHSA and CSD were input hierarchically, replacing outliers with the corresponding parameter of the first aggregated geography that is within the threshold range. An example of this process is illustrated for four CCRs in Table 2 below for health geographies. In the first three examples shown in Table 2, the CCR in the original CHSA data is outside the bounds set by the upper and lower thresholds of the CCR (0.1 to 1.7), and they are all trimmed in the analysis.

In the first example, the corresponding CCR for the same year, age and gender from the LHA, within which that CHSA is located) is outside the admissible range. The HSDA is inside the admissible range and is therefore assigned as the CCR for that CHSA in that year, age and gender. For the second example, we observe that the LHA is the least aggregated area to be within the range, and thus its CCR is assigned to that CHSA for that year, age and gender. In the third example, all the parameters except for the provincial level are outside of the admissible range, which means that the provincial-level CCR is assigned. By contrast, in the last example, the CCR of the CHSA is inside the admissible range, so it is taken as is.

For individuals aged 76 and older, given the low level of migration in this group, we take the CCR at the provincial level in a similar fashion to the methodology used by Statistics Canada for its population projection, since this would be a better approximation of the mortality in this age group.[25]

[25] In its population projections for provinces, Statistics Canada assigns the mortality schedule at the national level for old ages to provinces and territories with small populations (Statistics Canada; 2020 pp. 42). In a similar fashion, BC Stats assigned the provincial-level CCR schedule to all CHSAs for ages 76 and over due to the small populations in this age range even at the HA level.

Table 2: Example of Hierarchical Adjustment of the CCR Parameters Used in the HP Model in P.E.O.P.L.E. for each CHSA

Example Number	CHSA CCR	LHA CCR	HSDA CCR	HA CCR	BC CCR	Final CCR
1	4.00	2.50	1.31	0.98	0.90	**1.31**
2	3.17	1.03	1.07	1.00	1.05	**1.03**
3	5.00	3.12	1.89	1.80	1.60	**1.60**
4	0.95	1.02	1.34	1.26	0.98	**0.95**

Note: In the hierarchy of B.C. health administrative regions, CHSAs nest within LHAs, which nest within HSDAs, and so on. In the above table, precedence for selecting the geography to use for trimming the CCR parameters runs from left to right.

The final parameters for each CHSA and CSD from the previous step are then smoothed or averaged across time to remove year-specific effects. For the CWR and gender split at birth, the final parameters of each CHSA were averaged over the years 2016 to 2019. In the projections, these parameters are held constant at this average level throughout the projection horizon.

For the CCR, BC Stats estimated a locally weighted polynomial (LOWESS) regression (Cleveland and Devlin; 1988) that related the age to the CCRs for each region using data from 2016 to 2019 with a bandwidth of 7%.[26] This approach fits a non-parametric function between age and the CCR for gender in every CHSA and CSD. The fitted function between age and the CCR was assumed constant over the horizon of the projections.

However, this approach still has some limitations stemming from the shifts in fertility, mortality, and migration trends in the aftermath of the COVID-19 pandemic and the growth of remote work. This approach assumes that the demographic trends during the horizon of the projection will return to the level observed between 2016 to 2019. BC Stats continues to monitor the changes in the components of population change stemming from the COVID-19 pandemic and,

[26] The bandwidth was selected to balance the smoothing of outliers and capturing demographic trends in each region driven by demographic events of certain age groups.

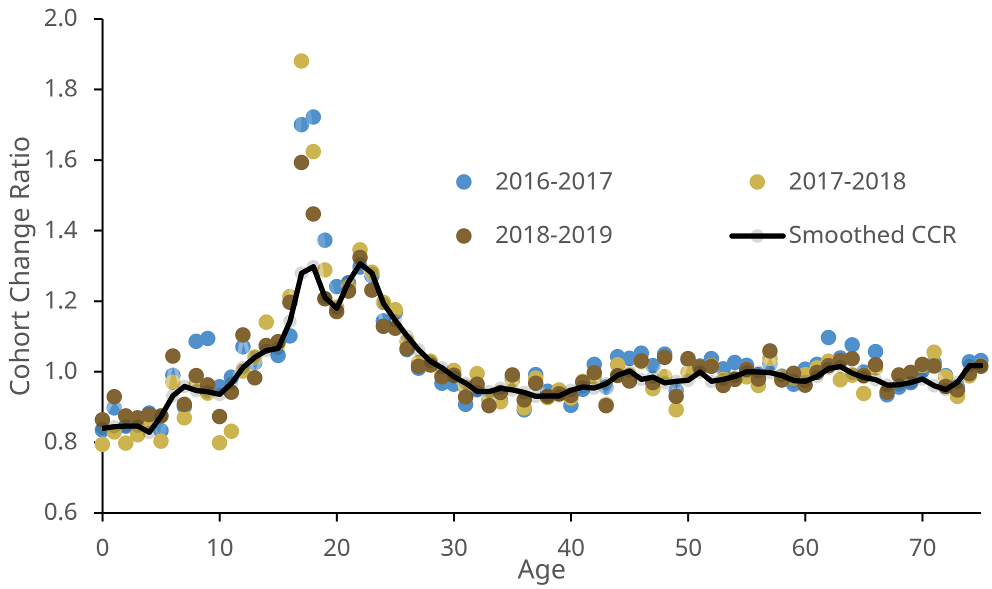
where necessary, will adjust its methodology for small-area population projections accordingly.[27]

To illustrate the implementation of this smoothing/average process on the CCR, Figure 10 presents the CCR observed in females aged up to 75 years old between 2016 and 2019 for Downtown Vancouver (CHSA 3211). As shown, the CCR remained relatively constant between 2016 and 2019 with some random fluctuation that have a relatively low variance in this period, except for ages in the late teens. The CCR used in the new P.E.O.P.L.E. population projections is the output of the LOWESS regression as depicted by the dark line in Figure 10. The output of the LOWESS regression represents an average across time for every year. Averaging across the cohort also occurs in the late teen ages where the LOWESS regression diminishes the effect of the outliers observed in this age range.

In the case of Downtown Vancouver (CHSA 3211), we can observe that the CCR is below one for ages less than twelve years old and after the mid-thirties. For the late twenties, the smoothed CCR exceeds 1.3. This allows us to illustrate the role of the CCR in the HP model. In particular, the CCR is a measure that tries to capture mortality and immigration trends in a single measure. As such, the CCR below one observed in ages less than twelve and in adults after their mid-thirties may reflect the immigration of families with younger children that move out of the downtown area to the suburbs. Similarly, the CCR above one in young adults may reflect migration to downtown areas in search of early-career employment and social opportunities.

[27] BC Stats is considering adapting the approach presented here by applying a time series approach to the parameters of the HP model in a similar approach as proposed in Hauer (2019).

Figure 10: Cohort Change Ratio for Females in Downtown Vancouver (CHSA 3211, 2016-2019)



The last step of implementing the HP model consists of combining these parameters with the latest population estimates to produce the population projections for each CHSA and CSD. The parameters of the HP model are assumed constant throughout the horizon of the projection and then combined with the last population estimates of each CHSA and CSD iteratively using the algorithm described in Figure 8. After normalizing the output, this process produces a time-varying population distribution by gender and single year of age for each CHSA and CSD that depends on the characteristics of each region and the latest population estimates.

Figure 11 illustrates the population distributions by gender and single year of age for the City of Langley (CHSA 2311) and Walnut Grove/Fort Langley (CHSA 2341) for years 2023 and 2046. The population distribution in 2023 is obtained from the population estimates, while the distribution in 2046 was produced using BC Stats' implementation of the HP model. As shown in Figure 11, the population distribution produced by BC Stats' implementation of the HP model captures the shape related to the migration and mortality trends of these areas, and the population distribution in 2046 shows a significant degree of aging for both regions.

Figure 11: Population Distribution of the 2023 Population Estimates and 2046 Projection for City of Langley (CHSA 2311) and Walnut Grove/Fort Langley (CHSA 2312) in P.E.O.P.L.E.

3.2.3. Computing Components of Population Growth

As mentioned above, the HP model is a simplified cohort-component model that blends migration and mortality into one measure: the Cohort Change Ratio. As a result, the model does not produce separate outputs for mortality and migration.

To project the number of births, deaths and net migration in each region, BC Stats uses birth and mortality data for CHSA from the Vital Statistics Agency of British Columbia. The data encompasses deaths and births for the 231 CHSAs between 2006 and 2022. BC Stats aligns the number of births and deaths at the CHSA level with the provincial totals reported by Statistics Canada and combines them with the population estimates to obtain crude mortality and fertility rates for each region.

For the projection, the crude mortality and fertility rates for each region are assumed to be stationary across time and are projected by adjusting a simple autoregressive model to the logarithm of these indicators as described in equations (7) and (8) below:

$$ln(CMR_i^{t+1}) = \alpha + \beta \cdot ln(CMR_i^t) + \theta \cdot Pandm + u_i^{t+1} \quad (7)$$

$$ln(CFR_i^{t+1}) = \delta + \gamma \cdot ln(CFR_i^t) + \theta \cdot Pandm + \varepsilon_i^{t+1} \quad (8)$$

where $ln(CMR_i^t)$ is the natural logarithm of the Crude Mortality Rate (CMR) in region *i*, on period *t.*[28] $Pandm$ is a dummy variable to control for the COVID-19 pandemic. A similar model is estimated for the Crude Fertility Rate (CFR), which also incorporates a dummy variable to control for the effects of the pandemic.[29] These models are adjusted using Ordinary Least Squares (OLS).

To produce the projections of the CMR and CFR, the output of the model is used whenever the absolute value of β or γ is smaller than one. In case this condition is not met, the CMR or CFR are assumed to have a unit root, and, therefore, the projection assumes that the expected value of the respective indicator will be equal to the last observed value.[30] The number of deaths (D_i^t) and births (B_i^t) of each region are calculated as shown in equations (9) and (10):

$$D_i^t = P_i^t \cdot CMR_i^t \quad (9)$$

$$B_i^t = P_{i,f}^t \cdot CFR_i^t \quad (10)$$

where P_i^t is the total population residing in region *i* on period *t*, $P_{i,f}^t$ is the total population of females residing in region *i* on period *t,* D_i^t is the number of deaths occurring in region *i* between period *t* and *t+1*, and B_i^t is the number of births expected in region *i* between period *t* and *t+1.* Therefore, the number of births and

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[28] The CMR was defined as the number of deaths in the twelve-month period from July 1st to June 30th of every year recorded in region *i* divided by the number of people living in this region at the start of the period (Smith *et al*; 2013).

[29] The CFR is defined as the number of births in the twelve-month period from July 1st to June 30th of every year recorded in region *i* divided by the number of females living in this region at the start of the period.

[30] In the cases when the absolute value of β or γ is larger than or equal to one, the variable is frequently deemed not stationary, and the use of a model of this type frequently produces an unbounded forecast of the variable. See Alho and Spencer (2005) for more details on the use of time series models in the context of demographic variables.

deaths in each region between periods *t* and *t*+1 is computed by multiplying the respective crude rate by the population at risk.

The net migration of each region (M_i^t) is calculated as a residual of the demographic balancing equation.[31] In particular, the net migration in region *i* occurring between period *t* and *t+1* is calculated as:

$$M_i^t = \Delta P_i^t - (B_i^t - D_i^t) \quad (9)$$

where ΔP_i^t is the change in the total population between period *t* and *t+1*, and B_i^t and D_i^t are the number of births and deaths, respectively, obtained from equations (7) and (8). Therefore, net migration is calculated as a residual to balance the projected level of population change from the Hamilton and Perry (1962) model as proposed by Swanson *et al*. (2010) and Marquez (2021).

[31] The demographic balancing equation is an accounting identity that relates the population change in one region as the sum of the components of population change: births, deaths and net migration. This equation is defined as $\Delta P_i^t = B_i^t - D_i^t + M_i^t$, where ΔP_i^t is the population change in region *i* between period *t* and *t+1* (Smith *et al*.; 2013).

4. Limitations and Next Steps

Population projections, as with any forecast, have limitations. These limitations are related not only to the quality of the data used but also to the assumptions used to build these population projections.

Population estimates used for the P.E.O.P.L.E. sub-provincial population projections are currently based on the 2021 Census of Population. Future editions of the P.E.O.P.L.E. model will require periodic adjustments to reflect the re-basing of Statistics Canada population estimates to correct for the Census net undercount adjustment after every Census; the re-basing adjustment for the 2026 Census is expected to happen in 2028. Moreover, in future editions of P.E.O.P.L.E., BC Stats will continue to move further in using Census Subdivisions (CSDs) as the base geography. This will enable the use of other data available at the CSD level of geography to better harmonize its population estimates with Statistics Canada.

Also, trends in fertility, mortality, and migration have shifted significantly in the aftermath of the COVID-19 pandemic. In particular, the growth in remote work and the changes in mortality induced by the COVID-19 pandemic and the opioid crisis have significantly affected demographic dynamics at the sub-provincial level. BC Stats is analyzing the data to evaluate if these shifts require further methodological adjustments to the P.E.O.P.L.E. model to capture these shifts in the future.

In recent years, international migration has emerged as B.C.'s most important driver of population change. Changes in immigration policy at the federal level and geopolitical events that affect immigration, such as the Russia-Ukraine conflict, may significantly impact future population growth. While aspects of federal immigration policy are reflected in the P.E.O.P.L.E. model via the assumptions used for the provincial-level projection, further work remains to capture the effects of these policies at the sub-provincial level. Finally, changing climate conditions may play a role in population movements over the timeline of the forecast. The current forecast does not include assumptions that consider climate impacts on a community-by-community basis at the provincial or sub-provincial levels.

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6. Appendix A: Data Sources

The following data sources were used as inputs to the new P.E.O.P.L.E. projections:

Data source	Provider
BC Assessment property assessment database (Data Advice)	BC Assessment
P.E.O.P.L.E. sub-provincial population estimates and projections	BC Stats
Provincial population projections	BC Stats
Labour force statistics	Statistics Canada
Population estimates for various Census geographies	Statistics Canada
Population profiles from the 2021 Census of Population	Statistics Canada
Residential building permit statistics	Statistics Canada
BC Labour Market Outlook	WorkBC
Major Projects Inventory	Workforce Development and Skills Training Division, Ministry of Post-Secondary Education and Future Skills
Official Community Plans and approved land use plans	Selected municipalities: Abbotsford, Burnaby, Campbell River, Chilliwack, Coquitlam, Cranbrook, Dawson Creek, Delta, Fort St. John, Kamloops, Kelowna, Kimberley, Langford, Langley, Penticton, Maple Ridge, Merritt, Mission, Nanaimo, New Westminster, North Vancouver, Port Alberni, Port

	Coquitlam, Port Moody, Prince George, Richmond, Surrey, Vernon, Victoria, West Kelowna, White Rock, Williams Lake

The following provides additional details on the data sources used to obtain CSD-level employment forecasts as described in section 3.2.

- **BC Labour Market Outlook.** Work BC prepares a Labour Market Outlook (LMO) annually which provides employment forecasts by Place of Work at the 2-digit NAICS industry level for each of the province's seven Economic Regions (ERs). LMO employment projections for the period 2021-2032 were used to produce ER-level employment forecasts extending over the full forecast period.
- **Major Projects Inventory.** The Major Projects Inventory (MPI) is used to help guide the provincial/ER employment control totals beyond the timeframe available for the LMO projections. An analysis of the MPI was conducted to identify projects indicative of sustained employment activity over the long term and to determine whether adjustments to ER-level employment forecasts are needed beyond the final LMO projection year. For the new P.E.O.P.L.E. projections, no adjustments associated with the MPI were deemed to be necessary.
- **Census data on place of work and commuter flows**. Statistics Canada produces cross-tabulations of employment and commuter flows by work destination according to the Census. Cross-tabulations for Census years spanning 2001-2021 were used to produce CSD-level projections of place-of-work employment that directly informed the CSD growth targets.
- **Labour force statistics**. Labour force participation and unemployment rates for B.C. as reported by Statistics Canada were used together with provincial population projections prepared by BC Stats to estimate the potential size of the workforce in each ER. The workforce estimates were used as a consistency check on the LMO-based employment forecasts adjusting down any forecasts that exceed the ER workforce size as deemed necessary.

BC Stats is the provincial government's leader in statistical and economic research, information and analysis essential for evidence-based decision-making. The goal is to increase overall business intelligence—information decision makers can use.

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