Advancing Winter Road Maintenance Systems with Data Intelligence and Analytics

Project Overview

Our University of Alberta (UofA) research partners are developing the Cold Road Intelligence and Management System, or CRIMS, as part of a three-year project to help the City of Edmonton modernize how it plans, monitors, and reviews snow and ice control. As the project completes its first year, the UofA research partners have made substantial progress in building the data, modelling and dashboard foundation needed to turn winter transportation data into practical decision support. The research addresses five themes reflecting important current challenges in the City's Snow and Ice Control (SNIC) program:

1. Road conditions monitoring and prediction
2. Equitable winter accessibility
3. Climate-resilient pavement design
4. Facility planning and management
5. Data-driven decision support

By combining multiple data sources with AI-based prediction and geospatial analysis tools, the project is developing practical decision-support tools within a unified dashboard. These include:

1. Live winter road condition maps and short-term condition forecasts
2. Equity and accessibility indicators
3. Pavement resilience planning tools
4. Optimized RWIS placement recommendations
5. Evidence-based guidance for future operations and investment.

Ultimately, this work will support more informed winter maintenance decisions, safer streets and pathways, better use of public resources, improved winter accessibility and a more resilient transportation system for Edmonton residents. The research can also help inform the City's review of SNIC policy by providing evidence related to extreme weather planning, resource scaling, accessibility priorities, infrastructure adaptation and the evaluation of innovative operational strategies.

Progress Overview

The project completed its first year in May 2026. The research provides a practical foundation for several areas under consideration in the City's SNIC policy review, including operational monitoring, resource deployment, accessibility, climate-resilient infrastructure,

and evidence-based service improvement. This report summarizes current progress, initial outputs, next steps, and expected benefits by each research theme.

As future City operational, financial, procurement, and asset management data become available, the CRIMS framework could provide a stronger evidence base for more detailed options analysis, risk assessment, implementation planning, and resource discussions. This may support future analysis related to surge capacity costs, contractor activation, treatment material comparisons, fleet system integration, and life cycle savings.

Themes 1, 4, and 5: Winter Road Conditions Monitoring and Predictions, ITS Facility Planning and Management, and CRIMS

Summary

Themes 1, 4, and 5 work together to help the City better understand, review, and improve winter road maintenance. Theme 1 develops tools to collect, classify, map, and eventually support short term forecasting of road surface conditions (RSC) using multi-sensor data, including Road Weather Information Systems (RWIS) data. Theme 4 uses this information to support evidence-based planning of the City's RWIS network and identify where additional stations would provide the greatest operational value. Theme 5 brings these outputs together through the CRIMS, a decision support system being developed to turn project findings into practical tools for City staff. Together, these themes help the City see where conditions are poor, where information is uncertain, how maintenance response affects recovery, and where added response, monitoring, or longer-term investment may be needed.

Progress and Initial Outputs

Year 1 has made substantial progress in building the data, modelling, and dashboard foundation needed to turn RSC observations into practical information for City staff. The main outputs are summarized below:

- Winter data foundation: The UofA research partners equipped road patrol vehicles with a smartphone-based image collection system using a customized app along with mobile RWIS sensors, allowing conditions to be observed from vehicles already operating across the network. From January to April 2026, the project collected approximately 225,000 location-tagged RSC images and roughly 470,000 sensor readings of road surface state and grip. The UofA research partners also gathered substantial winter maintenance records, including Automatic Vehicle Location (AVL)/Global Positioning System (GPS), plow activity, and sanding/spreading records. Together, these data connect RSC, friction, maintenance activity, location, time and vehicle movement into a scalable winter operations data layer. This helps the City understand where conditions

are changing, what response occurred, where monitoring gaps exist, and how roads recover during and after winter events (see Figures 1 and 2).

- Automated data quality control: To ensure this large volume of data can support reliable tools the City can trust, the UofA research partners built an automated process that screens out low-quality or potentially inaccurate records before they are used. As a result, the City's road condition information is built on cleaner, more representative, and more dependable data, which directly improves the accuracy of the condition maps, grip estimates, and dashboard outputs described below (see Figure 3).
- Road condition mapping: The UofA research partners developed initial models that convert vehicle camera images into RSC information, including three-class and five-class categories and grip estimates. The three-class model supports broad operational reporting, while the five-class model adds detail on wheel-track and snow-coverage patterns that can help assess recovery after maintenance. For the City, these models can reduce manual image review and provide consistent information for monitoring recovery, comparing before and after conditions, assessing maintenance effectiveness, and supporting transparent reporting. Contextual interpretation work also helps identify factors that affect confidence (see Figures 4 and 5).
- Reliability-aware modelling: The UofA research partners are developing a framework to show not only the estimated road condition, but also how reliable that estimate is. This is important because conditions can change between vehicle observations due to snowfall, traffic, temperature, and maintenance activity. For the City, this helps separate fresh and reliable observations from stale or uncertain information, supporting smarter triaging and decisions about where to send follow-up patrols or treatment (see Figure 6).
- Prototype decision-support dashboard: The UofA research partners have built an early prototype dashboard and are continuing to develop it as the main integration point for CRIMS. At this stage, the prototype is being used to show how road imagery, GPS and AVL data, AI-based condition results, grip estimates, confidence indicators, and maintenance activity data can be brought together. As the system is refined, it will help the City connect observed road conditions, maintenance response, and post-event performance in one place (see Figure 7).

Next Steps and Implementation

Implementation can occur in stages. In the near term, the City could use Year 1 outputs to support event review, patrol coverage assessment, identification of monitoring gaps, and evaluation of how road conditions change following plowing and sanding. These capabilities could help identify locations where conditions remain poor or recovery is slower than expected, providing evidence to support more targeted deployment of City or contracted resources during major winter events.

In Year 2, the project is expected to continue advancing friction-based modelling, reliability-aware condition mapping, preliminary short-term road condition forecasting, RWIS location-allocation analysis, and CRIMS dashboard refinement. The UofA research partners will also continue exploring how road condition and confidence indicators can be connected with available fleet GPS, AVL, and maintenance activity data. By Year 3, the project is expected to provide RWIS placement guidance and a more integrated CRIMS platform that brings together condition mapping, reliability indicators, maintenance activity, and performance measures. Overall, the practical value to the City is a clearer and more defensible way to connect winter severity, operational response, and service outcomes.

Future Outcomes and Benefits

For the City, the most important impact is improved operational visibility. Instead of relying only on limited field observations or manual reporting, CRIMS can help show what is happening across the network, how reliable the latest observations are, and where follow-up patrol or treatment may be needed. The UofA research partners are also developing a reliability-aware framework that can identify when road condition information is becoming outdated, helping staff understand where confidence is high and where uncertainty is growing. This has practical value for smarter triaging, more targeted deployment, and more transparent reporting on level of service. During severe events, these tools could help the City determine where standard operations may be insufficient, where additional crews or contractors may be most valuable, and whether added resources improve recovery time and service delivery. Short-horizon forecasting could also help operations adjust priorities as conditions shift between snowfall, freezing, thawing, and ponding.

This work also creates the foundation for future RWIS planning. Because RWIS stations are costly to install and maintain, the City needs evidence-based tools to determine where additional monitoring would provide the greatest value. Year 1 data collection and mapping will support future location-allocation analysis, helping the City identify monitoring gaps, compare sensor placement scenarios, and develop optimized RWIS expansion recommendations.

Theme 2: Equitable Transportation Accessibility

Theme 2 develops practice-ready strategies and metrics to assess and prioritize equity and accessibility in winter travel. It focuses on ensuring that pedestrians, cyclists, transit users, and other non-automobile travellers can reach destinations safely, comfortably, and efficiently during winter. The work includes a large-scale survey of Edmonton residents, the development of equity and accessibility indicators for integration into CRIMS, and the

investigation of additional data sources to monitor winter conditions and identify preferred operational improvements.

Progress and Initial Outputs
In Year 1, the UofA research partners co-designed a survey with the City to track existing winter travel patterns, determine winter operation challenges, and rank people's preferred strategies for winter weather operations:

- Large-scale survey: The survey was distributed through the City of Edmonton Insight Community (a panel of over 25,000 residents and people who own property in Edmonton) and to email lists of existing Edmonton partnerships with community organizations that focus on equity or non-auto transportation. Following collaborative design from September 2025 to March 2026, the survey was released in April 2026 to coincide with the end of the winter season. Several late snowstorms occurred in April 2026, improving the frame of reference for survey-takers regarding winter weather operations.
- Preliminary results from 5,693 survey responses: The survey gathered 6,990 survey responses, which were cleaned in-house by Administration to 5,693 survey responses. University researchers gained access to the data in May 2026 and are currently conducting an initial data analysis. Results presented in the appendix are not finalized. It should be noted that some analysis techniques (e.g., best-object scaling) will not be feasible because of the question format needed for the Insight Community panel.

Next Steps and Implementation
The UofA research partners will continue different forms of data analysis, including comparing different groups of people to identify equity gaps, discrete choice modelling to find factors that affect preferences, and qualitative analysis of the comments. The descriptive statistics will also be finalized. The UofA research partners will then shift toward identifying how the survey results will inform possible equity and accessibility metrics. These static or real-time metrics will be tested for feasibility in the CRIMS platform, bolstered by any other available non-automobile data.

Future Outcomes and Benefits
This theme will measure the equity and effectiveness of winter transportation operations using indicators such as snow removal efficiency, safety, satisfaction, and time to reach key destinations. For the survey analysis, metrics will be used to identify disparities between neighbourhoods and key forms of non-automobile infrastructure. Together, these metrics and survey results will contribute to a broader set of GIS-oriented data, forming part of the CRIMS platform. In addition, the theme will provide benefits to the Snow and Ice Control

Team on how best to prioritize new winter weather operations for non-automobile modes and enhance their existing services.

Theme 3: Climate-informed Pavement Vulnerability Framework

Summary

Theme 3 develops tools to help the City understand how climate change may affect Edmonton's roads and identify where pavement design and rehabilitation practices may need to adapt. The framework combines future climate projections, pavement temperature modelling, groundwater conditions, subgrade vulnerability, and network-level mapping. The goal is to support more targeted, climate-informed pavement planning rather than applying the same design assumptions across the entire city.

Progress and Initial Outputs

In Year 1, the UofA research partners established the climate and groundwater foundation needed to assess future pavement vulnerability. Initial outputs include:

- Five climate zones for Edmonton: The city was divided into five zones using regional climate projections, allowing future pavement risks to be assessed based on local conditions rather than a single city-wide assumption.
- Future climate trends: Projections were developed for temperature, precipitation, and snow accumulation under a range of future emissions scenarios. The results show that Edmonton is expected to become warmer, increasing heat-related demands on pavement materials.
- Initial asphalt binder findings: Early analysis indicates that Edmonton may need to gradually adopt asphalt binders designed for higher temperatures to improve pavement performance and resilience.
- Subgrade and groundwater vulnerability screening: A framework was developed for 28 Edmonton sites to examine how groundwater, terrain, and moisture movement may affect the soils supporting pavement. The results show that future groundwater conditions will vary across the city, reinforcing the need for location-specific design and drainage strategies.

Next Steps and Implementation

In Years 2 and 3, localized climate, groundwater, and subgrade findings will be incorporated into American Association of State Highway and Transportation Officials (AASHTO) Pavement ME Design to assess local, collector, industrial, and arterial roads. The models will be calibrated using City data on roughness, rutting, and cracking to estimate future pavement performance and vulnerability. The UofA research partners will then evaluate adaptation options, including higher-temperature binders, pavement thickness

changes, drainage and subgrade improvements, and alternative materials, to support location-specific design and rehabilitation recommendations.

Future Outcomes and Benefits

Final outputs will include pavement vulnerability maps, prioritized design and maintenance recommendations, and CRIMS-ready tools to inform design standards, rehabilitation, asset management, and capital planning. The framework will help the City identify high-risk areas, select appropriate adaptation measures, improve rehabilitation priorities, extend pavement life, and reduce rutting, cracking, and subgrade weakening. Comparing the expected performance of adaptation options can also provide a technical basis for future life-cycle cost analysis.

Appendix

Themes 1, 4, and 5

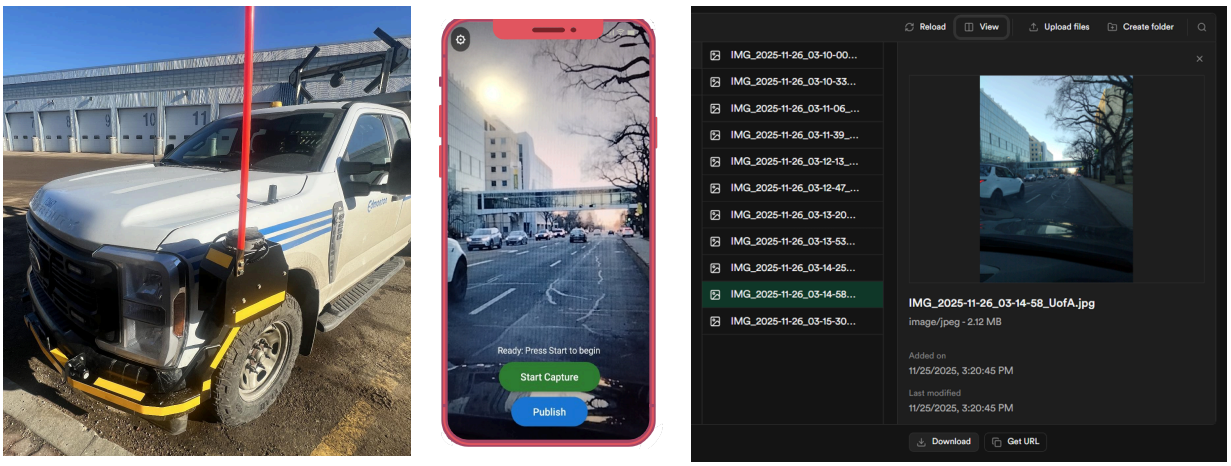


Figure 1: Road image collection and mobile RWIS setup

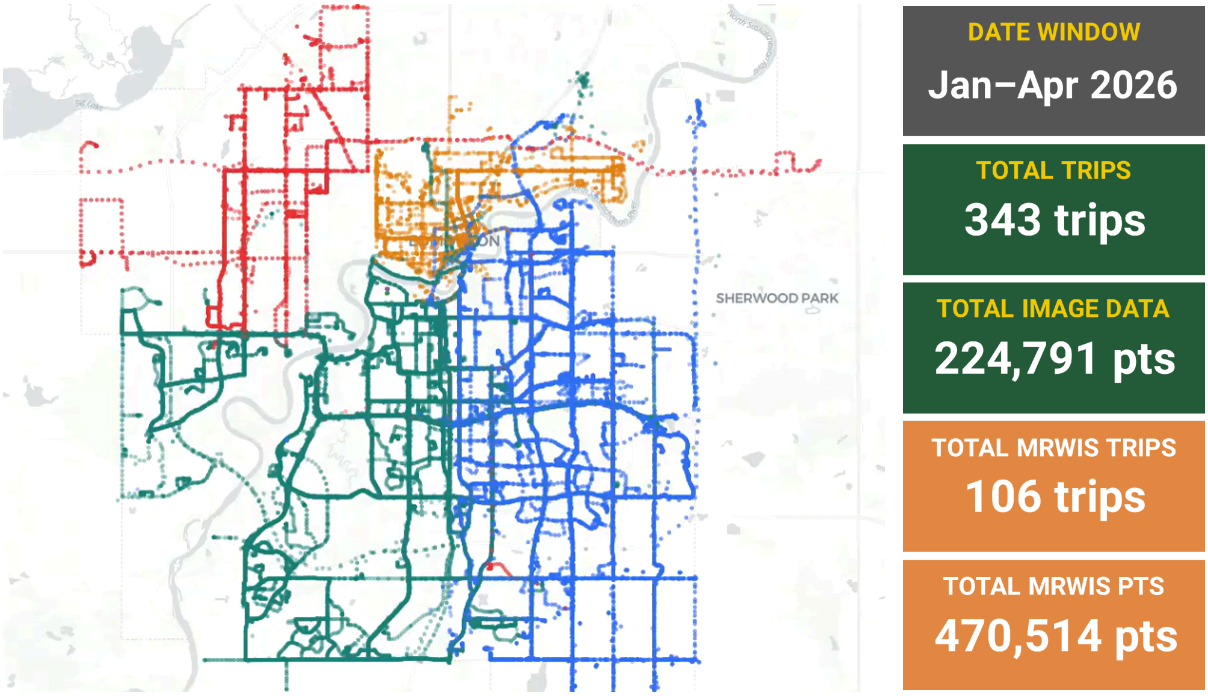


Figure 2: Winter road condition data collected across the Edmonton network

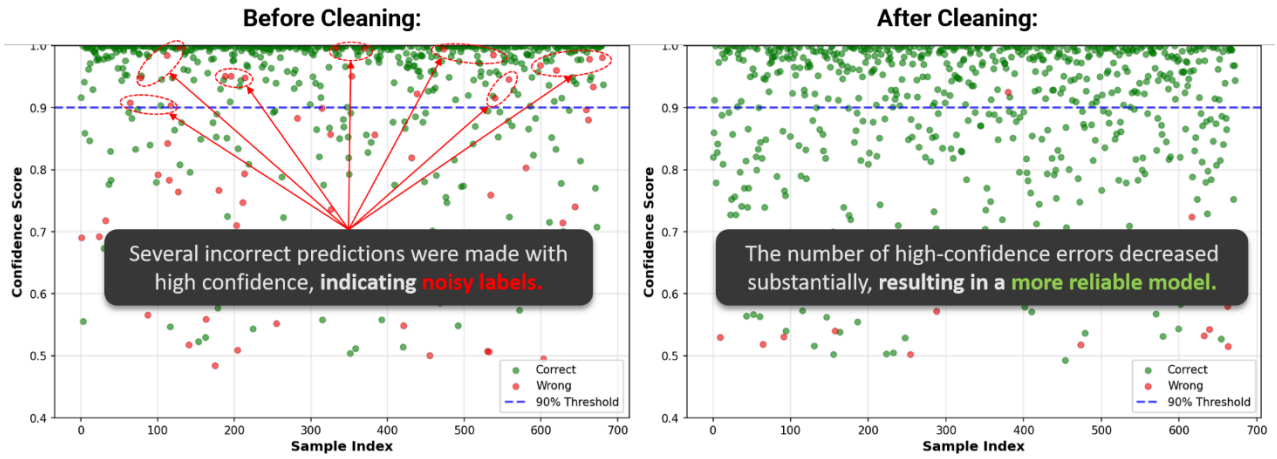


Figure 3: Automated data quality control for more reliable road condition modelling

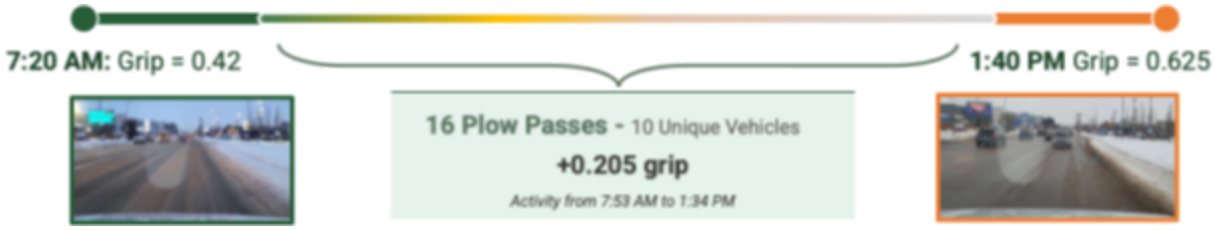


Figure 4: Illustrative event review example linking road images, grip observations, and maintenance activity records

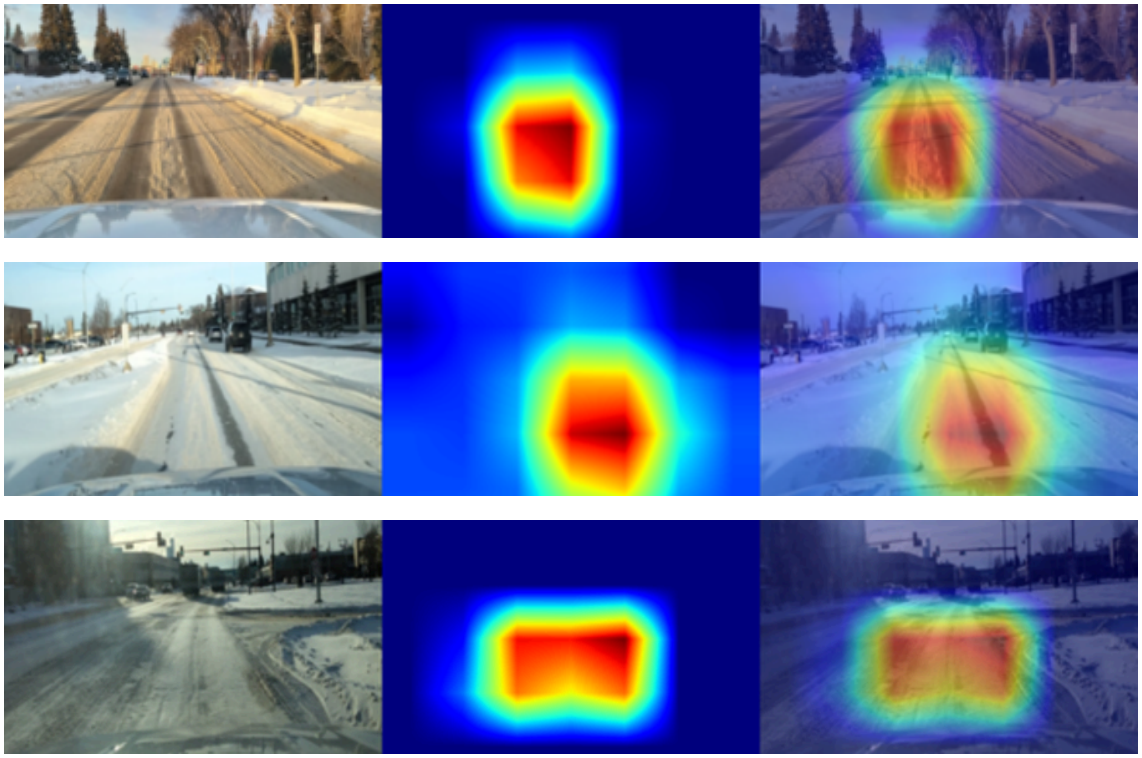


Figure 5: Context-aware interpretation of road images

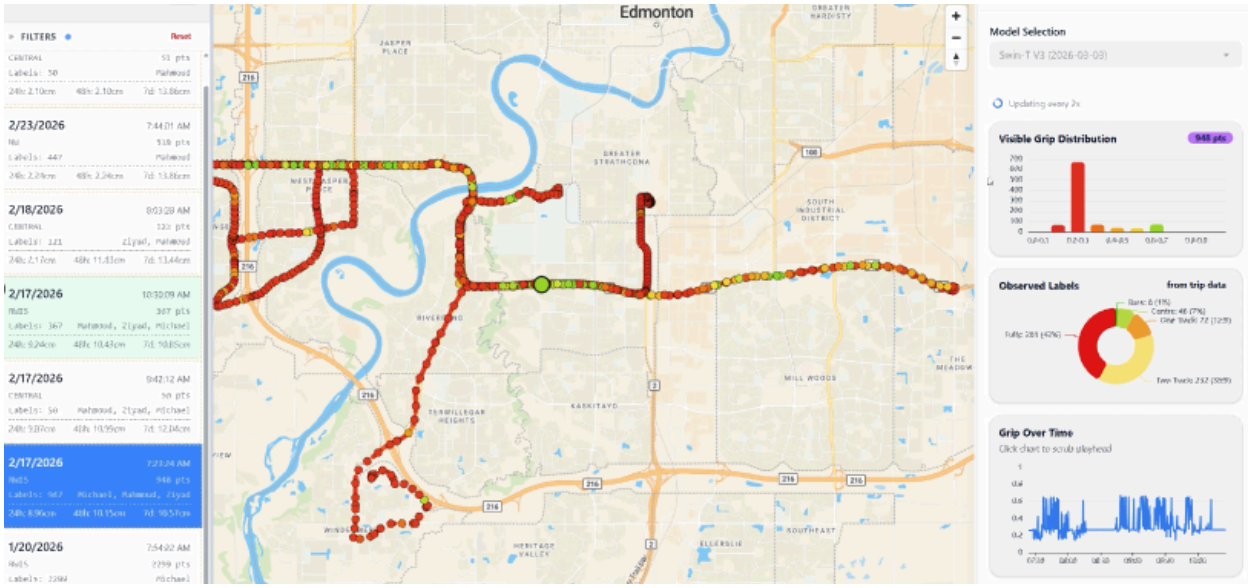


Figure 6: Prototype reliability-aware road surface condition map

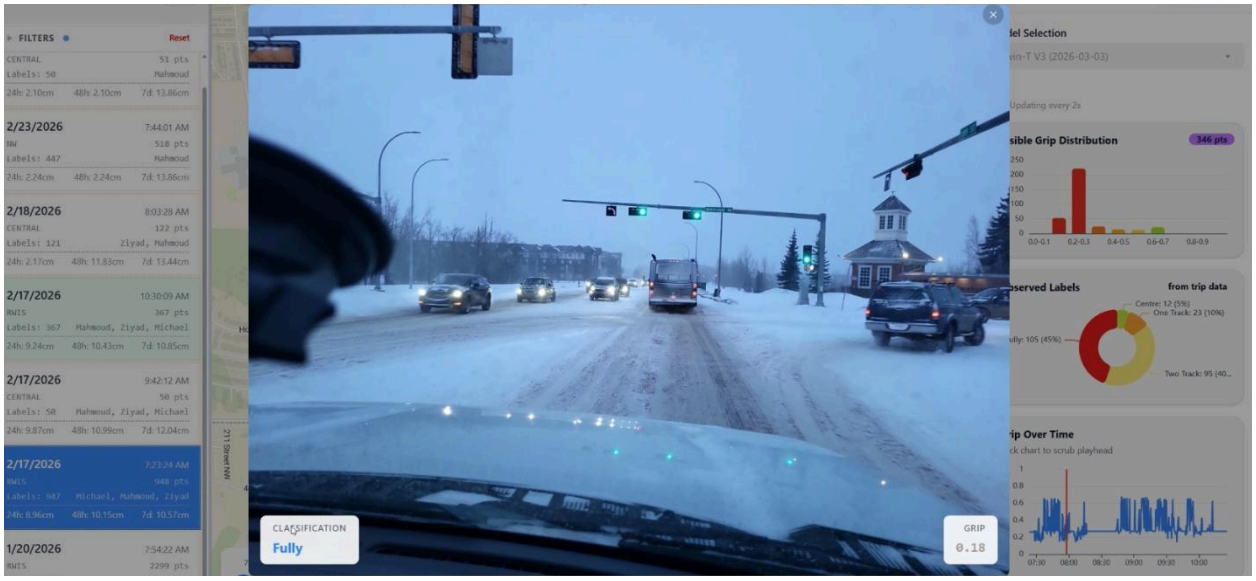


Figure 7: Example single-observation road condition model output

Theme 2

Highlights of Results (n=5,693)

- 13.6 per cent, 47.7 per cent, 6.3 per cent, and 1.1per cent of respondents were often or daily users of public transit, walking, rolling (bicycle, e-bike, scooter), or an assisted mobility device (walker, scooter, wheelchair) for winter travel, respectively
- 25.6 per cent of respondents look at the City of Edmonton's Snow Clearing Map for roadways, and 7.9 per cent of respondents look at the map for active pathways
- 44.6 per cent of transit users, 72.5 per cent of pedestrians, 83.0 per cent of rollers, and 93.6 per cent of assisted mobility device users were prevented from reaching their destinations at least once during the past winter due to snow and ice conditions
- Of sustainable mode users (n=4,250, those listed above), 14.3 per cent said they had to stay at home during most or every snowstorm in the past winter because conditions were unsafe to travel using their chosen mode
- For those who use the infrastructure, the most dissatisfied infrastructure for snow and ice removal last winter were: homeowner maintained sidewalks, curb ramps and curb cuts, city maintained sidewalks, painted bike lanes, and shared pathways (ranging from 2.49 to 2.89 mean, with 3.00 representing neutral)
- For those who use the infrastructure, the most satisfied infrastructure for snow and ice removal last winter were: LRT stations, entryways to recreation centres, transit centres, entrances/staircase to LRT stations and transit centres, and parking lots at city facilities (ranging from 3.61 to 3.27, 3.00 representing neutral)
- Respondents rated the following operations and strategies from 0 (not important at all) to 100 (extremely important):

Operations and Strategies	Average Importance Score (Out of 100)
Ensure priority area sidewalks, bus stops, and curb ramps (near schools, hospitals, etc.) are cleared in 1 day following the end of snowfall	81.2
Snow clearing at select curb ramps/intersections, cleared to bare ground, within 2 days following the end of snowfall	71.8
Snow clearing (stacking not removal) on bus loading areas and shelters in select priority areas within 2 days following the end of a snowfall	68.2
Removal of windrows (snow stacks) on residential roadways	67.8
Snow clearing (stacking not removal) at major transit stations within 1 day following the end of snowfall	66.2
All shared pathways, cleared to a level passable surface, within 2 days following the end of snowfall	65.1
Snow clearing (stacking not removal) on shared pathways within 1 day following the end of snowfall	58.7

Bare ground clearing (stacking not removal) of residential roadways after every snowfall	53.7
Park internal walks cleared within 2 days following the end of snowfall	45.8
Snow removal (haul off site) on all bike lanes within 1 day following the end of snowfall	31.2

Theme 3

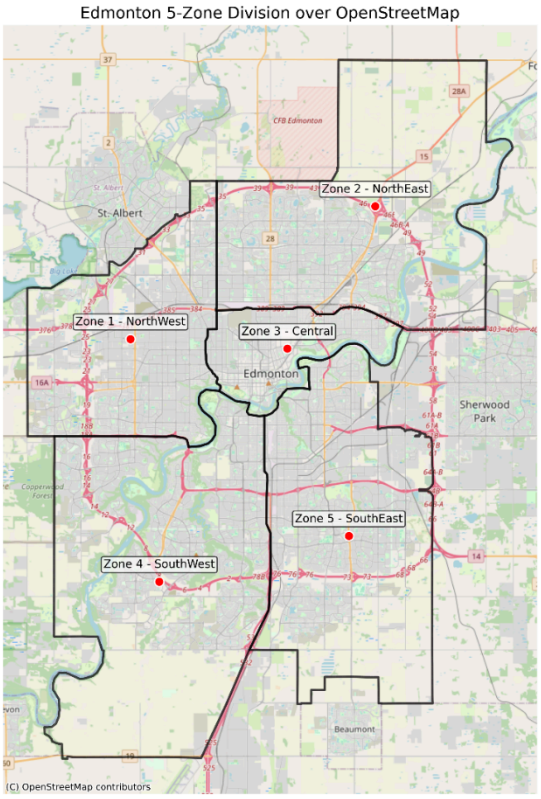


Figure 1: Zonal division of Edmonton and representative centroids used for climate extraction layered on top of open street map

Shared Socioeconomic pathway (SSP) is a climate-scenario framework that represents alternative future socioeconomic development and greenhouse-gas emission trajectories. The SSP scenarios range from futures with strong climate mitigation and relatively low radiative forcing to futures with high emissions and substantially greater warming. The notation after the SSP represents the approximate radiative force level in W/m^2 by 2100.

SSP1-2.6	Low emission, strong-mitigation/sustainability pathway
SSP2-4.5	Intermediate-emission or “middle-of-the-road” pathway
SSP3-7.0	High-emission pathway associated with fragmented development and limited mitigation
SSP5-8.5	Very-high-emission, fossil-fuel-intensive pathway

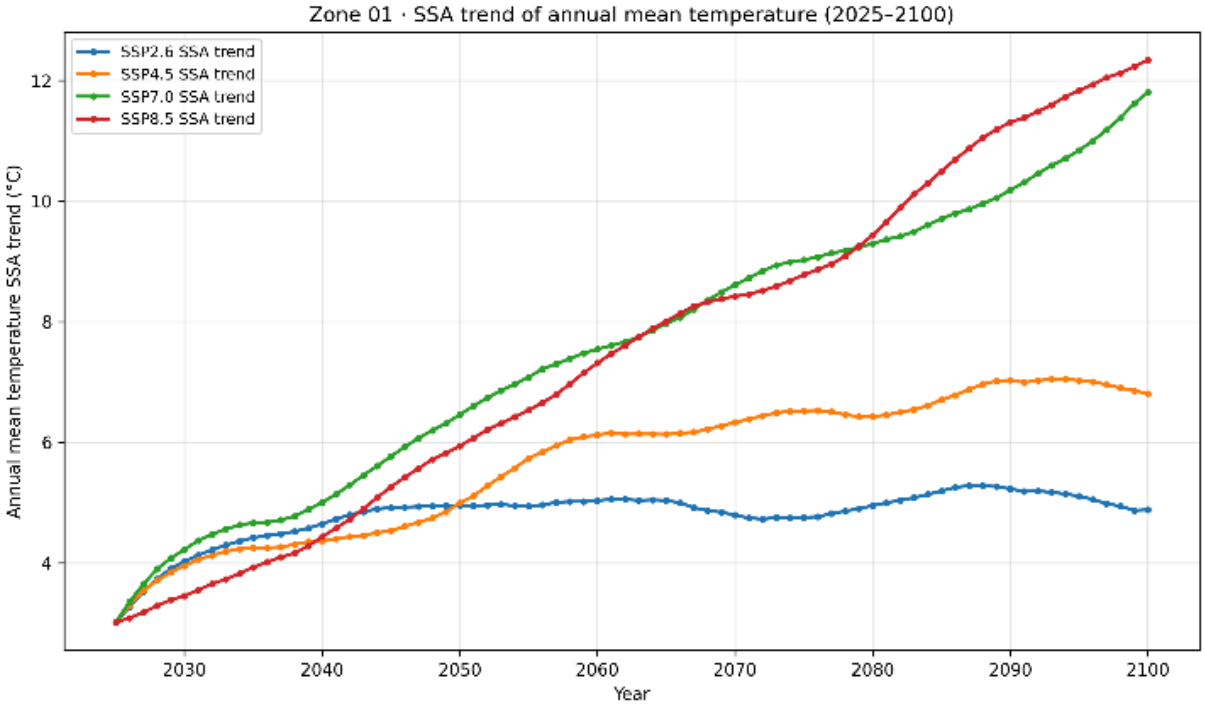


Figure 2: Annual mean temperature trend for all 4 SSP scenarios (NorthWest zone)

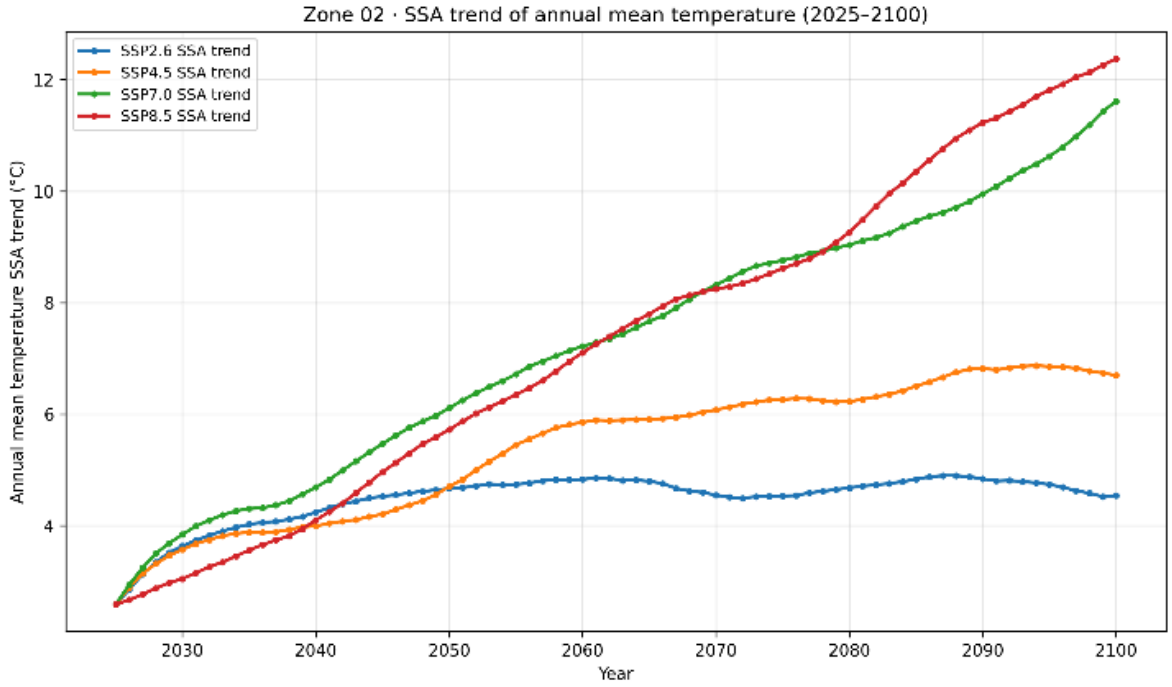


Figure 3: Annual mean temperature trend for all 4 SSP scenarios (NorthEast zone)

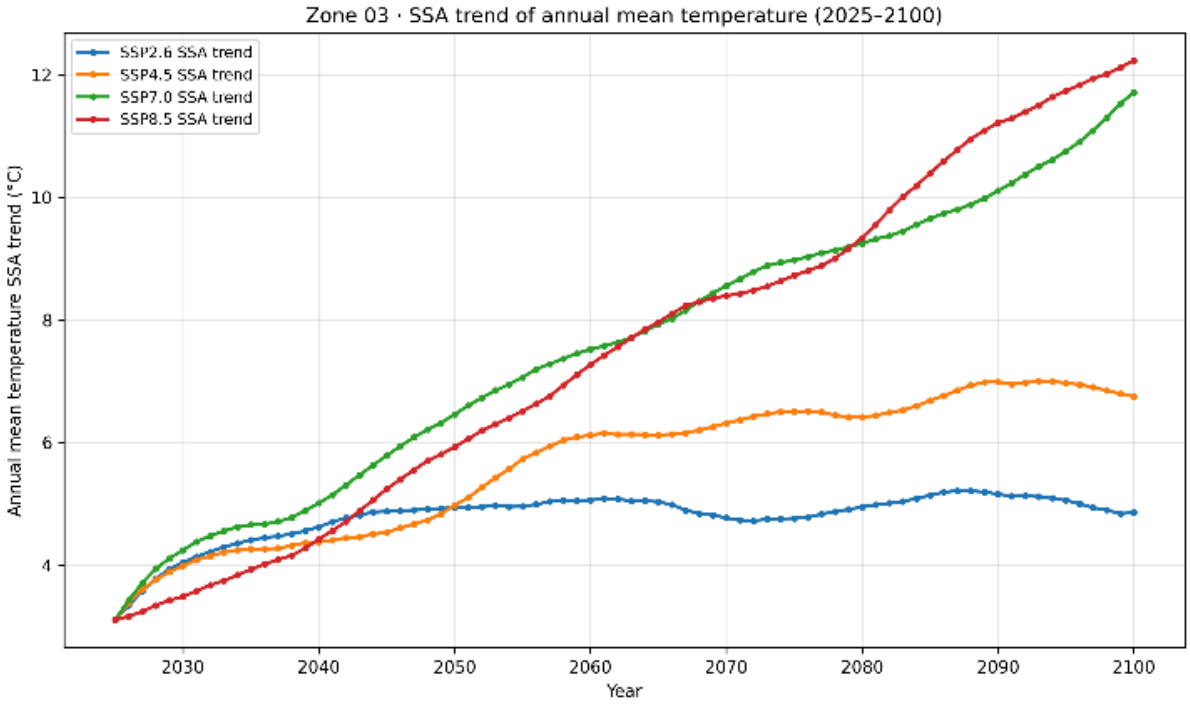


Figure 4: Annual mean temperature trend for all 4 SSP scenarios (Central zone)

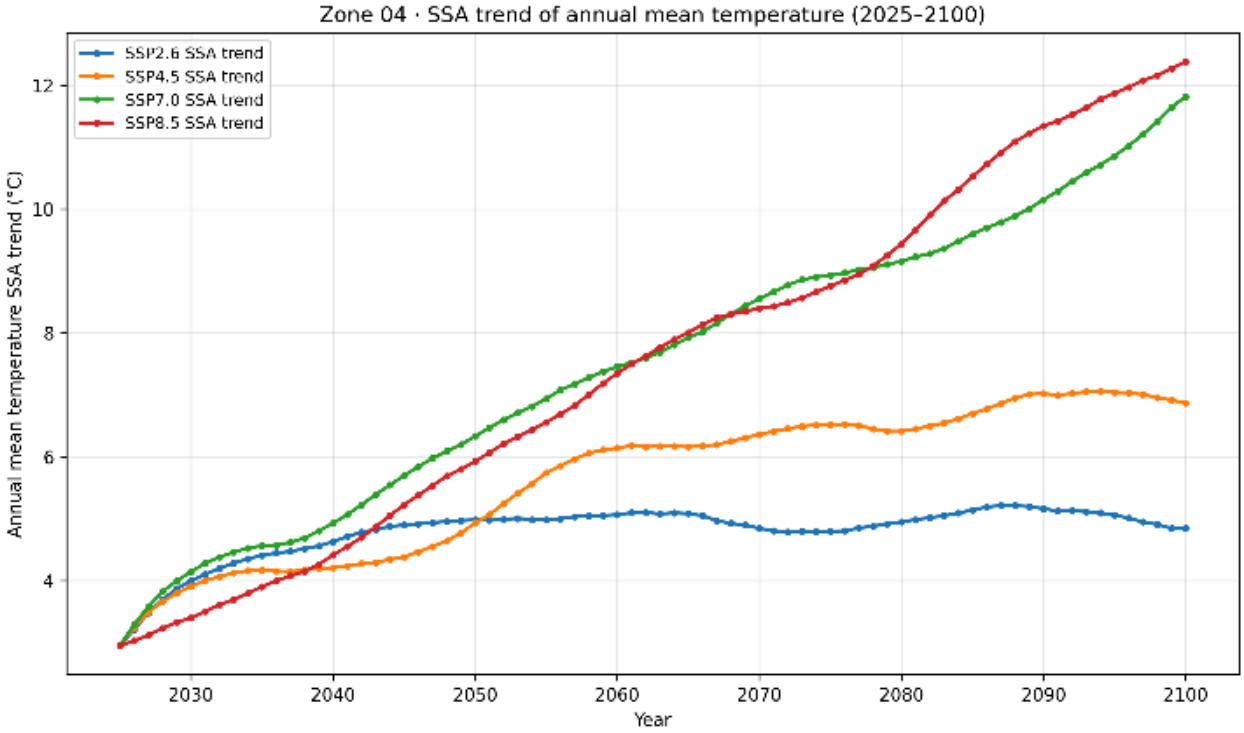


Figure 5: Annual mean temperature trend for all 4 SSP scenarios (SouthWest zone)

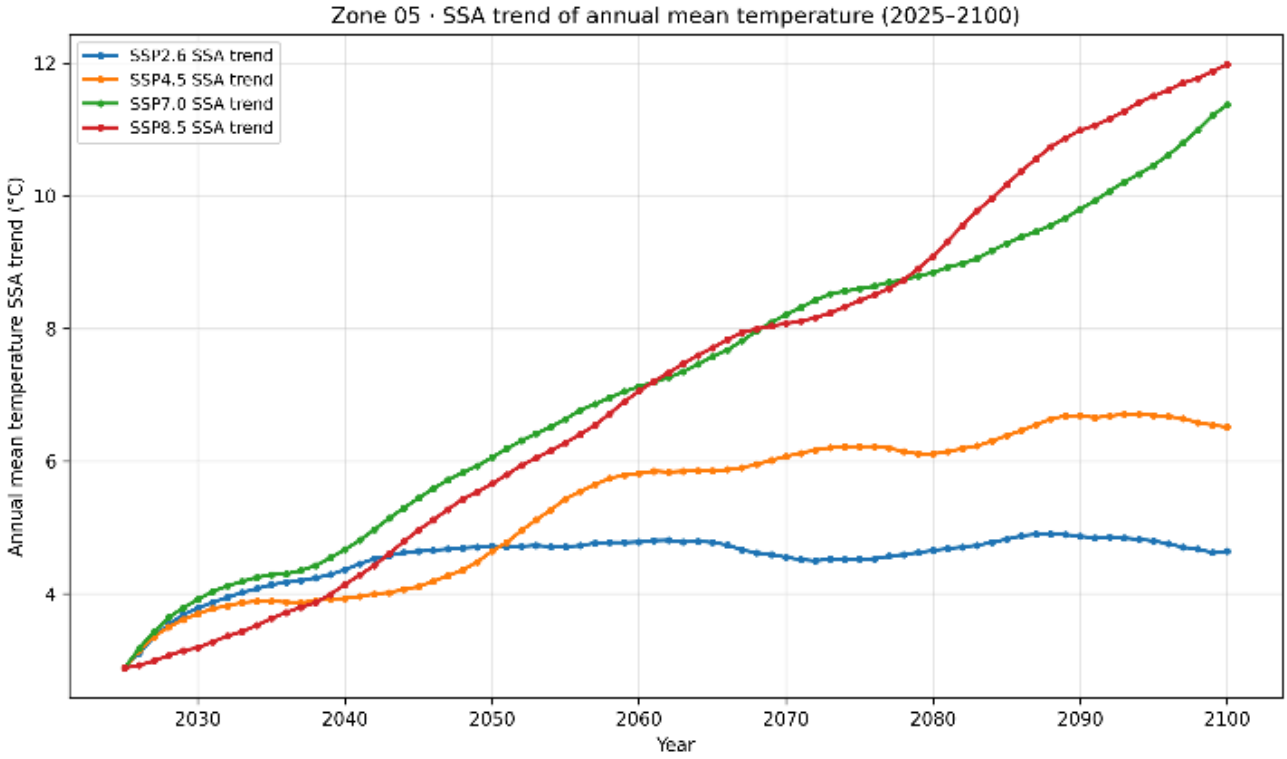


Figure 6: Annual mean temperature trend for all 4 SSP scenarios (SouthEast zone)

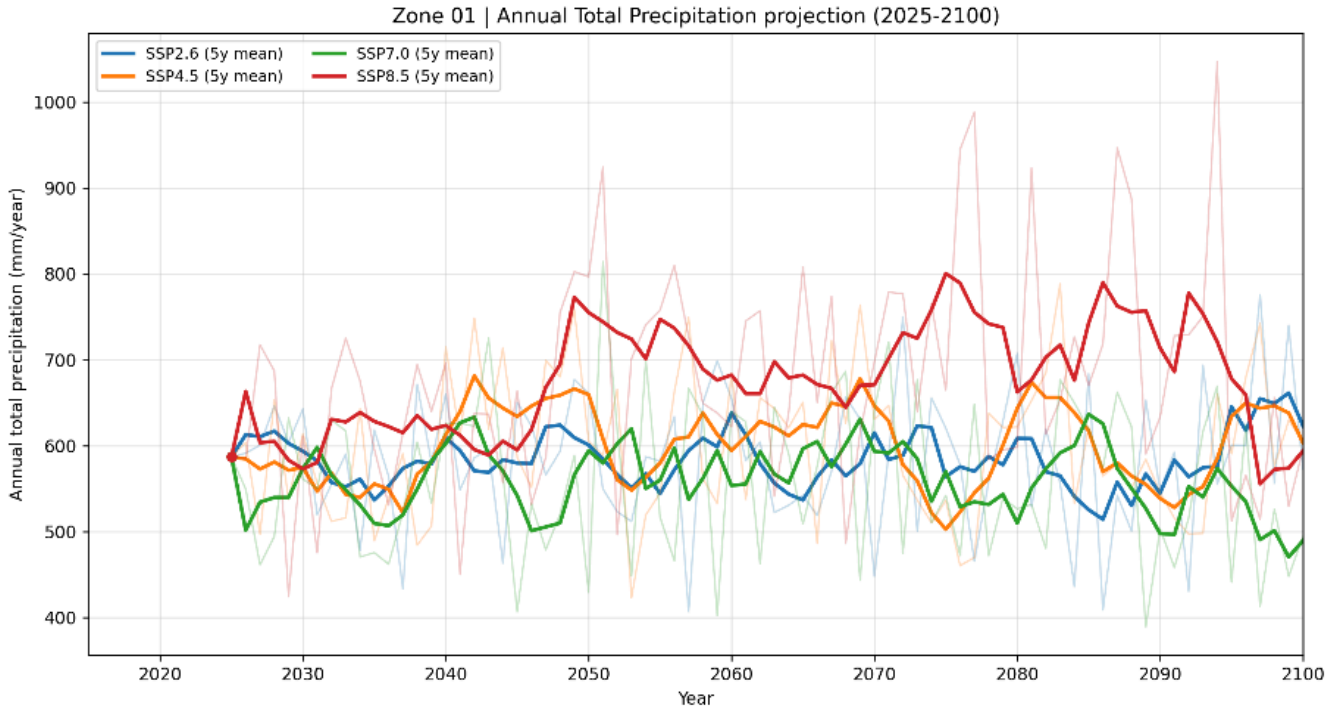


Figure 7: Annual total precipitation trend for all 4 SSP scenarios (NorthWest zone)

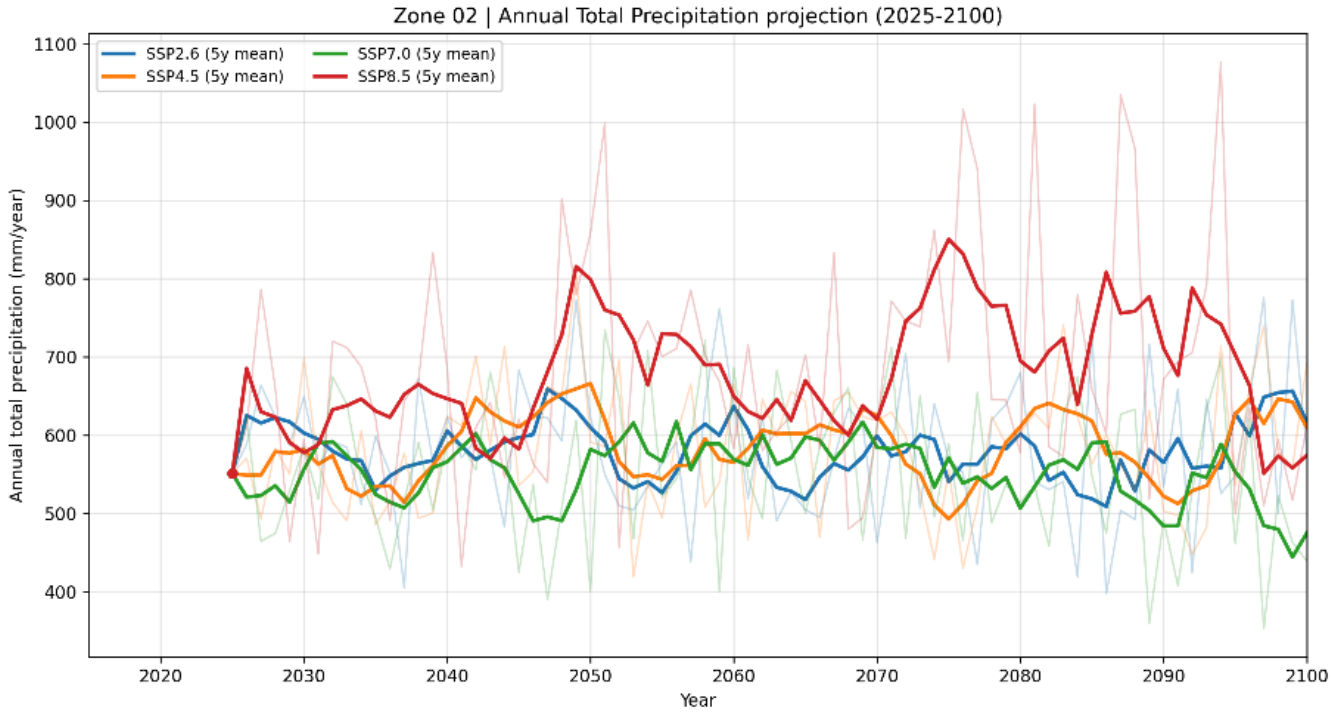


Figure 8: Annual total precipitation trend for all 4 SSP scenarios (NorthEast zone)

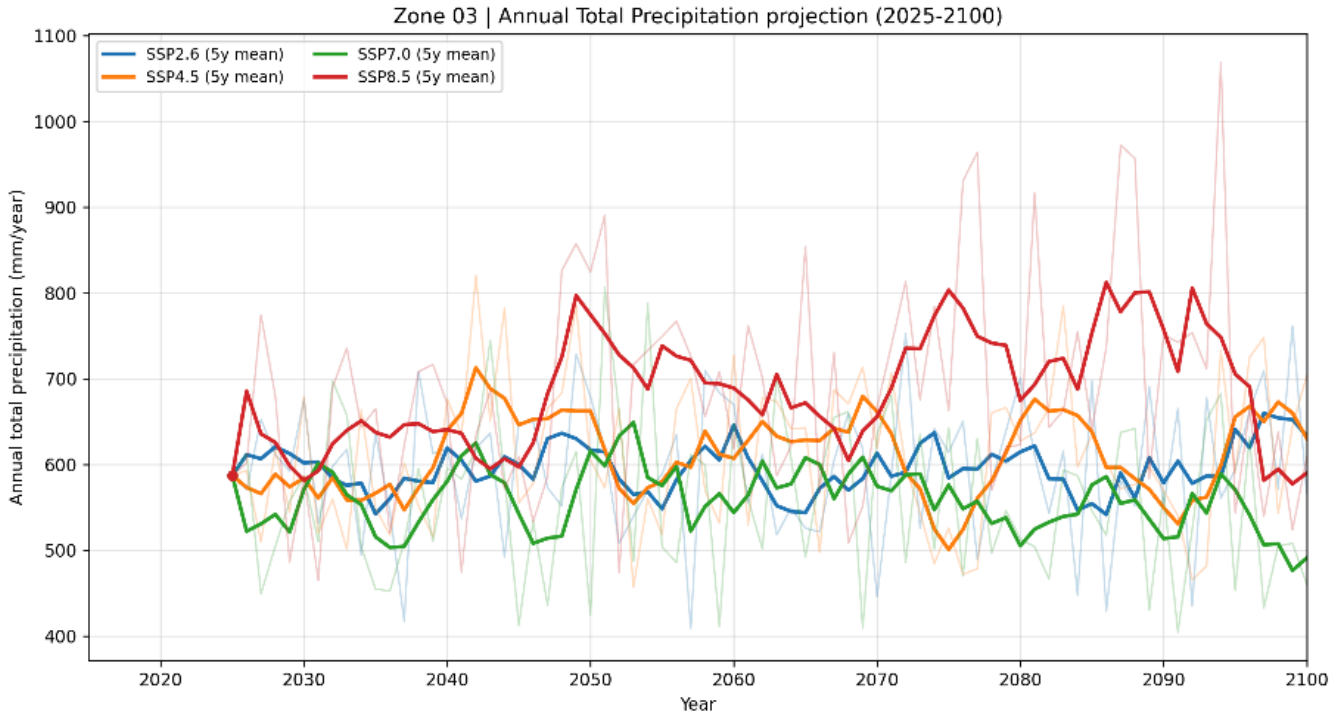


Figure 9: Annual total precipitation trend for all 4 SSP scenarios (Central zone)

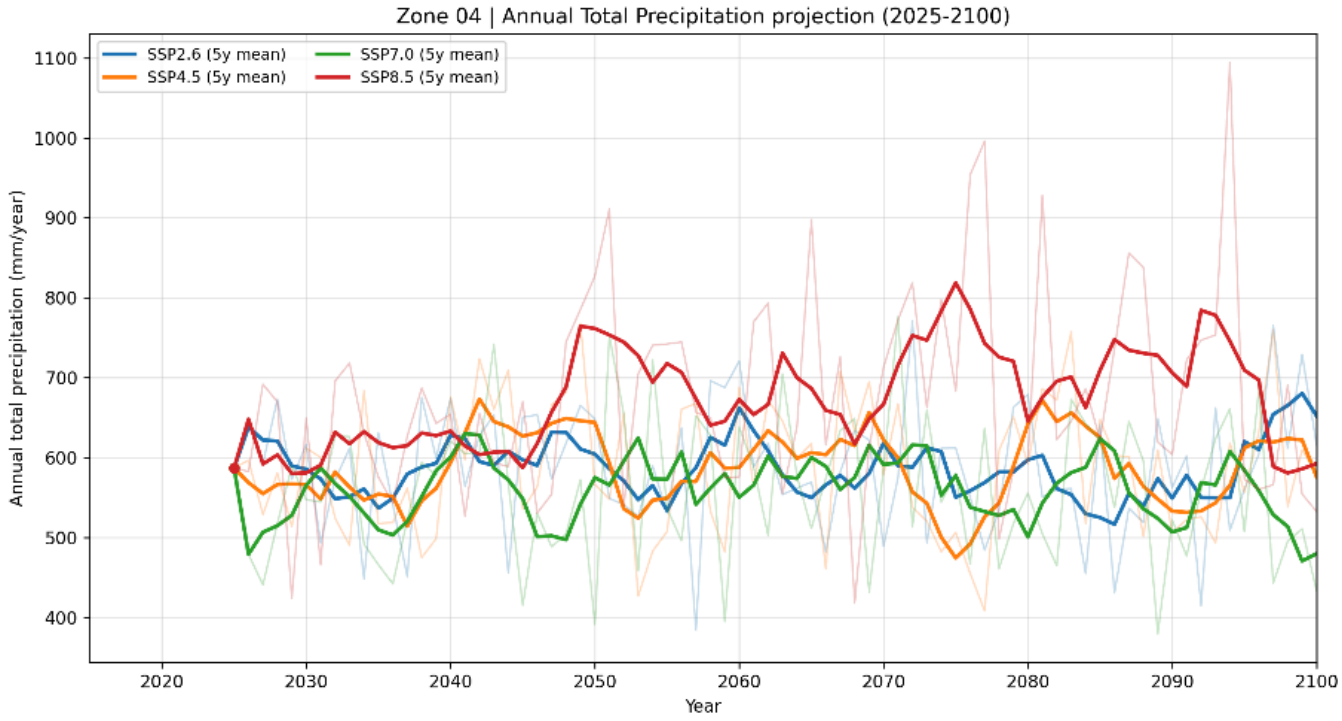


Figure 10: Annual total precipitation trend for all 4 SSP scenarios (SouthWest zone)

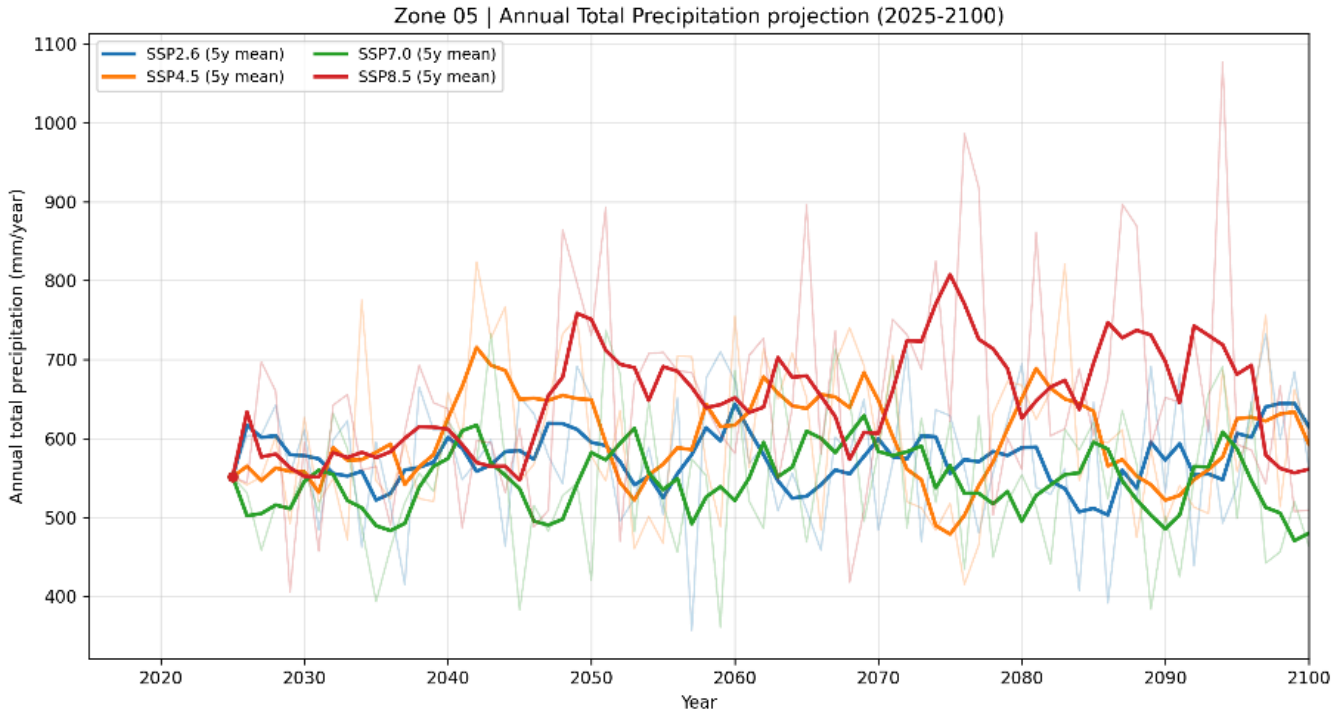


Figure 11: Annual total precipitation trend for all 4 SSP scenarios (SouthEast zone)

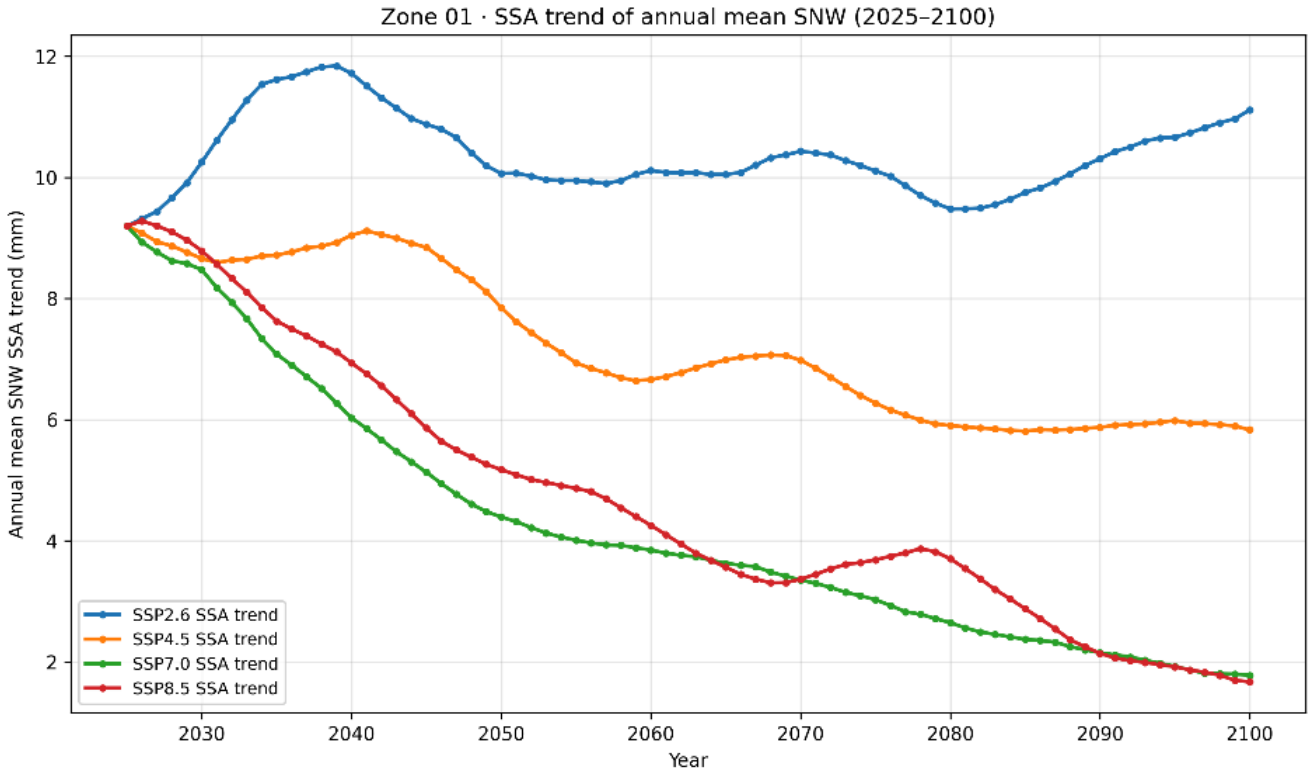


Figure 12: Annual mean snow water equivalent trend for all 4 SSP scenarios (NorthWest zone)

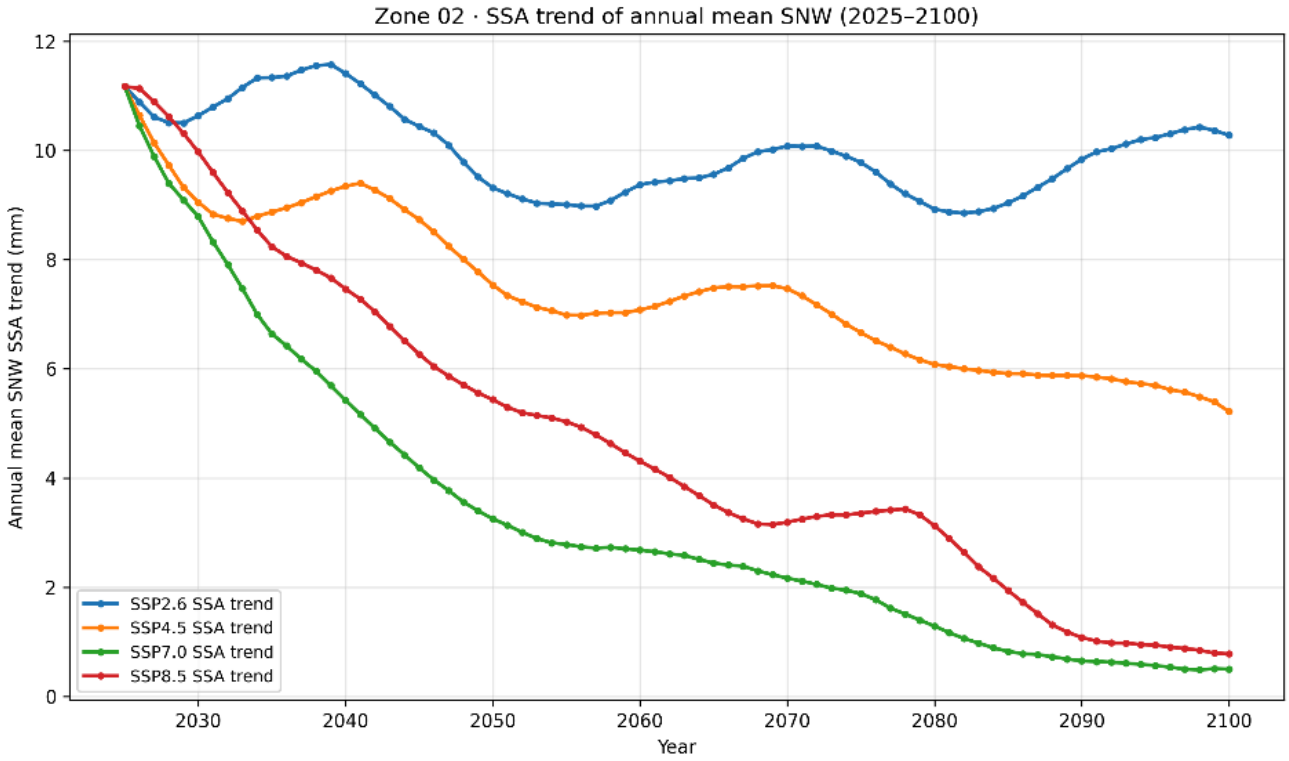


Figure 13: Annual mean snow water equivalent trend for all 4 SSP scenarios (NorthEast zone)

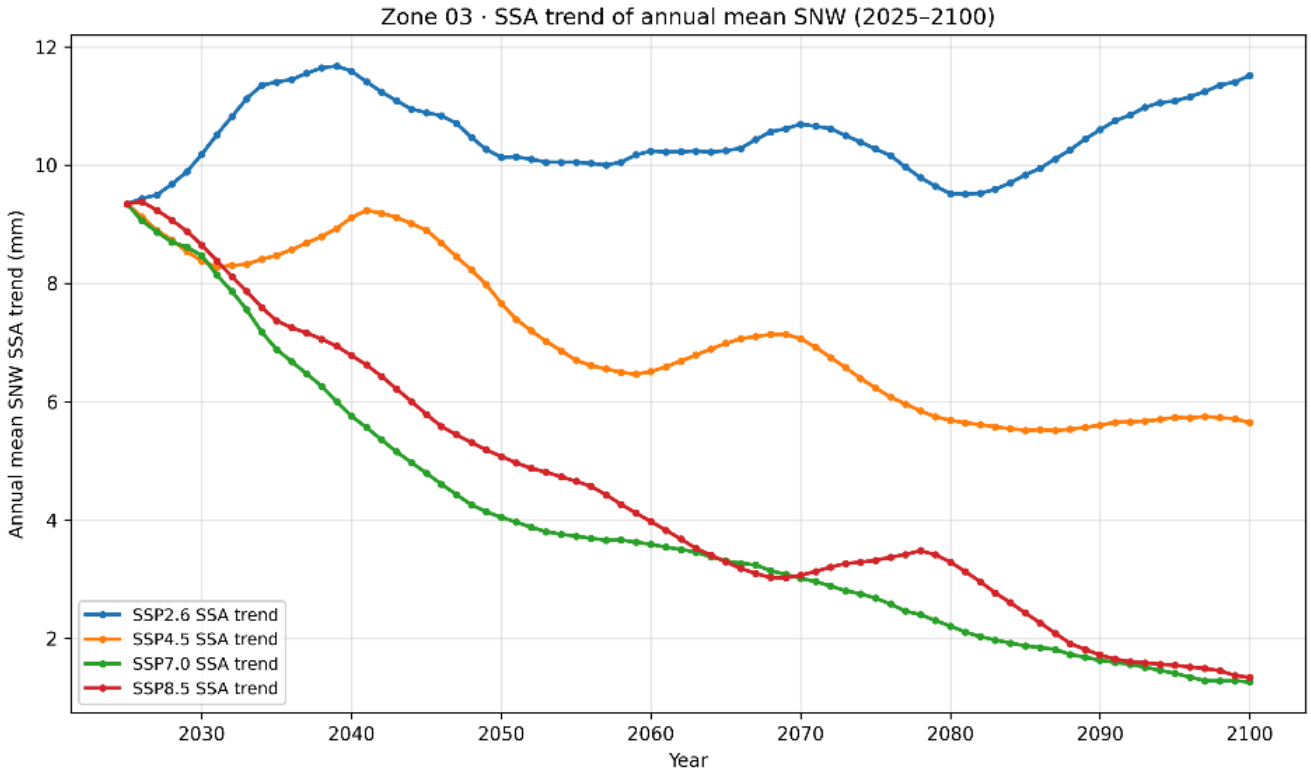


Figure 14: Annual mean snow water equivalent trend for all 4 SSP scenarios (Central zone)

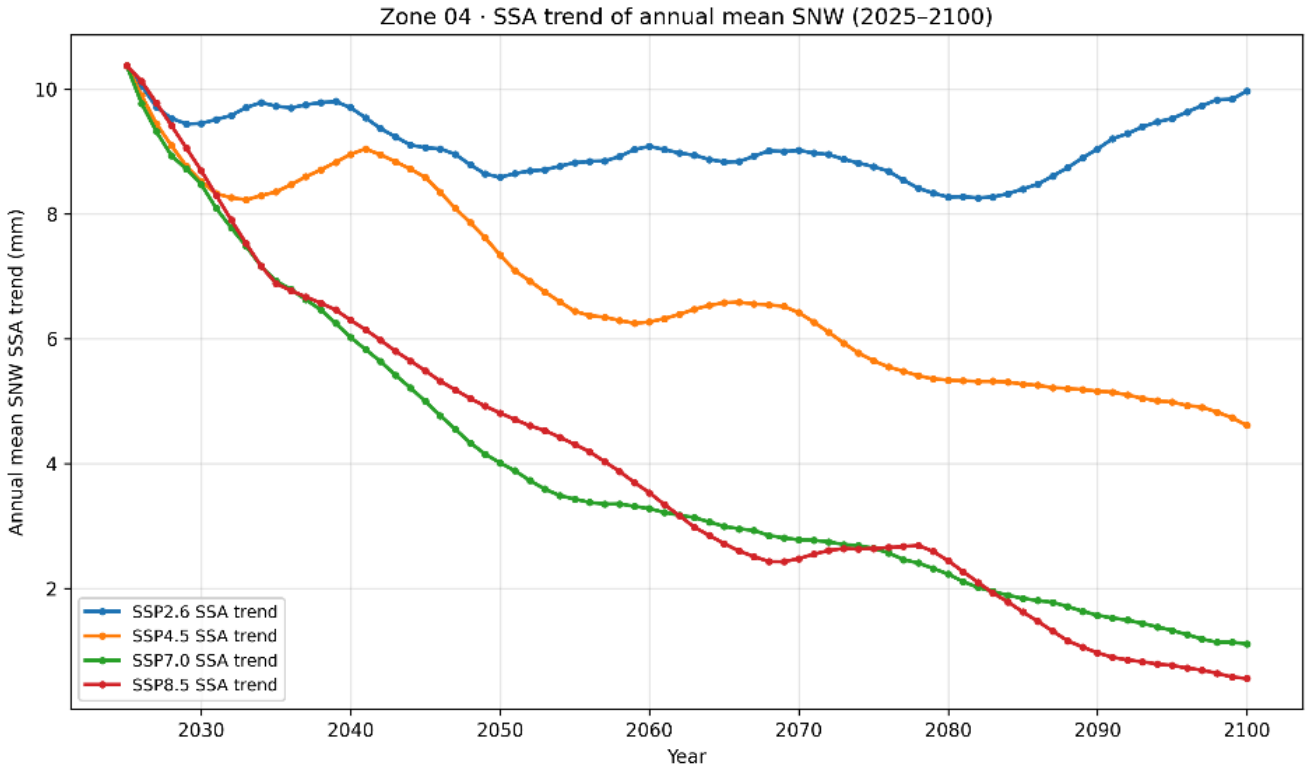


Figure 15: Annual mean snow water equivalent trend for all 4 SSP scenarios (SouthWest zone)

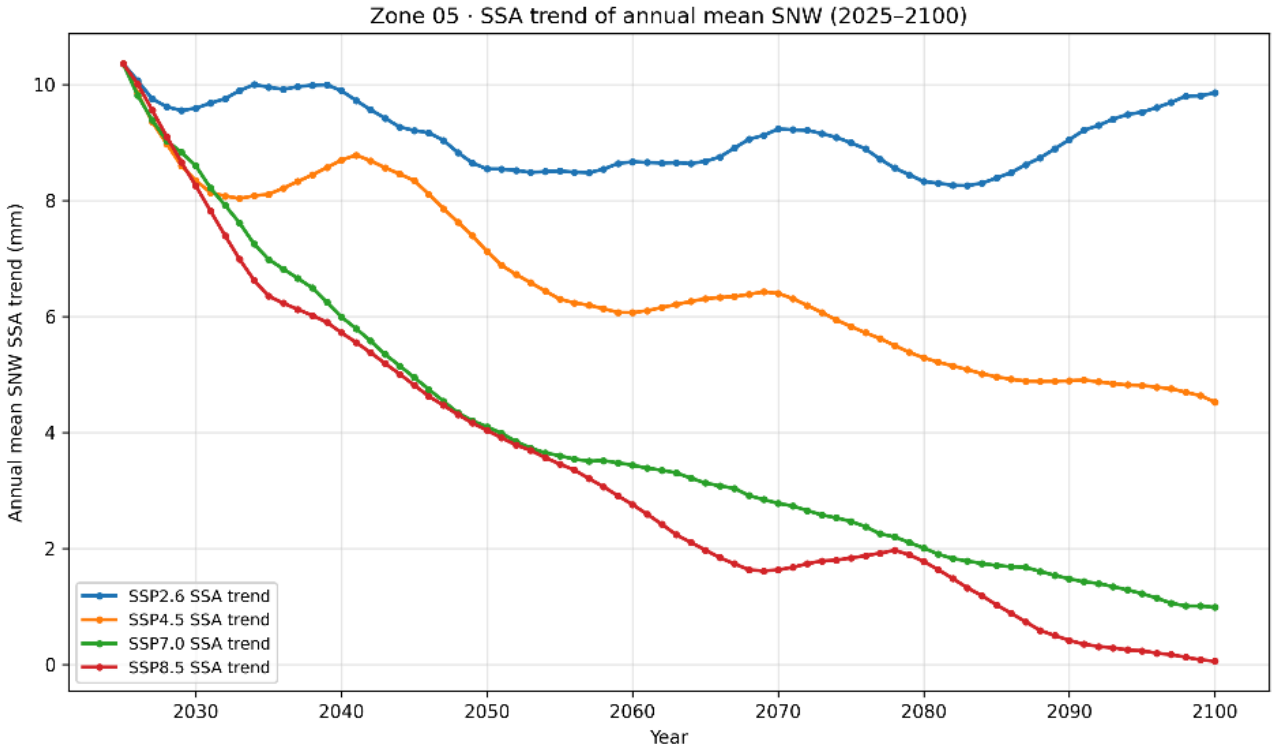


Figure 16: Annual mean snow water equivalent trend for all 4 SSP scenarios (SouthEast zone)

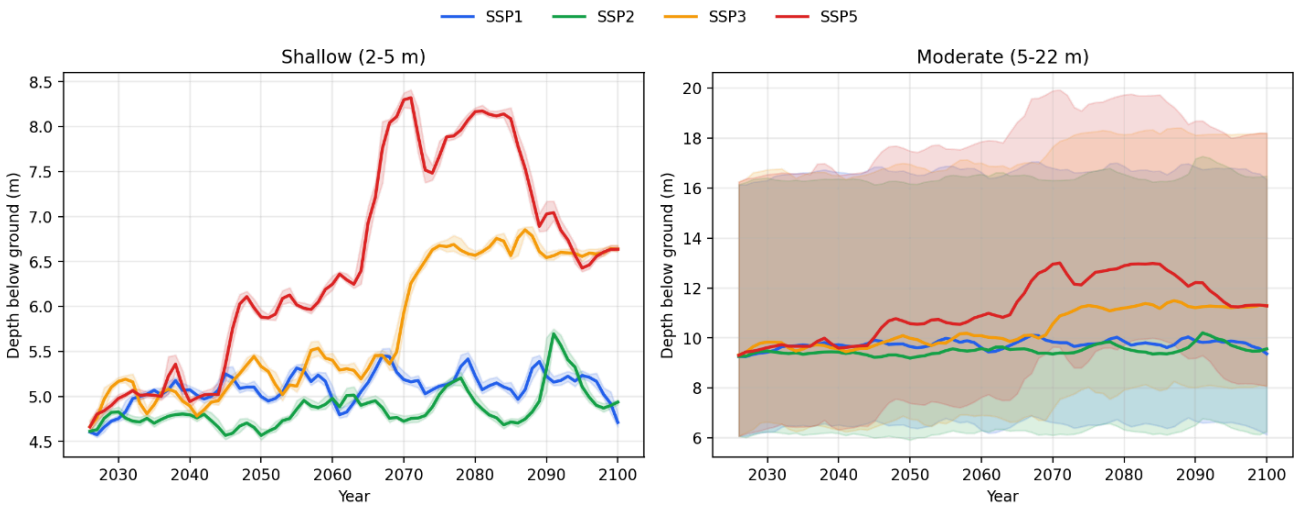


Figure 17: Groundwater Level Projections for Shallow depth zone and Moderate depth zone sites (Central zone)

TABLE 1: Projected Mean Annual Temperature Change per Decade by Edmonton Zone and SSP Scenario, 2025-2100.

Zone	Zone Name	SSP 2.6 (° C/decade)	SSP4.5 (° C/decade)	SSP7.0 (° C/decade)	SSP8.5 (° C/decade)
1	NorthWest	0.098	0.493	1.045	1.289
2	NorthEast	0.125	0.522	1.071	1.343
3	Central	0.104	0.481	1.026	1.271
4	SouthWest	0.100	0.504	1.064	1.301
5	SouthEast	0.093	0.487	1.035	1.278

TABLE 2: Projected Snow Water Equivalent Change per Decade by Edmonton Zone and SSP Scenario, 2025-2100.

Zone	Zone Name	SSP2.6 (mm/decade)	SSP4.5 (mm/decade)	SSP7.0 (mm/decade)	SSP8.5 (mm/decade)
1	NorthWest	0.008	-0.164	-0.212	-0.292
2	NorthEast	-0.156	-0.163	-0.392	-0.476
3	Central	0.045	-0.135	-0.226	-0.297
4	SouthWest	-0.119	-0.178	-0.374	-0.317
5	SouthEast	-0.032	-0.152	-0.351	-0.309

TABLE 3: Projected Annual Precipitation Change per Decade by Edmonton Zone and SSP Scenario, 2026-2100.

Zone	Zone Name	SSP2.6 (mm/decade)	SSP4.5 (mm/decade)	SSP7.0 (mm/decade)	SSP8.5 (mm/decade)
1	NorthWest	-0.437	1.573	-1.495	8.209
2	NorthEast	-3.138	3.039	-3.686	6.078
3	Central	1.857	3.523	-2.384	9.206

4	SouthWest	-2.241	0.552	0.943	8.574
5	SouthEast	-0.777	-0.823	0.705	8.451