City of Toronto Support for NAD'83 CSRS Integration

Dan Lymer

Data Integration Services

Technical Services Division

City of Toronto

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Table of Contents

1. Introduction

With the recent introduction of Ontario Regulation 216/10 under the Surveyors Act on June 7, 2010, plans registered or deposited with the Registry Office must be integrated in the North American Datum 1983 (NAD'83) in either the NAD'83 Adopted or the NAD'83 CSRS datum definition with the coordinates expressed in either the 3 Degree Modified Transverse Mercator or 6 Degree Universal Transverse Mercator Projections.

To support integration under the Regulation, the City of Toronto has prepared this guide to facilitate surveyors and other groups using the City's horizontal control network to integrate their projects in NAD'83 CSRS.

2. Background

The control network for the City of Toronto was established in 1961 by Metropolitan Toronto contracting the Geodetic Survey of Canada to install primary and second order control throughout the City. The initial adjustment of the network was performed in 1968 using NAD'27 as the reference datum. Densification continued with the expansion of the second order stations and the addition of third order control. With the 1974 Provincial adjustment, the perimeter control of the Toronto control network was fixed to that adjustment, so the Toronto 1968 adjustment is compatible with the Provincial 1974 adjustment.

With the introduction of NAD'83 Adopted, the City of Toronto chose not to readjust its control network to this datum because of the cost of transforming its spatial data versus the negligible benefits of moving to NAD'83 Adopted. Also, since NAD'83 Adopted was not based on GPS observations, significant distortions existed in the network. With the introduction of GPS, which provides higher accuracy and precision, the subsequent release of NAD'83 CSRS provided a far more reliable version of NAD'83, compatible for use with GPS. The following diagram illustrates the differences between CSRS and each of NAD'27 and NAD'83 Adopted datum's for the primary control points shown. The diagram provides an indictor of the distortion present in NAD'27 and the NAD'83 Adopted adjustments compared to NAD'83 CSRS. The difference in distances also only indicate the distortion in the primary network and does not reflect the anomalies in the secondary and tertiary networks which would present distortions in addition to those shown on the diagram.

The diagram demonstrates that the significant differences between NAD'83 CSRS and NAD'83 Adopted values create distortions at a level that would impact the use of GPS reference stations for real time positioning work.

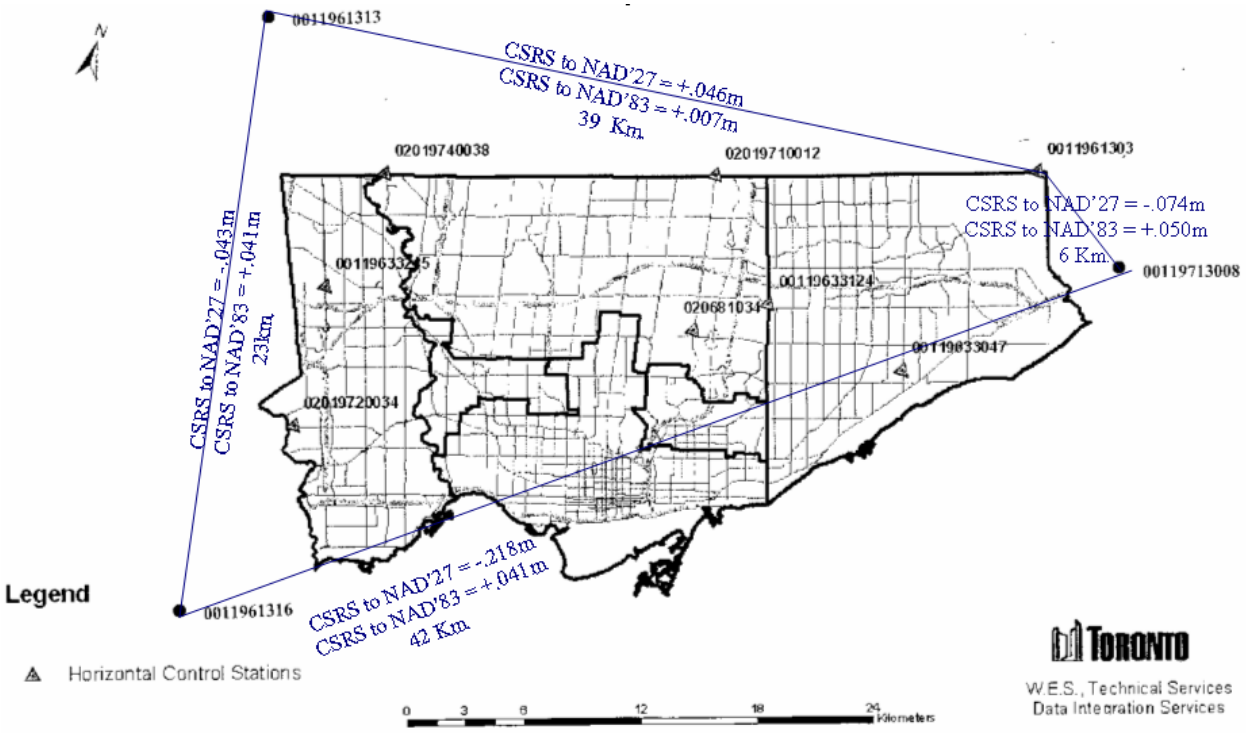

Fig.1, Comparison of distance differences between Primary Control Stations Bounding Toronto

2.1 NAD'83 CSRS Control Adjustment

The establishment of the Canadian Base Network (CBN) and the Ontario High Precision Network (OHPN) created the opportunity for the City of Toronto to initiate the long term move to NAD'83 CSRS and to effectively employ GPS technology with reference stations. To do this the City had to resurvey a significant part of its network in NAD'83 CSRS to establish base control in NAD'83 CSRS and create a grid shift file to enable the transformation of its spatial data assets from NAD'27 (1968 adjustment) to NAD'83 CSRS (described in the following section 2.2). With the assistance of Geo Connections and the Ontario and Canadian control survey agencies, the City began a NAD'83 CSRS survey of its primary and secondary horizontal networks in 2002. GPS observations on approximately 120 of the primary and secondary control points and conventional observations from previous surveys of the control network were used in a NAD'83 CSRS adjustment of approximately 2,400 points across the City. A map of the City showing the 2,400 points published for use are shown in Appendix 1.

2.2 Grid Shift Development

From those 2,400 adjusted CSRS values and the corresponding NAD'27 values for those control points, NRCan worked with the City to develop a grid shift file in the same grid shift binary format (.gsb) as the NTv.2 grid shift file. A grid shift file enables the transformation of coordinates between different datum definitions. The Toronto grid shift file 'TO27CSv1.gsb' can be used in GIS and GPS applications that currently use the NTv2.gsb for transformations between different datum definitions. In addition, NRCan provides their NTv.2 application, free of charge to users that can be used with the Toronto grid shift file to transform coordinates. The Toronto grid shift file has residual values that are less than 0.05m for 95% of the values used in the grid shift generation. The target for the grid shift project was to have residual values less than an upper limit of 0.1m for the project. Results showed 99% of all residuals are under 0.1m.

2.3 GPS Reference Stations

Following the creation of the 2,400 NAD'83 CSRS adjusted points and the Toronto grid shift file, the City set up two GPS reference stations in the City. The stations support real time positioning for City staff and provide static data for GPS post processing in the Receiver INdependent EXchange (RINEX) format for use by the public. The stations are shown on Figure 2 below.

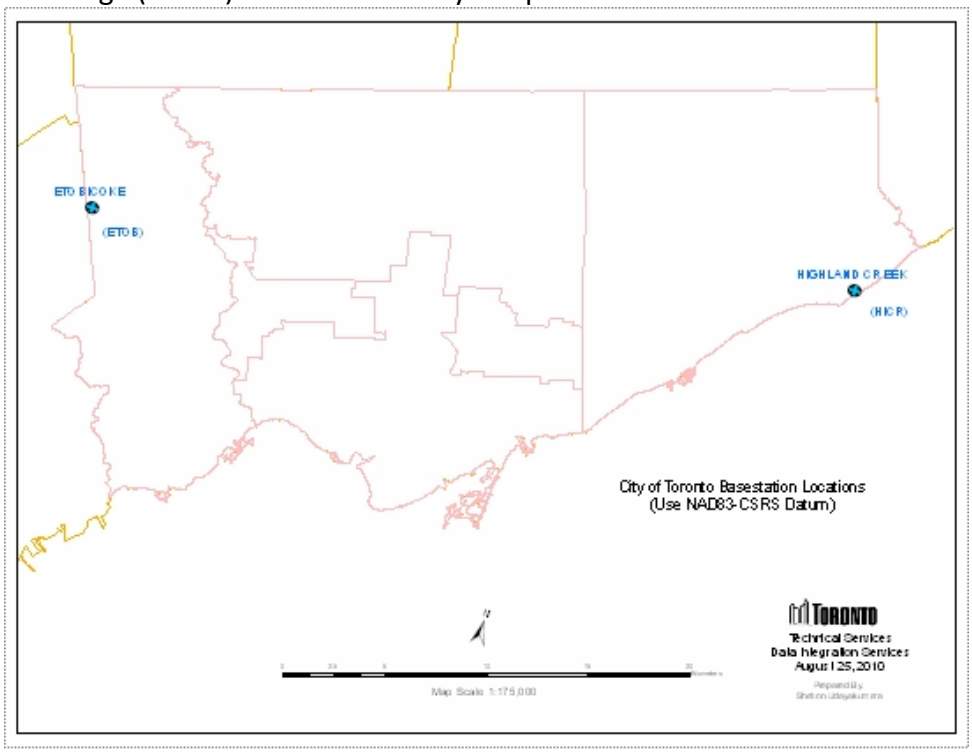

Fig.2 Location of City GPS reference Stations producing RINEX Data

2.4 Validation of CSRS implementation

To test the CSRS implementation the following three components had to be in place:

1) 2,400 points adjusted in CSRS.

2) Grid shift file for transforming between NAD'27 and NAD'83 CSRS

3) GPS reference stations enabling real time positioning.

This test was done with GPS RTK observations on the numerous adjusted CSRS stations or NAD'27 adjusted stations with values transformed to CSRS using the grid shift file. These comparisons provided indicators regarding the reliability of:

- The CSRS adjusted coordinates
- The precision and accuracy of RTK
- The consistency and reliability of the grid shift file
- The effect of using a network RTK correction versus a single base station for RTK corrections

The testing was done using RTK GPS on 49 stations distributed across the City. These points are either:

- part of the original GPS network used for CSRS adjustment
- stations in the CSRS adjustment input using historical conventional observations
- stations transformed using the TO27CSv1.gsb grid shift file to NAD'27

The GPS base station used for the survey was integrated in NAD'83 CSRS and the grid shift file was applied to the CSRS observed coordinates to create transformed NAD'27 values for comparison with the published NAD'27 values for those points. Appendix 2 shows the results of that testing. 49 horizontal control points in different quadrants of the City were observed. All those points had published NAD'27 values and most had adjusted CSRS values for comparison with the RTK observed values. The testing compared the published NAD'27 values with the CSRS observed values from the GPS reference stations with the grid-shift applied to transform from NAD'27. The spreadsheet also shows the comparisons of the RTK observed CSRS values to the values from the CSRS adjustment based on either GPS or conventional observations. The ReadMe page in the file explains how the following tabs are set up. Gross differences were examined in the Redo and Resection pages of the spreadsheet and most stations with larger differences were attributable to the stations being damaged or displaced. The largest difference was 0.08 metres on station 020901012.

3. Integration in CSRS utilizing the City Network and Resources

The City's official datum remains NAD'27/1968 adjustment until such time as the business users and the maintainers of those spatial data decide to migrate the City's geo-spatial data sets to NAD'83 CSRS.

In the interim, to support the implementation of integrated surveys as defined in Ontario Regulation 216/10 under the Surveyors Act, the following resources are being made available by the City to support integration. These resources will not in all cases satisfy the requirements of O. Reg. 216/10, based on the source of the CSRS coordinates and the integration methods used. Therefore, it is up to the Ontario Land Surveyor to exercise their professional judgement in assessing the inherent error in each of these options. Together with the method of survey chosen for integration, the Surveyor will need to decide which option should be used to satisfy the requirements of the Regulation.

3.1 City of Toronto Standards for O. Reg. 216/10 and Day to Day Operations

For submissions of deposited or registered plans under O. Reg. 216/10 that will be submitted to the City of Toronto, the defined datum will be NAD'83 CSRS and the coordinates will be expressed in the 3 degree MTM projection. Excluding the submission of cadastral surveys under O. Reg. 216/10, the City's current day to day operations still use NAD'27/1968 adjustment in the MTM projection. The City has not yet developed plans to transition its business to NAD'83 CSRS.

3.2 CSRS Adjusted Control Points

The 2,400 CSRS adjusted control points from the City network are being made available on the COSINE website along with the City of Toronto grid shift file TO27CSv1.gsb. The City is currently expanding its network of CSRS adjusted horizontal control points. The current 2400 points are shown in Appendix 1. The City is working on a program of increasing the number of points in CSRS across the City. The criteria for densification of CSRS control are:

- Areas of Capital Construction
- Areas where the spacing between stations is greater than 2 km.
- Areas of future development

- Areas where the use of GPS is diminished by multipath or obstructions and increased density is needed to support conventional survey methods.

In the Appendix 1 map of the point distribution, the shaded area on the map indicates where the spacing between stations is greater than 2km. The City program is targeting the next three years to extend the CSRS adjustment to address the spacing issue and densify control in highly urbanized areas where GPS cannot be used effectively. Following that, ongoing network support will target those areas of proposed construction and development.

3.3 NRCan's PPP (Precise Point Positioning)

http://www.geod.nrcan.gc.ca/products-produits/ppp_e.php

City staff tested PPP using data downloaded from one of its GPS reference stations on different days for durations of 1, 3 and 6hrs of dual frequency RINEX data. The resulting standard deviations for Northings and Eastings from PPP from both reference stations indicated that observations of approximately 3 hours of data will create a confidence region of 0.05 metres at 95% confidence for the observed points. Based on conditions such as blocked satellites, multi-path, satellite geometry and satellite availability results may vary widely. The following figures show the standard deviations at the GPS reference station for observations of 1, 3 and 6 hour durations taken from the PPP reports.

Observation Duration	Etobicoke Reference Station estimated coordinates / standard deviations
Day 1	
1 hr.	Latitude (NAD83(CSRS)): 43 42 04.6546 (dms) / **0.018 (m)** Longitude (NAD83(CSRS)): -79 36 25.7461 (dms) / **0.030 (m)** Ellipsoidal Height (NAD83(CSRS)): 137.379 (m) / 0.026 (m)
3 hr.	Latitude (NAD83(CSRS)): 43 42 04.6545 (dms) / **0.007 (m)** Longitude (NAD83(CSRS)): -79 36 25.7456 (dms) / **0.014 (m)** Ellipsoidal Height (NAD83(CSRS)): 137.379 (m) / 0.021 (m)
6 hr.	Latitude (NAD83(CSRS)): 43 42 04.6541 (dms) / **0.004 (m)** Longitude (NAD83(CSRS)): -79 36 25.7456 (dms) / **0.009 (m)** Ellipsoidal Height (NAD83(CSRS)): 137.376 (m) / 0.015 (m)
Day 2	
1 hr.	Latitude (NAD83(CSRS)): 43 42 04.6558 (dms) / **0.015 (m)** Longitude (NAD83(CSRS)): -79 36 25.7397 (dms) / **0.029 (m)** Ellipsoidal Height (NAD83(CSRS)): 137.388 (m) / 0.030 (m)
3 hr.	Latitude (NAD83(CSRS)): 43 42 04.6546 (dms) / **0.006 (m)** Longitude (NAD83(CSRS)): -79 36 25.7465 (dms) / **0.012 (m)** Ellipsoidal Height (NAD83(CSRS)): 137.356 (m) / 0.017 (m)
6 hr.	Latitude (NAD83(CSRS)): 43 42 04.6543 (dms) / **0.003 (m)** Longitude (NAD83(CSRS)): -79 36 25.7450 (dms) / **0.013 (m)** Ellipsoidal Height (NAD83(CSRS)): 137.361 (m) / 0.015 (m)

Fig. 3 PPP standard deviations over two days for durations of 1, 3 and 6 hrs.

Coordinates derived from PPP agree well with adjusted CSRS coordinates for those reference stations. The following chart shows the PPP positions comparing well with the City adjusted CSRS coordinate at approximately 3 hours observation duration.

TEST OF THE PRECISE POINT POSITION (PPP) METHODOLOGY

FOR THE CITY OF TORONTO CONTROL SURVEY SERVICES

ON THE ETOBICOKE BASE STATION (ETOB-02020020001)

FOR TWO DAYS STATIC OBSERVATION (OCTOBER 21st AND 23rd)

THE DAYS WERE DIVIDED IN 4 TIME DURATION (1h, 3h, 6h AND 12h)

ADJUSTED POSITION OF ETOB BASE STATION IS

CSRS(NAD83) MTM		CSRS(NAD83) MTM	
NORTHINGS	4840154.741	EASTINGS	296163.637

	1 HOUR OBS		3 HOUR OBS		6 HOUR OBS		12 HOUR OBS	
	NORTH	EAST	NORTH	EAST	NORTH	EAST	NORTH	EAST
OCT 20-21	4840154.783	296163.777	4840154.746	296163.625	4840154.737	296163.659	4840154.731	296163.656
	-0.042	-0.140	-0.005	0.012	0.004	-0.022	0.010	-0.019
OCT 22-23	4840154.746	296163.634	4840154.743	296163.645	4840154.731	296163.645	4840154.731	296163.65
	-0.005	0.003	-0.002	-0.008	0.010	-0.008	0.010	-0.013
AVERAGE	-0.023	-0.069	-0.003	0.002	0.007	-0.015	0.010	-0.016

It is shown from the above results that we need at least 3 hours observation and not more than 4 hours.

This will give a result of 2 to 4 cm difference between PPP methodology and the City of Toronto Horizontal Network.

Therefore the PPP solution for CSRS(NAD83) position can be used by the City of Toronto.

Fig. 4 Comparisons of PPP coordinates versus City Adjusted coordinates over time.

3.4 Use of RINEX Data from City GPS Reference Stations

As shown in figure 2 (page 7 of this report), the City operates two GPS reference stations and logs RINEX data from the receivers for use by surveyors for cadastral survey integration. The reference stations are integrated into the City's CSRS network. Requests for data for GPS post processing can be directed to 416-392-4845.

3.5 RTK Correction Services

GPS vendors provide RTK correction services throughout the Toronto area. Those organizations provide this service for fee on a subscription or on an occasional use basis. For users of the correction services, validation of the integration of the observations is advised. This can be done through observations on established CSRS stations on the ground and comparing corrections from other CSRS integrated GPS reference stations.

3.6 Use of the TO27CSv1.gsb Grid Shift

The City makes its grid shift file TO27CSv1.gsb available through the COSINE website. The grid shift file can be used in a large number of GIS and GPS applications. For users without access to these applications, the NTv.2 application can be used with the TO27CSv1.gsb grid shift. The NTv.2 application is available from the Natural Resources Canada website.
http://www.geod.nrcan.gc.ca/tools-outils/index_e.php

As noted in the previous sections, the average error derived from testing the grid shift file was 0.05m at 95% confidence, which is at the level of acceptable error as defined for urban integration under the 216/10 O. Reg. This means that most of the error budget is expended in the datum transformation of NAD'27 coordinates to CSRS using the grid shift. To use this for deriving coordinates in CSRS for City control points with only NAD'27 values, the users will have to exercise caution. While the error is not consistent across the City, this may be a viable means of transformation in most areas of the City. In other areas, shift values do not accurately map the distortions in the NAD'27 adjustment and the use of the grid shift will not satisfy the error limits in the Regulation. So using the grid shift to transform NAD'27 coordinates to CSRS is the least recommended option for CSRS integration in the City.

4. Appendices

Appendix_1_COT_CSRS_1.pdf

Appendix_2_rtkspreadsheet_v2.pdf