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Metrolinx Survey Control in Transit Corridor Supplement

MX-SURV CTRL-STD-2018-REV0

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Preface

This is the first edition of the Metrolinx Survey Control in Transit Corridor Supplement (MX-SURV-CTRL-STD-2018-REV0). It supplements existing provincial specifications (Engineering Survey Manual, Jan 2016, Vertical Control Survey Specifications, May 2011 and Ontario Specifications for GPS Control Surveys, June 2004) in addressing challenges and remedies that are specific to control surveys for Metrolinx transit projects in an urban environment. Metrolinx transit projects require engineering surveying with particularly stringent accuracy requirements and this document helps support this.

The supplement is targeted at land surveyors and engineers with experience in geodetic control surveying. It provides direction for planning and conducting both horizontal and vertical control surveys in support of Metrolinx linear projects in Urban Corridors. Existing provincial specifications will only be cited if there is a change required.

Suggestions for revisions and improvement can be sent to the Metrolinx Engineering and Design Standards (E&DS) team, Attention: Director of E&DS. Be sure to submit a standards justification form which includes a description of the proposed change, background of the application and any other useful rationale. Include your name, company affiliation (if applicable), e-mail address, and phone number.

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1 Introduction

1.1 Purpose

Surveys for detailed design, construction and precision engineering start by referencing high accuracy geo-spatial control points. This new standard helps ensure that all control points used for such Metrolinx projects have the required geo-spatial accuracy. This Metrolinx standard will provide technical requirements for horizontal and vertical control surveys for the purpose of meeting the following accuracy criteria where required by Metrolinx.

1.1.1 Horizontal Accuracy Class

a) Network accuracy – 2cm at 95% confidence interval

b) Local accuracy – 1 cm at 95% confidence interval

1.1.2 Vertical Accuracy Class

a) 1st Order

The control survey framework created in accordance with this document may also assist with secondary activities including, but not limited to, geo-referencing of cadastral surveys, preliminary design activities and topographic mapping work..

Much of the guidance for such control projects can be found in the following three existing provincial specifications (Engineering Survey Manual, Jan 2016, Vertical Control Survey Specifications, May 2011 and Ontario Specifications for GPS Control Surveys, June 2004) and it is recommended that surveyors engaged in control work familiarize themselves with this content. Only the changes required for some sections of these specifications will be cited in this document.

Provincial standards do not address the unique challenges of rail corridor projects and the current practice of using GPS as the only observation method is typically limited in tight urban transit corridors surrounded by tall buildings. This document supplements the existing provincial specifications in addressing these challenges. In addition, Metrolinx transit projects require engineering surveying with particularly stringent accuracy requirements and part of the supplement is designed to help support this.

1.2 Audience

The supplement is targeted at land surveyors and engineers who are familiar with and have experience in geodetic control surveying and is not intended as a substitute for formal training.

Consultants engaged in control survey activities for Metrolinx transit projects should have the necessary experience and educational background to successfully complete control survey projects in compliance with this document. Note that project contract documents may specify that an Ontario Land Surveyor be designated with responsibility for completing work under this supplement.

2 Definitions

Term	Definition
Glonass	(GLObalnaya NAvigatsionnaya Sputnikovaya Sistema) a space-based global navigation satellite system belonging to and maintained by the Russian Federation.
Hysteresis	The phenomenon in which the value of a physical property lags behind changes in the effect causing it. In land surveying it refers to the lag in stabilization of the tribrach following the application of a torque (turning the instrument).
Intervisible baseline (or pair)	Two survey points that are visible to one another when viewed through optical surveying instruments.
Navstar	(NAVigation Satellite Timing And Ranging) a space-based global navigation satellite system belonging to and maintained by the United States.

3 Abbreviations

Abbreviation	Definition
ATR	Automatic Target Recognition
BFFB	Backward Forward Forward Backward
CBN	Canadian Base Network
CGVD28	Canadian Geodetic Vertical Datum 1928
COSINE	COntrol Survey INformation Exchange (Ontario database)
CSRS	Canadian Spatial Reference System
Eng2016	Engineering Survey Manual, Jan 2016
GCS	Geodetic Coordinate System
GDOP	Geometric Dilution of Precision
GIS	Geographic Information System
GLONASS	GLObalnaya NAvigatsionnaya Sputnikovaya Sistema or GLObal
GNSS	Global Navigation Satellite Systems (referring to all such systems
GPS	Global Positioning System (referring to the U.S.
GPS2004	Ontario Specifications for GPS Control Surveys, June 2004
GRS 1980	Geodetic Reference System 1980
GTHA	Greater Toronto Hamilton Area
HT 2_0	Height Transfer 2 (NRCAN Geoid Model)
LGO	Leica Geo Office (software)
LRT	Light Rail Transit
MNRF	Ministry of Natural Resources & Forestry (Ontario)
MTM	Modified Transverse Mercator (map projection)
MTO	Ministry of Transportation Ontario
NAD27	North American Datum 1927
NAD83	North American Datum 1983
NAVSTAR	NAVigation Satellite Timing And Ranging

NGS	National Geodetic Survey (U.S.A.)
NRCAN	Natural Resources Canada
PIN	Primary Integration Network
PPM	Parts Per Million
PSF	Project Scale Factor
RTK	Real-time Kinematic
RTN	Real-time Network
TEC	Total Electron Content
UTM	Universal Transverse Mercator (map projection)
Vert2011	Vertical Control Survey Specifications, May 2011
WGS84	World Geodetic System 1984

4 Geodetic Coordinate Systems (GCS)

A Geodetic Coordinate System is a three-dimensional grid that allows a variety of types of geographic information to be spatially related to one another consistently.

The basis for a Geodetic Coordinate System is a global mathematical model that approximates the size and shape of the Earth by means of an earth-centred ellipsoid of rotation.

This framework is physically represented on the ground by networks of permanent 'survey control points', the absolute global positions of which are known to various prescribed levels of accuracy. This realization on the ground by means of survey control points is called a datum.

Because the Earth is subject to crustal motion, datums are periodically updated or readjusted to keep pace with any movement over time. This leads to different epochs (also called 'versions' or 'adjustments') of datums.

The positions of points are communicated by means of coordinates which are commonly part of a map projection (eg. northing & easting in MTM, UTM or others).

The Geodetic Coordinate System (GCS) is therefore a collection of four elements:

a) mathematical model (ellipsoid)

b) datum

c) adjustment, and

d) map projection

Geodetic Coordinate Systems support a wide variety of geospatial activity including establishment of property boundaries, mapping, engineering design and creation of databases of information that help relate non-geographic data to geographic position (Geographic Information Systems or GIS) for archival, dissemination and analysis purposes.

Datums are typically split into horizontal and vertical and the survey techniques used for each are distinct. A horizontal control survey may use Global Navigation Satellite

Systems (GNSS) or conventional angle and distance reading techniques or a combination of both, while a vertical control survey typically uses precise differential leveling techniques.

4.1 Datums & Adjustments for Metrolinx Transit Projects

4.1.1 Horizontal Datum - North American Datum 1983 (Canadian Spatial Reference System)

The horizontal datum to be used as the basis for all Metrolinx control surveys is the most current Metrolinx--adopted adjustment of NAD83(CSRS).

Due primarily to crustal motion, the datum adjustment (or version) is regularly updated or readjusted to take into account velocities of the points comprising the datum. In Ontario, the resulting differences from version to version are typically quite small. By periodically adopting a version update, the Parcel Mapping and Georeferencing section of the Mapping and Information Resources Branch at the Ministry of Natural Resources and Foresty (MNRF Ontario) balances the competing considerations of maintaining a stable horizontal datum for the user community while ensuring that the horizontal datum stays reasonably current with the changes in the Earth's surface.

4.1.2 Project-Specific Local Horizontal Datums

Metrolinx projects may be located in jurisdictions that use an older datum not directly compatible with NAD83 (CSRS). In these cases, Metrolinx may specify a customized local datum to be used for engineering surveys together with a pre-determined seven parameter similarity transformation to enable conversion between the local datum and NAD83(CSRS). Where Metrolinx has not provided a 7 parameter transformation, consultants may be required to derive it. For further guidance see Section 9 of this Supplement Document. All control survey deliverables should be provided in both datums.

4.1.3 Vertical Datum - Canadian Geodetic Vertical Datum 1928 (1978 Southern Ontario Adjustment)

The vertical datum to be used for Metrolinx control surveys is the "CGVD28-78 S.Ont.".

In some jurisdictions of the Greater Toronto Area, the 1978 Southern Ontario Adjustment has not been adopted. In such cases, the datum is referred to as "CGVD28 - pre78". As is the case with local horizontal datums, Metrolinx will provide transformation parameters to allow for conversion between the two systems. All work shall be completed and delivered using the 1978 Southern Ontario Adjustment.

4.2 Map Projections for Metrolinx Transit Projects

A map projection is a method used to represent the 3-dimensional surface of the earth on a 2-dimensional plane by means of the application of pre-defined mathematical transformation parameters. The transformation produces grid coordinates such as those of the Modified Transverse Mercator (MTM) or Universal Transverse Mercator (UTM) coordinate systems.

The MTM coordinate system provides for less distortion with a scale factor = 0.9999 compared to the UTM system with a scale factor = 0.9996 at the central meridian.

Metrolinx has adopted the MTM coordinate system. As some municipalities require the project to be performed in the UTM then in this case the control survey results shall be provided in both UTM and MTM. The control results must be accompanied with meta data and comments indicating projection, zone, false easting, central meridian and central meridian scale factor.

As the scale factor changes at different locations, one average Project Combined Scale Factor (PCSF) may be required to be computed for each project area. The PCSF is used to convert the Grid distances to Ground distances.

4.3 Types of Survey Control Networks

Horizontal Control Networks for Metrolinx projects are hierarchical and consist of the following three categories:

4.3.1 Primary Integration Network (PIN).

A minimum of three existing monuments classified as NAD83(CSRS) Class 'A', Class 'B' or 'Real Time Kinematic Providers' basestations as defined in COSINE. Where possible, this network should surround the entire project area. Static GNSS observations shall be observed directly between all of these stations. It is suggested that archived GNSS observation data from different RTN providers not be 'mixed'.

4.3.2 Key Station Network.

Stations at each end and within the work area set in safe & secure locations in accordance with the requirements of section 3.1 of 'GPS2004', at nominal 1 km intervals (or at an interval specified in the project contract documents) where static GNSS observations are possible. Ideally these stations will be set as intervisible pairs so that direction error propagation may be controlled during conventional total station observations. Each end of the work area must be composed of intervisible pairs of points. Each Key Station should be connected by static GNSS observations to a minimum of the two closest PIN stations.

4.3.3 Project Network.

Stations set in safe & secure locations in accordance with the requirements of section 3.1 of 'GPS2004', along the project corridor at intervals of 100 m minimum and 250 m maximum. These are stations where GNSS observations would be compromised due to obstructions or multipath and, together with the Key Stations will form an uninterrupted total station traverse from end-to-end in the project corridor. Note that Key Stations may fulfill the interval requirement within the Project Network if they are set along the project corridor.

Vertical control networks for Metrolinx Transit Corridor projects will consist of first order benchmarks spaced at maximum 1 km intervals or at an interval specified in the project contract documents. These should be located in safe and secure locations beyond the limits of construction or tunnel mining.

5 Vertical Control Surveys

5.1 Existing Specification

All Metrolinx vertical control surveys will meet first order specification. Vertical Control Survey Specifications, May 2011 (Vert2011) is applicable for Metrolinx projects with the following changes (referencing Vert2011 section numbers):

1. Introduction - disregard

2. Definitions

    b) Primary benchmarks must be published first-order or higher benchmarks from either the Provincial COSINE database or the Canadian Active Control System database. Municipal or any other benchmarks that do not appear in either of these databases may not be used as Primary benchmarks.

3. General Specifications

    a) (REPLACE ALL WITH) "A digital level with on-board line leveling program capable of displaying on-going distance balance, multiple sight statistics, BFFB prompt and recording of all raw data. Minimum accuracy specification: 1km double-run 1 standard deviation <= 0.3mm"

    b) (REPLACE) "3 kilometres" with "maximum 1 kilometre or to be specified by project contract documents."

    e) (REPLACE ALL WITH) "Lines of sight to the top or bottom areas of the rod must incorporate all stadia lines. (Stadia lines must be visible on the face of the rod.)" disregard third order comment

    m) Disregard

6. First Order Specifications

    a) To be specified by project contract documents

    c) (REPLACE) "daily" with "weekly"

7. Second Order Specifications

    Disregard - not applicable

8. Third Order Specifications

    Disregard - not applicable

9. Classification of New Benchmarks

    Disregard - not applicable

5.2 Planning

Before any field observations commence, a schematic diagram shall be submitted to Metrolinx Compliance or a project-specific designated authority for review, comment, and approval prior to any work being performed. The diagram shall show all benchmarks with intended line leveling connections and Primary benchmark stability tests.

6 Horizontal Control Surveys

6.1 Introduction

Transit Corridor Control Surveys pose a specific set of challenges not encountered in other geodetic work. The primary of these is narrow linear network geometry. While GNSS is less susceptible to error arising from terrestrial network geometry (and more susceptible to error arising from geometry of the satellite constellation), the urban environment limits its useful application due to obstructions and signal multipath from buildings and construction works. Conventional survey observations shall be used to supplement the survey network where the use of static GNSS is limited.

Conventional survey methods are particularly sensitive to network geometry due to error propagation. Error propagation can be limited by using GNSS positioning techniques. This usually means that a combination of the two techniques is required in order to provide sufficient control point coverage for Metrolinx transit projects in urban corridors. Proper adjustment of the errors from these combined observations (static GNSS plus total station distance/angle reading) requires additional attention.

6.2 Existing Specification

Ontario Specifications for GPS Control Surveys, June 2004 (GPS2004) is applicable for static GNSS observations that are completed for the Primary Integration and Key Station Networks for Metrolinx projects with the following changes (referencing GPS2004 section numbers):

1. Introduction - disregard

2. Accuracy

   2.1 NAD83(CSRS)

   (ADD) "For local accuracy, the maximum length of the semi-major axis of the relative confidence interval between adjacent connected stations within the project area will be 1cm.

   For network accuracy, the maximum length of the semi-major axis of the relative confidence interval between any station connected to a Primary Station or any two stations connected by static GNSS will be 2cm."

   2.2 NAD83 (ORIGINAL) - disregard.

3. Reconnaissance

   3.2 Monumentation

   (REMOVE) references to wood or steel markers. (REPLACE) "monument type C" with "monument type C or, where required, brass control survey cap provided by the municipality in which the project is located."

3.3 Monument Position Sketches

(ADD) "This represents the minimum requirement. Pay attention to any additional requirements specified by the municipality in which the project is located and adhere to these requirements."

4. Network Design

4.1 through 4.4 - disregard. See "Types of Survey Control Networks" in the Introduction section, 2c of this supplement document.

4.5 Repeated Baselines

(ADD) "All intervisible baselines between pairs of points designed to provide azimuth control in conventional surveys shall be repeated."

5. Equipment Selection

5.1 Receiver

(REPLACE ALL WITH) "A minimum of four geodetic quality multi-frequency receivers capable, at a minimum, of logging L1/L2 GPS and L1/L2 Glonass signals."

5.2 Antenna

(REPLACE ALL WITH) "Multi-frequency geodetic antennae must be used. Absolute antenna calibrations should be used and shall be used when mixing antenna types. Commercially-available GNSS processing software allows for integration of absolute calibration files. The calibrations are available for download from the website of the U.S. National Geodetic Survey:

https://www.ngs.noaa.gov/ANTCAL/

IMPORTANT: the absolute calibrations are datum version (or epoch) specific and the surveyor must ensure that the correct version is used.

6. Field Observations

6.4 Length of Observation Session

(REPLACE) "30km" and "30 kilometres" with "50 km"

7. GPS Data Processing - (REPLACE) all references to "GPS" with "GNSS"

7.1 Software and Processing Procedures

(REPLACE) "30km" with "50 km"

(REPLACE) "Dual frequency data" with "At a minimum, GPS L1 and L2"

(REMOVE) "L1-fixed solutions may be accepted for short baselines (less than 10km in length) if they provide better solutions than the combined L1/L2-fixed solutions."

(REMOVE) "or NAD83 (Original)"

8. Analysis and Adjustment

8.1 Least Squares Adjustment Software

(ADD) "The software should be capable of executing weighted-station adjustments for the purposes of combining GNSS & conventional data into one adjustment."

(REPLACE) "GeoLab" with "Geolab or StarNet Pro"

8.3 Minimally Constrained Adjustment

(REMOVE) "NAD83 (Original)"

8.4 Fixed Constrained Adjustment

8.4.1 NAD83 (CSRS)

(REPLACE) "fixed to their NAD83 (CSRS) 3-D ellipsoidal coordinates." with "horizontally-fixed to their NAD83(CSRS) latitude and longitude along with the ellipsoidal elevation of one geodetic benchmark as pre-calculated using the appropriate geoid model. The geoid model must be applied to the adjustment."

(ADD) "Note that the resulting ellipsoidal coordinates and error estimates (weighted stations) must be taken from this adjustment result to be used later in a combined GNSS/Conventional adjustment in the case where conventional data (distance and angle observations) form part of the Production Network." - see "Additional Adjustment Notes" below.

8.4.2 NAD83 (Original) - disregard

8.5 Weighted Constraint Adjustment - disregard - see section 6 of this supplement, "Additional Adjustment Notes" below.

10. Reports and Returns

10.4 Adjustment Procedure and Analysis

(REMOVE) "and the order of accuracy of the NAD83 (Original) network from the constrained adjustments"

10.5 Project Deliverables

(REMOVE) "All digital data must be submitted on compact disc."

(REPLACE) "Version 2" with "Version 3"

(REPLACE) "Geolab" with "Geolab or StarNet Pro"

(REMOVE) "UTM and"

6.3 Planning

6.3.1 Geodetic Control Plan

A Geodetic Control Plan shall be submitted to Metrolinx Compliance for review, comment, and approval prior to any work being performed. The Geodetic Control Plan will consist at a minimum of the following items;

Once a control area reconnaissance has been performed, a proposed control network diagram depicting all levels of control listed above will be created and submitted in the plan.

A control network pre-analysis is required and involves loading the control network configuration and the predefined measurement accuracy parameters into a least squares software program and computing the statistical positional errors of each survey control point.

The control network pre-analysis will be prepared in a comprehensible format that is similar to either Geolab or StarNet Pro Least Squares Adjustment Software. This format will consist of a display of the parameters for the required accuracies noted above, an input file of named points and approximate coordinates that combines the proposed GNSS observations and the total station traverse with closed horizons, and an output file that lists the station and relative error ellipses at a 95% confidence level which clearly demonstrates the results have met or exceeded the required accuracies noted above.

Once the configuration of the network is established, the GNSS observation scheme will be designed and submitted as part of the plan. Note the above requirement for connections and observation times between PIN, Key & Production networks as well as above requirements (GPS2004, sec 4.5) for repeat baselines between sessions and intervisible baselines.

Based on existing station obstruction information and prior to conducting observations, the proposed sessions will be checked with GNSS constellation forecasting (mission planning) software to ensure that the satellite geometry is favourable. Any periods with a GDOP higher than 6 or with a total number of available NAVSTAR (i.e. GPS) satellites less than 4 will be identified and strictly avoided in the mission planning. The ionospheric activity forecast should be checked one day in advance of any observations and any days with abnormally high Total Electron Content (TEC) or days characterized by unusually high sunspot or solar flare activity should be avoided.

7 Conventional (Total Station) Control Surveys

7.1 Introduction

As mentioned above, the primary challenge of control surveys in a transit corridor is the limitation in ability to apply GNSS techniques due to obstructions and multipath. This challenge can be acute given the typically more rigorous accuracy requirements of the engineering surveys that are required for successful outcomes in Metrolinx transit projects when compared, for example, to highway construction. Of particular concern are tunnel control surveys - specialized engineering surveys with their own set of challenges and specifications covered elsewhere but nonetheless relying on the surface control networks discussed here.

7.2 Existing Specification

Engineering Survey Manual, 2016 (Eng2016) is primarily directed at lower-accuracy project control, engineering and topographic surveys completed for MTO highway projects. These surveys typically rely on the higher accuracy control surveys that fall under the other two specifications (GPS2004 & Vert2011). A review of the Control Surveys sections in Eng2016, can be helpful in providing guidance for Conventional or

Total Station Control Surveys that are required for Metrolinx Project Control Networks in transit corridors. The following terms will replace the related sections within Eng2016 and are mandatory for completion of Metrolinx Control Surveys in urban corridors:

7.3 Equipment

For conventional terrestrial observations connecting all Project and Key Control points, the following are the minimum requirements for equipment to be used:

7.3.1 Total Station

A modern data-collecting digital total station with 4-axis compensation, capable of measuring both horizontal and vertical angles to an accuracy of 1 second of arc (standard deviation) and a distance measurement accuracy of 1 mm ± 1.5 ppm (standard deviation) will be used for distance and angle measurements on the Project control between the Primary and Key stations.

7.3.2 Automatic Target Recognition

It is strongly recommended that the total station be equipped with automatic target recognition (ATR - automated prism sighting by means of integral servo motors). The ATR should have a pointing accuracy equal to or better than 1 second of arc (standard deviation).

7.3.3 Total Station Accessories

Precision optical prisms, carriers, plummets, tripods and tribrachs will be used with sufficient number to allow "forced centring" observations (leaving the tripods and tribrachs in place and advancing the total station and prisms). All tribrachs (or carriers) will be equipped with optical plummets. Minimum centring accuracy of plummets will be 0.5 mm @ 1.5 m.

During angle reading, the total station will be turning, either manually or by servo motor, causing torsion to be applied from the instrument to the tribrach and then from the tribrach to the tripod and finally from the tripod to the ground. It is important the operator ensures sufficient clamping force has been applied to the tribrach before taking any sightings and that the individual legs of the tripod are tightly attached to the tripod head such that no flex occurs. The elasticity of the tribrach components leads to a lag in stabilization following the application of a torque (turning). This hysteresis must be known and specified by the tribrach manufacturer. The minimum torsional rigidity specification for all tribrachs shall be 1 second of arc (3 cm3 hysteresis).

7.3.4 Checks and Calibrations

a) Tribrach and total station level bubbles - may require periodic re adjustment;

b) Optical plummets - may require periodic adjustment;

c) Tripod legs - may require periodic tightening;

d) Total Station Calibration Routines - stresses to total station components may result from transportation or large swings in temperature. As a minimum, checking, on-board testing and adjustment routines shall be used at the beginning of each control survey and on a weekly basis thereafter. These shall also be used after the instrument has been transported for any significant distance, after any episodes of instrument 'jarring' or when the temperature changes significantly (±20 °C).

7.4 Observations

All visible stations should be sighted from each occupation.

Angle observations at each station shall consist of all angles necessary to close the horizon i.e. for three stations A, B, C, when set up on middle station B, angles ABC and CBA shall be observed and recorded.

A minimum of six sets of double reading (Face 1 and Face 2) is recommended for all angle observation sets as this compensates for primary systematic instrumental errors. Five of the six sets of angles shall meet the measurement criteria of 2 seconds of arc from the mean angle, otherwise additional sets be re-observed until the measurement criteria is achieved.

Distances shall be measured and recorded for each sighting. Instrument & target heights shall be recorded.

The total station traverse shall proceed along the route of survey using forced centering techniques (leaving the tripods and tribrachs in place and advancing the total station and prisms).

All raw data must be recorded in an automated fashion during observation.

8 Analysis and Adjustment

Once all of the measurements are complete, the data shall be checked and processed to create least squares adjustment input files. Sets of angles that do not meet the measurement criteria of 2 seconds of arc from the mean angle shall be discarded. Distance observations that differ by more than 5mm from the mean shall likewise be discarded.

Observations shall be adjusted using Geolab or StarNet Pro least squares adjustment software. One set of error estimates shall be specified for angle and distance observations in the input file. These should be the same as specified by the total station manufacturer or be the result of observation pre-processing and standard deviation calculation. Additional error estimates for centering and pointing shall be specified.

A minimally-constrained adjustment, fixing the horizontal coordinates of two intervisible Key or Primary Points (either published values or values resulting from the fully-constrained GNSS adjustment) at either end of the linear traverse shall be completed. Assessment of 95% confidence intervals resulting from this adjustment should be compatible with values resulting from the pre-analysis completed for the Geodetic Control Plan. An assessment shall be made of the comparison to other known coordinates of other Key or Primary points that form part of the traverse. These comparisons should indicate consistent error propagation along the length of the traverse in accordance with the expected error at each occupation. Residuals shall be examined closely for outliers. Likewise, any deviation from a linear increase in error over the distance of the traverse shall be investigated as this may indicate the inclusion of either blunder or systematic error in the adjustment.

Further analysis may be made by introducing additional constraints at the opposite end of the traverse and looking at coordinate differences for other Key or Primary points.

This traverse, with no constraints, shall form the basis of the final combined adjustment that incorporates the GNSS observations in the Primary and Key Station Networks.

Additional Adjustment Notes

Because both GNSS positioning and conventional error propagation methods are likely to be used in a combined Primary/Key/Project network, methodology shall be employed in order to ensure appropriate observation weighting of the two methods.

Once the fully-constrained GNSS adjustment is completed, weighted stations of all Primary and Key points that also form part of the conventional traverse shall be extracted. This covariance matrix shall be added to the unconstrained conventional traverse adjustment input file creating a combined adjustment of GNSS covariance, conventional error estimates and conventional observations. The results of this adjustment shall be gauged in accordance with section 8.3 of GPS2004.

The Key and/or Primary GNSS stations in the combined adjustment serve to limit the error propagation of the conventional observations and it is the results of the combined adjustment that provide the best estimates of the positions of all of the horizontal control points in the project.

9 Datum Transformations

Several Municipalities within the Greater Toronto Hamilton Area (GTHA) maintain existing control networks based on the legacy NAD27 or NAD83 Original Datum. As their complete mapping base and infrastructure is referenced to the legacy datum in certain instances Metrolinx may require the project to be completed within the constraints of their existing control network datum. Typically the legacy control networks do not meet the Metrolinx datum specifications and accuracy requirements. This section describes the method of developing datum transformation parameters while working within these legacy control networks while still maintaining the required accuracies.

The legacy control networks typically contain errors that exceed the Metrolinx requirements and require upgrading. If the errors are systematic and within an acceptable tolerance then the network upgrade shall be resolved by remeasuring the control network, modeling the errors and defining conformal transformation parameters relative to NAD83 CSRSv6, CGVD28:78adj. If the errors are not systematic or not within an acceptable tolerance then Metrolinx shall be advised and shall provide guidance.

Note that an advanced knowledge of geodesy and geodetic transformation tools is required to derive and apply datum transformation parameters. This includes an understanding of geocentric and map projected coordinates, existing datums, geoid models, ellipsoid and orthometric elevations and conformal transformation techniques.

An example of the process of deriving 2D/1D and 3D GCS transformation parameters is described in Appendix A.

A Appendix A

The following process example describes the derivation of the 2D/1D and 3D conformal datum transformation parameters.

A.1 Step 1 Derive coordinates in Datum A (Measured fixed to Active GNSS Control)

a) Perform survey to derive NAD83 CSRSv6(2010) UTM17, Ellipsoid Elevations (GRS80)

b) Extract Ellipsoid / Orthometric separations from HTv2.0 Geoid Model

c) Compute Orthometric Elevations

Note*: This example uses the UTM17 map projection coordinates. The methodology is the same when using MTM Z 10 coordinates but the derived parameters must match the common projection.*

Table A -1: Datum A. Measured NAD83 CSRS (2010) UTM 17 Coordinates - CGVD28:78adj Elevations

Monument	Northing	Easting	Elevation (Ellipsoid)	Geoid Separation (HTv2.0)	Elevation (Ortho)
	N1(measured)	E1(measured)	A (measured)	B (extract)	C = (A - B)
75023082	4823989.980	614010.001	47.750	-36.412	84.162
75033043	4825510.082	612407.572	69.463	-36.392	105.855
MISS	4825704.668	604767.699	128.102	-36.325	164.427
75930050	4827634.709	610144.712	105.209	-36.366	141.575
ETOB	4839639.539	612229.636	137.499	-36.362	173.861
75900107	4831989.746	605725.673	162.796	-36.323	199.119
75900102	4833102.093	604604.854	165.972	-36.313	202.285
75900143	4833377.552	604324.966	167.131	-36.310	203.441
42010217	4835091.563	602633.536	173.109	-36.294	209.403
BRAM	4836145.665	599245.361	191.264	-36.263	227.527
42050299	4836333.150	601235.196	170.759	-36.281	207.040

A.2 Step 2 Derive coordinates in Datum B (Published in Legacy Datum)

a) Obtain / derive published coordinates and elevations from legacy system

b) Compute pseudo ellipsoid elevations by applying Geiod separation to the published Ortho elevations. Note that the NAD83 Original does not typically have ellipsoid elevations.

Table A -2: Datum B. Published NAD83 Original UTM 17 Coordinates with CGVD28:Pre78adj Elevations

Monument	Northing	Easting	Elevation (Pseudo Ellipsoid)	Geoid Separation (HTv2.0)	Elevation (Ortho)
	N2(published)	E2(published)	D = (E + F)	E (extract)	F (published)
75023082	4823990.237	614009.950	47.861	-36.412	84.273
75033043	4825510.346	612407.522	69.574	-36.392	105.966
MISS	4825704.955	604767.634	128.214	-36.325	164.539
75930050	4827634.984	610144.663	105.322	-36.366	141.688
ETOB	4839639.833	612229.627	137.616	-36.362	173.978
75900107	4831990.043	605725.628	162.909	-36.323	199.232
75900102	4833102.396	604604.810	166.086	-36.313	202.399
75900143	4833377.856	604324.922	167.246	-36.310	203.556
42010217	4835091.876	602633.493	173.224	-36.294	209.518
BRAM	4836145.990	599245.314	191.380	-36.263	227.643
42050299	4836333.470	601235.154	170.875	-36.281	207.156

A.3 Step 3 Compare Datum A vs Datum B

a) Sort coordinates along project corridor to assist in observing trends in delta's

b) If trend is uniform within the acceptable tolerance for "best fitting" legacy datums using a conformal transformation then continue to Step 4. If not then remove outliers or select alternate common points.

Table A -3: Difference of above coordinates (Datum A - Datum B)

Monument	Delta Northing	Delta Easting	Delta Ellipsoid elevation	Delta Geoid Separation	Delta Elevation (Ortho)
	(N1-N2)	(E1-E2)	(A - D)	(B-E)	(C-F)
75023082	-0.257	0.051	-0.111	0.000	-0.111
75033043	-0.264	0.050	-0.111	0.000	-0.111
MISS	-0.287	0.066	-0.112	0.000	-0.112
75930050	-0.275	0.048	-0.113	0.000	-0.113
ETOB	-0.294	0.009	-0.117	0.000	-0.117
75900107	-0.298	0.045	-0.113	0.000	-0.113
75900102	-0.303	0.044	-0.114	0.000	-0.114
75900143	-0.305	0.044	-0.115	0.000	-0.115
42010217	-0.313	0.043	-0.115	0.000	-0.115
BRAM	-0.325	0.047	-0.116	0.000	-0.116
42050299	-0.319	0.042	-0.116	0.000	-0.116
Average	-0.295	0.044	-0.114	0.000	-0.114

A.4 Step 4 - Convert Datum A and B from UTM to Geocentric Coordinates using Ellipsoid Elevations

Table A -4: Datum A – Geocentric

Monument	X	Y	Z
75023082	836606.283	-4553101.099	4372840.169
75033043	834865.537	-4552352.417	4373976.255
MISS	827320.135	-4553549.928	4374247.246
75930050	832410.192	-4551312.813	4375567.293
ETOB	833173.033	-4542796.289	4384252.341
75900107	827590.777	-4549130.305	4378812.110
75900102	826365.951	-4548562.615	4379632.194
75900143	826060.379	-4548422.647	4379835.520
42010217	824208.206	-4547542.018	4381098.917
BRAM	820755.642	-4547404.166	4381911.092
42050299	822694.902	-4546927.993	4382010.991

Table A -5: Datum B - Geocentric

Monument	X	Y	Z
75023082	836606.22	-4553101.012	4372840.432
75033043	834865.473	-4552352.325	4373976.524
MISS	827320.054	-4553549.823	4374247.532
75930050	832410.130	-4551312.714	4375567.571
ETOB	833173.008	-4542796.173	4384252.634
75900107	827590.714	-4549130.190	4378812.404
75900102	826365.889	-4548562.497	4379632.492
75900143	826060.318	-4548422.528	4379835.820
42010217	824208.145	-4547541.893	4381099.223
BRAM	820755.576	-4547404.034	4381911.408
42050299	822694.841	-4546927.865	4382011.302

A.5 Step 5 - Compute Datum Shifts

Specialized geodetic survey and computational expertise together with geodetic processing software may be required to derive datum shift parameters.

A.5.1 2D-Helmert 4-parameter conformal transformation

Derive using Datum A and Datum B UTM 2D coordinates as illustrated in Step 1 and Step 2 above

Table A -6: From Datum A to Datum B are as follows:

Rotation Origin:		
	Northing UTM Z17	606882.3033 m
	Easting UTM Z17	4831331.6381 m
No.	Parameter	Value
1	dE	-0.0447 m

2	dN	+0.2926 m
3	Rotation	+0° 00' 00.60247"
4	Scale	+2.0871 ppm or 1.0000020871

A.5.2 Vertical Shift

Derive from the average delta elevation as illustrated in Step 3 above.

dh	"+0.114"

A.5.3 3D Molodensky-Badekas 10 parameter conformal transformation

Derive using Datum A and Datum B Geocentric coordinates as illustrated in Step 4 above

Table A -7: From Datum A to Datum B are as follows:

Height mode: Ellipsoidal		
Transformation model: Molodensky-Badekas 10 Parameter (Geocentric)		
Geoid model: HT2_0 GRS80		
Rotation origin:		
	X: 828797.8449 m	
	Y: -4549360.4120 m	
	Z: 4378298.9606 m	
No.	Parameter	Value
1	Shift dX	-0.0609 m
2	Shift dY	0.1108 m
3	Shift dZ	0.2909 m
4	Rotation about X	0.09228 arcseconds
5	Rotation about Y	-0.42554 arcseconds
6	Rotation about Z	0.41625 arcseconds
7	Scale	2.1075 ppm or 1.0000021075

A.6 Step 6 Apply Transformation Parameters

A.6.1 CAD Drawings

The 2D/ 1D datums transformations allow the conversion of CAD coordinates from Datum A to Datum B using standard CAD commands (Rotate, Scale about an insert point and Move) for X, Y, Z axis.

The reciprocal 2D/ 1D datums transformations from Datum B to Datum A may be performed by reversing the order of the standard CAD commands and changing the signs on the parameters (-Move for X, Y, Z axis, (1- Scale), - Rotate about the insert point)

A.6.2 RTK GNSS

The 3D -Molodensky-Badekas 10 Parameter datum geocentric transformation together with Active control broadcastin corrections in NAD83 CSRSv6 and the HTv2 Geiod model allows the RTK GPS unit to measure directly in the project GCS.

-End of Document-