LECTURER NOTES ON LAND SURVEY-II

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Tacheometric Surveying

STUDY NOTES

Unit - II

Tacheometric is a branch of surveying in which horizontal and vertical distances are determined by taking angular observation with an instrument known as a tachometer. Tacheometric surveying is adopted in rough in rough and difficult terrain where direct leveling and chaining are either not possible or very tedious. The accuracy attained is such that under favorable conditions the error will not exceed 1/100. and if the purpose of a survey does not require accuracy, the method is unexcelled. Tacheometric survey also can be used for Railways, Roadways, and reservoirs etc. Though not very accurate. Tacheometric surveying is very rapid, and a reasonable contour map can be prepared for investigation works within a short time on the basis of such survey.

Uses of Tachometry

Tachometry is used for

preparation of topographic map where both horizontal and vertical distances are required to be measured;

survey work in difficult terrain where direct methods of measurements are inconvenient;

reconnaissance survey for highways and railways etc;

Establishment of secondary control points.

Instruments used in tachometric surveying

An ordinary transits theodolite fitted with a stadia diaphragm is generally used for tacheometric surveying. The stadia diaphragm essentially consists of one stadia hair above and the other an equal distance below the horizontal cross hair, the stadia hair being mounted in the same ring and in the same vertical plane as the horizontal and vertical cross-hair.

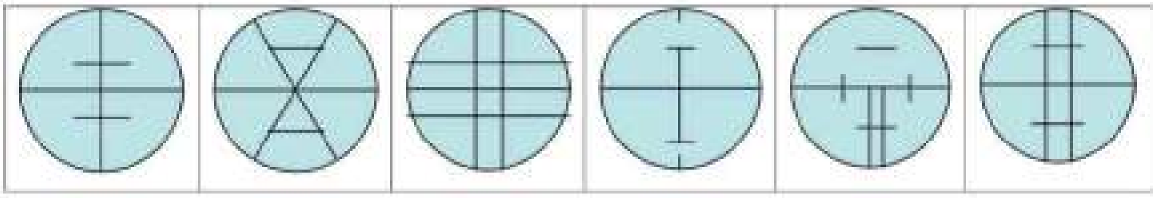
The telescope used in stadia surveying are three kinds,

The Simple external focusing telescope.

The external focusing anal lactic telescope (porro's telescope).

The internal focusing telescope.

The first type is known as stadia theodolite, while the second type is known as tacheometer. The tacheometer has the advantage over the first and third type due to fact that the additive constant of the instrument is zero.



The instruments employed in tachometry are the engineer's transit and the leveling rod or stadia rod, the theodolite and the subtense bar, the self-reducing theodolite and the leveling rod, the distance wedge and the horizontal distance rod, and the reduction tacheometer and the horizontal distance rod.

Features of tacheometer or Characteristic of tacheometer

The multiple constant (f/i) should have a normal value of 100 and the error contained in this value should not exceed 1 in 1000.

The axial horizontal lines should be exactly midway between the other two lines.

The telescope should be fitted with an anallatic lens to make the additive constant (f + d) exactly to zero.

The telescope should be truly analectic.

The telescope should be powerful having a magnification of 20 to 30 diameters. The Aperture of the object should be 35 to 45 mm in diameter.

Levelling and Stadia Staff Rod

For short distances, ordinary leveling staves are used. The leveling staff normally 4m long, and it can be folded with here parts. The graduations are so marked that a minimum reading of 0.005 or 0.001 m can be taken.

Different systems of Tacheometric Measurement

The various systems of tacheometric survey may be classified as follows, The Stadia Method

i. Fixed Hair Method and
ii. Movable Hair Method

The Tangential System

Measurements by means of special instruments.

The principle is common to all system is to calculate the horizontal distance between two points A and B their deference in elevation, by observing 1) the angle at the instrument at A subtended by known short distance along a staff kept at B and 2) the vertical angle to B from A

Stadia systems

In this systems staff intercepts, at a pair of stadia hairs present at diaphragm, are considered. The stadia system consists of two methods:

a) Fixed-hair method and
b) Movable-hair method

Fixed-hair method

In this method, stadia hairs are kept at fixed interval and the staff interval or intercept (corresponding to the stadia hairs) on the leveling staff varies. Staff intercept depends upon the distance between the instrument station and the staff.

Movable- hair method

In this method, the staff interval is kept constant by changing the distance between the stadia hairs. Targets on the staff are fixed at a known interval and the stadia hairs are adjusted to bisect the upper target at the upper hair and the lower target at the lower hair. Instruments used in this method are required to have provision for the measurement of the variable interval between the stadia hairs. As it is inconvenient to measure the stadia interval accurately, the movable hair method is rarely used.

Non-stadia systems

This method of surveying is primarily based on principles of trigonometry and thus telescopes without stadia diaphragm are used. This system comprises of two methods:

(i) Tangential method and
(ii) Subtense bar method.

Tangential method

In this method, readings at two different points on a staff are taken against the horizontal cross hair and corresponding vertical angles are noted.

Subtense bar method.

In this method, a bar of fixed length, called a subtense bar is placed in horizontal position. The angle subtended by two target points, corresponding to a fixed distance on the subtense bar, at the instrument station is measured. The horizontal distance between the subtense bar and the instrument is computed from the known distance between the targets and the measured horizontal angle.

Principles of Stadia Method

(Figure 23.1) A tacheometer is temporarily adjusted on the station P with horizontal line of sight. Let a and b be the lower and the upper stadia hairs of the instrument and their actual vertical separation be designated as i. Let f be the focal length of the objective lens of the tacheometer and c be horizontal distance between the optical centre of the objective lens and the vertical axis of the instrument. Let the objective lens is focused to a staff held vertically at Q, say at horizontal distance D from the instrument station.

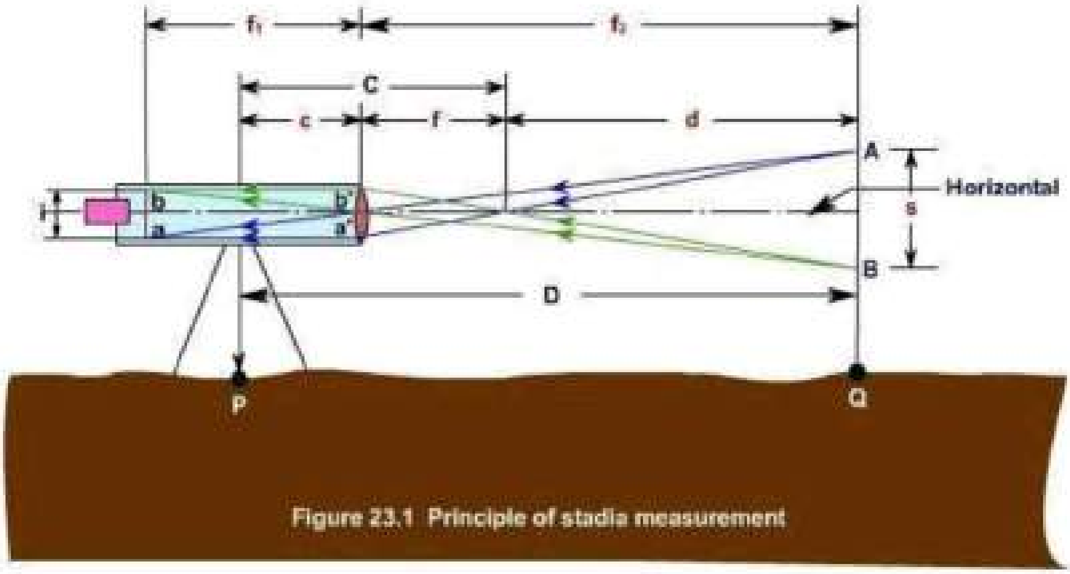


Figure 23.1 Principle of stadia measurement

By the laws of optics, the images of readings at A and B of the staff will appear along the stadia hairs at a and b respectively. Let the staff interval i.e., the difference between the readings at A and B be designated by s. Similar triangle between the object and image will form with vertex at the focus of the objective lens (F). Let the horizontal distance of the staff from F be d. Then, from the similar Ds ABF and a' b' F,

$$\frac{AB}{d} = \frac{a'b'}{f}$$

$$Or, d = \frac{AB}{a'b'} x f = \frac{s}{i} x f$$

$$\therefore d = \frac{f}{i} x s$$

as a' b' = ab = i. The ratio (f / i) is a constant orf a particular instrument and is known as stadia interval factor, also instrument constant. It is denoted by K and thus

d = K.s --------------------- Equation (23.1)

The horizontal distance (D) between the center of the instrument and the station point (Q) at which the staff is held is d + f + c. If C is substituted for (f + c), then the horizontal distance D from the center of the instrument to the staff is given by the equation

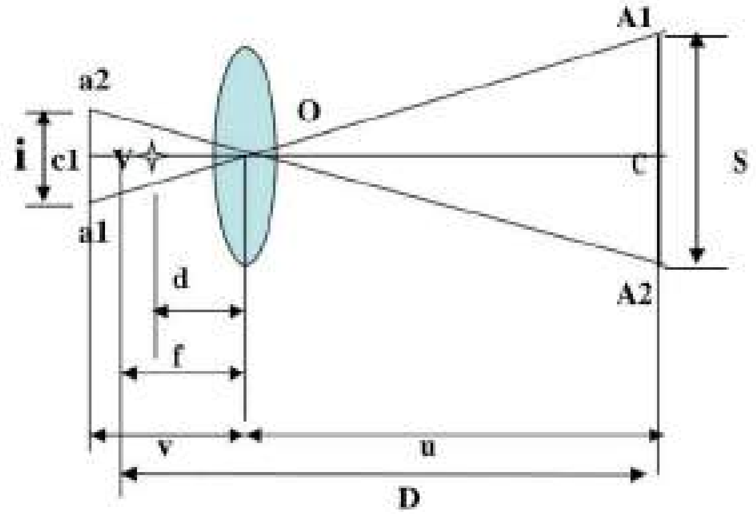
D = Ks + C --------------------- Equation (23.2)

The distance C is called the stadia constant. Equation (23.2) is known as the stadia equation for a line of sight perpendicular to the staff intercept.

Theory of Stadia Tacheometry

The following is the notation used in stadia tacheometry

O	=	Optical centre of object glass.
A_1, A_2, C	=	Readings on staff cut by three hairs
a_1, a_2, C	=	Bottom Top, and Central Hair of diaphragm
$a_1 a_2$, = i	=	length of image
A_1, A_2, = S	=	Staff Intercept
V	=	Vertical axis of instrument



f =Focal length of a object glass

d =distance between optical centre and vertical axis of instrument

u=distance between optical centre and staff

v=distance between optical centre and image.

For similar triangles a_1, O a_2 and A_1, OA_2,

$$\frac{i}{s} = \frac{v}{u} \quad \text{or} \quad v = \frac{iu}{s} \qquad (1)$$

From the properties of length,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \qquad (2)$$

Putting the value of v in Eq. (2)

$$\frac{1}{iu/s} + \frac{1}{u} = \frac{1}{f}$$

Or

$$\frac{s}{iu} + \frac{1}{u} = \frac{1}{f}$$

Or

$$\frac{1}{u}\left(\frac{s}{i} + 1\right) = \frac{1}{f}$$

Or

$$u = \{\frac{s}{\;} + 1\}$$
$$f\ i$$

But, $D = u + d$ ---------------------------- (3)

$$D = \{\frac{s}{\;} + 1\}\ f +$$
$$d\ i$$

$$\frac{s}{\;} \times f + f + d = \{\frac{f}{\;}\} \times s + (f +$$
$$d)\ i\ i$$

The quanta ties (f/i) and (f + d) are known as techeometric constants. (f/i) is called the multiplying constant, as already stated, and (f + d) the additive constant. by adopting an anal latic lens in the telescope of a tacheometric, the multiplying constant is made 100, and the additive constant zero. However, in some tacheometers the additive constants are not exactly zero, but vary from 30 cm to 60 cm

Inclined Stadia Measurements

It is usual that the line of sight of the tacheometer is inclined to the horizontal. Thus, it is frequently required to reduce the inclined observations into horizontal distance and difference in elevation.

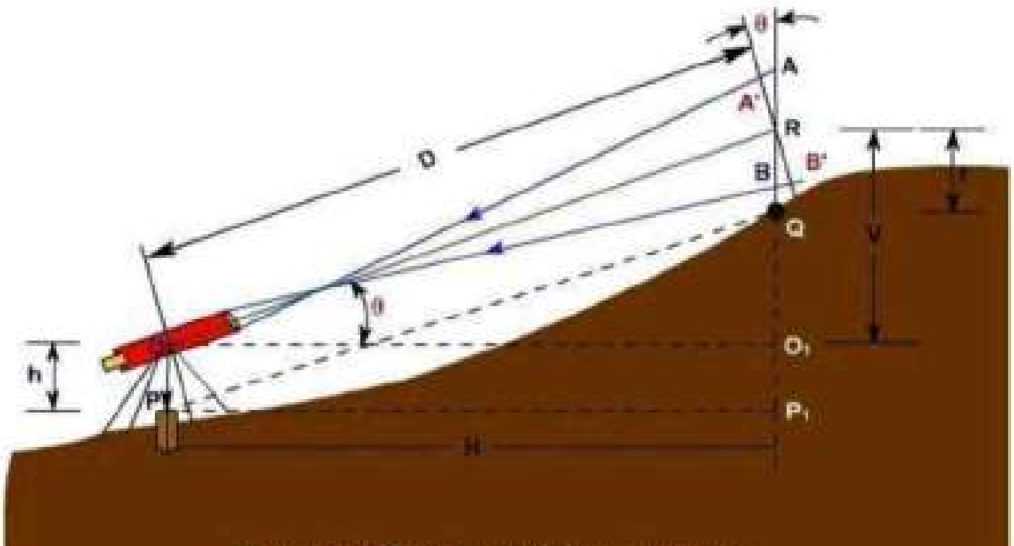


Figure 23.2 Principle of stadia measurement

Let us consider a tacheometer (having constants K and C) is temporarily adjusted on a station, say P (Figure 23.2). The instrument is sighted to a staff held vertically, say at Q. Thus, it is required to find the horizontal distance PP1 (= H) and the difference in elevation P1Q. Let A, R and B be the staff points whose images are formed respectively at the upper, middle and lower cross hairs of the tacheometer. The line of sight, corresponding to the middle cross hair, is inclined at an angle of elevation q and thus, the staff with a line perpendicular to the line of sight. Therefore A'B' = AB cos q = s cos q where s is the staff intercept AB. The distance D (= OR) is C + K. scos q (from Equation 23.2). But the distance OO1 is the horizontal distance H, which equals OR cos q. Therefore the horizontal distance H is given by the equation.

H = (Ks cos q + C) cos q

Or H = Ks cos2 q + C cos q ---------------- Equation (23.3)

in which K is the stadia interval factor (f / i), s is the stadia interval, C is the stadia constant (f + c), and q is the vertical angle of the line of sight read on the vertical circle of the transit.

The distance RO1, which equals OR sin q, is the vertical distance between the telescope axis and the middle cross-hair reading. Thus V is given by the equation

V = (K s cos q + c) sin q

V = Ks sin q cos q + C sin q ---------------- Equation (23.4)

[redacted] Equation (23.5)

Thus, the difference in elevation between P and Q is (h + V - r), where h is the height of the instrument at P and r is the staff reading corresponding to the middle hair.

Uses of Stadia

The stadia method of surveying is particularly useful for following cases:

1. In differential leveling, the back sight and foresight distances are balanced conveniently if the level is equipped with stadia hairs.
2. In profile leveling and cross sectioning, stadia is a convenient means of finding distances from level to points on which rod readings are taken.
3. In rough trigonometric, or indirect, leveling with the transit, the stadia method is more rapid than any other method.
4. For traverse surveying of low relative accuracy, where only horizontal angles and distances are required, the stadia method is a useful rapid method.
5. On surveys of low relative accuracy - particularly topographic surveys-where both the relative location of points in a horizontal plane and the elevation of these points are desired, stadia is useful. The horizontal angles, vertical angles, and the stadia interval are observed, as each point is sighted; these three observations define the location of the point sighted.

Errors in Stadia Measurement

Most of the errors associated with stadia measurement are those occur during observations for horizontal angles (Lesson 22) and differences in elevation (Lesson 16). Specific sources of errors in horizontal and vertical distances computed from observed stadia intervals are as follows:

1. **Error in Stadia Interval factor**

This produces a systematic error in distances proportional to the amount of error in the stadia interval factor.

2. **Error in staff graduations**

If the spaces on the rod are uniformly too long or too short, a systematic error proportional to the stadia interval is produced in each distance.

3. **Incorrect stadia Interval**

The stadia interval varies randomly owing to the inability of the instrument operator to observe the stadia interval exactly. In a series of connected observations (as a traverse) the error may be expected to vary as the square root of the number of sights. This is the principal error affecting the precisio

Curves: Definition and Types | Curves| Surveying

Definition of Curves:

Curves are regular bends provided in the lines of communication like roads, railways etc. and also in canals to bring about the gradual change of direction. They are also used in the vertical plane at all changes of grade to avoid the abrupt change of grade at the apex.

Curves provided in the horizontal plane to have the gradual change in direction are known as Horizontal curves, whereas those provided in the vertical plane to obtain the gradual change in grade are known as vertical curves. Curves are laid out on the ground along the centre line of the work. They may be circular or parabolic.

Classification of Curves:

(i) Simple,

(ii) Compound

(iii) Reverse and

(iv) Deviation

(i) Simple Curve:

A simple curve consists of a single arc of a circle connecting two straights. It has radius of the same magnitude throughout. In fig. 11.1 T1 D T2 is the simple curve

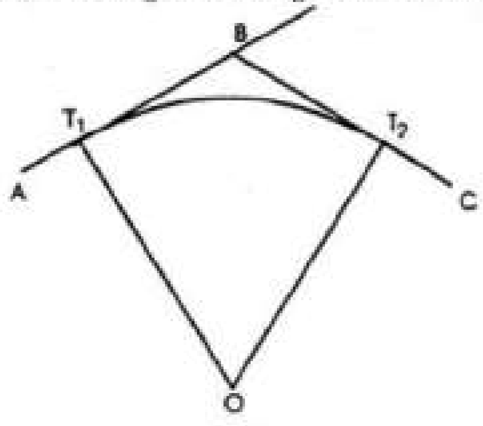


Fig 11.1

with T1O as its radius.

(ii) Compound Curve:

A compound curve consists of two or more simple curves having different radii bending in the same direction and lying on the same side of the common tangent. Their centres lie on the same side of the curve. In fig. 11.2, T1 P T2 is the compound curve with T1O1 and PO2 as its radii.

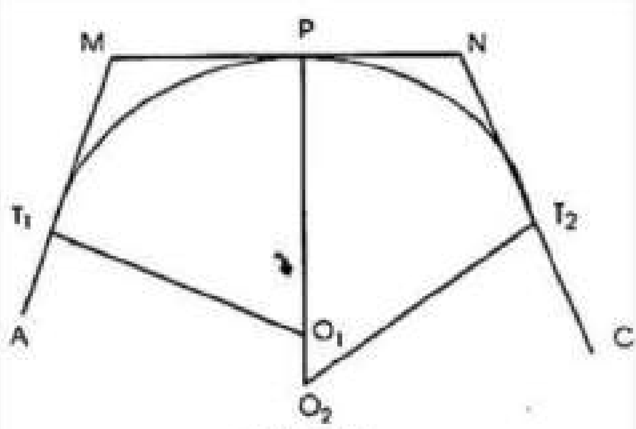


Fig 11.2

(iii) Reverse (or Serpentine) Curve:

A reverse or serpentine curve is made up of two arcs having equal or different radii bending in opposite directions with a common tangent at their junction. Their centres lie of opposite sides of the curve. In fig. 11.3 T1 P T2 is the reverse curve with T1O1 and PO2 as its radii.

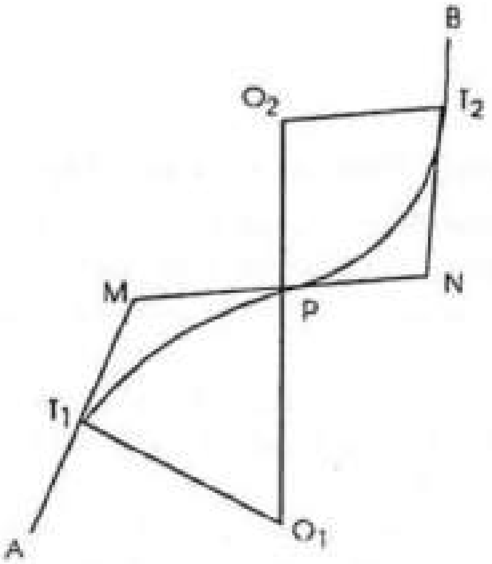


Fig 11 3

Reverse curves are used when the straights arc parallel or intersect at a very small angle. They are commonly used in railway sidings and sometimes on railway tracks and roads meant for low speeds. They should be avoided as far as possible on main railway lines and highways where speeds are necessarily high.

(iv) Deviation Curve:

A deviation curve is simply a combination of two reverse curves. It is used when it becomes necessary to deviate from a given straight path in order to avoid intervening obstructions such as a bend of river, a building, etc. In fig. 11.4. T_1 EDFT$_2$ is the deviation curve with T_1O, EO_1 and FO_2 as its radii.

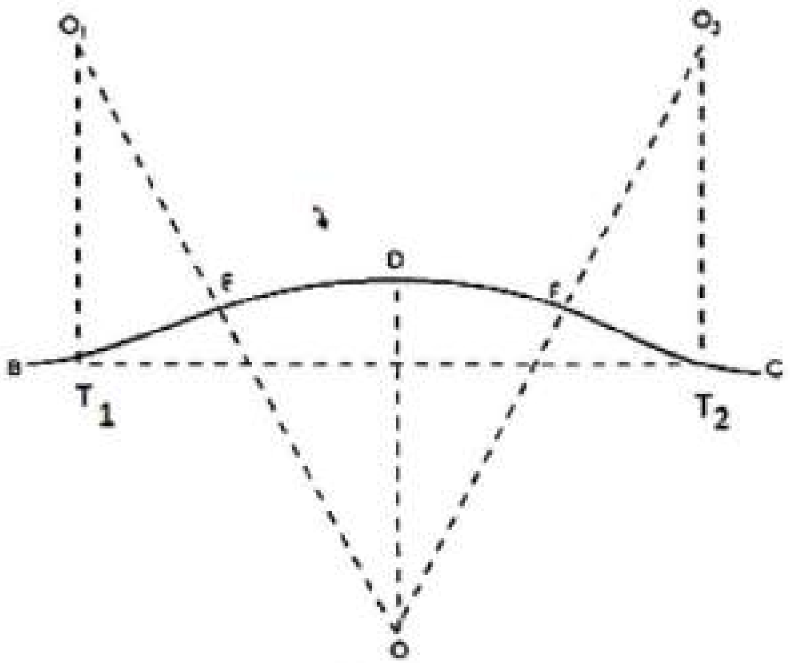


Fig 11.4

Names of Various Parts of a Curve: (Fig. 11.5):

(i) The two straight lines AB and BC, which are connected by the curve are called the tangents or straights to the curve.

(ii) The points of intersection of the two straights (B) is called the intersection point or the vertex.

(iii) When the curve deflects to the right side of the progress of survey as in fig. 11.5, it is termed as right-handed curve and when to the left, it is termed as left-handed curve.

(iv) The lines AB and BC are tangents to the curves. AB is called the first tangent or the rear tangent BC is called the second tangent or the forward tangent.

(v) The points (T_1 and T_2) at which the curve touches the tangents are called the tangent points. The beginning of the curve (T_1) is called the tangent curve point and the end of the curve (T2) is called the curve tangent point.

(vi) The angle between the tangent lines AB and BC (ABC) is called the angle of intersection (I)

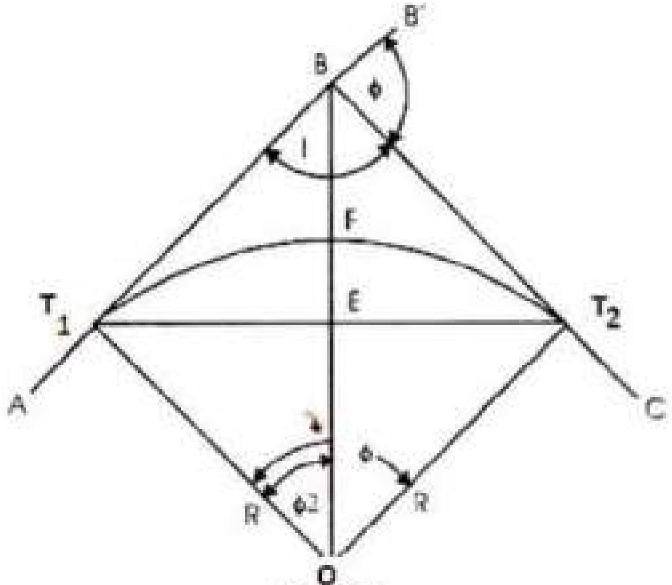


Fig 11.5

(vii) The angle by which the forward tangent deflects from the rear tangent is called the deflection angle (ϕ) of the curve.

(viii) The distance the two tangent point of intersection to the tangent point is called the tangent length (BT_1 and BT_2).

(ix) The line joining the two tangent points (T_1 and T_2) is known as the long-chord

(x) The arc T_1FT_2 is called the length of the curve.

(xi) The mid-point (F) of the arc (T_1FT_2) in called summit or apex of the curve.

(xii) The distance from the point of intersection to the apex of the curve BF is called the apex distance.

(xiii) The distance between the apex of the curve and the midpoint of the long chord (EF) is called the versed sine of the curve.

(xiv) The angle subtended at the centre of the curve by the arc T_1FT_2 is known as the Central angle and is equal to the deflection angle (ϕ).

Elements of a Curve (Fig. 11.5):

(*i*) Angle of intersection + Deflection angle = 180°

or $I + \phi = 180°$ ... ...(Eqn. 11.1)

(*ii*) $\angle T_1OT_2 = 180° - I = \phi$ ... ...(Eqn. 11.2.)

(*i.e.* the central angle = the deflection angle).

(*iii*) Tangent length $= BT_1 = BT_2 = OT_1 \tan \frac{\phi}{2}$

$= R \tan \frac{\phi}{2}$ ... ...(Eqn. 11.3)

(*iv*) Length of Long Chord $= 2T_1E = 2 \times OT_1 \sin\left(\frac{\phi}{2}\right)$

$= 2R \sin \frac{\phi}{2}$ ... ... (Eqn. 11.4)

(*v*) Length of the curve = Length of the arc T_1FT_2

$= R\phi$ (in radians)

$= \frac{\pi R\phi}{180°}$ ... ... (Eqn. 11.5)

(*vi*) Apex distance $= BF = BO - OF$

$= R \sec \frac{\phi}{2} - R$

$= R\left(\sec\left(\frac{\phi}{2}\right) - 1\right)$ ... ...(Eqn. 11.6)

(*vii*) Versed sine of the curve $= EF = OF - OE$

$= R - R \cos \frac{\phi}{2}$

$= R\left(1 - \cos\frac{\phi}{2}\right) = R \text{ versine } \frac{\phi}{2}$ ... ...(Eqn. 11.7)

Designation of Curves:

A curve may be designated either by the radius or by the angle subtended at the centre by a chord of particular length In India, a curve is designated by the angle (in degrees) subtended at the centre by a chord of 30 metres (100 ft.) length. This angle is called the degree of the curve (D).

The relation between the radius and the degree of the curve may be determined as follows:

Refer to fig 11.6:

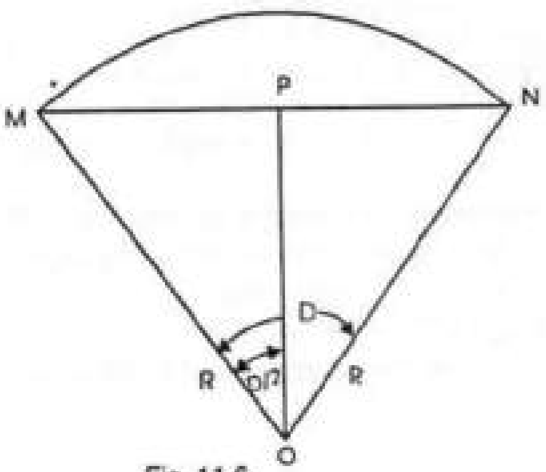


Fig. 11.6

Let R= The radius of the curves in meters

D= The degree of the curve

MN= The chord, 30m long

P= The mid-point of the chord

In Δ OMP, OM = R

$$MP = \frac{1}{2} MN = 15 \text{ m}$$

$$\angle MOP = \frac{D}{2}$$

Then, $\sin \frac{D}{2} = \frac{MP}{OM}, \frac{15}{R}$

or $R = \frac{15}{\sin \frac{D}{2}}$ (Exact) ... ...(Eqn. 11.8)

But when D is small, $\sin \frac{D}{2}$ may be assumed approximately equal to

$= \frac{D}{2}$ in radians.

$$R = \frac{15}{\frac{D}{2} \times \frac{\pi}{180^\circ}} = \frac{15 \times 360}{\pi D}$$

$$= \frac{171.87}{D}$$

or say, $R = \frac{1719}{D}$ (approximate) ... ... (Eqn. 11.9)

The approximate relation holds good up to 5° curves. For higher degree curves, the exact relation should be used.

Methods of Curve Ranging:

A curve may be set out:

1. By linear methods, where chain and tape are used.

2. By angular or instrumental methods, where a theodolite with or without a chain is used.

Before starting setting out a curve by any method, the exact positions of the tangent points between which the curve lies, must be determined.

For this, proceed as follows: (Fig. 11.5)

(i) Having fixed the directions of the straights, produce them to meet at point (B).

(ii) Set up a theodolite at the intersection point (B) and measure the angle of intersection (I). Then find the deflection angle (ϕ) by subtracting (I) from 180° . i.e., $\phi = 180^\circ - I$

(iii) Calculate the tangent length from the Eqn. 11.3:

$$\left(\text{tan lenght} = R\tan\frac{\phi}{2}\right)$$

(iv) Measure the tangent length (BT_1) backward along the rear tangent BA from the intersection point B, thus locating the position of T_1.

(v) Similarly, locate the position of T_2 by measuring the same distance forward along the forward tangent BC from B,

Having located the positions of the tangent points T_1 and T_2; their changes may be determined. The change of T_1 is obtained by subtracting the tangent length from the known change of the intersection point B. And the change of T_2 is found by adding the length of the curve to the change to T_1.

Then the pegs are fixed at equal intervals on the curve. The interval between the pegs is usually 30 m or one chain length. This distance should actually be measured along the arc, but in practice it is measured along the chord, as the difference between the chord and the corresponding arc is small and hence negligible. In order that this difference is always small and negligible, the length of the chord should not be more than 1/20th of the radius of the curve. The curve is then obtained by joining all these pegs.

The distances along the centre line of the curve are continuously measured from the point of beginning of the line up to the end, i.e., the pegs along the centre line of the work should be at equal interval from the beginning of the line to the end. There should be no break in the regularity of their spacing in passing from a tangent to a curve or from a curve to a tangent.

For this reason, the first peg on the curve is fixed at such a distance from the first tangent point (T_1) that its change becomes the whole number of chains i.e. the whole number of peg interval. The length of the first chord is thus less than the peg interval and is called as a sub- chord. Similarly, there will be a sub chord at the end of the curve. Thus, a curve usually consists of two-chords and a number of full chords. This is made clear from the following example.

Linear Methods of Setting out Curves

The following are the methods of setting out simple circular curves by linear methods and by the use of chain and tape: 1. By ordinates from the Long chord 2. By Successive Bisection of Arcs. 3. By Offsets from the Tangents. 4. By Offsets from Chords Produced.

Method # 1. By Ordinates from the Long Chord (Fig. 11.8):

Let T1T2=L= the length of the Long chord

ED= O0= the offset at mid-point (e) of the long chord (the versed sine)

PQ=Ox= the offset at distance x from E

Draw QQ1 parallel to T1 T2 meeting DE at Q1

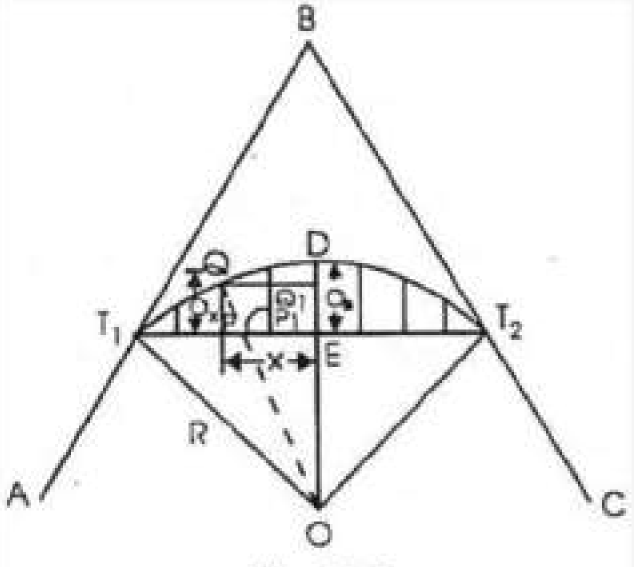


Fig. 11.8

Join OQ cutting T_1T_2 in P_1.

From the ΔOQQ_1, $OQ^2 = QQ_1^2 + OQ_1^2$

But $OQ = R$; $QQ_1 = x$

and $OQ_1 = OE + EQ_1 = (R - Q_3) + O_x$

$R^2 = x^2 \{(R - O_0) + O_0\}^2$

or $(R - O_0) + O_x = \sqrt{R^2 - x^2}$

Hence $O_x = \sqrt{R^2 - x^2} - (R - O_\infty)$

(Exact) ... ...**(Eqn. 11.10)**

Where $O_0 = ED = OD - OE$

$= R - \sqrt{R^2 \left(\frac{L}{2}\right)^2}$ ... ...**(Eqn. 11.10, a)**

When the radius of the curve is large as compared with the length of the long chord, the offset may be equated by the approximate formula which is derived as follows:

Here O_x is assumed to be equal to the radial ordinate QP_1.

$QP \times 2R = T_1P \times PT_2$

or $QP_1 = \frac{T_1P \times PT_2}{2R}$

Now $T_1P = x$, and $PT_2 = L - x$

$Q_x = \frac{x(L - x)}{2R}$ **(approximate)** ... ...**(Eqn. 11.11)**

Note:

In the exact equation (11.1), the distance x of the point P is measured from the mid-point of the long chords; while in the approximate equation (11.11), it is measured from the first tangent point (T1).

Procedure of Setting Out the Curve:

(i) Divide the long chord into an even number of equal parts.

(ii) Calculate the offsets by the equation 11.10 at each of the points of division.

Note:

1. Since the curve is symmetrical on both sides of the middle- ordinate, the offsets for the right-hand half of the curve are the same as those for the left-hand half.

2. If the offsets are found by the approximate equation (11.11), the long chord should be divided into a convenient number of equal parts and the calculated offsets laid out at each of the points of division.

This method is used for setting out short curves e.g., curves for street bends.

Method # 2. By Successive Bisections of Arcs (Fig 11.10):

It is also known as Versine Method. Join T1 T2 and bisect it at E. Set out the offset ED the versed since equal to:

$R(1 - \cos\frac{\Phi}{2}$, thus fixing the point Don the curve

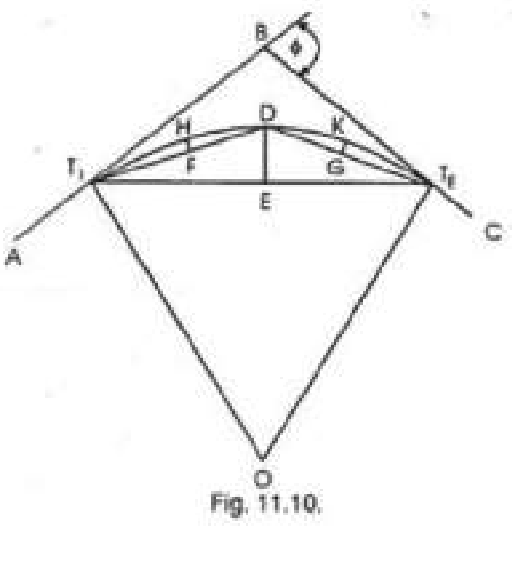


Fig. 11.10.

Join T1D and DT2 and bisect them at F and G respectively. Then set outsets FH and GK at F and G each equal to $R\left(1-\cos\frac{\phi}{4}\right)$ thus fixing two more points H and K on the curve. Then each of the offsets to be set out at mid points of the chords T1H, HD, DK and KT2 is equal to $R\left(1-\cos\frac{\phi}{8}\right)$. By repeating this process, set out as many point as are required.

This method is suitable where the ground outside the curve is not favorable to the tangents.

Method # 3. By Offsets from the Tangents:

The offsets may be either radial or perpendicular to the tangents.

(a) By Radial Offsets (Fig 11.11a):

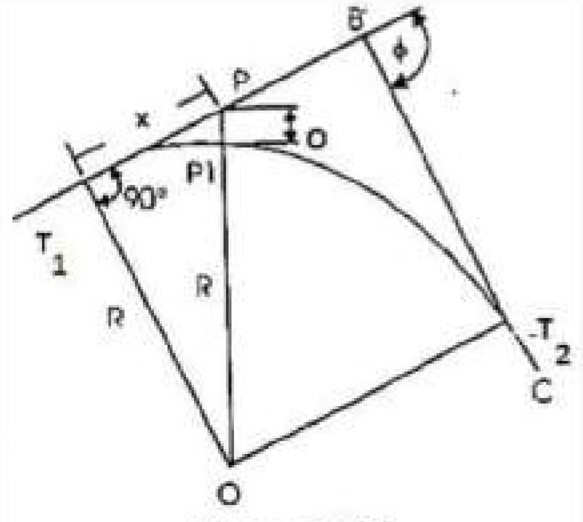


Fig 11.11 (a)

Let $O_x = PP_1$ = the radial offset at P at a distance of x from T_1 along the tangent AB

$$PP_1 = OP - OP_1, \text{ where } OP = \sqrt{R^2 + x^2} \text{ and } OP_1 = R$$

$$O_x = \sqrt{R^2 + x^2} - R \qquad \text{(exact) ... ...(Eqn. 11.12)}$$

When the radius is large, the offsets may be calculated by the approximate formula, which may be derived as under:

$$PT_1^2 = PP_1 \times (2R + PP_1)$$

i.e. $$x^2 = O_x (2R + O_x) = 2RO_x + O_x^2$$

Since O_x^2 is very small as compared with 2R, it may be neglected.

$$x^2 = 2R.O_x$$

or $$O_x = \frac{x^2}{2R} \quad \text{(approximate)} \qquad \text{... ...(Eqn. 11.13)}$$

(b) By Offsets perpendicular to the Tangents (Fig 11.11,b):

Let $O_x = PP_1$ = the perpendicular offset at P at a distance of x from T_1 along the tangent AB.

Draw P_1P_2 parallel to BT_1, meeting OT_1 at P_2

Then $P_1P_2 = PT_1 = x$; $T_1P_2 = PP_1 = O_x$.

Now $T_1P_2 = OT_1 - OP_2$

where $OT_1 = R$, and $OP_2 = \sqrt{R^2 - x^2}$

$$O_x = R - \sqrt{R^2 - x^2} \quad \text{(exact)} \qquad \text{...(Eqn. 11.14)}$$

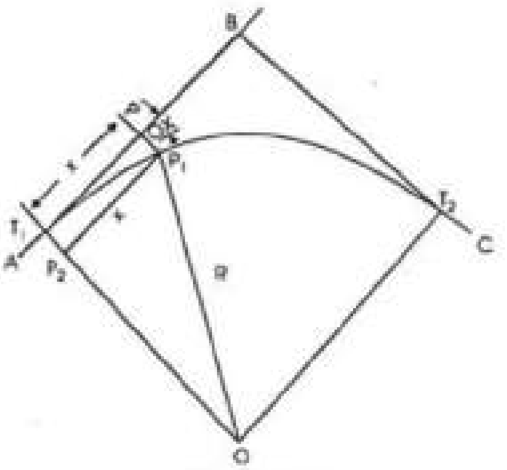


Fig. 11.11 (b)

The approximate formula may be obtained similarly as in (a) above ,

$$O_x = \frac{x^2}{2R} \quad \text{(approximate)} \qquad \text{...(Eqn. 11.15)}$$

Procedure of setting out the curve:

(i) Locate the tangent points T1 and T2.

(ii) Measure equal distances, say 15 or 30 m along the tangent from T1.

(iii) Set out the offsets calculated by any of the above methods at each distance, thus obtaining the required points on the curve.

(iv) Continue the process until the apex of the curve is reached.

(v) Set out the other half of the curve from the second tangent.

This method is suitable for setting out sharp curves where the ground outside the curve is favourable for chaining.

Method # 4. By Offsets from Chords Produced (Fig. 11.12):

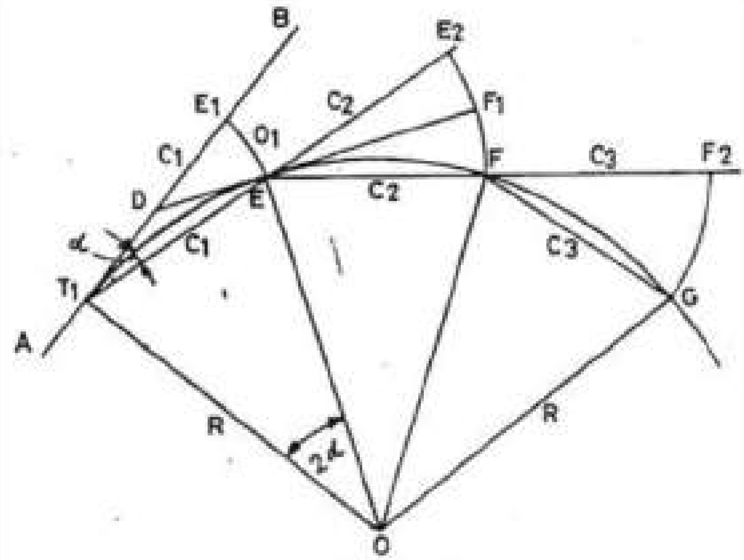


Fig. 11.12

Let AB = the first tangent; T1 = the first tangent point E, F, G etc. on the successive points on the curve T1E = T1E1 = C1 = the first chords.

EF, FG, etc. = the successive chords of length C2, C3 etc., each being equal to the full chord.

∠ BT1E = α in radians = the angle between the tangents BT1 and the first chord T1E.

E1E = O1 = the offset from the tangent BT1

E2F = O2 = the offset from the chord T1E produced.

Produce T1E to E2 such tharEE2 = C2. Draw the tangent DEF1 at E meeting the first tangent at D and E2F at F1.

∠BT1E= α in the radians= the angle between the tangents BT1and the first chord T1E.

E1E=O1= the offset from the tangent BT1

E2F=O2= the offset from the chord T1E produced.

Produce T1E to E2 such that EE2= C2. Draw the tangent DEF1at E meeting the first tangent at D and E2Fat F1.

The formula for the offsets may be derived a under:

∠ BT1E=x

∠T1OE=2x

The angle subtended by any chord at the center is twice the angle between the chord and the tangent

$$\frac{\text{arc } T_1E}{\text{Radius } OT_1} = 2\alpha$$

But arc T_1E is approximately equal to chord $T_1E = C_1$

$$\frac{C_1}{R} = 2\alpha$$

or $$\alpha = \frac{C_1}{2R}$$

Also $$\frac{\text{arc } E_1E}{T_1E} = \alpha$$

But arc E_1E is approximately equal to chord $E_1E = O_1$

$$O_1 = C_1 \times \alpha$$

Putting here the value of α as calculated above.

$$O_1 = C_1 \times \frac{C_1}{2R} = \frac{C_1^2}{2R} \quad \ldots \quad \ldots \quad \ldots\text{(Eqn. 11.16)}$$

$$O_2 = \text{offset } E_2F = E_2F_1 + F_1F$$

To find out F_2F_1, consider the two triangles T_1EE_1 and EF_1E_2

$\angle E_2EF_1 = \angle DET_1$ (vertically opposite angles) :

$\angle DET_1 = \angle DT_1E$, since $DT_1 = DE$, both being trangents to the circle.

$$\angle E_1EF_1 = \angle DET_1 = \angle DT_1E$$

Both the Δs being nearly isosceles, may be taken as approximately similar.

$$\frac{E_2F_1}{EE_2} \approx \frac{E_1E}{T_1E_1}$$

$\angle$ α

i.e.

$$\frac{E_2F_1}{C_2} = \frac{O_1}{C_1}$$

or

$$E_2F_1 = \frac{C_2 \times O_1}{C_2}$$

$$= \frac{C_2}{C_1} \times \frac{C_1^2}{2R} = \frac{C_1C_2}{2R}$$

F_1F being the offset from the tangent at E, is equal to

$$\frac{EF^2}{2R} = \frac{C_2^2}{2R}$$

the second offset, $O_2 = \frac{C_1C_2}{2R} + \frac{C_2^2}{2R}$,

$$= \frac{C_2(C_1 + C_2)}{2R} \qquad \text{... (Eqn. 11.17)}$$

Similarly the third offset, $O_3 = \frac{C_3(C_2 + C_3)}{2R}$

Since $C_2 = C_3 = C_1$ ....etc,

$$O_3 = \frac{C_2^2}{R} \qquad \text{... ... ...(Eqn. 11.18)}$$

Each of the remaining offsets O4,O5 etc expect the last one (On) is equal to O3. Since the length of the last chord is usually less than the length of the chord, the last offset,

$$O_n = \frac{C_n(C_{n-1} + C_n)}{2R} \qquad \text{... ... ...(Eqn. 11.19)}$$

Procedure of Setting out the Curve (Fig. 11.12):

(i) Locate the tangent points (T1 and T2) and find out their changes. From these changes, calculate lengths of first and last sub-chords and find out the offsets by using the equations 11.16 to 11.19.

(ii) Mark a point E1 along the first tangent T1B such that T1E1 equals the length of the first sub-chord.

(iii) With the zero end of the chain (or tape) at T1 and radius = T1E1, swing an arc E1E and cut off E1E = O1, thus fixing the first point E on the curve.

(iv) Pull the chain forward in the direction of T1E produced until the length EE2 becomes equal to the second chord C2.

(v) Hold the zero end of the chain at E. and radius = C2, swing an arc E2F and cut off E2F = O2, thus fixing the second point F on the curve.

(vi) Continue the process until the end of the curve is reached. The last point fixed in this way should coincide with the previously located point T2. If not, find the closing error. If it is large i.e., more than 2 m, the whole curve are moved sideways by an amount proportional to the square of their distances from the tangent point T1. The closing error is thus distributed among all the points.

This method is very commonly used for setting out road curves.

Angular Methods for Setting out Curves

The following two methods are the methods of setting out simple circular curves by angular or instrumental methods: 1. By Rankine's Tangential Angles. 2. By Two Theodolites.

Method # 1. Rankine's Method of Tangential or Deflection Angles: (Fig. 11.14):

In this method, the curve is set out by the tangential angles (also known as deflection angles) with a theodolite and a chain (or tape). The method is also called as chain and theodolite method.

The deflection angles are calculated as follows:

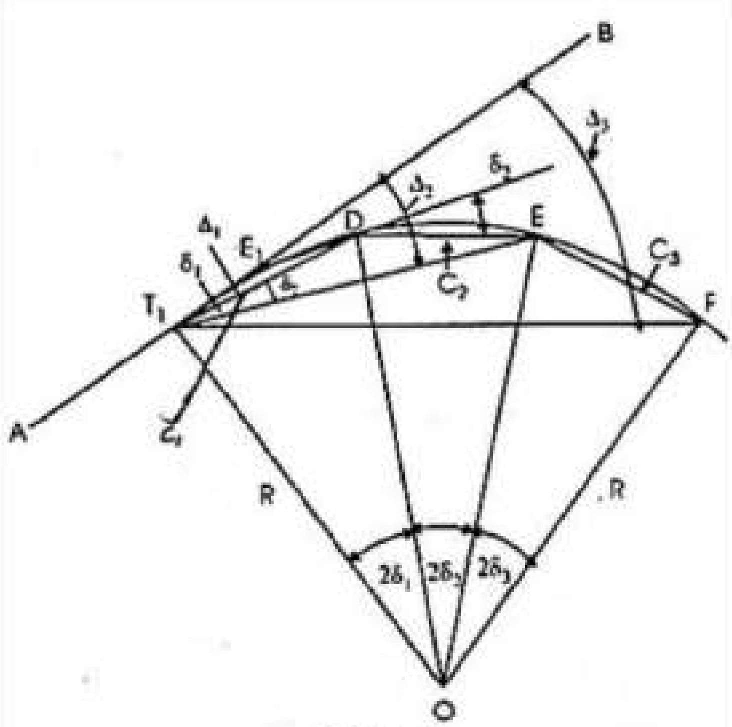


Fig. 11.14

Let T1 and T2 be the tangent points and AB the first tangent to the curve.

D, E, F, etc. =the successive points on the curve,

R = the radius of the curve.

C1, C2, C3 etc. = the lengths of the chords T1D, DE, EF etc., i.e., 1st, 2nd, 3rd chords etc.

ADVERTISEMENTS:

δ 1, δ 2, δ 3 etc. = the tangential angles which each of the chords T1 D1, DE, EF, etc., makes with the respective tangents T1, D, E. etc.

Δ1, Δ2, Δ 3 etc. = the total tangential or deflection angles which the chords T1D, DE, EF, etc. make with the first tangent AB.

Now the chord T_1D is approximately equal to arc $T_1D = C_1$

$$\angle BT_1D = \delta_1 = \frac{1}{2}\angle T_1OD = 2\delta_1 \quad \angle T_1OD = 2\delta_1$$

$$\frac{\text{arc}\,T_1D}{\text{Radius}\,OT_1} = \angle T_1OD \text{ in radians}$$

or $$\frac{C_1}{R} = 2\delta_1 \text{ radians}$$

or $$\delta_1 = \frac{C_1}{R} \text{ radians}$$

$$= \frac{C_1}{2R} \times \frac{180}{\pi} \text{ degrees}$$

$$= \frac{C_1}{2R} \times \frac{180}{\pi} \times 60 \text{ minutes} \qquad \ldots \qquad \ldots\text{(Eqn. 11.20)}$$

Similarly, $\delta_2 = 1718.9\,\frac{C_2}{R}$; $\delta_3 = 1718.9\,\frac{C_3}{R}$; and so on

$$\delta_n = 1718.9\,\frac{C_n}{R} \text{ minutes} \qquad \ldots \qquad \ldots\text{(Eqn. 11.21)}$$

Since each of the chord lengths C2, C3, C4............ Cn-1 is equal to the length of the full chord, $\delta 2 = \delta 3 = \delta 4$.............. δ n-1.

The total tangential angle (Δ_1) for the first chord (T_1D)

$$= \angle BT_1D = \delta_1$$

$$\therefore \quad \Delta_1 = \delta_1$$

The total tangential angle (Δ_2) for the second chord (DE) = $\angle BT_1E$

But $\angle BT_1E = \angle BT_1D + \angle DT_1E$

It is well known preposition of geometry that the angle between the tangent and a chord equals the angle which the chord subtends in the opposite segment.

Now ∠DT1E is the angle subtended by the chord DE in the opposite segment, therefore, it is equal to the tangential angle ($\delta 2$) between the tangent D and the chard DE

$$\therefore \qquad \Delta_2 = \delta_1 + \delta_2 = \Delta_1 + \delta_2$$

Similarly,

$$\Delta_3 = \delta_1 + \delta_2 + \delta_3 = \Delta_2 + \delta_3$$

$$\Delta_n + \delta_1 + \delta_2 + \delta_3 \ldots\ldots\ldots\ldots\ldots\ldots + \delta_n$$

$$= \Delta_{n-1} + \delta_n \qquad \ldots \qquad \ldots\text{(Eqn. 11.22)}$$

Check:

The total deflection angle BT1 T2 $= \Delta n = \frac{\phi}{2}$

where ϕ is the deflection angle of the curve.

If the degree of die curve (D) is known, the deflection angle for 30 m chord is equal 1/2D degrees, and that for the sub-chord of length C1,

$$= \frac{C_1}{30} \times \frac{D}{2} \text{ degrees}$$

$$\delta_1 = \frac{C_1 \times D}{60}\ ; \quad \delta_2 = \delta_3 \ldots\ldots\ldots \delta_{n-1} = \frac{D}{2}\ ;$$

$$\delta_n = \frac{C_n \times D}{60} \qquad \ldots \qquad \ldots \qquad \ldots\text{(Eqn. 11.23)}$$

Procedure of Setting out the Curve:

(i) Locate the tangent points (T1 and T2) and find out their changes. From these changes, calculate the lengths of first and last sub-chords and the total deflection angles for all points on the curve as described above.

(ii) Set up and level the theodolite at the first tangent point (T1).

(iii) Set the Vernier A of the horizontal circle to zero and direct the telescope to the ranging rod at the intersection point B and bisect it.

(iv) Loosen the Vernier plate and set the Vernier A to the first deflection angle $\Delta 1$, the telescope is thus directed along T1D. Then along this line, measure T1D equal in length to the first sub-chord, thus fixing the first point D on the curve.

(v) Loosen the upper clamp and set the Vernier A to the second deflection angle $\Delta 2$, the line of sight is now directed along T1E. Hold the zero end of the chain at D and swing the other end until the arrow held at that end is bisected by the line of sight, thus fixing the second point (E) on the curve.

(vi) Continue the process until the end of the curve is reached. The end point thus located must coincide with the previously located point (T2). If not, the distance between them is the closing error. If it is within the permissible limit, only the last few pegs may be adjusted; otherwise the curve should be set out again.

Note:

In the case of a left-handed curve, each of the values $\Delta 1$, Δ 2 Δ 3 etc, should be subtracted from 360° to obtain the required value to which the vernier is to be set i.e. the vernier should be set to (360° $-$ Δ1), (360° $-$ Δ2), (360° $-$ Δ 2) etc. to obtain the 1st, 2n, 3rd etc, points on the curve.

This method gives highly accurate results and is most commonly used for railway and other important curves.

Table of Deflection Angles

Point	Chainage in metres	Length of chord in metres	Deflection Angle (δ)	Total Angle (Δ)	Theodolite vernier Reading	Remarks
T_1	39 + 6.30	° ′ ″	° ′ ″	° ′ ″		
1	40 + 00	23.70	1 58 30	1 58 30	1 58 40	The curve is a right-handed one. The least count of the instrument in 20 ″
2	41 + 00	30	2 30 00	4 28 30	4 28 40	
3	42 + 00	30	2 30 00	6 58 30	6 58 40	
4	43 + 00	30	2 30 00	9 28 30	9 28 40	
5	44 + 00	30	2 30 00	11 58 30	11 58 40	
6	45 + 00	30	2 30 00	14 28 30	14 28 40	
7	46 + 00	30	2 30 00	16 58 40	16 58 40	
T_2	46 + 12.30	12.30	1 01 30	18 00 00	18 00 00	

Method # 2. Two-Theodolite Method (Fig. 11.16):

This method is very useful in the absence of chain or tape and also when ground is not favorable for accurate chaining. This is simple and accurate method but requires essentially two instruments and two surveyors to operate upon them, so it is not as commonly used as the method of deflection angles. In this method, the property of circle 'that the angle between the tangent and the chord equals the angle which that chord subtends in the opposite segment' is used.

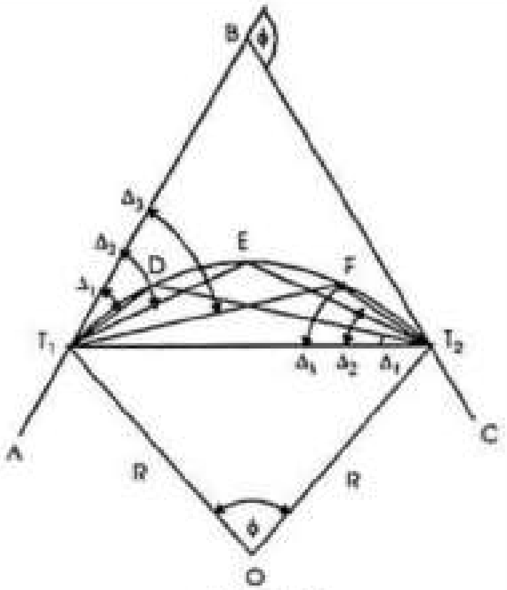


Fig. 11.16

Let D, E, F, etc. be the points on the curve. The angle ($\Delta 1$) between the tangent T1B and the chord T1D i.e. ∠BT1 D = ∠T1T2D. Similarly, ∠BT1E = $\Delta 2$ = ∠T1T2 E, and ∠BT1F = $\Delta 3$ = ∠T1T2F etc. The total deflection angles $\Delta 1$, $\Delta 2$, $\Delta 3$, etc. are calculated from the given data as in the first method (i.e. as in Rankine's method of deflection angles).

Procedure of setting out the curve:

(i) Set up two theodolites, one at T1 and the other at T2.

(ii) Set Vernier of the horizontal circle of each of the theodolites to zero.

(iii) Turn the instrument at T1 to sight the intersection point B and that at T2 to sight T1.

(iv) Set the Vernier of each of the instruments to read the first deflection angle $\Delta 1$. Now the line of sight of the instrument at T1 is along T1D and that of the instrument at T2 is along T2D. Their point of intersection is the required point on the curve Direct the assistant to move the ranging rod until it is sighted exactly by both the theodolites, thus fixing the point D on the curve.

(v) Then set the Vernier of each of the instrument to the second deflection angle $\Delta 2$, proceed as before to obtained the second point (E) on the curve.

(vi) Repeat the process until the whole curve is set out.

Note:

It may so happen that the point T1 may not be visible from the point T2. In such a case, direct the telescope of the instrument at T2 towards B with the Vernier A set to zero. Now loosen the Vernier plate and set the Vernier A to read an angle of $\left(360° - \frac{\phi}{2}\right)$. The telescope is thus directed along T2 T1. For the first point D on the curve, set the Vernier A to read $\left(360° - \frac{\phi}{2} + \Delta_1\right)$. Similarly, for the second point E, set the Vernier A to $\left(360° - \frac{\phi}{2} + \Delta_2\right)$, and so on.

Transition Curves:

A non-circular curve of varying radius introduced between a straight and a circular curve for the purpose of giving easy changes of direction of a route is called a transition or easement curve. It is also inserted between two branches of a compound or reverse curve.

Advantages of providing a transition curve at each end of a circular curve:

(i) The transition from the tangent to the circular curve and from the circular curve to the tangent is made gradual.

(ii) It provides satisfactory means of obtaining a gradual increase of super-elevation from zero on the tangent to the required full amount on the main circular curve.

(iii) Danger of derailment, side skidding or overturning of vehicles is eliminated.

(iv) Discomfort to passengers is eliminated.

Conditions to be fulfilled by the transition curve:

(i) It should meet the tangent line as well as the circular curve tangentially.

(ii) The rate of increase of curvature along the transition curve should be the same as that of increase of super-elevation.

(iii) The length of the transition curve should be such that the full super-elevation is attained at the junction with the circular curve.

(iv) Its radius at the junction with the circular curve should be equal to that of circular curve.

There are three types of transition curves in common use:

(1) A cubic parabola,

(2) A cubical spiral, and

(3) A lemniscate, the first two are used on railways and highways both, while the third on highways only.

When the transition curves are introduced at each end of the main circular curve, the combination thus obtained is known as combined or Composite Curve.

Super-Elevation or Cant:

When a vehicle passes from a straight to a curve, it is acted upon by a centrifugal force in addition to its own weight, both acting through the centre of gravity of the vehicle. The centrifugal force acts horizontally and tends to push the vehicle off the track.

In order to counteract this effect the outer edge of the track is super elevated or raised above the inner one. This raising of the outer edge above the inner one is called super elevation or cant. The amount of super-elevation depends upon the speed of the vehicle and radius of the curve.

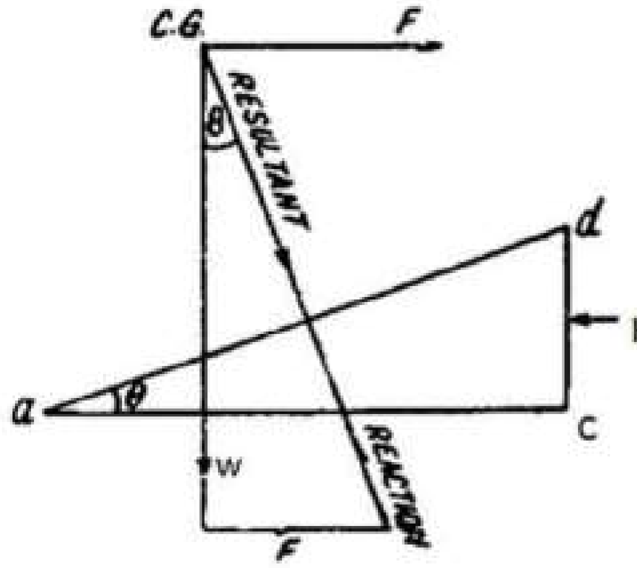


Fig. 11.24

Let:

W = the weight of vehicle acting vertically downwards.

F = the centrifugal force acting horizontally,

v = the speed of the vehicle in meters/sec.

g = the acceleration due to gravity, 9.81 meters/sec^2.

R = the radius of the curve in meters,

h = the super-elevation in meters.

b = the breadth of the road or the distance between the centres of the rails in meters.

Then for equilibrium, the resultant of the weight and the centrifugal force should be equal and opposite to the reaction perpendicular to the road or rail surface.

The centrifugal force, $F = \frac{Wv^2}{gR}$

$$\therefore \quad \frac{F}{W} = \frac{v^2}{gR}$$

If θ is the inclination of the road or rail surface, the inclination of the vertical is also θ

$$\tan\theta = \frac{dc}{ac} = \frac{F}{W} = \frac{v^2}{gR}$$

uper-elevation $= b \tan\theta$.

$$= \frac{bv^2}{gR} \qquad \ldots \qquad \ldots \qquad \textbf{(Eqn. 11.28)}$$

Characteristics of a Transition Curve (Fig 11.25):

Here two straights AB and BC make a deflection angle Δ, and a circular curve EE' of radius R, with two transition curves TE and E'T' at the two ends, has been inserted between the straights.

(i) It is clear from the figure that in order to fit in the transition curves at the ends, a circular imaginary curve ($T_1F_1T_2$) of slightly greater radius has to be shifted towards the centre as (E_1 EF E E_1. The distance through which the curve is shifted is known as shift (S) of the curve, and is equal to $\frac{L^2}{24R}$, where L is the length of each transition curve and R is the radius of the desired circular curve (EFE'). The length of shift (T_1E_1) and the transition curve (TE) mutually bisect each other.

Fig. 11.25:

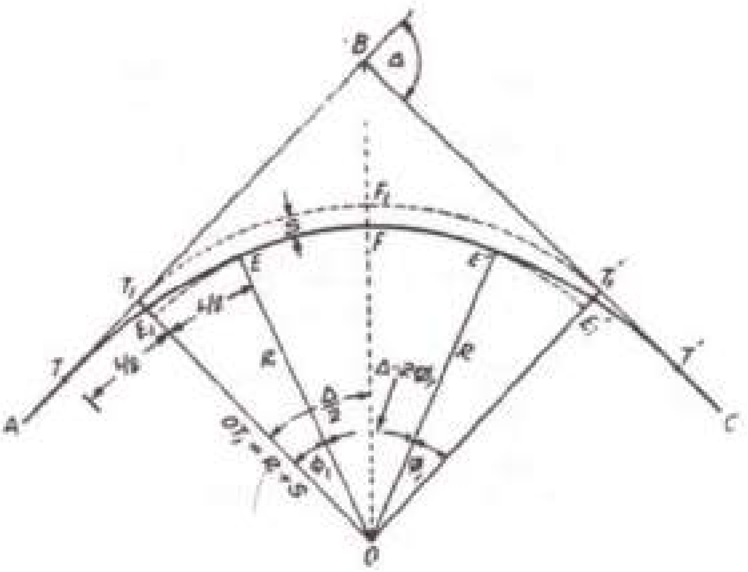


Fig 11.25

(ii) The tangent length for the combined curve

$$= OT_1 \tan\frac{\Delta}{2} + \frac{L}{2}$$

$$= (R + S)\tan\frac{\Delta}{2} + \frac{L}{2}$$

(iii) The spiral angle $\phi_1 = \frac{\frac{L}{2}}{R} = \frac{L}{2R}\ radians$

(iv) The central angle for the circular curve:

$\angle EOE' = \Delta 2\phi_1$

(v) Length of the circular curve EFE'

$$= \frac{\pi R(\Delta - 2\phi_1)}{180^\circ}, \text{ where } \Delta \text{ and } \phi_1 \text{ are in degrees.}$$

(vi) Length of the combined curve TEE'T''

$$= TE + EE' + E'T'$$

$$= L + \frac{\pi R(\Delta - 2\phi_1)}{180^\circ} + L$$

$$= \frac{\pi R(\Delta - 2\phi_1)}{180^\circ} + 2L$$

(vii) Change of beginning (T) of the combined curve = Change of the intersection point (B)-total tangent length for the combined curve (BT).

(viii) Change of the junction point (E) of the transition curve and the circular curve = Change of T + length of the transition curve (L).

(ix) Change of the other junction point (E') of the circular curve and the other transition curve-change of E + length of the circular curve.

(x) Change of the end point (T') of the combined curve = change of E' + length of the transition curve.

Check:

The change of T thus obtained should be = change of T + length of the combined curve.

Note:

The points on the combined curve should be pegged out with through change so that there will be sub-chords at each end of the transition curve and of the circular curve.

(xi) The deflection angle for any point on the transition curve distant l from the beginnings of combined curve (T).

$$\alpha = \frac{l^2}{6RL} \text{ radians} = \frac{1800 l^2}{\pi RL} \text{ minutes.}$$

$$= \frac{573 l^2}{RL} \text{ minutes.}$$

Check:

The deflection angle for the full length of the transition curve:

$$\alpha = \frac{l^2}{6RL} = \frac{L^2}{6RL} \quad (\because l = L)$$

$$= \frac{L}{6R} \text{ radians} = \frac{1}{3}\phi_1$$

(xii) The deflection angles for the circular curve are found from:

$$\delta_n = 1718.9 \ \frac{C_n}{R} \text{ minutes.}$$

Check:

The deflection angle for the full length of the circular curve:

$$\Delta_n = \frac{1}{2} \times \text{Central angle}$$

i.e., $\Delta_n = \frac{1}{2} \times (\Delta - 2\emptyset_1)$

(xiii) The offsets for the transition curve are found from:

Perpendicular offset, $y = \frac{x^3}{6RL}$, where x is measured along the tangent TB

Tangentail offset , $y = \frac{l^3}{6RL}$, where I is measured along the curve

Check : *(a)* The offset at half the length of the transition curve.

$$y = \frac{l^3}{6RL} = \frac{(L/2)^3}{6RL} \quad (\because l = L/2)$$

$$= \frac{L^2}{48R} = \frac{1}{2}S$$

(*b*) The offset at junction point on the transition curve.

$$y = \frac{l^3}{6RL} = \frac{L^3}{6RL} = \frac{L^2}{6R} \quad (\because l = L)$$

$$= 4S$$

(xiv) The offsets for the circular curve from chords producers are found from:

$$O_n = \frac{C_n (C_{n-1} + C_n)}{2R}$$

Method of Setting Out Combined Curve by reflection Angles (Fig. 11.25):

The first transition curve is set out from T by the deflection angles and the circular curve from the junction point E. The second transition curve is then set out from T' and the work is checked on the junction point E' which has been previously fixed from E.

(i) Assume or calculate the length of the transition curve.

(ii) Calculate the value of the shift by:

$$S = \frac{L^2}{24R}$$

(iii) Locate the tangent point T by measuring backward the total tangent length BT (article 11.14, ii) from the intersection point B along BA, and the other tangent T by measuring forward the same distance from B along BC.

(iv) Set up a theodolite at T, set the Vernier A to zero and bisect B.

(v) Release the upper clamp and set the Vernier to the first deflection angle (x_1) As obtained from the table of deflection angles, the line of sight is thus directed along the first point on the transition curve. Place zero end of the tape at T and measure along this line a distance equal to first sub chords, thus locating first point on the transition curve.

(vi) Repeat the process, until the end of the curve E is reached.

Check:

The last deflection angle should be equal to $\phi_1/3$, and the perpendicular offset from the tangent TB for the last point E should be equal to 4S.

Note:

The distance to each of the successive points on the transition curve is measured from T.

(vii) Having laid the transition curve, shift the theodolite to E and set it up and level it accurately.

(viii) Set the Vernier to a reading(360° -2/3 $\phi 1$) for a right-hand curve (or 2/3 $\phi 1$) for a left-hand curve and lake a back sight on T. Loosen the upper clamp and turn the telescope clockwise through an angle 2/3 $\phi 1$ the telescope is thus directed towards common tangent at E and the Vernier reads 360° . Transit the telescope, now it points towards the forward direction of the common tangent at E i.e. towards the tangent for the circular curve.

(ix) Set the Vernier to the first tabulated deflection angle for the circular curve, and locate the first point on the circular curve as already explained in simple curves.

(x) Set out the complete circular curve up to E' in the usual way

Check:

The last deflection angle should be equal to $\frac{1}{2}(\Delta - 2\phi_1)$

(xi) Set out the other transition curve from T as before. The point E' to be set from T should be the same as already set out from E.

Method of Setting Out a Combined Curve by Tangential Offsets (Fig. 11.25):

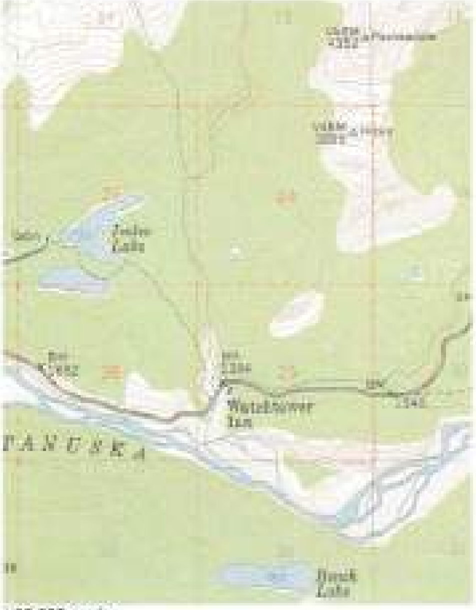
(i) Assume or calculate the length of the transition curve.

(ii) find the value of the shift train, $S = \frac{L^2}{24R}$

(iii) Locate the tangent points T and T as in article (11.15, iii),

(iv) Calculate the offset for the transition curve as in article (11.14 xiv)

(v) Locate die points on the transition curve as well as on the circular curves by setting out the respective offsets.



1:63,360 scale

Map Scales

U.S. Department of the Interior
U.S. Geological Survey
Earth Science
Information Center (ESIC)

To be most useful, a map must show locations and distances accurately on a sheet of paper of convenient size. This means that everything included in the map—ground area, distance, rivers, lakes, roads, and so on—must be shown proportionately smaller than it really is. The proportion chosen for a particular map is its scale.

Large Is Small

Simply defined, scale is the relationship between distance on the map and distance on the ground. A map scale might be given in a drawing (a graphic scale), but it usually is given as a fraction or a ratio—1/10,000 or 1:10,000.

These "representative fraction" scales mean that one unit of measurement on the map—1 inch or 1 centimeter—represents 10,000 of the same units on the ground. If the scale were 1:63,360, for instance, then 1 inch on the map would represent 63,360 inches or 1 mile on the ground (63,360 inches divided by 12 inches = 5,280 feet or 1 mile). The first number (map distance) is always 1. The second number (ground distance) is different for each scale; the larger this second number is, the smaller the scale of the map.

"The larger the number, the smaller the scale" sounds confusing, but it is easy to understand. A map of an area 100 miles long by 100 miles wide drawn at a scale of 1:63,360 would be more than 8 feet square! To make this map a more convenient size, either the scale used or the amount of area included must be reduced.

If the scale is reduced to 1:316,800, then 1 inch on the map represents 5 miles on the ground, and an area 100 miles square can be mapped on a sheet less than 2 feet square (100 miles at 5 miles/inch equals 20 inches, or 1.66 feet). On the other hand, if the original 1:63,360 scale is used but the mapped area is reduced to 20 miles square, the resulting map will also be less than 2 feet square.

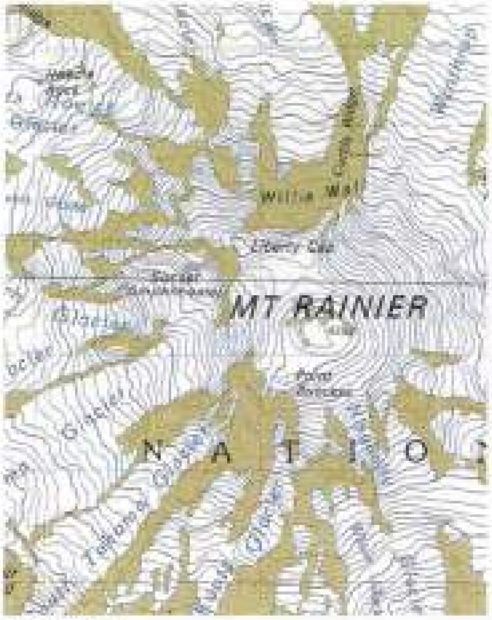
Such maps would be much handier. But would they be more useful? In the small-scale map (1:316,800), there is less room; therefore, everything must be drawn smaller, and some landmarks must be left out altogether. On the other hand, the larger scale map (1:63,360) permits more detail, but it also covers much less ground.

Many areas have been mapped at different scales. When choosing a map—that is, when choosing a scale—the most important consideration is its intended use. A town engineer, for instance, may need a very detailed map in order to precisely locate house lots, power and water lines, and streets and alleys in a community. A commonly used scale for this purpose is 1:600 (1 inch on the map represents 50 feet on the ground). This scale is so large that many features—such as buildings, roads, railroad tracks—that are usually represented on smaller scale maps by symbols can be drawn to scale.

1:500,000 scale

1:20,000 scale

1:24,000 scale



1:100,000 scale

1:250,000 scale

U.S. Geological Survey Scales

The U.S. Geological Survey publishes maps at various scales. The scale used for most U.S. topographic mapping is 1:24,000. Maps published at this scale cover 7.5 minutes of latitude and 7.5 minutes of longitude; they are commonly called "7.5-minute quadrangle" maps. Map coverage for the United States has been completed at this scale, except for Puerto Rico, which is mapped at 1:20,000 and 1:30,000, and a few States that have been mapped at 1:25,000. Most of Alaska has been mapped at 1:63,360, with some populated areas also mapped at 1:24,000 and 1:25,000.

The 1:24,000 scale is fairly large. A map at this scale provides detailed information about the natural and manmade features of an area, including the locations of important buildings and most campgrounds, caves, ski lifts, watermills, and even drive-in theaters. Footbridges, drawbridges, fence lines, private roads, and changes in the number of lanes in a road are also shown at this scale. They would be omitted, usually, from maps in the 1:50,000 to 1:100,000 scale range; these maps cover more area while retaining a reasonable level of detail. Maps at these scales most often use the 15-minute or 30-by-60 minute quadrangle formats.

Small-scale maps (1:250,000 and smaller) show large areas on a single map sheet, but details are limited to major features—boundaries, State parks, airports, major roads, and railroads.

USGS Topographic Maps

Scale	Series	1 inch represents	1 centimeter represents	Standard quadrangle size (latitude-longitude)	Quadrangle area (square miles)
1:20,000	Puerto Rico 7.5 minute	1,667 feet (about)	200 meters	7.5 × 7.5 min.	71
1:24,000	7.5 minute	2,000 feet	240 meters	7.5 × 7.5 min.	49 to 70
1:25,000	7.5 × 15 minute	2,083 feet (about)	250 meters	7.5 × 15 min.	98 to 140
1:50,000	Intermediate	.8 mile (about)	500 meters	NA	county
1:62,500	15 minute	1 mile (about)	625 meters	15 × 15 min.	197 to 282
1:63,360	Alaska 1:63,360	1 mile	634 meters (about)	15 × 20 to 36 min.	207 to 281
1:100,000	Intermediate	1.6 miles (about)	1 kilometer	30 × 60 min.	1,568 to 2,240
1:100,000	Intermediate	1.6 miles (about)	1 kilometer	NA	county
1:125,000	30 minute	2 miles (about)	1.25 kilometers	30 × 30 min.	788 to 1,128
1:250,000	United States	4 miles (about)	2.5 kilometers	1° × 2° or 3°	4,580 to 8,669
1:250,000	Antarctica	4 miles (about)	2.5 kilometers	1° × 3° to 15°	4,089 to 8,336
1:500,000	Antarctica	8 miles (about)	5 kilometers	2° × 7.5°	28,174 to 30,462
1:500,000	State maps	8 miles (about)	5 kilometers	NA	NA
1:1,000,000	United States	16 miles (about)	10 kilometers	4° × 6°	73,734 to 102,759

For more information contact any
Earth Science Information Center (ESIC)
or call 1-800-USA-MAPS

or the following office:

Glossary

Contours: Imaginary lines joining all the points of equal elevation or altitude above mean sea level. They are also called "level lines".
Contour Interval: Interval between two successive contours. It is also known as vertical interval, usually written as V. I. Generally, it is constant for a given map.
Cross-section: A side view of the ground cut vertically along a straight line. It is also known as a section or profile.
Hachures: Small straight lines drawn on the map along the direction of maximum slope, running across the contours. They given an idea about the differences in the slope of the ground.
Topographic Map: A map of a small area drawn on a large scale depicting detailed surface features both natural and man made. Relief in this map is shown by contours.

under the new series retained the numbering system and the layout plan of the abandoned India and Adjacent Countries Series.

The topographical maps of India are prepared on 1 : 10,00,000, 1 : 250,000, 1 : 1,25,000, 1 : 50,000 and 1: 25,000 scale providing a latitudinal and longitudinal coverage of 4 x 4 , 1 x 1 , 30' x 30', 15' x 15' and 5' x 7' 30", respectively. The numbering system of each one of these topographical maps is shown in Fig. 5.1 (on page 51).

International Map Series of the World: Topographical Maps under International Map Series of the World are designed to produce standardised maps for the entire World on a scale of 1: 10,00,000 and 1:250,000.

Reading of Topographical Maps: The study of topographical maps is simple. It requires the reader to get acquainted with the legend, conventional sign and the colours shown on the sheets. The conventional sign and symbols depicted on the topographical sheets are shown in Fig. 5.2 (on page 52).

Methods of Relief Representation

The earth's surface is not uniform and it varies from mountains to hills to plateaus and plains. The elevation and depressions of the earth's surface are known as physical features or relief features of the earth. The map showing these features is called a relief map.

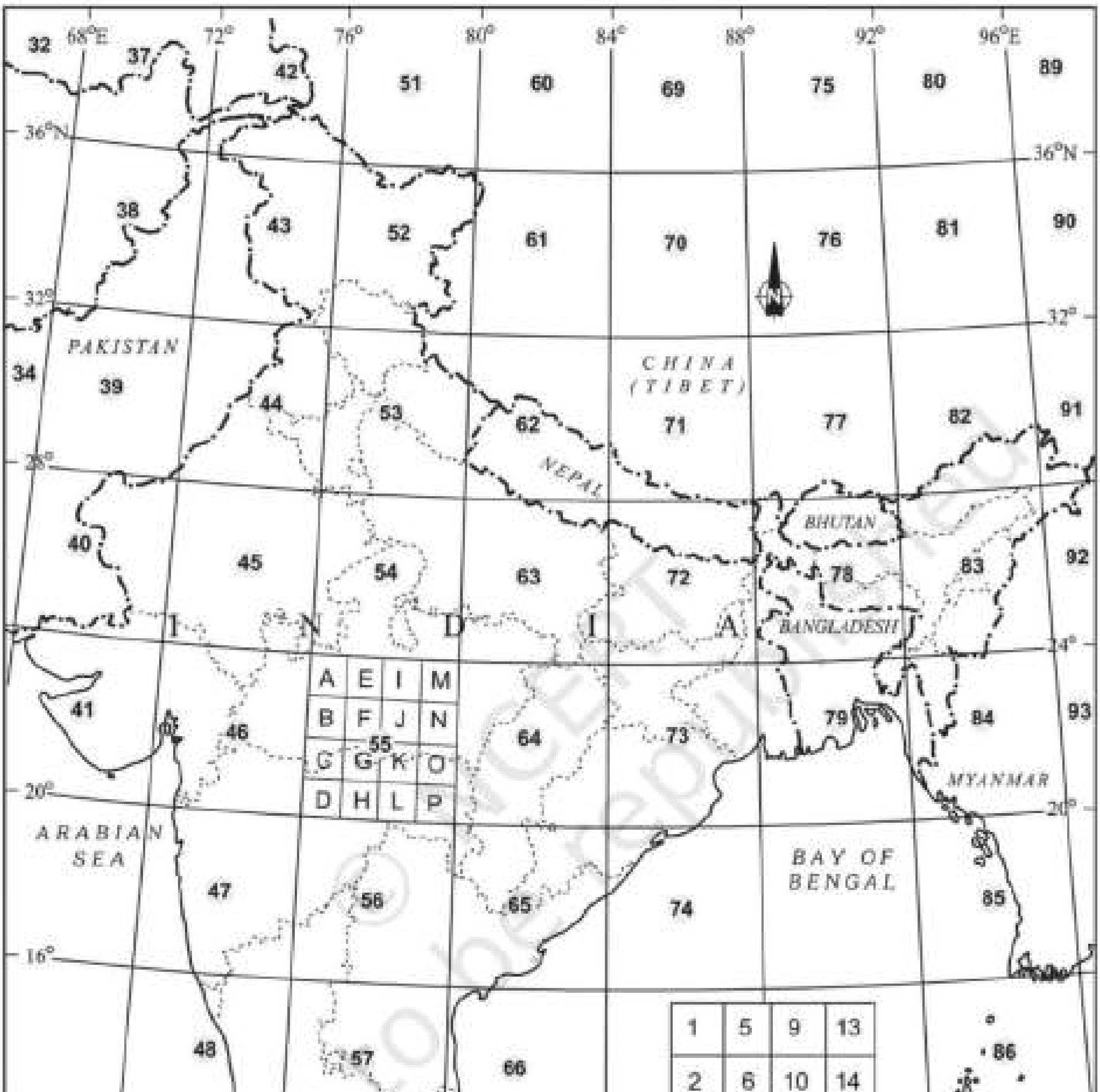


Figure 5.1 Reference Map of Topographical Sheets Published by Survey of India

Figure 5.2 Conventional Signs and Symbols

A number of methods have been used to show the relief features of the Earth's surface on maps, over the years. These methods include hachure, hill shading, layer tints, benchmarks and spot heights and contours. However, contours and spot heights are predominantly used to depict the relief of an area on all topographical maps.

Contours

Contours are imaginary lines joining places having the same elevation above mean sea level. A map showing the landform of an area by contours is called a *contour map*. The method of showing relief features through contour is very useful and versatile. The contour lines on a map provide a useful insight into the topography of an area.

Earlier, ground surveys and levelling methods were used to draw contours on topographical maps. However, the invention of photography and subsequent use of aerial photography have replaced the conventional methods of surveying, levelling and mapping. Henceforth, these photographs are used in topographical mapping.

Contours are drawn at different vertical intervals (VI), like 20, 50, 100 metres above the mean sea level. It is known as *contour interval*. It is usually constant on a given map. It is generally expressed in metres. While the vertical interval between the two successive contour lines remains constant, the horizontal distance varies from place to place depending upon the nature of slope. The horizontal distance, also known as the *horizontal equivalent* (HE), is large when the slope is gentler and decreases with increasing slope gradient.

Some basic features of contour lines are

- A contour line is drawn to show places of equal heights.
- Contour lines and their shapes represent the height and slope or gradient of the landform.
- Closely spaced contours represent steep slopes while widely spaced contours represent gentle slope.
- When two or more contour lines merge with each other, they represent features of vertical slopes such as cliffs or waterfalls.
- Two contours of different elevation usually do not cross each other.

Drawing of Contours and Their Cross Sections

We know that all the topographical features show varying degrees of slopes. For example, a flat plain exhibits gentler slopes and the cliffs and gorges are associated with the steep slopes. Similarly, valleys and mountain ranges are also characterised by the varying degree of slopes, i.e. steep to gentle. Hence, the spacing of contours is significant since it indicates the slope.

Types of slope

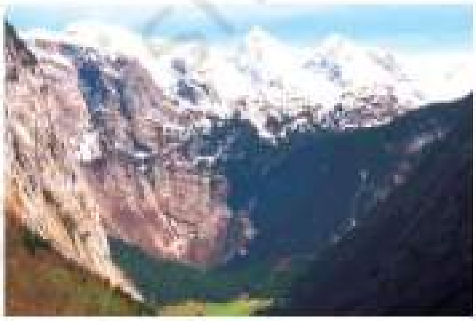
The slopes can broadly be classified into gentle, steep, concave, convex and irregular or undulating. The contours of different types of slopes show a distinct spacing pattern.

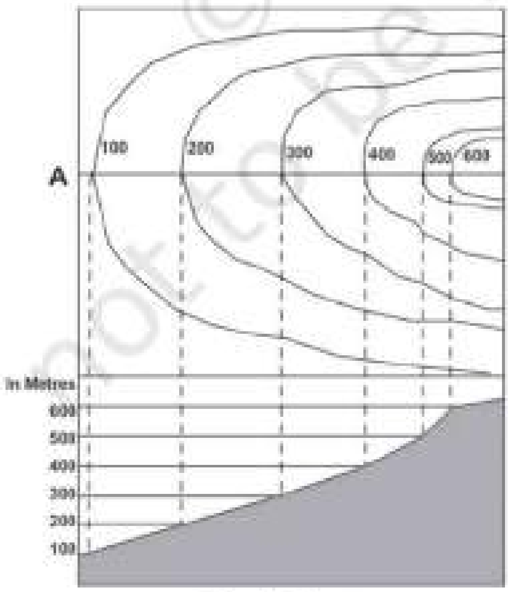
Gentle Slope

When the degree or angle of slope of a feature is very low, the slope will be gentle. The contours representing this type of slope are far apart.

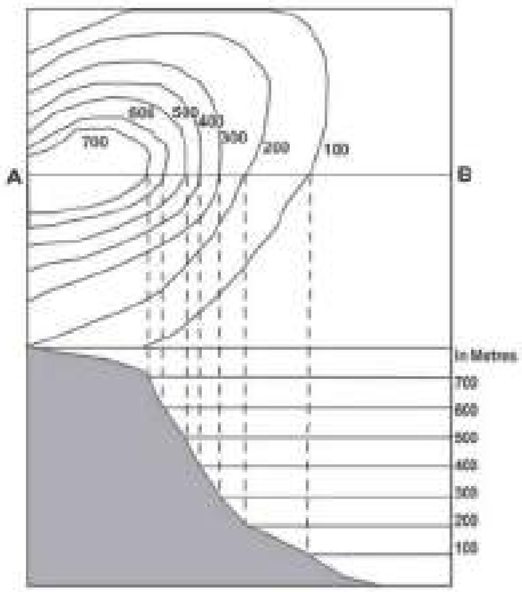
Steep Slope

When the degree or angle of slope of a feature is high and the contours are closely spaced, they indicate steep slope.





Gentle Slope



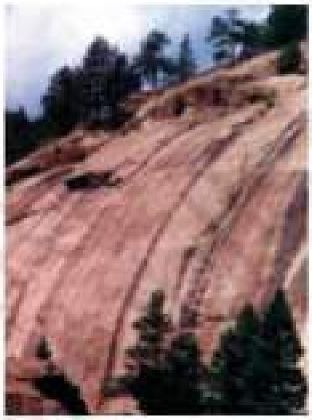
Steep Slope

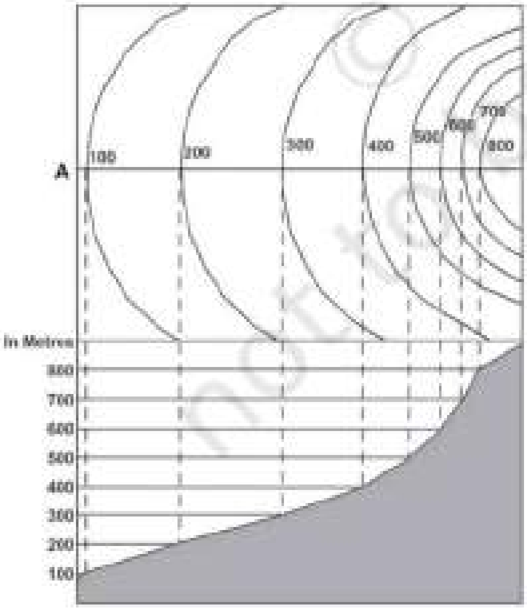
Concave Slope

A slope with a gentle gradient in the lower parts of a relief feature and steep in its upper parts is called the *concave slope*. Contours in this type of slope are widely spaced in the lower parts and are closely spaced in the upper parts.

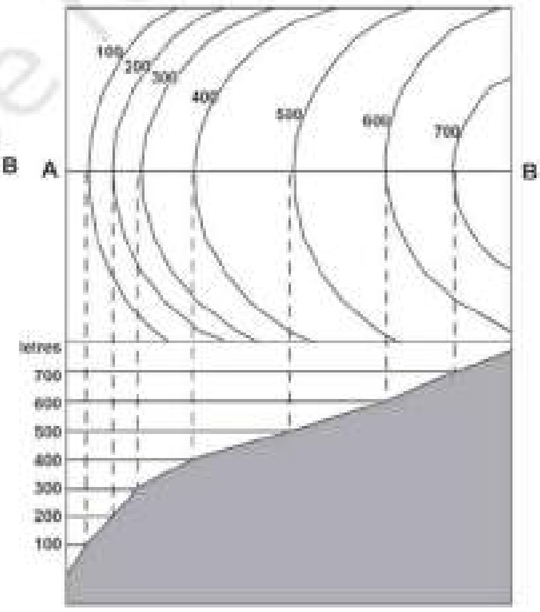
Convex Slope

Unlike concave slope, the *convex slope* is fairly gentle in the upper part and steep in the lower part. As a result, the contours are widely spaced in the upper parts and are closely spaced in the lower parts.





Concave Slope

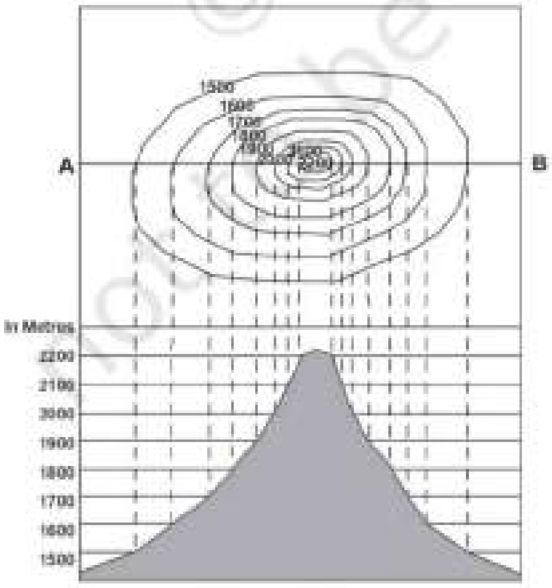


Convex Slope

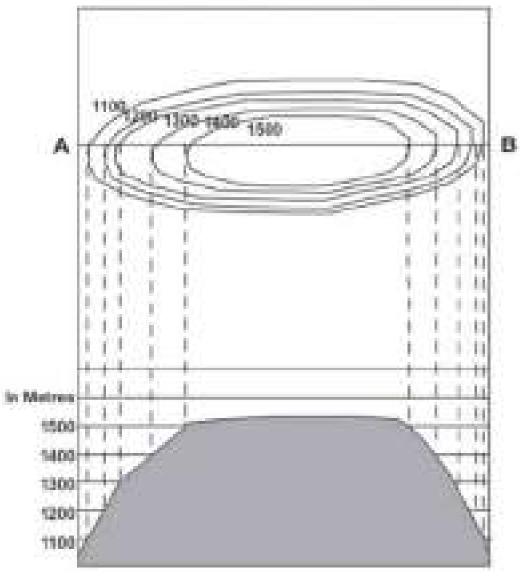
Types of Landform

Conical Hill
It rises almost uniformly from the surrounding land. A conical hill with uniform slope and narrow top is represented by concentric contours spaced almost at regular intervals.

Plateau
A widely stretched flat-topped high land, with relatively steeper slopes, rising above the adjoining plain or sea is called a *plateau*. The contour lines representing a plateau are normally close spaced at the margins with the innermost contour showing wide gap between its two sides.



Conical Slope



Plateau

VALLEY

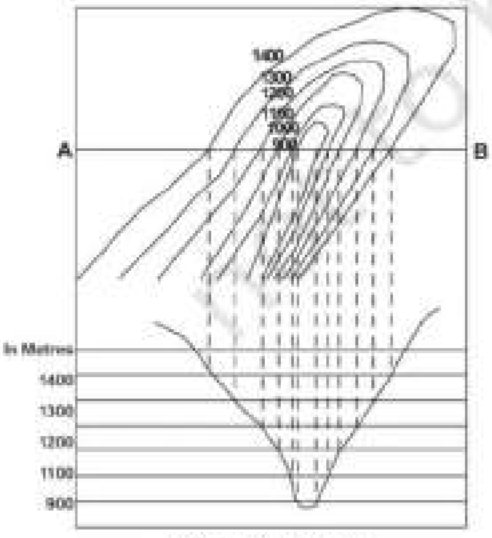
A geomorphic feature lying between two hills or ridges and formed as a result of the lateral erosion by a river or a glacier is called a *valley*.

'V'-shaped Valley

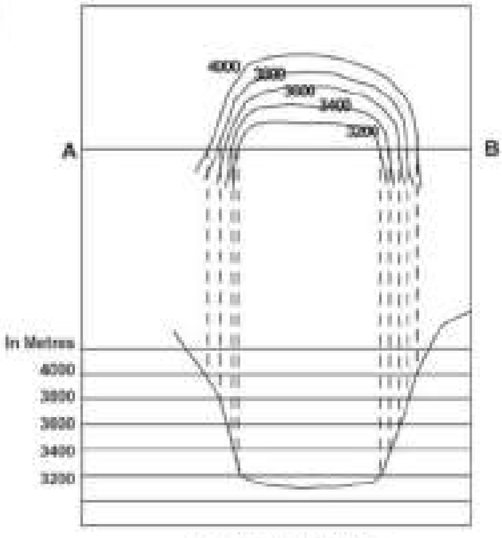
It resembles the letter V. A V-shaped valley occurs in mountainous areas. The lowermost part of the V–shaped valley is shown by the innermost contour line with very small gap between its two sides and the lowest value of the contour is assigned to it. The contour value increases with uniform intervals for all other contour lines outward.

'U' – shaped Valley

A U–shaped valley is formed by strong lateral erosion of glaciers at high altitudes. The flat wide bottom and steep sides makes it resemble the letter 'U'. The lowermost part of the U–shaped valley is shown by the innermost contour line with a wide gap between its two sides. The contour value increases with uniform intervals for all other contour lines outward.



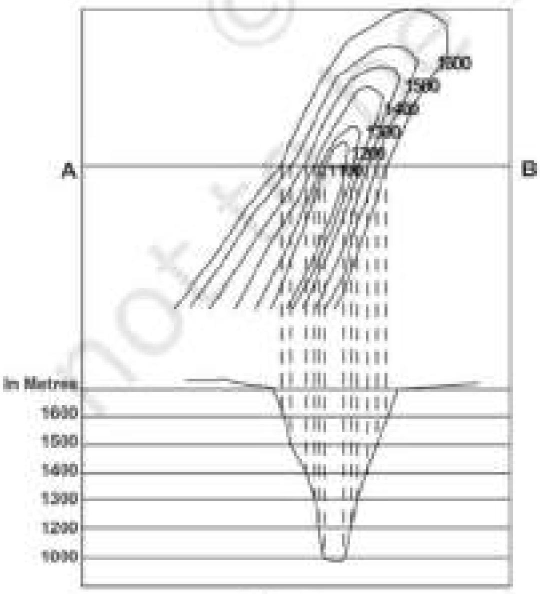
V-Shaped Valley



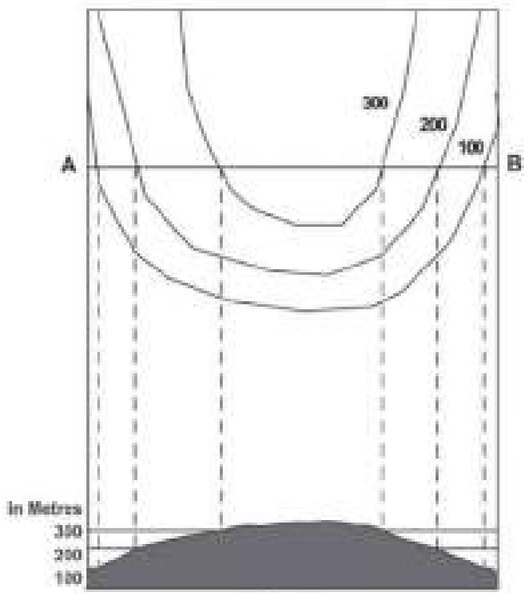
U-Shaped Valley

Gorge
In high altitudes, gorges form in the areas where the vertical erosion by river is more prominent than the lateral erosion. They are deep and narrow river valleys with very steep sides. A gorge is represented by very closely-spaced contour lines on a map with the innermost contour showing small gap between its two sides.

Spur
A tongue of land, projecting from higher ground into the lower is called a *spur*. It is also represented by V-shaped contours but in the reverse manner. The arms of the V point to the higher ground and the apex of 'V' to the lower ones.



Gorge



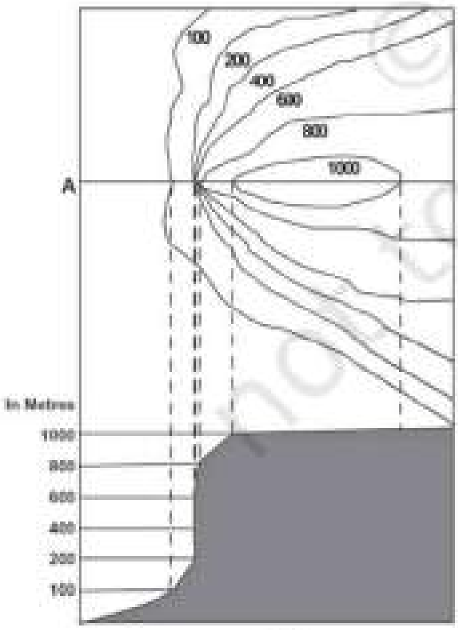
Spur

Waterfall and Rapids

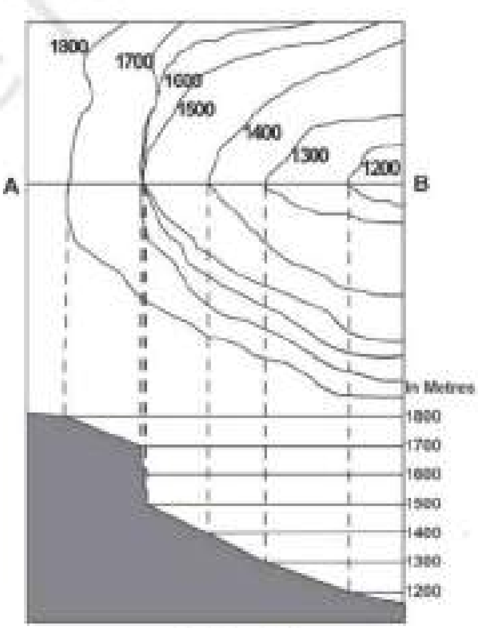
A sudden and more or less perpendicular descent of water from a considerable height in the bed of a river is called a *waterfall*. Sometimes, a waterfall succeeds or precedes with a cascading stream forming *rapids* upstream or downstream of a waterfall. The contours representing a waterfall merge into one another while crossing a river stream and the rapids are shown by relatively distant contour lines on a map.

CLIFF

It is a very steep or almost perpendicular face of landform. On a map, a cliff may be identified by the way the contours run very close to one another, ultimately merging into one.



Cliff



Waterfall

Steps for Drawing a Cross-section

The following steps may be followed to draw cross-sections of various relief features from their contours :

1. Draw a straight line cutting across the contours on the map and mark it as AB.
2. Take a strip of white paper or graph and place its edge along the AB line.
3. Mark the position and value of every contour that cuts the line AB.
4. Choose a suitable vertical scale, eg ½ cm =100 metres, to draw horizontal lines parallel to each other and equal to the length of AB. The number of such lines should be equal or more than the total contour lines.
5. Mark the appropriate values corresponding to the contour values along the vertical of the cross-section. The numbering may be started with the lowest value represented by the contours.
6. Now place the edge of the marked paper along the horizontal line at the bottom line of the cross-section in such a way that AB of the paper corresponds to the AB of the map and mark the contour points.
7. Draw perpendiculars from AB line, intersecting contour lines, to the corresponding line at the cross-section base.
8. Smoothly join all the points marked on different lines at the cross-section base.

Identification of Cultural Features From Topographical Sheets

Settlements, buildings, roads and railways are important cultural features shown on topographical sheets through conventional signs, symbols and colours. The location and pattern of distribution of different features help in understanding the area shown on the map.

Distribution Of Settlements

It can be seen in the map through its site, location pattern, alignment and density. The nature and causes of various settlement patterns may be clearly understood by comparing the settlement map with the contour map.

- Agricultural, orchard, wasteland, industrial, etc.
- Facilities and Services such as schools, colleges, hospitals, parks, airports, electric substations, etc.

Transport and Communication: The means of transportation include national or state highways, district roads, cart tracks, camel tracks, footpaths, railways, waterways, major communication lines, post offices, etc.

Settlement: Settlements are studied under the following heads :

- Rural Settlements: The types and patterns of rural settlements, i.e. compact, semi-compact, dispersed, linear, etc.
- Urban Settlements: Type of urban settlements and their functions, i.e. capital cities, administrative towns, religious towns, port towns, hill stations, etc.

Occupation: The general occupation of the people of the area may be identified with the help of land use and the type of settlement. For example, in rural areas the main occupation of majority of the people is agriculture; in tribal regions, lumbering and primitive agriculture dominates and in coastal areas, fishing is practised. Similarly, in cities and towns, services and business appear to be the major occupations of the people.

Map Interpretation Procedure

Map interpretation involves the study of factors that explain the causal relationship among several features shown on the map. For example, the distribution of natural vegetation and cultivated land can be better understood against the background of landform and drainage. Likewise, the distribution of settlements can be examined in association with the levels of transport network system and the nature of topography.

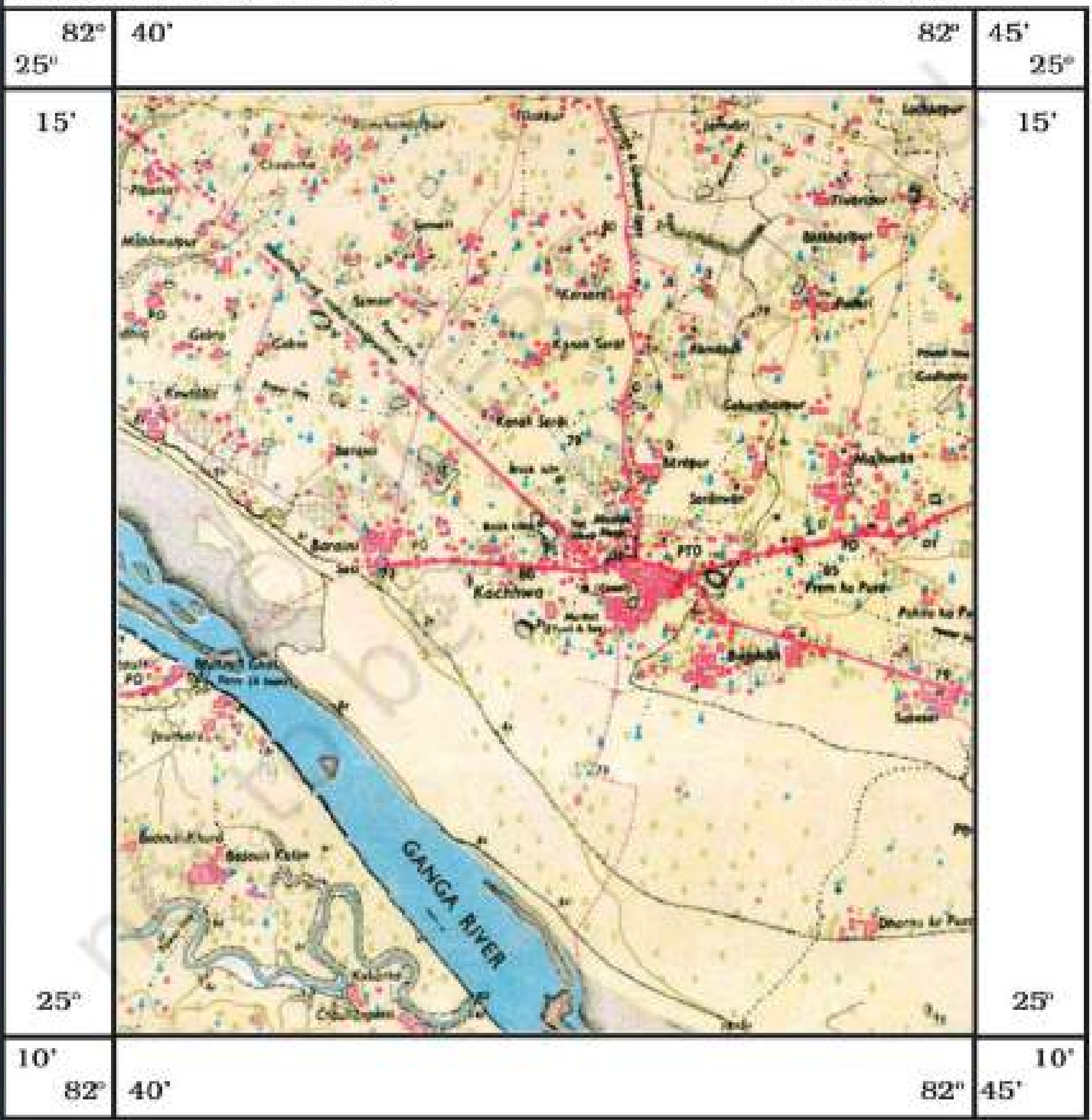
The following steps will help in map interpretation:

- Find out from the index number of the topographical sheet, the location of the area in India. This would give an idea of the general characteristics of the major and minor physiographic divisions of the area. Note the scale of the map and the contour interval, which will give the extent and general landform of the area.

1. Convert 1:50,000 into a statement of scale.
2. Name the major settlements of the area.
3. What is the direction of flow of the river Ganga?

Uttar Pradesh

Mirzapur and Varanasi District — Part of 63K/12

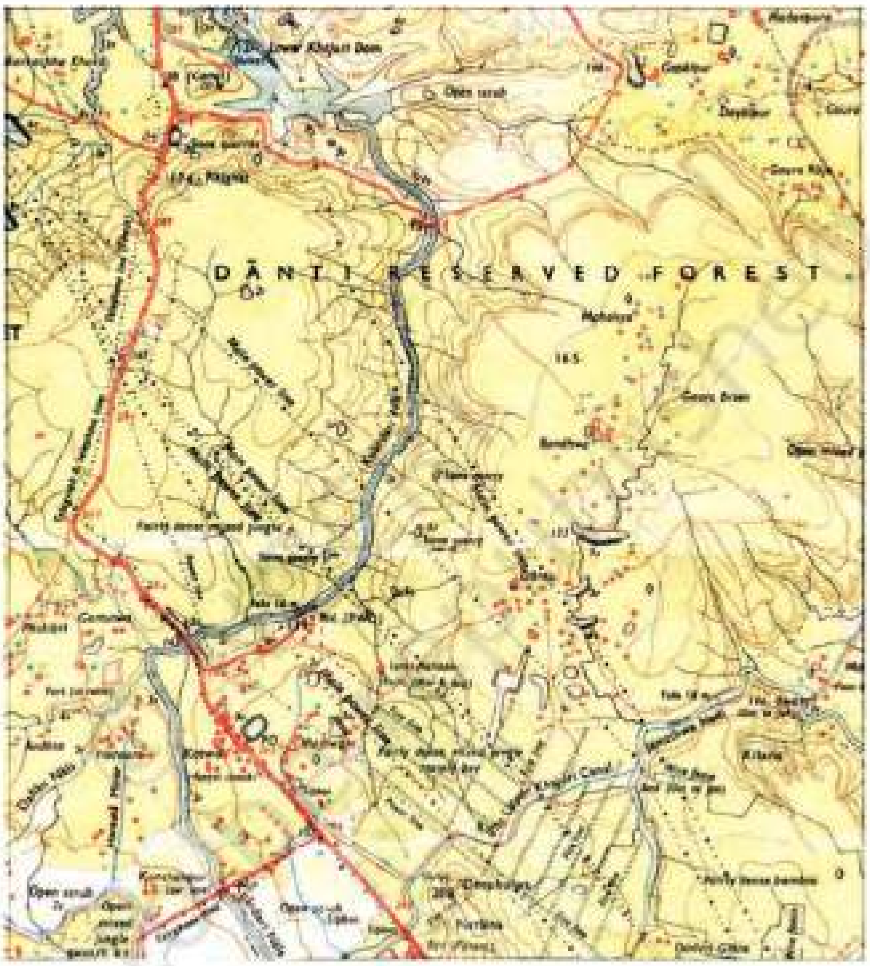


R. F. 1: 50,000

Part of the Topographical Sheet No 63K/12

Uttar Pradesh

Mirzapur and Varanasi District | Part of 63K/12

82° 25°	35'	82°	40' 25°
5'			5'
25°			25°
0' 82°	35'	82°	0' 40'

R. F. 1: 50,000

Part of the Topographical Sheet No 63K/12

4.1.2 Purpose of this Chapter

The purpose of this chapter is to define the specifications that shall be followed while performing aerial surveys, photogrammetry and geospatial data processing for CDOT.

CDOT contracts out all aerial surveys as the aerial photography and mapping equipment is not available in the department. As such CDOT relies upon the expertise and experience of the aerial mapping consultant to provide guidance and products that will meet the needs of the project. The survey fieldwork is most often performed by the aerial consultant however it may also be performed by CDOT survey crews.

The guidelines and specifications described in this chapter are geared towards development of design scale mapping that has been historically referred to as 1"=50' scale mapping with 1' contours. The vast majority of aerial mapping contracted by CDOT calls for mapping standards associated with this scale. Where requirements differ from this scale, the necessary equipment, ground control, flight planning and other key components of the project design may need to be modified. This may be accomplished either to ensure a higher standard is met or to realize efficiencies that may be offered to meet a lower standard. Any variation from the specifications in this chapter shall have the prior approval of the CDOT Region Survey Coordinator.

While it is recognized that technical developments, particularly in airborne LiDAR, are making wider application of aerial data possible for design scale mapping, this chapter provides specifications and guidelines for LiDAR data used alone or in conjunction with photogrammetry supplementing field survey data on the hard road surfaces. Certain circumstances may call for consideration of wider data application such as full detail extraction from a high-density LiDAR point cloud. Where accessibility, safety, economics or other concerns call for such consideration it should be done in consultation between a professional aerial surveyor, such as an ASPRS Certified Photogrammetrist, map scientist or state licensed aerial survey professional and the CDOT Region Survey Coordinator. This will facilitate development of a custom project design, specifications, and deliverables that meet unique CDOT project requirements.

Again, any variation from the specifications in this chapter shall have the prior approval of the CDOT Region Survey Coordinator.

4.1.3 Aerial Surveys

Aerial surveys utilize photographic, LiDAR, electronic, digital, or other data obtained from an airborne platform. Photographic data processed by means of photogrammetry and LiDAR processing using AGPS and IMU data represent the principal applications of aerial surveys to satisfy the needs of CDOT. Aerial survey data is combined with field survey data to produce high precision mapping and meet the accuracy standards described in this Chapter.

4.1.4 Aerial Photogrammetry

Aerial photogrammetry is the science of deducing the physical dimensions of objects on or above the surface of the Earth from measurements on aerial photographs of the objects. The end result produces the coordinate (X, Y, and Z) position of a particular point, a planimetric feature, and a graphic representation of the terrain from a DTM.

Aerial photogrammetry is often used for the following:

1. Highway reconnaissance
2. Environmental
3. Preliminary design
4. Geographic Information System (GIS)

The information produced from aerial photographs of the existing terrain allows both designers and environmental personnel to explore alternate routes without having to collect additional field information.

The photographs can be used to layout possible alignments for a more detailed study.

Photogrammetry has evolved into a limited substitution for topographic ground surveying. It can relieve survey crews of the most tedious time-consuming tasks required to produce topographic maps and DTMs. However, ground surveys will always remain an indispensable part of aerial surveys as a basis for accuracy refinement, quality control and a source of supplemental information unavailable to aerial data acquisition.

4.1.5 Photogrammetric Advantages / Disadvantages

Surveys collected by aerial photogrammetry methods have both advantages and disadvantages when compared with ground survey methods as follows:

Advantages:

1. Photos provide a permanent record of the existing terrain conditions at the time the photograph was taken.
2. Photos can be used to convey information to the general public, and other federal, state, or local agencies.
3. Photos can be used for multiple purposes within CDOT such as reconnaissance, preliminary design, environmental, and Right of Way.
4. Topographic mapping and DTMs of large areas can be accomplished relatively quickly and at a lower cost when compared to ground survey methods.
5. Photogrammetry can be used in locations that are difficult or impossible to access from the ground.

Disadvantages:

1. Seasonal conditions, including weather, vegetation, and shadows can affect both the taking of photographs and the resulting measurement quality. If the ground is not visible in the photograph it cannot be mapped.
2. Overall accuracy is relative to camera quality and flying height. Elevations derived from photogrammetry are less accurate than ground surveys (when compared to conventional or GPS ground survey methods using appropriate elevation procedures).
3. Identification of planimetric features can be difficult or impossible (*e.g.* type of curb and gutter, size of culverts, type of fences, and information on signs).
4. Underground utilities cannot be located, measured, or identified.
5. Right of Way and property boundary monuments cannot be located, measured, or identified.
6. Since photogrammetric features are compiled from a plan view, buildings are measured around overhangs and eaves rather than at building footprints, resulting in some areas of DTM occlusion under overhangs, eaves, and overhead walkways. Areas under bridges are similarly affected.

4.1.6 Aerial LiDAR

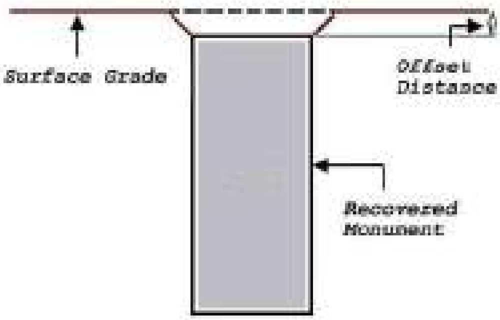
LiDAR is collected using a laser that measures distance to an object by emitting timed pulses and measuring the time between emission and reception of reflected pulses. The measured time interval is converted to a distance. Modern LiDAR sensors are capable of recording several returns per pulse. Multiple returns occur when the beam footprint strikes multiple targets before terminating. The sequence of returns from a single pulse, (For example, first, 2^{nd}, 3^{rd}, last or first and last), is also recorded along with an intensity value.

AGPS and IMU data are collected on board the aircraft during flight. Base station information must be

4.2 Ground Control for Aerial Surveys

4.2.1 General

Aerial survey data must be referenced to ground control points in order to maximize the absolute accuracy achievable for the aerial data. This is achieved by survey crews establishing photo ground control within the project area. Targets are placed over ground control so that the location of the point is easily identified on the imagery. The field measurement of the horizontal and vertical elevation (X, Y and Z) of the control points will be used in the downstream processes of photogrammetry and/or point cloud calibration to register the data sets to field survey values. Elevations, (Z), must be provided at surface grade. If a target is laid over a monument that is below grade, the offset elevation must be applied to the elevation since the aerial control target will be measured at surface grade. The diagram at left illustrates monument targeted below grade.



4.2.2 Ground Control Targeting Requirements

Ground control requirements for aerial mapping will be predicated upon flying height, terrain, equipment, accuracy requirements and technology applied for data acquisition. To meet the design scale accuracy requirements described in this Chapter, an aerial mapping project should be controlled by pairs of inter-visible points not more than 1,500' apart. A control point targeting plan at this density would satisfy ground control requirements for a photogrammetric approach using a mapping grade, large format film camera with FMC flying at 1,500' AGL.

By applying AGPS/IMU, INS technologies and modern digital sensors it is possible to reduce the density of targeted ground control significantly. However, multiple variables must be considered. These include specific sensor capabilities and specifications, flying height, frequency and quality of AGPS signal and distance to GPS base stations.

CDOT recommends the following when applying AGPS technologies:

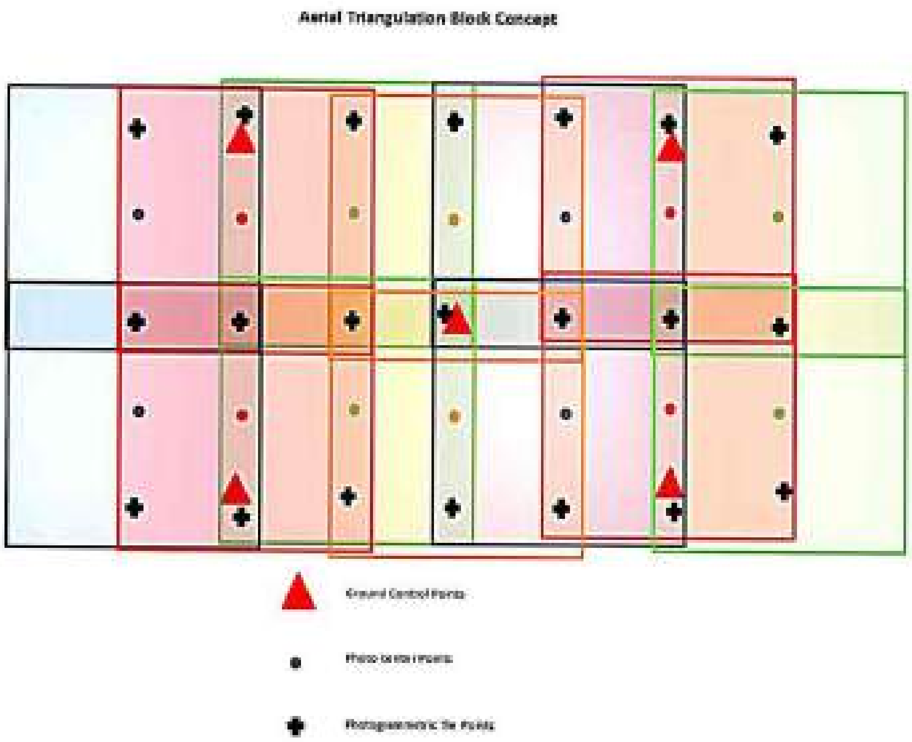
1. A minimum of five (5) targets or PID points for any aerial mapping project;
2. A maximum spacing of 1 mile between pairs of points along a mapping corridor;
3. A minimum of one control point to tie lines together where broken to accommodate a heading change along a corridor.

The aerial mapping consultant is responsible for determining and specifying all aerial control monument locations, material, spacing, and configurations for the survey. The CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining what monumentation shall be used for control points.

See Chapter 1 – General, Appendix Survey Monuments M-629-1, for additional information.

4.2.3 Photogrammetry

The control points must be visible from a minimum of two overlapping photographs. To apply the basic principle of photogrammetry, at least three photo ground control points are needed for any single stereo model, (one overlapping pair of photographs) or block of adjoining stereo models. This establishes the spatial relationship between the ground and the model coordinates. One or more additional points are required to determine the accuracy of the model based residual error and to identify any data entry errors. When controlling multiple models or blocks of photography, aerial triangulation is applied serving to bridge control across multiple stereo models by combining their relative orientations with the ground control measurements. The following diagram illustrates the aerial triangulation concept for a small block of photographs.



The photo coordinates of identifiable points on the ground (*i.e.* photo ground control points) are measured on multiple photographs, (at least two), along with other image locations, or tie points, common to multiple photographs to begin the aerial triangulation process. From these measurements and the camera calibration data, a trigonometric calculation determines the camera (focal point) location and sensor attitude for each exposure. Finally, a least squares adjustment is applied to the entire block, refining relative orientations of each image and registering the block to ground control for absolute orientation.

The aerial triangulation output allows analysis of stereo models using a digital softcopy workstation to produce photogrammetric mapping and terrain modeling. Digital workstations allow the operator to accurately compile and record data in 3D. The aerial triangulation data can also be used in combination with the camera calibration data and DTM to produce orthophotography.

More modern aerial survey acquisitions apply AGPS or a combination of AGPS and IMU technology. This is supported by collection of data at static ground base stations during the aerial survey. AGPS provides additional control to aerial photography by establishing a coordinate value for each photo center. In addition to AGPS, aerial imagery may be combined with IMU data to provide a more accurate photo center along with the camera attitude and heading, (tip, tilt, swing), also known as direct geo-referencing. For photogrammetry, the direct geo-referencing provides additional input to aerial triangulation process, facilitating more automation. Modern aerial triangulation software automates the selection of photogrammetry tie points. This allows a much larger number of tie points to be incorporated into the aerial triangulation solution improving overall results.

4.2.4 Aerial LiDAR

LiDAR requires both AGPS and IMU data. These inputs provide a relative positioning solution. A minimum of two base stations should be used to provide a basis of comparison for the repeatability of the solution and redundancy in case of equipment failure. While not necessarily within the mapping boundaries, base stations must be tied to the ground survey network associated with the mapping project. To meet the 0.25' class vertical accuracy described in this Chapter, CDOT recommends that base stations not be more than 25 miles from the sensor at any time during the data acquisition. Application of this technology can reduce the number of targeted control points required. This may be helpful by reducing the necessity for Wing Point Control as these points tend to fall beyond the transportation right of ways and may be difficult to place.

The aerial mapping consultant is responsible for determining control requirements for the aerial survey. Final photo control monument locations, spacing, and configurations for the survey may be influenced by conditions. It is important that the aerial mapping consultant and field survey team work in close coordination to ensure control requirements for the project are met. Additional considerations include the type of sensor employed, the technology applied, and the required positional accuracy of the data. The CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining how many and where each photo control point shall be located.

4.2.5 Equipment Checking and Calibration

Checks and calibrations on all types of electronic survey equipment are essential to obtain and maintain the minimum tolerances required for aerial surveys. Equipment must be properly maintained, regularly checked, and calibrated for accuracy at the beginning of any aerial survey project to ensure that the equipment is operating properly in accordance with Chapter 2 – General Procedures, and Chapter 3 – GPS Surveys of this manual. It is the aerial consultant's responsibility to ensure no errors due to poorly maintained or malfunctioning equipment will affect the project. For surveys lasting longer than six months, the checking, and calibration of equipment shall be repeated once every six months to ensure equipment will meet the needs and specifications for the project.

See Chapter 2 - General Procedures, and Chapter 3 – GPS Surveys, for additional information.

4.2.6 Permission to Enter Property Form 730a

If it becomes necessary for a survey crew to enter property outside of CDOT Right of Way the property owner or occupant shall be contacted before a survey crew enters the property. The purpose of this contact is to inform the owner or occupant that an entry is required, to explain what survey activities are to be performed, to indicate the duration of the survey and any effect it may have on the property. A permission to Enter Property Form 730a should be completed in order that survey crews will have permission, in writing, for performing their assigned functions. The owner or occupant at this time is to be advised to use section "Conditions requested by Owner" of the permission form to place certain restrictions on the activities (*i.e.* time limitations, where vehicles may drive, cutting of brush, digging holes or if notice needs be given before entering property).

See Chapter 2 – General Procedures, Appendix CDOT Permission to Enter Property Form 730a, for additional information.

4.2.7 Underground Utility Locates Prior to Installing Photo Control Monumentation

Once the aerial control survey sites are identified, and if installation of new monumentation is required, each site shall be marked with a lath with white paint and/or flagging and underground utility locates shall be called for prior to establishing the monument. Depending on specific project requirements, some control points may only require semi-permanent monumentation such as a nail in asphalt or rod iron bar and cap outside of the ROW, in which case locates will not be required.

See Chapter 2 – General Procedures, Underground Utility Locates Prior to Installing Monumentation, for additional information.

4.2.8 Aerial Ground Control Monumentation

Survey crews establish ground control points for aerial surveys. Targets are placed over the control points on the ground so that the location of the point is easily identified in the aerial survey. Depending on the contract scope of work, control survey may be performed by either the aerial mapping consultant or by CDOT survey crews. The aerial consultant will be responsible for the targeting of control points to ensure identification in the aerial imagery.

Photo control points typically consist of the following:

1. Photo Center points
2. Photo Wing points

4.2.9 Center Point Control

Center (*i.e.* flight line) point control is established as close to the center of the flight line as possible. Their location and configuration is dependent upon the flight height. For highway work the closest to the flight line center that is most often achievable on the ground is on the shoulder of the highway. Whenever possible CDOT primary control monuments that have been previously established on the ground by a primary control survey as defined in Chapter 5 – Preliminary Surveys shall be used for all photo center control monuments. This allows the aerial control survey to be horizontally and vertically referenced and tied directly to the primary control established on the ground as the framework for the survey control network without having to install additional monuments. This also greatly reduces the amount of field surveying needed to establish photo ground control since the primary control monuments need only to be targeted.

CDOT control monument caps or disk shall not be set for any photo center control point, unless the point has or will be established as part of a CDOT Class A – Primary survey as defined in Chapter 5 – Preliminary Surveys.

For projects where no CDOT primary control monuments have been previously established on the ground, the aerial center control point shall be monumented with a CDOT Type 5 or Type 6 aluminum monument and stamped with the appropriate aerial control point number or name. In areas where a Type 5 or Type 6 monument is not suitable or desired, the monument shall consist of a material that when set solidly into the ground will prove to hold the required Minimum Horizontal and Vertical Accuracy Tolerance for the aerial control survey.

Examples of these types of monuments may include the following:

1. Public Land Survey System (PLSS) monuments
2. Right of Way monuments
3. Federal, State, or local agency monuments
4. Benchmark monuments
5. Boundary monuments
6. CDOT Type 5 or Type 6 monuments
7. 5/8 inch rebar with no cap (set for temporary monuments only)
8. Nail set in asphalt (set for temporary monuments only)

CDOT Type 5 or Type 6 photo center control monument materials shall be furnished by CDOT in accordance with M & S Standards M-629-1.

See Chapter 1 – General, Appendix Survey Monuments M-629-1, for additional information.

4.2.10 Wing Point Control

Wing point control is established at the right or left outer edge of the flight lines. These points become more critical for flight plans that include multiple flight strips run parallel to one another. Their location and configuration is dependent upon the flight plan.

CDOT control monument caps or disk shall not be set for any photo wing control point, unless the point has or will be established as part of a CDOT Class A – Primary survey as defined in Chapter 5 – Preliminary Surveys.

Wing point control shall be monumented with a CDOT Type 5 or Type 6 aluminum monument and stamped with the appropriate aerial control point number or name. In areas where a Type 5 or Type 6 monument is not suitable or desired, the monument shall consist of a material that when set solidly into the ground will prove to hold the required Minimum Horizontal and Vertical Accuracy Tolerance for the photo control survey.

Examples of these types of monuments may include the following:

1. Public Land Survey System (PLSS) monuments
2. Right of Way monuments
3. Federal, State, or local agency monuments
4. Bench mark monuments
5. Boundary monuments
6. CDOT Type 5 or Type 6 monuments
7. 5/8 rebar with no cap (set for temporary monuments only)
8. 60d or larger nail set in asphalt (set for temporary monuments only)

CDOT Type 5 or Type 6 wing control monument materials shall be furnished by CDOT in accordance with M & S Standards M-629-1.

See Chapter 1 – General, Appendix Survey Monuments M-629-1, for additional information.

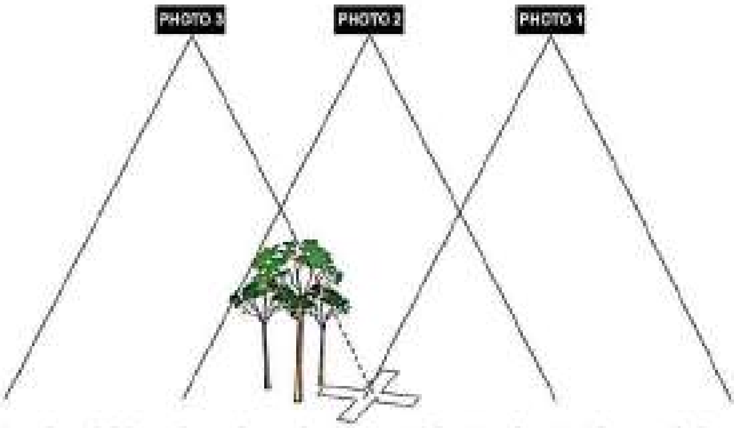
4.2.11 Aerial Control Targets (Paneling)

Targets (*i.e.* paneling) shall be placed on the ground symmetrical and centered over aerial control points in order that the location of the point is easily identified in the imagery. The paneling width and configuration is dependent upon the flight height for aerial photography. The material or biodegradable paint used to target the control should contrast surface surrounding the target. (IE: White in most instances, however, if the surface is very light colored, a black target may be preferable.)

4.2.11.1 Photogrammetry

For photogrammetric measurement made during the aerial triangulation process, the target must be clearly visible on multiple images. A minimum of two adjacent images allows measurement but accuracy increases with the number of images the target can be seen from. Ideally, targets should be visible from aerial view between 90 and 60 degrees above horizon in all directions. Trees or structures may obscure view of the target. See below.

Diagram 1: Example of a visibility problem: Target visible on only one of two possible image pairs.



Ideally, the targets should be placed on the ground just prior to the aerial survey, and should be maintained until the aerial mission has been flown and the data has been accepted. This reduces the risk of the targets being disturbed prior to the aerial survey.

4.2.11.2 LiDAR

The aerial consultant is responsible for ensuring that the aerial target design meets the identification needs for the aerial survey. The reflectivity of the surround surface must be considered. The reflective properties for various surfaces may differ slightly between LiDAR and RGB light. For example, moist grass can be highly reflective making a white target difficult to identify in LiDAR intensity imagery. The density of the LiDAR GSD must also be considered. Target legs will need to have a minimum width 2X greater that the planned GSD of the LiDAR data. Length of legs should be 4X the width. Secondly, the area around the control point should be level for a radial distance greater than the nominal spacing between LiDAR returns. Lower densities of returns may necessitate larger target dimensions. At very low density it may be necessary to validate LiDAR horizontal accuracy by using the known coordinates for large features in the imagery such as building corners or asphalt areas on the ground. If the LiDAR was flown in conjunction with aerial photography these coordinates may be obtained photogrammetrically.

4.2.12 Aerial Control Target Design & Material

The target design shall be symmetrical and centered on the aerial control point. There are three designs commonly applied for aerial surveys. These include four-legged "X" targets, three-legged "Y" targets), and two-legged "L" targets. More than one type can be used for a project if there is a need to distinguish between different types of control, such as wing and center control point targets. The length and width of the target legs will depend on the specifications of the flight mission. The principal drivers will be flying height or GSD of the resulting data.

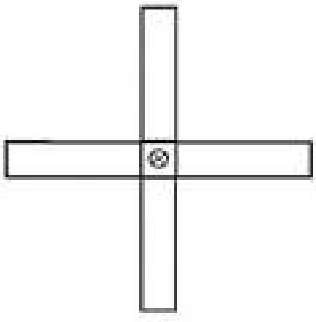


Diagram 2: "X" Type Target

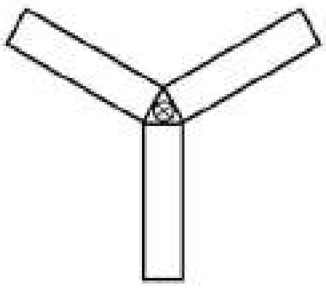


Diagram 3: "Y" Type Target

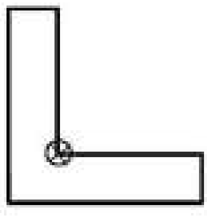


Diagram 4: "L" Type Target

If paint is used to target aerial control point locations it must be of a type that is biodegradable and washes away within six months. Suggested materials for targeting include opaque polyethylene film (visquine of four to six mils thickness), unbleached white muslin or white cotton bunting. In flat terrain, plywood or masonite, painted flat white, may be used. When using either polyethylene film or material, it may be necessary to secure the target to the ground, either by stakes or nails. Placing rocks or dirt along the edges of the material may also help to keep it flat on the ground.

Natural target features, also known as Photo ID points or PID's may be used in lieu of artificial targets provided that a reasonably large angle of intersection exists to positively identify a point. Examples include sidewalk intersections, corner of concrete slabs, existing paint markings on asphalt, or other clearly visible feature from which a precise location can be interpreted. The illustration at right is an example of a PID control point observed at a sidewalk corner. This point would be ideal for photogrammetry or LiDAR control. The elevation should be measured at the sidewalk surface at the edge of the where it aligns with the sidewalk surface extending to the right.

The aerial mapping consultant is responsible for determining and specifying target dimensions, material, and configurations for the survey crews to layout. The CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining how monuments are to be targeted.

4.2.13 Removal of Aerial Control Target Material

To maintain proper public relations all man made target material placed over aerial control points shall be removed and the site cleaned up within seven days of confirmation that aerial survey was successfully acquired and no re-flights are necessary.

Unless directed otherwise, all aerial control monuments on public property shall be left in place and undisturbed for future use if needed. Monuments set on private property may require removal depending on what has been agreed to by the property owner or tenant. The removal must be completed on a schedule agreed to by the owner or tenant. Aerial control monuments shall only be removed with the approval of the CDOT Region Survey Coordinator.

4.3 Aerial Control Horizontal Survey

4.3.1 Aerial Control Horizontal Survey Datum

All aerial control horizontal surveys shall be referenced and tied into the CDOT primary control survey as defined in Chapter 5 – Preliminary Surveys.

As defined in Chapter 5 – Preliminary Surveys, the purpose of a primary control survey is to establish a network of physically monumented coordinate points in and along a highway corridor that provide a common horizontal and vertical datum for the entire project. The primary control survey provides the means for tying all of the geographic features and design elements of a project to one common horizontal and vertical coordinate system. The primary control survey is performed at a higher level of accuracy than the aerial control survey, as such the aerial control survey shall be considered secondary control.

For projects where no CDOT primary control survey has been completed, the CDOT Region Survey Coordinator shall be contacted and a determination made if a primary control survey is to be completed prior to the aerial control survey. CDOT discourages the practice of performing any aerial control survey without a previously established primary control survey already in place, as this causes accuracy and coordinate conversion problems at a later date.

If a primary control survey will not be performed, all aerial control horizontal surveys shall be referenced to and tied into the National Spatial Reference System (NSRS) as defined by the National Geodetic Survey (NGS)

As stated in Chapter 5 – Preliminary Surveys, NGS defines and manages the NSRS, the framework for Latitude, Longitude, height, scale, gravity, and orientation throughout the United States. The NSRS provides the foundation for transportation, communication, and defense systems, boundary and property surveys, land records systems, mapping and charting, and a multitude of scientific and engineering applications. NGS also conducts research to improve the collection, distribution, and use of spatial data.

The National Geodetic Survey defines and manages the National Spatial Reference System (NSRS). The NSRS is a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States and is designed to meet the nation's economic, social, and environmental needs. The NSRS has traditionally been defined by survey marks in the ground. More recently, the horizontal datum is defined by the continuously operating reference stations (CORS).

The current datums are the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88). NAD 83 (2011) epoch 2010.0 is the latest realization of the horizontal datum. Both the horizontal and vertical datums will be replaced around 2022.

See Chapter 5 – Preliminary Survey, and Chapter 3 - GPS Surveys, for additional information.

4.3.2 Minimum Aerial Control Horizontal Survey Accuracy Tolerance

All aerial control horizontal surveys shall meet the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

4.3.3 GPS Photo Control Horizontal Survey Methods

All aerial control horizontal surveys performed by GPS methods shall be performed in accordance with Chapter 3 – GPS Surveys, and shall meet the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary surveys.

Unless field conditions do not permit, (*e.g.* obstructions of the sky by trees, buildings, etc.) only Global Positioning System (GPS) survey methods shall be performed for all aerial control horizontal surveys.

Those aerial control horizontal surveys performed by survey methods other than GPS shall be approved in advance by the CDOT Region Survey Coordinator.

Unless approved otherwise by the CDOT Region Survey Coordinator, all GPS aerial control monuments (center and wing points) shall be observed by Static or Fast Static GPS survey methods and procedures in accordance with Chapter 3 – GPS Surveys. RTN data may be acceptable for supplemental ground truth purposes or other applications upon approval. Any type of RTK survey used must be post-processed and its application approved by the CDOT Region Survey Coordinator.

4.3.4 Conventional Aerial Control Horizontal Survey Methods

All aerial control horizontal surveys performed by conventional survey methods shall consist of a closed traverse or closed loop survey in accordance with Chapter 5 – Preliminary Surveys, and shall meet the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

4.4 Aerial Control Vertical Survey

4.4.1 Photo Control Vertical Survey Datum (NAVD 88)

All aerial control vertical surveys shall be referenced and tied to the North American Vertical Datum of 1988 (NAVD 88) or the latest vertical datum produced by NGS. This is typically accomplished when referencing and tying the aerial control vertical survey to a CDOT primary control survey that has been previously referenced and tied to NAVD 88 datum in accordance with Chapter 5 – Preliminary Surveys.

For projects where no CDOT primary control survey has been completed, elevations for any aerial control vertical survey shall be established from existing national bench marks and referenced and tied to the North American Vertical Datum of 1988 (NAVD 88) in accordance with the methods and procedures as defined in Chapter 5 – Preliminary Surveys.

4.4.2 Minimum Aerial Control Vertical Accuracy Tolerance

All aerial control vertical surveys shall meet the Minimum Vertical Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

As required in Chapter 5 – Preliminary Surveys, the following Minimum Vertical Accuracy Tolerance shall apply to all CDOT Class B – Secondary surveys including photo aerial surveys (center and wing points):

The square root of the total horizontal distance of the differential level loop in miles multiplied by 0.035 feet.

$$0.035 ft \sqrt{d}$$

4.4.3 GPS Aerial Control Vertical Survey Methods

All aerial control vertical surveys performed by GPS methods shall be performed in accordance with Chapter 3 – GPS Surveys, and shall meet the Minimum Vertical Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

As required in Chapter 3 – All GPS derived elevations shall be verified or supplemented with elevations by a more accurate survey method as follows:

1. Differential leveled elevations in accordance with the methods and procedures as stated in Chapter 5 – Preliminary Surveys.
2. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as stated in Chapter 5 – Preliminary Surveys.

4.4.4 Conventional Aerial Control Vertical Survey Methods

All aerial control vertical surveys performed by conventional survey methods shall consist of a closed loop survey in accordance with Chapter 5 – Preliminary Surveys, shall meet the Minimum Vertical Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

4.5 Aerial Control Survey Report

4.5.1 General

Upon completion of the aerial control survey, whether performed by the consultant or CDOT survey crews, an Aerial Survey Report shall be completed and filed with the CDOT Region Survey Coordinator. The project shall not be accepted as final without the Aerial Control Survey Report.

4.5.2 Aerial Control Survey Report

The Aerial Survey Report shall include the following information:

1. CDOT Project name
2. CDOT Project number
3. CDOT Project Code number
4. Highway number
5. Beginning and ending mile post
6. Sections, Townships, and Ranges
7. Permission to Enter Property Forms
8. Survey Equipment Checking and Calibration Report
9. Date of survey
10. Date of targeting
11. Date to be photographed
12. Survey crew names, titles and duties
13. Surveyor's seal and signature
14. Description of all found or set photo control monuments (center and wing points)
15. Underground Utility Locates
16. Description of targeting design and material (center and wing points)
17. Basis of Bearing
18. Basis of Elevation
19. Coordinate Datum
    a. Horizontal Datum
    b. Vertical Datum
    c. Project Elevation
    d. State Plane Coordinate Zone
    e. Project Combined Factor
    f. Meters to Feet Conversion (U.S. Survey Foot = 3937/1200)
    g. Northing Reduction (truncated)
    h. Easting Reduction (truncated)
    i. For local low-distortion coordinate systems: A detailed statement of how to convert from the primary system, (such as State Plane), to project coordinates.
20. Geodetic Coordinate listing
    a. Point's number or name
    b. Latitude
    c. Longitude
    d. State Plane coordinate North
    e. State Plane coordinate East
    f. Ellipsoid height (if GPS used)
    g. Orthometric height (elevation)
    h. Geoid model (if applied)
    i. Mapping angle
    j. Scale
    k. Point description (including, highway, milepost, and monument type, *e.g.* Type 2)

21. Project Coordinate listing
    a. Point's four digit number
    b. Northing
    c. Easting
    d. Elevation (orthometric)
    e. Point description (including, highway, milepost, and monument type, *e.g.* Type 2)

4.6 Aerial Topo Mapping Standards

4.6.1 CDOT CADD Standards

Topographic aerial survey data features and contours shall be output to MicroStation/InRoads DGN, DTM, and TIN format applying CDOT's current configuration files.

4.6.2 MicroStation/InRoads Configurations for Consultants

CDOT provides MicroStation configuration files and instructions for installation on-line at the CDOT Business Center website. Downloads to configure for a number of MicroStation V8 versions are available here: https://www.codot.gov/business/designsupport/cadd/microstation-inroads-configuration

The configuration will provide seed files, cell libraries and set-up MicroStation Level menus.

4.6.3 MicroStation Level Structure

CDOT's MicroStation/InRoads configuration provides the graphic attributions for all features identified and collected for mapping purposes. The MicroStation configuration provides MicroStation "Level" names beginning with a category, followed by feature name, and finally a feature descriptor. (E.g. TOPO_BUILDING_Garage) Many Levels include a feature descriptor that is beyond the degree of interpretation that can be accomplished successfully from aerial surveys. For these features there will be Levels with "Miscellaneous", "Other" or "Unknown" descriptors that shall be used for photogrammetric feature compilation. Where the feature can be identified to the full degree provided by the descriptor, it should be assigned the correct MicroStation Level.

4.6.4 Aerial Survey – Photogrammetric Feature Identification

Required features that cannot be identified by aerial survey methods will be field collected by means of a post-aerial or pre-aerial ground survey. Likewise, required features mapped within the aerial project scope that could not be positively or fully identified by the photogrammetrist shall be field identified in a Post-Aerial survey. The map compilation process shall use MicroStation Levels with feature descriptors as indicated in 4.6.3 to ensure their identification for the post-aerial ground survey. It should be anticipated that completion of the feature identification will require ground surveys.

The aerial mapping consultant is responsible for determining which features can be identified. The CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining which features require further identification.

4.6.5 Post Aerial or Pre-Aerial TMOSS Supplemental Surveys

TMOSS Supplemental surveys shall be performed on the ground to compliment the aerial survey within the existing constructed transportation corridor template, and shall be performed in accordance with the methods, procedures, horizontal and vertical accuracies tolerances as required in Chapter 5 – Preliminary Surveys. The supplemental survey fieldwork may be performed by the consultant or by CDOT survey crews as required in the project scope and shall utilize CDOT Level Structure.

The purpose of the supplemental survey is to locate those features that require a higher level of accuracy than that of the aerial survey, to locate those features that cannot be located by the aerial survey, and to collect information not apparent to the photogrammetrist from the aerial survey.

The aerial mapping consultant is responsible for determining which aerial survey features may need supplemental identification, the CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining which features require supplemental surveying.

4.6.6 Minimum Horizontal and Vertical Accuracy Tolerance for TMOSS Supplemental Survey

All supplemental surveys performed on the ground to complete the aerial survey shall be performed in accordance with the methods, procedures, and the Minimum Horizontal and Vertical Accuracy Tolerance as required in Chapter 5 – Preliminary Surveys.

No payment will be made for supplemental survey data conducted by the consultant until the data has been verified (See Method of Verifying Accuracy Tolerance 4.7.4, for additional information) to be within the required topographic survey Minimum Horizontal and Vertical Accuracy Tolerance as required in Chapter 5 – Preliminary Surveys . Any data not within the required tolerances will be rejected, reworked by the consultant, re-verified to be within required tolerances, and re-submitted at no additional cost to CDOT.

4.7 Aerial Mapping Tolerances

The American Society for Photogrammetry and Remote Sensing (ASPRS) has published aerial map accuracy standards titled ASPRS Positional Accuracy Standards for Digital Geospatial Data. The first edition was published in 2014, (Edition 1, Version 1.0 – November, 2014). The intention is to conform to universally accepted standards by adopting these expressions to state project accuracy requirements. ASPRS Accuracy Classes are expressed in terms of Root Mean Square Error (RMSE). The tables below provide ASPRS Accuracy Classes for horizontal and vertical accuracy, along with the corresponding expression of accuracy at 95% confidence. The tables are modeled after those provided by ASPRS. The ASPRS Accuracy Class in the tables below represents the typical project accuracy tolerance for CDOT Aerial Mapping. The accuracy tolerance is stated in relation to the project primary control monuments.

NOTE: The project scope of work may indicate different accuracy tolerances as appropriate to the individual project and approved by the CDOT Region Survey Coordinator.

4.7.1 Aerial Mapping Horizontal Accuracy Tolerance

Horizontal Accuracy Class: 0.25'

For ASPRS 0.25' Horizontal Accuracy Class the corresponding NSSDA expression at 95% confidence is 0.61'. This represents an increase in accuracy compared to the CDOT historical requirement of 1' at 95% confidence. The new requirement acknowledges the benefits offered by digital mapping production processes that have eliminated many sources of horizontal error propagation between source data and final map products. The stated Horizontal Accuracy Class requirement should apply to well-defined planimetric features compiled from any aerial source.

Horizontal Accuracy Class	RMSEx or y	RMSEr	Horizontal Accuracy at the 95% Confidence Level
0.25'	0.25'	0.35'	0.61'

See ASPRS Positional Accuracy Standards for Geospatial Data, Table 7.1 Horizontal Accuracy Standards for Geospatial Data, page A7.

RMSEr represents the RMSE in radial terms by combining X and Y distances.

4.7.1.1 Orthophotography

Horizontal Accuracy Class: 0.5'

The ASPRS Classes for orthophotography are expressed in RMSEx or y. This standard does not associate product accuracy with the GSD of the source imagery, pixel size of the orthoimagery, or map scale for scaled maps. Orthophotography is output as a fixed resolution raster data product. The resolution precision of the data output limits achievable horizontal accuracy compared to data compiled directly from 3D models. For CDOT purposes, orthophotography for standard mapping and GIS work will meet requirements Orthophoto pixels shall represent 0.25' on the ground. The table below represents the expected Horizontal Accuracy Tolerance associated with the orthophotography output at 0.25' resolution.

Horizontal Accuracy Class	RMSEx or y	RMSEr	Orthoimage Mosaic Seamline Maximum Mismatch	Horizontal Accuracy at the 95% Confidence Level	Nominal GSD of Source Imagery
0.5'*	0.5'	0.71'	1.00'	1.22'	0.13 to 0.25'

*for 0.25' foot pixels

See ASPRS Positional Accuracy Standards for Geospatial Data, Table B.3 Common Horizontal Accuracy Classes According to the new Standard, page A13 and Table B.5 Digital Orthoimagery Accuracy Examples for Current Large and Medium Format Metric Cameras, page A13.

Nominal GSD column represents the maximum acceptable GSD for source imagery. No up-sampling of imagery from a GSD lower than the intended output resolution of the orthophotography is acceptable.

4.7.2 Aerial Mapping Vertical Accuracy Tolerance

Vertical Accuracy Class: 0.25'

Aerial mapping minimum vertical accuracy tolerance applies to areas outside of the existing constructed transportation corridor template. The ASPRS Class that corresponds most closely with a tolerance for +/- 1/2 foot at 95% is represented in the table below. The ASPRS Class provides corresponding accuracy tolerances for open areas and hard surfaces as "Non-Vegetated Vertical Accuracy" (NVA) and for vegetated areas, as "Vegetated Vertical Accuracy" (VVA), each in 95% confidence expressions. The stated Vertical Accuracy Class requirement should apply to elevation data compiled from any aerial source.

ASPRS - Vertical Accuracy Class RMSE	Vertical Accuracy at the 95% Confidence Level	
	NVA - Non-Vegetated Vertical Accuracy	VVA - Vegetated Vertical Accuracy
0.25'	0.49'	0.74'

See ASPRS Positional Accuracy Standards for Geospatial Data, Table B.7 Vertical Accuracy/Quality Examples for Digital Elevation Data, page A15 regarding Absolute Accuracy.

4.7.3 Existing Constructed Transportation Corridor Template

The existing constructed transportation corridor template is defined as the area between the points of slope selection. Typically for a two lane highway, this area includes the transportation corridor Z distance, the transportation corridor shoulder, and the transportation corridor traveled way on both sides of the centerline. For an interstate highway, this area includes all of the median as well as the area described above. In urban areas, this includes all the area between the backsides of the sidewalks on both sides of the street.

4.7.4 Obscured Areas

Obscured areas are defined as areas within the aerial mapping project limits where vegetation or tree canopy, dense smoke features are obscuring the aerial perspective. These areas will be identified in such cases where planimetric feature compilation cannot be completed or where there is insufficient elevation data to meet the specified vertical accuracy tolerance for vegetated areas. The areas will be identified with a MicroStation polygon feature and provided to the CDOT Region Survey Coordinator to consider for supplemental ground survey.

4.7.5 Vertical Accuracy Testing - Method of Verifying Accuracy Tolerance

4.7.5.1 Photogrammetry

Accuracy tolerance requirements are evaluated by comparing a cross section string, or a series of random checkpoints taken in the field with the same cross section location, or series of random point locations, extracted from a terrain TIN model produced from the original aerial survey data. The field cross section string is collected by conventional topographic survey methods and is held as the true representation of what exists in the field in relation to the primary control monuments. The interval between observations on the cross section shall be taken at a minimum of 30 feet, include all changes of slope, and shall not exceed the interval of the aerial mapping at the particular cross section.

The field cross section string or random checkpoints are then processed and compared to the TIN model aerial survey cross section or random points. The difference between the sections is evaluated to determine if the delivered product is within the minimum horizontal and vertical aerial mapping tolerances.

The number and location of random checkpoints or cross section strings will vary according to project size, field conditions and specific project requirements. The scope of work shall include a description of the verification requirements on a project by project basis.

4.7.5.2 Aerial LiDAR

Accuracy testing of LiDAR TIN models will be accomplished in the same manner as above. TIN models produced from Aerial LiDAR shall be produced using only breaklines and "Key Points", a DTM representation of the "Ground" class data returns that has been thinned based on a mathematical algorithm that eliminates redundant points without compromising the intended vertical accuracy requirement. This process significantly reduces file size. Aerial LiDAR TIN models will be produced from DTM data that may contain much fewer breaklines since point density is higher and intelligently concentrated to the key points necessary to accurately portray the terrain surface.

4.8 Aerial Surveys and Photogrammetry Specifications

4.8.1 General

The aerial mapping consultant shall provide specifications meeting the project needs for the following:

1. Camera/Sensor(s)
2. Film or digital imaging requirements, for example: 3-band (RGB), 4-band (RGB&NIR)
3. Scanner type and resolution if film used.
4. Aircraft *
5. Crew *
6. Photogrammetry/geospatial data processing equipment and software

** Only required for flights below 1,000' Above Ground Level (AGL) and flights in FAA designated "Special Use Airspace" or those requiring a written Prior Permission Request (PPR) to land at a military airport.*

All aerial surveys will be conducted in full compliance with FAA rules and regulations. It is the aerial mapping consultant's responsibility to obtain necessary FAA or military authorizations to fly in Special Use Airspace as defined by the FAA's aeronautical charts. The CDOT Region Survey Coordinator may provide assistance as necessary in the form of a letter supporting the request as being in the public interest.

The aerial mapping consultant shall work closely with the CDOT Region Survey Coordinator when determining the aerial mapping specifications.

4.8.2 American Society for Photogrammetry & Remote Sensing (ASPRS)

Personnel qualifications must be appropriate to the planned technical approach. A Certified Photogrammetrist having experience with the planned approach should oversee project design and quality control. Approach and resulting products shall follow relevant guidelines and meet or exceed the current standards set forth by the American Society for Photogrammetry & Remote Sensing (ASPRS) for use in aerial surveys.

See Appendix "ASPRS Positional Accuracy Standards for Geospatial Data", for additional information.

It is the aerial mapping consultant's responsibility to ensure that aerial surveys are conducted in accordance with equipment manufacturers recommendation's and stated limitations in terms of accuracy. The aerial mapping consultant will be ultimately responsible for the aerial system's output suitability in terms of compatibility with downstream processes and final product specifications.

4.8.3 Project Location and Limits

The location and limits of the aerial survey project is indicated in the project provisions. The CDOT Region Survey Coordinator or designee is responsible for determining the aerial survey location and limits. The aerial mapping consultant shall work closely with the CDOT Region Survey Coordinator when determining the aerial survey location and limits.

Location and limits of the aerial survey project need to be clearly defined to ensure complete coverage is acquired. There are several alternative methods to define the location and limits such as on hard copy maps or electronic maps such as GoogleEarth or Bing Maps. (Please note that web-based maps should only be used for planning and general illustration purposes since their spatial accuracy is limited and inconsistent.) Further clarification of the aerial survey location and limits may be provided with some text descriptions. The location and limits of the aerial survey should specify the following:

1. Beginning and end sections
2. Required width
3. Minimum distance on either side of the existing transportation corridor

The aerial survey location and limits shall include the following in addition to the project provisions:

1. For crossroad interchanges with grade separations, the aerial survey shall also include 1,000 feet of the crossroad on each side of the existing transportation corridor centerline.
2. For at-grade intersections, the aerial survey shall also include 500 feet of the crossroad on each side of the existing transportation corridor centerline.
3. The aerial survey shall also include the area necessary for a complete hydraulic design as required in the project provisions and in Chapter 5 – Preliminary Surveys.
4. Aerial Photography shall extend one full photograph beyond the end of the aerial survey location and limits.
5. Aerial LiDAR data shall extend a minimum 300' beyond all project limits and 900' past corridor end limits.

4.8.4 Aerial Survey Field Conditions

Field conditions during aerial surveys shall be conducive to the preparation of the final aerial survey products within the required tolerances.

Aerial surveys shall not be conducted when the ground is obscured by clouds, haze, fog, dust, snow, or vegetation, when streams are not within their normal banks, or when flooding conditions exist unless specific waiver is given by the CDOT Region Survey Coordinator.

Aerial survey approach using AGPS must also consider Positional Dilution of Precision (PDOP) during the flight mission. PDOP should be lower than 3.0 and at least six (6) GPS satellites must be available at 10 degrees or more above the horizon at all times throughout the mission. Space weather in the form of excess charged ions entering the earth's magnetic fields can also present an issue. This condition is caused by solar storms that are also responsible for the "Northern" or "Southern" Light phenomenon. While this condition is rarely at a level that causes significant disruption to signal accuracy, it should be checked before flight. The National Oceanic and Atmospheric Agency's website, http://www.swpc.noaa.gov/, provides forecasts of for this condition. In Colorado, flights shall *not* be conducted when the predicted K-index exceeds four (4.0).

As a guideline, aerial surveys will be accomplished during the period when deciduous trees are barren, and between 10 A.M. and 2 P.M. (when the sun angle is not less than 30 degrees). The same rule applies to aerial LiDAR systems collecting imagery in conjunction with the LiDAR.

Note: If a project plan calls for a LiDAR-only flight, sun angle becomes irrelevant.

4.8.5 Flight Plan

Prior to any aerial survey the mapping consultant shall submit a flight plan showing the proposed flight lines on a topographic map of the project area or in a digital file that can be geo-referenced with existing mapping or a web-based GIS application. The aerial mapping consultant is responsible for the flight plan and shall work closely with the CDOT Region Survey Coordinator when establishing the flight plan. CDOT reserves the right to comment on the elements of the flight plan, but is not responsible for approval. The consultant is responsible for ensuring that the aerial survey coverage will be adequate to produce the final results required for all the deliverable products.

The flight plan shall at a minimum include the following:

1. Flight lines labeled to show flight height and negative scale or nominal Ground Sample Distance (GSD).
2. CDOT primary control monument locations labeled by number or name.
3. Photo control monuments to be targeted, labeled by number or name

4. The flight plan should be accompanied by a statement describing the intended data acquisition and map production approach to be applied, i.e. AGPS data acquisition, conventional film approach and optical analytical plotter, scanned film and softcopy photogrammetry, fully digital softcopy photogrammetry, or any other aerial survey sensor & approach.
5. Camera calibration report and calibration file as appropriate to sensor(s) planned.
6. Manufacturer's Specification sheets for digital cameras or LiDAR systems planned.

4.8.6 Aircraft

Aircraft maintenance and operation shall be in accordance with Federal Aviation Administration (FAA) and Civil Aeronautics Board (CAB) regulations.

4.8.7 Aerial Data Acquisition

The planning and aerial data acquisition will follow relevant guidelines and shall meet or exceed all of the current American Society for Photogrammetry & Remote Sensing (ASPRS) standards for the following:

1. Flight height (determined by the desired mapping scale and contour interval)
2. Forward and side overlap (typically 60% forward and 30% side for photography)
3. Side overlap for LiDAR (typically 30% but may require increase for urban areas)
4. Aircraft motion; crab, tip and tilt and acceptable departures for each parameter (photography)
5. Nominal Ground Sampling Distance GSD (digital photography)
6. Density of returns; point per unit area (LiDAR)
7. Estimated pulse footprint size (LiDAR)
8. Sensor manufacturer's estimate of accuracy at planned flying height (digital cameras and LiDAR)
9. PDOP – Shall be below 3.0 for the entire flight mission (LiDAR and any photo acquisitions using AGPS data to reduce ground control targeting requirements.)
10. On-board AGPS shall collect data at 1 Hz or more with a constellation of at least 6 GPS satellites at all times during flight.
11. For aerial LiDAR data acquisitions and any photo acquisitions using AGPS data to reduce ground control targeting requirements, CDOT recommends that the Aerial Survey Consultants use minimum of two (2) ground base stations collecting data at 1 Hz or more within 25 miles of the data acquisition platform at all times during flight. Continuous Operating Reference Stations (CORS) may be acceptable as ground base stations assuming they meet the data collection and distance criteria above during the mission.

NOTE: Any aerial data acquisition system employing AGPS shall follow the relevant items 9 through 11 above.

4.8.8 Raw Data

These subsections define the requirements for raw data including digital imagery and LiDAR data.

4.8.8.1 Imagery Quality

The film original negatives or original imagery produced shall meet the current American Society for Photogrammetry & Remote Sensing (ASPRS) standards for clarity and contrast and shall meet or exceed all project needs for the following:

The film original negatives or original imagery produced shall meet the current American Society for Photogrammetry & Remote Sensing (ASPRS) standards for clarity and contrast and shall meet or exceed all project needs for the following:

1. Color (negatives, or RGB imagery)
2. Black and white or monochromatic imagery
3. Infrared (negatives or multispectral imagery)
    a. Color or RGB, IR
    b. Monochromatic imagery

If film is used it shall be exposed in accordance with the manufacturer's recommendations.

The film shall be scanned to digital imagery using a high precision film scanner at a resolution of 15 microns or finer. All digital imagery shall be delivered in a universal digital format so it can be used in a softcopy photogrammetry workflow.

Imagery shall become the property of CDOT. Once the aerial survey has been submitted and accepted all imagery files shall be sent to the CDOT Region Survey Coordinator or designee for inclusion in the project archive.

The required horizontal and vertical accuracy will determine the flight height and photo scale or image GSD of the original photography. (See Section 4.8.5 item 1.)

4.8.8.2 Film Labeling

If film is used it must be labeled prior to scanning. Each negative shall be marked clearly with the following:

1. Numerical abbreviation of the month, day, and year of exposure (*e.g.* 4/19/82)
2. CDOT Project Code (five digits)
3. Flight line number
4. Frame number (e.g. XXXXX 5-15)

The exposures shall run in a series of numbers beginning with the number 1 for each flight line.

The first and last negatives of each flight strip shall carry the approximate time of day of the exposure, the approximate scale, and the nominal focal length of the lens used. This information shall be suitably spaced between the date and the project number (e.g. 4/19/82 11:30 1:12000 6" XXXXX 5 of 15). All lettering and numbering on the negative shall be approximately ¼ inch high and shall result in easily read, sharp and uniform letter and numbers on all photographs (both contact prints and enlargements) printed from the negatives.

4.8.8.3 Aerial Triangulation

Aerial triangulation shall be done under the direction of an ASPRS Certified Photogrammetrist or state licensed aerial survey professional. The process will be conducted in accordance with guidelines set forth for aerial triangulation in the current ASPRS Positional Accuracy Standards for Digital Geospatial Data manual.

The following table provides an example of the accuracy guidelines to output data 0.25 foot in RMSE (0.5 foot at 95% confidence.)

Product Accuracy (RMSEx, RMSEy, RMSEz)	AT Accuracy	
	RMSEx and RMSEy	*RMSEz
0.25'	0.13'	0.13'

See ASPRS Positional Accuracy Standards for Geospatial Data, Table B.2 Aerial Triangulation and Ground Control Accuracy Requirements, Orthophotography and/or Planimetric Data and Elevation Data, page A12.

**If products are for planimetric data or orthophotography only, the RMSEz may be relaxed to 0.25 feet. (See Table B.1 Aerial Triangulation and Ground Control Accuracy Requirements, Orthophotography and/or Planimetric Data Only.)*

Aerial triangulation best practices should include a validation run of the block adjustment with up to 20% of the ground control withheld from the solution. This provides a quantitative quality control step revealing accuracy at known points not incorporated as control in the aerial triangulation. The final block adjustment should include all control points in the solution for application in subsequent geospatial data processing and production.

Aerial triangulation digital output will be delivered along with raw TIF imagery in a universal format approved by the CDOT Region Survey Coordinator. The intent is to ensure that project raw data is available to CDOT should there be a requirement to re-visit or extend the project at a later date. Industry standard output formats from software such as Hexagon (Intergraph) ISAT, Trimble Inpho, Bingo, or any PAT-B output may be acceptable. The provided digital output should provide the following at a minimum:

1. Summary of Aerial Triangulation adjustment results (Including RMSE at Ground Control)
2. Ground control
3. Camera file (calibration data)
4. Photo files
5. Photo measurements
6. Adjusted coordinates
7. Photo centers
8. Exterior orientations

Aerial triangulation digital output will be delivered on portable USB hard drive. (See: 4.9.11 Raw Data Files.)

4.8.8.4 Digital Image Naming Convention

Original digital imagery or scanned film images will be delivered in a TIF format, 8 bit per band. (i.e.: RGB imagery will be delivered in 24-bit TIF format.)

Each TIF image shall be named as followings:

1. CDOT Project Code
2. Flight line number
3. Frame number (For example: 00300-03005)

The first five digits shall be the CDOT Project Code, dash, two digits for flight line number and three for the frame number.

Information such as date & time of exposure, width or number of pixel columns, height or number of pixel rows, and other attribute information shall be available by right clicking on an image in a Windows environment.

Raw digital imagery will be delivered on portable USB hard drive. (See: 4.9.11 Raw Data Files.)

4.8.8.5 Aerial LiDAR - General

Aerial LiDAR may present opportunities to benefit an aerial survey based on advantages described under section 4.1.6. If approved, the consultant will apply industry standard tools and established best practices to ensure source data meets the quality standards required for the map accuracy specification. Data shall be processed to minimize noise, calibrated internally, swath to swath, and finally calibrated to the ground control points. The **ASPRS Positional Accuracy Standards for Geospatial Data** will be the reference document governing accuracy requirements. This includes relative accuracy within a swath as well as swath-to- swath accuracy requirements for internal data calibration. Tables are metric and not all vertical accuracy examples are provided, however, units can be converted and interpolations can be accomplished for any accuracy requirement. An example of vertical accuracy/quality requirements for CDOT 1' contours is as follows:

Vertical Accuracy Class	Absolute Accuracy		Relative Accuracy		
	RMSEz Non-Vegetated	NVA at 95th Percentile	Within Swath Hard Surface Repeatability (Max. Diff.)	Swath-to-Swath Non-Veg. Terrain (RMSEz)	Swath-to-Swath Non-Veg. Terrain (Max. Diff.)
0.25'	0.25'	0.75'	0.15'	0.2'	0.4'

See ASPRS Positional Accuracy Standards for Geospatial Data, Table 7.2 Vertical Accuracy Standards for Digital Elevation Data, page A7.

4.8.8.6 Aerial LiDAR Data Application

Any proposed application of aerial LiDAR approved to support topographic mapping will be planned such that a minimum of eight (8) pulses per square meter (ppm) are collected over the project area during flight. Systems collecting photography and LiDAR data simultaneously must be planned with consideration for limitations of both sensors. *(For example, camera specifications call for a flying height of no more than 1500' to meet the vertical accuracy requirement, the flying height shall not exceed that altitude regardless of whether the LiDAR can meet the requirement at higher altitude.)*

Topographic break lines, as well as planimetric features will be compiled by photogrammetric means. LiDAR ground returns at positions less than 1' distance from photogrammetrically compiled break lines shall be filtered out of the DTM to avoid any adverse effect of horizontal relative accuracy between data sets.

For any approach that combines photography and LiDAR flown separately, the consultant will describe the measures taken to ensure relative accuracy, or registration, between the two data-sets.

While broader applications, such as break line and planimetric data extraction from aerial LiDAR may be tested and considered by CDOT in the future, the guidelines and limitations for such applications have not yet been determined and therefore not included in this chapter.

4.8.8.7 LiDAR Data Calibration Results

A digital record of the LiDAR data calibration accomplished to arrive at final relative and absolute accuracy will be delivered along with the point cloud data in a universal industry standard format. The intent is to ensure that project raw data is available to CDOT should there be a requirement to re-visit the data calibration at a later date. At a minimum, the calibration record should show adjustments made to register to ground control and any internal swath to swath calibration test results demonstrating that specified relative accuracy requirements were met. LiDAR data calibration digital output will be delivered on portable USB hard drive along with the LiDAR Point Cloud. (See: 4.9.11 Raw Data Files.)

4.8.8.8 LiDAR Point Cloud

If LiDAR is flown to support production of topographic mapping the calibrated point cloud will be delivered to CDOT in ASPRS LAS 1.2 (or later) format unless otherwise specified in the scope of work. The data, at a minimum, will be "Ground" classified (see "2" below) and "Model Key Point" following the ASPRS numerical coding for LAS files.

Basic ASPRS LAS numerical coding for LiDAR Data Classes and their definitions are:
0 = Created, never classified
1 = Unclassified
2 = Ground
3 = Low Vegetation
4 = Medium Vegetation
5 = High Vegetation
6 = Building
7 = Low Point ("low noise")
8 = Key Point (Note - For LAS format 1.2 or 1.3 – model key points or subset of ground classified points used for DTM products.)
8 = High Point (For LAS 1.4 or later typically "high noise") - Note that this value was previously used for Model Key Points. *Bit 1* of the Classification Flag must now be used to indicate Model Key Points. This allows the Model Key Point Class to be preserved.
9 = Water
10 = Rail
11 = Road Surface
12 = Overlap points (Note – For LAS format 1.2 or 1.3 Overlap Points are those points that were immediately culled during the merging of overlapping flight lines. For LAS format 1.4, the *Withheld* bit should be set since these points are not subsequently classified.)
12 = Bridge Deck (Note – for LAS format 1.4)
13 = Wire - Guard
14 = Wire – Conductor (Phase)
15 = Transmission Tower
16 = Wire-structure Connector (e.g. Insulator)
17 = Reserved
18-63 = Reserved
64-255 = User definable – The specific use of these classes should be encoded in the Classification lookup Variable Length Record (VLR).
*(Minimum requirements are in **bold**.)*

If required, ASCII files should be in a six (6) column, comma delimited format as follows:
X,Y,Z, Class, Intensity, Echo
Where;
X = easting value in State Plane coordinates in US Survey Feet to 2 places of decimal
Y = northing value in State Plane coordinates in US Survey Feet to 2 places of decimal
Z = orthometric elevation in US Survey Feet to 2 places of decimal
Class = LAS point classification
Intensity = reflectance value of return expressed as an integer
Echo=sequence of return and total number of returns from the associated pulse *(e.g. 1/3, meaning 1st of 3 returns from a LiDAR pulse.)*

LiDAR Point Cloud data shall be delivered on portable USB hard drive. (See: 4.9.11 Raw Data Files.)

4.8.8.9 LiDAR Tile Layout, File Naming

LiDAR LAS files will be delivered in a rectangular tile format. Files should not exceed 2,000 feet by

2,000 feet, assuming data acquisition density of 8 ppm. For projects requiring a higher density of returns, it may be necessary to limit tile sizes to as small as 1,000' by 1,000'. An intuitive approach to file naming such as truncated lower left coordinate pairs or sequential numbering west to east or south to north is recommended. For projects that include orthophoto deliverables it is recommended that LiDAR tile layouts and naming coincide with the orthophotos. File naming should be pre-determined and approved by the CDOT Region Survey Coordinator or designee in the project planning stage. Any raw LiDAR (.LAS or ASCII) shall be accompanied by a tile index in the CDOT MicroStation configuration format. (See: 4.6.3 MicroStation Level Structure and 4.9.11 Raw Data Files)

4.8.8.10 Re-flights

Unacceptable photography / aerial data coverage shall be corrected at the consultant's expense. Re-flights shall be flown parallel to the original flight line. Re-flight aerial photography coverage shall overlap accepted coverage by two stereo models and shall meet the end and side lap requirements specified. The same camera used on the original flights shall be used on re-flight. Aerial LiDAR re-flights may be flown at right angles or parallel to the original flight lines in the opposing direction to ensure best mission to mission calibration. Overlap distance shall be adequate for line to line and/or mission to mission data calibration.

Modern Surveying Instruments

Modern equipments

- EDM – Electronic distance measurement equipment.
- Electronic theodolite.
- Total station.

- By the 1970's, relatively small, lightweight and easy-to-use electronic distance measuring devices, called **EDM's** were in use.
- The advance of technology and miniaturization of electronic components enabled the building of theodolites that measure angles electronically, called **Electronic Theodolite**
- Combination of an electronic theodolite and electronic distance meter, and software running on an external laptop computer known as a data collector, called **Total Station**
- **The Global Positioning System (GPS)** was designed for military applications. Its primary purpose was to allow soldiers to keep track of their position and to assist in guiding weapons to their targets
- A computerized data base management system for capture, storage, retrieval, analysis, and display of spatial data, called **GIS**

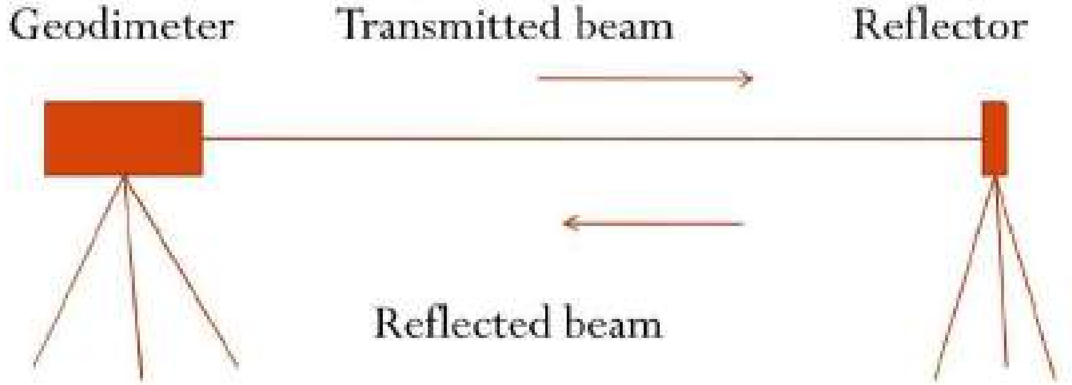
EDM

- Measurement of distance is accomplished with a modulated microwave or infrared carrier signal, generated by a small solid-state emitter within the instrument's optical path, and bounced off of the object to be measured. The modulation pattern in the returning signal is read and interpreted by the onboard computer in the EDM. The distance is determined by emitting and receiving multiple frequencies, and determining the integer number of wavelengths to the target for each frequency.

Principle

- In EDM the beam of light is the carrier and which is reflected back from mirror located at the other end. Such instrument are less expensive because one active instrument and battery are only needed at one end and instrument at other end is simply a reflecting mirror centered over ground centre mark

Principle



Hand held EDM

- Very handy
- Cheap
- Can be used with accuracy of 10mm or so
- Rapid measurement
- Long range
- High accuracy
- Measurement of moving target

Electronic Theodolite

- For precise surveys the vernier theodolites are replaced by modern theodolites such as optical and electronic theodolites.
- The electronic theodolites have optical system to scan both horizontal and vertical circles and display them digitally on a screen

TOTAL STATION

- **Basic Principle**

  A total station integrates the functions of a theodolite for measuring angles, an EDM for measuring distances, digital data and a data recorder. All total stations have similar constructional features regardless of their age or level of technology, and all perform basically the same functions.

Basic principle of total station

1. These instruments are measuring the distances of prism poles mounted with prisms with the help of Laser beam or Infrared rays.
2. These signals are emitted by the instrument EDM and reflected back to instruments by the prism mounted on the prism poles.
3. The time interval between emission and reception helps to calculate the distance as the speed of these signals are precisely known. **D = (t/2) x v**
   D-Distance, t-Total time taken, v-Velocity

Features:-

- Total solution for surveying work,
- Most accurate and user friendly,
- Gives position of a point (x, y and z) w. r. t. known point (base point),
- Measures distance and angles and displays coordinates,
- EDM is fitted inside the telescope,
- Digital display,

- On board memory to store data,
- Compatibility with computers,
- Measures distance and angles and displays coordinates,
- Auto level compensator is available,
- Can work in lesser visibility also,
- Can measure distances even without prismatic target for lesser distances,
- water proof,
- On board software are available,
- Can be used for curve layout after feeding data.

Total Stations can be used for:

- General purpose angle measurement
- General purpose distance measurement
- Slope measurement
- Provision of control surveys
- Contour and detail mapping
- Setting out and construction work

- Angular accuracy up to 1”
- Distance measured with laser up to 2 KM
- Distance measured with infrared rays up to 4 KM.(with single prism)
- Capable of storing up to 20,000 points.

Components of a Total Station

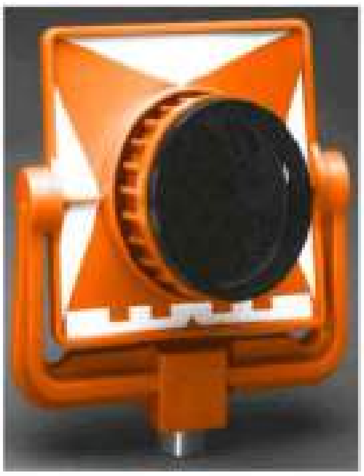
- EDM
- Electronic theodolite
- On-Board Micro-processor
- Data Collector
- Data Storage
- Prisms

Micro-processor

- **Averages** multiple **angle** measurements
- **Averages** multiple **distance** measurements
- Computes **horizontal** and **vertical distances**
- **Corrections** for temp, pressure and humidity
- **Computes** all the X, Y and Z **coordinates**

Specifications

- **Range**
  Reflector less : 3 – 70 meters
  Single Prism : 1 – 3000 m
- **Accuracy**
  Angles : 1" - 5"
  Distance : 3mm (with prism)
  :4mm (with out)
- **Data Storage :** 5000 points



Advantages of Total Station over Conventional instruments:

- Traditional survey methods are laborious and time consuming
- Fully automatic electronic measurement
- Digital display of staff reading and distance
- Data storage in instrument possible
- Direct transfer to personal computer of data stored in instruments
- Online operation through integrated interface to computer

Disadvantages

- Total stations are dependent on batteries and electronics. The LCD screen does not work well when it is cold.
- Battery life is also short, batteries and electronics both do not work well when wet.
- Loss of data is an important consideration.

Recent developments include a GPS unit with the total station

Fully integrated data storage and data processing, Bluetooth data transfer or GPRS

Geographical Information Systems (GIS)

Introduction

Geographical Information System (GIS) is a technology that provides the means to collect and use geographic data to assist in the development of Agriculture. A digital map is generally of much greater value than the same map printed on a paper as the digital version can be combined with other sources of data for analyzing information with a graphical presentation. The GIS software makes it possible to synthesize large amounts of different data, combining different layers of information to manage and retrieve the data in a more useful manner. GIS provides a powerful means for agricultural scientists to better service to the farmers and farming community in answering their query and helping in a better decision making to implement planning activities for the development of agriculture.

Overview of GIS

A Geographical Information System (GIS) is a system for capturing, storing, analyzing and managing data and associated attributes, which are spatially referenced to the Earth. The geographical information system is also called as a geographic information system or geospatial information system. It is an information system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically referenced information. In a more generic sense, GIS is a software tool that allows users to create interactive queries, analyze the spatial information, edit data, maps, and present the results of all these operations. GIS technology is becoming essential tool to combine various maps and remote sensing information to generate various models, which are used in real time environment. Geographical information system is the science utilizing the geographic concepts, applications and systems.

Geographical Information System can be used for scientific investigations, resource management, asset management, environmental impact assessment, urban planning, cartography, criminology, history, sales, marketing, and logistics. For example, agricultural planners might use geographical data to decide on the best locations for a location specific crop planning, by combining data on soils, topography, and rainfall to determine the size and location of biologically suitable areas. The final output could include overlays with land ownership, transport, infrastructure, labour availability, and distance to market centers.

History of GIS development

The idea of portraying different layers of data on a series of base maps, and relating things geographically, has been around much older than computers invention. Thousands years ago, the early man used to draw pictures of the animals they hunted on the walls of caves. These animal drawings are track lines and tallies thought to depict migration routes. While simplistic in comparison to modern technologies, these early records mimic the two-element structure of modern geographic information systems, an image associated with attribute information.

Possibly the earliest use of the geographic method, in 1854 John Snow depicted a cholera outbreak in London using points to represent the locations of some individual cases. His study of the distribution of cholera led to the source of the disease, a contaminated water pump within the heart of the cholera outbreak. While the basic elements of topology and theme existed previously in cartography, the John Snow map was unique, using cartographic methods, not only to depict but also to analyze, clusters of geographically dependent phenomena for the first time.

The early 20th century saw the development of "photo lithography" where maps were separated into layers. Computer hardware development spurred by nuclear weapon research led to general-purpose computer "mapping" applications by the early 1960s. In the year 1962, the world's first true operational GIS was developed by the federal Department of Forestry and Rural Development in Ottawa, Canada by Dr. Roger Tomlinson. It was called the "Canada Geographic Information System" (CGIS) and was used to store, analyze, and manipulate data collected for the Canada Land Inventory (CLI). It is an initiative to determine the land capability for rural Canada by mapping information about soils, agriculture, recreation, wildlife, forestry, and land use at a scale of 1:50,000.

data over the Internet, requiring uniform data format and transfer standards. More recently, there is a growing number of free, open source GIS packages, which run on a range of operating systems and can be customized to perform specific tasks. As computing power increased and hardware prices slashed down, the GIS became a viable technology for state development planning. It has become a real Management Information System (MIS), and thus able to support decision making processes.

Components of GIS

GIS enables the user to input, manage, manipulate, analyze, and display geographically referenced data using a computerized system. To perform various operations with GIS, the components of GIS such as software, hardware, data, people and methods are essential.

Software

GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are (a) a database management system (DBMS) (b) tools for the input and manipulation of geographic information (c) tools that support geographic query, analysis, and visualization (d) a graphical user interface (GUI) for easy access to tools. GIS software are either commercial software or software developed on Open Source domain, which are available for free. However, the commercial software is copyright protected, can be expensive and is available in terms number of licensees.

Currently available commercial GIS software includes Arc/Info, Intergraph, MapInfo, Gram++ etc. Out of these Arc/Info is the most popular software package. And, the open source software are AMS/MARS etc.

Hardware

Hardware is the computer on which a GIS operates. Today, GIS runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations. Minimum configuration required to Arc/Info Desktop 9.0 GIS application is as follows:

Product: ArcInfo Desktop 9.0

Platform: PC-Intel

Operating System: Windows XP Professional Edition, Home Edition

Service Packs/Patches: SP 1

SP2 (refer to Limitations)

Shipping/Release Date: May 10, 2004

Hardware Requirements

CPU Speed:	800 MHz minimum, 1.0 GHz recommended or higher
Processor:	Pentium or higher
Memory/RAM:	256 MB minumum, 512 MB recommended or higher

Display Properties: Greater than 256 color depth

Swap Space:	300 MB minimum
Disk Space:	Typical 605 MB NTFS, Complete 695 MB FAT32 + 50 MB for installation
Browser:	Internet Explorer 6.0 Requirement:

(Some features of ArcInfo Desktop 9.0 require a minimum installation of Microsoft Internet Explorer Version 6.0.)

Data

The most important component of a GIS is the data. Geographic data or Spatial data and related tabular data can be collected in-house or bought from a commercial data provider. Spatial data can be in the form of a map/remotely-sensed data such as satellite imagery and aerial photography. These data forms must be properly geo-referenced (latitude/longitude). Tabular data can be in the form attribute data that is in some way related to spatial data. Most GIS software comes with inbuilt Database Management Systems (DBMS) to create and maintain a database to help organize and manage data.

Users

GIS technology is of limited value without the users who manage the system and to develop plans for applying it. GIS users range from technical specialists who design and maintain the system to those who use it to help them do their everyday work.

These users are largely interested in the results of the analyses and may have no interest or knowledge of the methods of analysis. The user-friendly interface of the GIS software allows the nontechnical users to have easy access to GIS analytical capabilities without needing to know detailed software commands. A simple User Interface (UI) can consist of menus and pull-down graphic windows so that the user can perform required analysis with a few key presses without needing to learn specific commands in detail.

Methods

A successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization.

Functions of GIS

General-purpose GIS software performs six major tasks such as input, manipulation, management, query and analysis, Visualization.

Input

The important input data for any GIS is digitized maps, images, spatial data and tabular data. The tabular data is generally typed on a computer using relational database management system software. Before geographic data can be used in a GIS it must be converted into a suitable digital format. The DBMS system can generate various objects such as index generation on data items, to speed up the information retrieval by a query. Maps can be digitized using a vector format in which the actual map points, lines, and polygons are stored as coordinates. Data can also be input in a raster format in which data elements are stored as cells in a grid structure (the technology details are covered in following section).

The process of converting data from paper maps into computer files is called digitizing. Modern GIS technology has the capability to automate this process fully for large projects; smaller jobs may require some manual digitizing. The digitizing process is labour intensive and time-consuming, so it is better to use the data that already exist.

Today many types of geographic data already exist in GIS-compatible formats. These data can be obtained from data suppliers and loaded directly into a GIS.

Manipulation

GIS can store, maintain, distribute and update spatial data associated text data. The spatial data must be referenced to a geographic coordinate systems (latitude/longitude). The tabular data associated with spatial data can be manipulated with help of data base management software. It is likely that data types required for a particular GIS project will need to be transformed or manipulated in some way to make them compatible with the system. For example, geographic information is available at different scales (scale of 1:100,000; 1:10,000; and 1:50,000). Before these can be overlaid and integrated they must be transformed to the same scale. This could be a temporary transformation for display purposes or a permanent one required for analysis. And, there are many other types of data manipulation that are routinely performed in GIS. These include projection changes, data aggregation, generalization and weeding out unnecessary data.

Management

For small GIS projects it may be sufficient to store geographic information as computer files. However, when data volumes become large and the number of users of the data becomes more than a few, it is advised to use a database management system (DBMS) to help store, organize, and manage data. A DBMS is a database management software package to manage the integrated collection of database objects such as tables, indexes, query, and other procedures in a database.

There are many different models of DBMS, but for GIS use, the relational model database management systems will be highly helpful. In the relational model, data are stored conceptually as a collection of tables and each table will have the data attributes related to a common entity. Common fields in different tables are used to link them together with relations. Because of its simple architecture, the relational DBMS software has been used so widely. These are flexible in nature and have been very wide deployed in applications both within and without GIS.

Query

The stored information either spatial data or associated tabular data can be retrieved with the help of Structured Query Language (SQL). Depending on the type of user interface, data can be queried using the SQL or a menu driven system can be used to retrieve map data. For example, you can begin to ask questions such as:

- Where are all the soils are suitable for sunflower crop?
- What is the dominant soil type for Paddy?
- What is the groundwater available position in a village/block/district?

Both simple and sophisticated queries utilizing more than one data layer can provide timely information to officers, analysts to have overall knowledge about situation and can take a more informed decision.

Analysis

GIS systems really come into their own when they are used to analyze geographic data. The processes of geographic analysis often called spatial analysis or geo-processing uses the geographic properties of features to look for patterns and trends, and to undertake "what if" scenarios. Modern GIS have many powerful analytical tools to analyse the data. The following are some of the analysis which are generally performed on geographic data.

A. Overlay Analysis

The integration of different data layers involves a process called overlay. At its simplest, this could be a visual operation, but analytical operations require one or more data layers to be joined physically. This overlay, or spatial join, can integrate data on soils, slope, and vegetation, or land ownership. For example, data layers for soil and land use can be combined resulting in a new map which contains both soil and land use information. This will be helpful to understand the different behaviour of the situation on different parameters.

B. Proximity Analysis

GIS software can also support buffer generation that involves the creation of new polygons from points, lines, and polygon features stored in the database. For example, to know answer to questions like; How much area covered within 1 km of water canal? What is area covered under different crops? And, for watershed projects, where is the boundary or delineation of watershed, slope, water channels, different types water harvesting structures are required, etc.

Visualization

GIS can provide hardcopy maps, statistical summaries, modeling solutions and graphical display of maps for both spatial and tabular data. For many types of geographic operation the end result is best visualized as a map or graph. Maps are very efficient at storing and communicating geographic information. GIS provides new and exciting tools to extend the art of visualization of output information to the users.

Technology used in GIS

Data creation

Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a computer-aided design program with geo-referencing capabilities. With the wide availability of rectified imagery (both from satellite and aerial sources), heads-up digitizing is becoming the main avenue through which geographic data is extracted. Heads-up digitizing involves the tracing of geographic data directly on top of the aerial imagery instead of through the traditional method of tracing the geographic form on a separate digitizing tablet.

Relating information from different sources

If you could relate information about the rainfall of a state to aerial photographs of county, you might be able to tell which wetlands dry up at certain times of the year. A

GIS, which can use information from many different sources in many different forms, can help with such analyses. The primary requirement for the source data consists of knowing the locations for the variables. Location may be annotated by x, y, and z coordinates of longitude, latitude, and elevation, or by other geocode systems like postal codes. Any variable that can be located spatially can be fed into a GIS. Different kinds of data in map form can be entered into a GIS.

A GIS can also convert existing digital information, which may not yet be in map form, into forms it can recognize and use. For example, digital satellite images generated through remote sensing can be analyzed to produce a map-like layer of digital information about vegetative covers. Likewise, census or hydrologic tabular data can be converted to map-like form, serving as layers of thematic information in a GIS.

Data representation

GIS data represents real world objects such as roads, land use, elevation with digital data. Real world objects can be divided into two abstractions: discrete objects (a house) and continuous fields (rain fall amount or elevation). There are two broad methods used to store data in a GIS for both abstractions: Raster and Vector.

Raster

A raster data type is, in essence, any type of digital image. Anyone who is familiar with digital photography will recognize the pixel as the smallest individual unit of an image. A combination of these pixels will create an image, distinct from the commonly used scalable vector graphics, which are the basis of the vector model. While a digital image is concerned with the output as representation of reality, in a photograph or art transferred to computer, the raster data type will reflect an abstraction of reality. Aerial photos are one commonly used form of raster data, with only one purpose, to display a detailed image on a map or for the purposes of digitization. Other raster data sets will contain information regarding elevation, a DEM (digital Elevation Model), or reflectance of a particular wavelength of light.

Digital elevation model, map, and vector data, Raster data type consists of rows and columns of cells each storing a single value. Raster data can be images (raster images) with each pixel containing a color value. Additional values recorded for each cell may be a discrete value, such as land use, a continuous value, such as temperature, or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB (red, green, blue) colors, colormaps (a mapping between a thematic code and RGB value), or an extended attribute table with one row for each unique cell value. The resolution of the raster data set is its cell width in ground units.

Raster data is stored in various formats; from a standard file-based structure of TIF, JPEG formats to binary large object (BLOB) data stored directly in a relational database management system (RDBMS) similar to other vector-based feature classes. Database storage, when properly indexed, typically allows for quicker retrieval of the raster data but can require storage of millions of significantly sized records.

Vector

A simple vector map, using each of the vector elements: points for wells, lines for rivers, and a polygon for the lake. In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes. In the popular ESRI Arc series of programs, these are explicitly called shape files. Different geographical features are best expressed by different types of geometry:

Points

Zero-dimensional points are used for geographical features that can best be expressed by a single grid reference; in other words, simple location. For example, the locations of wells, peak elevations, features of interest or trailheads. Points convey the least amount of information of these file types.

Lines or polylines

One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines.

Polygons

Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types.

Each of these geometries are linked to a row in a database that describes their attributes. For example, a database that describes lakes may contain a lake's depth, water quality, pollution level. This information can be used to make a map to describe a particular attribute of the dataset. For example, lakes could be coloured depending on level of pollution. Different geometries can also be compared. For example, the GIS could be used to identify all wells (point geometry) that are within 1-mile (1.6 km) of a lake (polygon geometry) that has a high level of pollution.

Vector features can be made to respect spatial integrity through the application of topology rules such as 'polygons must not overlap'. Vector data can also be used to represent continuously varying phenomena. Contour lines and triangulated irregular networks (TIN) are used to represent elevation or other continuously changing values. TINs record values at point locations, which are connected by lines to form an irregular mesh of triangles. The face of the triangles represent the terrain surface.

Advantages and disadvantages

There are advantages and disadvantages to using a raster or vector data model to represent reality. Raster data sets record a value for all points in the area covered which may require more storage space than representing data in a vector format that can store data only where needed. Raster data also allows easy implementation of overlay operations, which are more difficult with vector data. Vector data can be displayed as vector graphics used on traditional maps, whereas raster data will appear as an image that may have a blocky appearance for object boundaries. Vector data can be easier to register, scale, and re-project. This can simplify combining vector layers from different sources. Vector data are more compatible with relational database environment. They can be part of a relational table as a normal column and processes using a multitude of operators.

The file size for vector data is usually much smaller for storage and sharing than raster data. Image or raster data can be 10 to 100 times larger than vector data depending on the resolution. Another advantage of vector data is it can be easily updated and maintained. For example, a new highway is added. The raster image will have to be completely reproduced, but the vector data, "roads," can be easily updated by adding the missing road segment. In addition, vector data allow much more analysis capability especially for "networks" such as roads, power, rail, telecommunications, etc. For example, with vector data attributed with the characteristics of roads, ports, and airfields, allows the analyst to query for the best route or method of transportation. In the vector data, the analyst can query the data for the largest port with an airfield within 60 miles and a connecting road that is at least two lane highway. Raster data will not have all the characteristics of the features it displays.

Voxel

Selected GIS additionally support the voxel data model. A voxel (a portmanteau of the words volumetric and pixel) is a volume element, representing a value on a regular grid in three dimensional space. This is analogous to a pixel, which represents 2D image data. Voxels can be interpolated from 3D point clouds (3D point vector data), or merged from 2D raster slices.

Non-spatial data

Additional non-spatial data can also be stored besides the spatial data represented by the coordinates of a vector geometry or the position of a raster cell. In vector data, the additional data are attributes of the object. For example, a forest inventory polygon may also have an identifier value and information about tree species. In raster data the cell value can store attribute information, but it can also be used as an identifier that can relate to records in another table.

Data capture

Data capture—entering information into the system—consumes much of the time of GIS practitioners. There are a variety of methods used to enter data into a GIS where it is stored in a digital format.

Existing data printed on paper or PET film maps can be digitized or scanned to produce digital data. A digitizer produces vector data as an operator traces points, lines, and polygon boundaries from a map. Scanning a map results in raster data that could be further processed to produce vector data.

Survey data can be directly entered into a GIS from digital data collection systems on survey instruments. Positions from a Global Positioning System (GPS), another survey tool, can also be directly entered into a GIS.

Remotely sensed data also plays an important role in data collection and consist of sensors attached to a platform. Sensors include cameras, digital scanners and LIDAR, while platforms usually consist of aircraft and satellites.

The majority of digital data currently comes from photo interpretation of aerial photographs. Soft copy workstations are used to digitize features directly from stereo pairs of digital photographs. These systems allow data to be captured in 2 and 3 dimensions, with elevations measured directly from a stereo pair using principles of photogrammetry. Currently, analog aerial photos are scanned before being entered into a soft copy system, but as high quality digital cameras become cheaper this step will be skipped.

Satellite remote sensing provides another important source of spatial data. Here satellites use different sensor packages to passively measure the reflectance from parts of the electromagnetic spectrum or radio waves that were sent out from an active sensor such as radar. Remote sensing collects raster data that can be further processed to identify objects and classes of interest, such as land cover.

When data is captured, the user should consider if the data should be captured with either a relative accuracy or absolute accuracy, since this could not only influence how information will be interpreted but also the cost of data capture.

In addition to collecting and entering spatial data, attribute data is also entered into a GIS. For vector data, this includes additional information about the objects represented in the system.

After entering data into a GIS, the data usually requires editing, to remove errors, or further processing. For vector data it must be made "topologically correct" before it can be used for some advanced analysis. For example, in a road network, lines must connect with nodes at an intersection. Errors such as undershoots and overshoots must also be removed. For scanned maps, blemishes on the source map may need to be removed from the resulting raster. For example, a fleck of dirt might connect two lines that should not be connected.

Raster-to-vector translation

Data restructuring can be performed by a GIS to convert data into different formats. For example, a GIS may be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion.

More advanced data processing can occur with image processing, a technique developed in the late 1960s by NASA and the private sector to provide contrast enhancement, false colour rendering and a variety of other techniques including use of two dimensional Fourier transforms.

Since digital data are collected and stored in various ways, the two data sources may not be entirely compatible. So a GIS must be able to convert geographic data from one structure to another.

Projections, coordinate systems and registration

A property ownership map and a soils map might show data at different scales. Map information in a GIS must be manipulated so that it registers, or fits, with information gathered from other maps. Before the digital data can be analyzed, they may have to undergo other manipulations—projection and coordinate conversions for example, that integrate them into a GIS.

The earth can be represented by various models, each of which may provide a different set of coordinates (e.g., latitude, longitude, elevation) for any given point on the earth's surface. The simplest model is to assume the earth is a perfect sphere. As more measurements of the earth have accumulated, the models of the earth have become more sophisticated and more accurate. In fact, there are models that apply to different areas of the earth to provide increased accuracy (e.g., North American Datum, 1927 - NAD27 - works well in North America, but not in Europe). See Datum for more information.

Projection is a fundamental component of map making. A projection is a mathematical means of transferring information from a model of the Earth, which represents a three-dimensional curved surface, to a two-dimensional medium—paper or a computer screen. Different projections are used for different types of maps because each projection particularly suits certain uses. For example, a projection that accurately represents the shapes of the continents will distort their relative sizes. See Map projection for more information.

Since much of the information in a GIS comes from existing maps, a GIS uses the processing power of the computer to transform digital information, gathered from sources with different projections and/or different coordinate systems, to a common projection and coordinate system. For images, this process is called rectification.

Spatial Analysis with GIS

Data modeling

It is difficult to relate wetlands maps to rainfall amounts recorded at different points such as airports, television stations, and high schools. A GIS, however, can be used to depict two- and three-dimensional characteristics of the Earth's surface, subsurface, and atmosphere from information points. For example, a GIS can quickly generate a map with isopleths or contour lines that indicate differing amounts of rainfall.

Such a map can be thought of as a rainfall contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. A two-dimensional contour map created from the surface modeling of rainfall point measurements may be overlaid and analyzed with any other map in a GIS covering the same area.

Additionally, from a series of three-dimensional points, or digital elevation model, isopleths lines representing elevation contours can be generated, along with slope analysis, shaded relief, and other elevation products. Watersheds can be easily defined for any given reach, by computing all of the areas contiguous and uphill from any given point of interest. Similarly, an expected thalweg of where surface water would want to travel in intermittent and permanent streams can be computed from elevation data in the GIS.

Topological modeling

In the past years, were there any gas stations or factories operating next to the swamp? Any within two miles (3 km) and uphill from the swamp? A GIS can recognize and analyze the spatial relationships that exist within digitally stored spatial data. These topological relationships allow complex spatial modeling and analysis to be performed. Topological relationships between geometric entities traditionally include adjacency (what adjoins what), containment (what encloses what), and proximity (how close something is to something else).

Networks

If all the factories near a wetland were accidentally to release chemicals into the river at the same time, how long would it take for a damaging amount of pollutant to enter the wetland reserve? A GIS can simulate the routing of materials along a linear network. Values such as slope, speed limit, or pipe diameter can be incorporated into network modeling in order to represent the flow of the phenomenon more accurately. Network modeling is commonly employed in transportation planning, hydrology modeling, and infrastructure modeling.

Cartographic modeling

The "cartographic modeling" was (probably) coined by Dana Tomlin in his PhD dissertation and later in his book which has the term in the title. Cartographic modeling refers to a process where several thematic layers of the same area are produced, processed, and analyzed. Tomlin used raster layers, but the overlay method (see below) can be used more generally. Operations on map layers can be combined into algorithms, and eventually into simulation or optimization models.

Map overlay

The combination of two separate spatial data sets (points, lines or polygons) to create a new output vector data set. These overlays are similar to mathematical Venn diagram overlays. A union overlay combines the geographic features and attribute tables of both inputs into a single new output. An intersect overlay defines the area where both inputs overlap and retains a set of attribute fields for each. A symmetric difference overlay defines an output area that includes the total area of both inputs except for the overlapping area.

Data extraction is a GIS process similar to vector overlay, though it can be used in either vector or raster data analysis. Rather than combining the properties and features of both data sets, data extraction involves using a "clip" or "mask" to extract the features of one data set that fall within the spatial extent of another data set.

In raster data analysis, the overlay of data sets is accomplished through a process known as "local operation on multiple rasters" or "map algebra," through a function that combines the values of each raster's matrix. This function may weigh some inputs more than others through use of an "index model" that reflects the influence of various factors upon a geographic phenomenon.

Automated cartography

Digital cartography and GIS both encode spatial relationships in structured formal representations. GIS is used in digital cartography modeling as a (semi) automated process of making maps, so called Automated Cartography. In practice, it can be a subset of a GIS, within which it is equivalent to the stage of visualization, since in most cases not all of the GIS functionality is used. Cartographic products can be either in a digital or in a hardcopy format. Powerful analysis techniques with different data representation can produce high-quality maps within a short time period. The main problem in Automated Cartography is to use a single set of data to produce multiple products at a variety of scales, a technique known as Generalization.

Geostatistics

Geostatistics is a point-pattern analysis that produces field predictions from data points. It is a way of looking at the statistical properties of those special data. It is different from general applications of statistics because it employs the use of graph theory and matrix algebra to reduce the number of parameters in the data. Only the second-order properties of the GIS data are analyzed.

When phenomena are measured, the observation methods dictate the accuracy of any subsequent analysis. Due to the nature of the data (e.g. traffic patterns in an urban environment; weather patterns over the Pacific Ocean), a constant or dynamic degree of precision is always lost in the measurement. This loss of precision is determined from the scale and distribution of the data collection.

To determine the statistical relevance of the analysis, an average is determined so that points (gradients) outside of any immediate measurement can be included to determine their predicted behavior. This is due to the limitations of the applied statistic and data collection methods, and interpolation is required in order to predict the behavior of particles, points, and locations that are not directly measurable.

Interpolation is the process by which a surface is created, usually a raster data set, through the input of data collected at a number of sample points. There are several forms of interpolation, each which treats the data differently, depending on the properties of the data set. In comparing interpolation methods, the first consideration should be whether or not the source data will change (exact or approximate). Next is whether the method is subjective, a human interpretation, or objective. Then there is the nature of transitions between points: are they abrupt or gradual. Finally, there is whether a method is global (it uses the entire data set to form the model), or local where an algorithm is repeated for a small section of terrain.

Interpolation is a justified measurement because of a Spatial Autocorrelation Principle that recognizes that data collected at any position will have a great similarity to, or influence of those locations within its immediate vicinity.

Digital elevation models (DEM), triangulated irregular networks (TIN), Edge finding algorithms, Theissen Polygons, Fourier analysis, Weighted moving averages, Inverse Distance Weighted, Moving averages, Kriging, Spline, and Trend surface analysis are all mathematical methods to produce interpolative data.

Address Geocoding

Geocoding is calculating spatial locations (X,Y coordinates) from street addresses. A reference theme is required to geocode individual addresses, such as a road centerline file with address ranges. The individual address locations are interpolated, or estimated, by examining address ranges along a road segment. These are usually provided in the form of a table or database. The GIS will then place a dot approximately where that address belongs along the segment of centerline. For example, an address point of 500 will be at the midpoint of a line segment that starts with address 1 and ends with address 1000. Geocoding can also be applied against actual parcel data, typically from municipal tax maps. In this case, the result of the geocoding will be an actually positioned space as opposed to an interpolated point.

It should be noted that there are several (potentially dangerous) caveats that are often overlooked when using interpolation. See the full entry for Geocoding for more information.

Various algorithms are used to help with address matching when the spellings of addresses differ. Address information that a particular entity or organization has data on, such as the post office, may not entirely match the reference theme. There could be variations in street name spelling, community name, etc. Consequently, the user generally has the ability to make matching criteria more stringent, or to relax those parameters so that more addresses will be mapped. Care must be taken to review the results so as not to erroneously map addresses incorrectly due to overzealous matching parameters.

Reverse geocoding

Reverse geocoding is the process of returning an estimated street address number as it relates to a given coordinate. For example, a user can click on a road centerline theme (thus providing a coordinate) and have information returned that reflects the estimated house number. This house number is interpolated from a range assigned to that road segment. If the user clicks at the midpoint of a segment that starts with address 1 and ends with 100, the returned value will be somewhere near 50. Note that reverse geocoding does not return actual addresses, only estimates of what should be there based on the predetermined range.

Data output and cartography

Cartography is the design and production of maps, or visual representations of spatial data. The vast majority of modern cartography is done with the help of computers, usually using a GIS. Most GIS software gives the user substantial control over the appearance of the data.

Cartographic work serves two major functions:

First, it produces graphics on the screen or on paper that convey the results of analysis to the people who make decisions about resources. Wall maps and other graphics can be generated, allowing the viewer to visualize and thereby understand the results of analyses or simulations of potential events. Web Map Servers facilitate distribution of generated maps through web browsers using various implementations of web-based application programming interfaces(AJAX, Java, Flash, etc).

Second, other database information can be generated for further analysis or use. An example would be a list of all addresses within one mile (1.6 km) of a toxic spill.

Graphic display techniques

Traditional maps are abstractions of the real world, a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Topographic maps show the shape of land surface with contour lines; the actual shape of the land can be seen only in the mind's eye.

Today, graphic display techniques such as shading based on altitude in a GIS can make relationships among map elements visible, heightening one's ability to extract and analyze information. For example, two types of data were combined in a GIS to produce a perspective view of a portion of San Mateo County, California.

The digital elevation model, consisting of surface elevations recorded on a 30-meter horizontal grid, shows high elevations as white and low elevation as black.
The accompanying Landsat Thematic Mapper image shows a false-color infrared image looking down at the same area in 30-meter pixels, or picture elements, for the same coordinate points, pixel by pixel, as the elevation information.

A GIS was used to register and combine the two images to render the three-dimensional perspective view looking down the San Andreas Fault, using the Thematic Mapper image pixels, but shaded using the elevation of the landforms. The GIS display depends on the viewing point of the observer and time of day of the display, to properly render the shadows created by the sun's rays at that latitude, longitude, and time of day.

Spatial ETL

Spatial ETL tools provide the data processing functionality of traditional Extract, Transform, Load (ETL) software, but with a primary focus on the ability to manage spatial data. They provide GIS users with the ability to translate data between different standards and proprietary formats, whilst geometrically transforming the data en-route.

GIS software

Geographic information can be accessed, transferred, transformed, overlaid, processed and displayed using numerous software applications. Within industry commercial offerings from companies such as ESRI and Mapinfo dominate, offering an entire suite of tools. Government and military departments often use custom software, open source products, such as Gram++, GRASS, or more specialized products that meet a well-defined need. Free tools exist to view GIS datasets and public access to geographic information is dominated by online resources such as Google Earth and interactive web mapping.

Originally up to the late 1990s, when GIS data was mostly based on large computers and used to maintain internal records, software was a stand-alone product. However with increased access to the Internet and networks and demand for distributed geographic data grew, GIS software gradually changed its entire outlook to the delivery of data over a network. GIS software is now usually marketed as combination of various interoperable applications and APIs.

Data creation

GIS processing software is used for the task of preparing data for use within a GIS. This transforms the raw or legacy geographic data into a format usable by GIS products. For example an aerial photograph may need to be stretched using photogrammetry so that its pixels align with longitude and latitude gradations. This can be distinguished from the transformations done within GIS analysis software by the fact that these changes are permanent, more complex and time consuming. Thus, a specialized high-end type of software is generally used by a skilled person in GIS processing aspects of computer science for digitization and analysis. Raw geographic data can be edited in many standard database and spreadsheet applications and in some cases a text editor may be used as long as care is taken to properly format data.

A geo-database is a database with extensions for storing, querying, and manipulating geographic information and spatial data.

Management and analysis

GIS analysis software takes GIS data and overlays or otherwise combines it so that the data can be visually analysed. It can output a detailed map, or image used to communicate an idea or concept with respect to a region of interest. This is usually used by persons who are trained in cartography, geography or a GIS professional as this type of application is complex and takes some time to master. The software performs transformation on raster and vector data sometimes of differing datums, grid system, or reference system, into one coherent image. It can also analyse changes over time within a region. This software is central to the professional analysis and presentation of GIS data. Examples include the ArcGIS family of ESRI GIS applications, Smallworld, Gram++ and GRASS.

Statistical

GIS statistical software uses standard database queries to retrieve data and analyse data for decision making. For example, it can be used to determine how many persons of an income of greater than 60,000 live in a block. The data is sometimes referenced with postal codes and street locations rather than with geodetic data. This is used by computer scientists and statisticians with computer science skills, with an objective of characterizing an area for marketing or governing decisions. Standard DBMS can be used or specialized GIS statistical software. These are many times setup on servers so that they can be queried with web browsers. Examples are MySQL or ArcSDE.

Readers

GIS readers are computer applications that are designed to allow users to easily view digital maps as well as view and query GIS-managed data. By definition, they usually allow very little if any editing of the map or underlying map data. Readers can be normal standalone applications that need to be installed locally, though they are often designed to connect to data servers over the Internet to access the relevant information. Readers can also be included as an embedded application within a web page, obviating the need for local installation. Readers are designed to be relatively simple and easy to use as well as free.

Web API

This is the evolution of the scripts that were common with most early GIS systems. An Application Programming Interface (API) is a set of subroutines designed to perform a specific task. GIS APIs are designed to manage GIS data for its delivery to a web browser client from a GIS server. They are accessed with commonly used scripting language such as VBA or JavaScript. They are used to build a server system for the delivery of GIS that is to make available over an Intranet.

Distributed GIS

Distributed GIS concerns itself with Geographical Information Systems that do not have all of the system components in the same physical location. This could be the processing, the database, the rendering or the user interface. Examples of distributed systems are web-based GIS, Mobile GIS, Corporate GIS and GRID computing.

Mobile GIS

GIS has seen many implementations on mobile devices. With the widespread adoption of GPS, GIS has been used to capture and integrate data in the field.

Open-source GIS software

Many GIS tasks can be accomplished with open-source GIS software, which are freely available over Internet downloads. With the broad use of non-proprietary and open data formats such as the Shape File format for vector data and the Geotiff format for raster data, as well as the adoption of OGC standards for networked servers, development of open source software continues to evolve, especially for web and web service oriented applications. Well-known open source GIS software includes GRASS GIS, Quantum GIS, MapServer, uDig, OpenJUMP, gvSIG and many others. PostGIS provides an open source alternative to geo-databases such as Oracle Spatial, and ArcSDE.

The future of GIS

Many disciplines can benefit from GIS technology. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS. These developments will result in a much wider use of the technology throughout science, government, business, and industry. The GIS applications including public health, crime mapping, national defense, sustainable development, agriculture, rural development, natural resources, landscape architecture, archaeology, regional and community planning, transportation and logistics. GIS is also diverging into location-based services (LBS). LBS allows GPS enabled mobile devices to display their location in relation to fixed assets (nearest restaurant, gas station, police station), mobile assets (friends, children, police car) or to relay their position back to a central server for display or other processing. These services continue to develop with the increased integration of GPS functionality with increasingly powerful mobile electronics such as cell phones, PDAs, laptops.

Web Mapping

In recent years there has been an explosion of mapping applications on the web such as Google Maps, and Live Maps. These websites give the public access to huge amounts of geographic data with an emphasis on aerial photography. Some of them, like Google Maps, expose an API that enable users to create custom applications. These vendors' applications offer street maps and aerial/satellite imagery that support such features as geocoding, searches, and routing functionality.

Remote Sensing Technology

Introduction

Remote Sensing (RS) is a technology that provides the means to collect and use geographic data to assist in the development of Agriculture. Remote Sensing in the most generally accepted meaning refers to instrument-based techniques employed in the acquisition and measurement of spatially organized or geographically distributed data on some properties such as spectral, spatial, physical of an array of target points of objects and materials from a define distance from the observed target. Remote sensing of the environment by geographers is usually done with the help of mechanical devices known as remote sensors. These gadgets have a greatly improved ability to receive and record information about an object without any physical contact. Often, these sensors are positioned away from the object of interest by using helicopters, planes, and satellites. Most sensing devices record information about an object by measuring an object's transmission of electromagnetic energy from reflecting and radiating surfaces.

Remote sensing imagery has many applications in mapping land use and cover, agriculture, soils mapping, forestry, city planning, archaeological investigations, military observation, and geological surveying.

Overview of Remote Sensing Technology

Remote Sensing is the technology that is now the principal tool by which the Earth's surface and atmosphere, the planets, and the entire Universe are being observed, measured, and interpreted from such vantage points as the terrestrial surface, earth-orbit, and outer space. The term "remote sensing" was coined by Ms Evelyn Pruitt in the mid-1950's when she was working with the U.S. Office of Naval Research (ONR) outside Washington, D.C as a oceanographer.

Remote Sensing is the most generally accepted meaning refers to "Instrument-based techniques employed in the acquisition and measurement of spatially organized data/information on some properties such as spectral, spatial, physical of an array of target points within the sensed scene that correspond to features, objects, and materials, doing this by applying one or more recording devices not in physical, intimate contact with the item(s) from at a finite distance from the observed target, in which the spatial arrangement is preserved. Various techniques involve pertinent to the sensed scene (target) by utilizing electromagnetic radiation, force fields, or acoustic energy sensed by recording cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, sound detectors, seismographs, magnetometers, gravimeters, scintillometers, and other instruments.

In simpler terms, Remote Sensing can be defined as "gathering data and information about the physical 'world' by detecting and measuring signals composed of radiation, particles, and fields emanating from objects located beyond the immediate vicinity of the sensor devices".

In the broadest sense, remote sensing is the small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing devices that is not in physical or intimate contact with the object such as by way of aircraft, spacecraft, satellite. In practice, remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area. Thus, Earth observation or weather satellite collection platforms, ocean and atmospheric observing weather buoy platforms, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and space probes are all examples of remote sensing. In modern usage, the term generally refers to the use of imaging sensor technologies including but not limited to the use of instruments aboard aircraft and spacecraft, and is distinct from other imaging-related fields such as medical imaging.

There are two kinds of remote sensing. (1) Passive sensors detect natural energy / radiation that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, infrared, and radiometers. (2) Active collection, on the other hand, emits energy in order to scan objects and areas whereupon a passive sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR is an example of active remote sensing where the time delay between emission and return is measured, establishing the location, height, speed and direction of an object.

Remote sensing makes it possible to collect data on inaccessible areas. Remote sensing applications include monitoring deforestation, the effects of climate change on Arctic and Antarctic regions, coastal and ocean depths, availability of water in the ground, and many more.

Orbital platforms collect and transmit data from different parts of the electromagnetic spectrum, which in conjunction with larger scale aerial or ground-based sensing and analysis, provides researchers with enough information to monitor trends such natural long and short term phenomena. Other uses include different areas of the earth sciences such as natural resource management, agricultural fields such as land usage and conservation, national security, ground-based and stand-off collection on border areas.

History of Remote Sensing

Beyond the primitive methods of remote sensing our earliest ancestors used to standing on a high mountains or tree to view the landscape. The modern discipline arose with the development of flight. The balloonist made photographs of cities from their balloons. The first tactical use was during the civil war. Messenger pigeons, kites, rockets and unmanned balloons were also used for early images. With the exception of balloons, these first, individual images were not particularly useful for map making or for scientific purposes.

Systematic aerial photography was developed for military use beginning in World War I and reaching a climax during the Cold War with the use of modified combat aircraft. A more recent development is that of increasingly smaller sensor pods such as those used by law enforcement and the military, in both manned and unmanned platforms. The advantage of this approach is that this requires minimal modification to a given airframe. Later imaging technologies would include Infra-red, conventional, doppler and synthetic aperture radar

The development of artificial satellites in the latter half of the 20th century allowed remote sensing to progress to a global scale as of the end of the cold war. Instrumentation aboard various Earth observing and weather satellites such as Landsat, the Nimbus and more recent missions such as RADARSAT and UARS provided global measurements of various data for civil, research, and military purposes. Space probes to other planets have also provided the opportunity to conduct remote sensing studies in extra-terrestrial environment, synthetic aperture radar aboard the Magellan spacecraft provided detailed topographic maps of Venus.

Recent developments include, beginning in the 1960s and 1970s with the development of image processing of satellite images. Several research groups in Silicon Valley including NASA, developed Fourier transform techniques leading to the first notable enhancement of imagery data.

The introduction of online web services for easy access to remote sensing data in the 21st century mainly low/medium-resolution images, like Google Earth, has made remote sensing more familiar to the every one and has popularized the science.

Data acquisition techniques

Electromagnetic Radiation

Remote sensing is the practice of measuring an object or a phenomenon without being in direct contact with it. It is non-intrusive. This requires the use of a sensor situated remotely from the target of interest. A sensor is the instrument (camera) that takes the remote measurements. There are many different types of sensors, but almost all of them share something what they "sense" or take measurements of is usually Electro-Magnetic Radiation (EMR) or light energy. EMR is energy propagated through space in the form of tiny energy packets called photons that exhibit both wave-like and particle-like properties. Unlike other modes of energy transport, such as conduction (heating a metal skillet) or convection (flying a hot air balloon), radiation (as in EMR) is capable of propagating through the vacuum of space. The speed of that EMR in a vacuum (outer space) is approximately 300,000 kilometers per second (3 x 108 meters/second-1 or 186,000 miles/second-1). This is an extremely fast communications medium with visible light with its red, green, and blue colors that we see daily are an example of EMR. But there is a much larger spectrum of such energy. We often characterize this spectrum or range in terms of the wavelengths of different kinds of EMR. For a variety of reasons, there are some wavelengths of EMR that are more commonly used in remote sensing than other wavelengths.

Recording Electromagnetic Radiation

There are two broad categories of sensor systems used in remote sensing — active and passive. Passive sensors rely on EMR from existing sources, most commonly the Sun. Due to the extreme temperatures and nuclear activity on the surface of the Sun, this massive energy source emits a broad and continuous range of EMR, of which visible light is only a small fraction. EMR emitted from the Sun travels through the vacuum of space, interacts with the atmosphere, and reflects off objects and phenomena on Earth's surface. That EMR must again interact with the atmosphere before arriving at a remote sensor system in the air or in orbit. Some of the Sun's energy is absorbed by target objects such as water, rocks etc. on the surface of Earth and these are often heated as a result. Absorbed energy can then be re-emitted at longer wavelengths. Certain passive sensor systems are designed to record portions of this emitted energy.

On the other hand, active sensors themselves generate the EMR that they need to remotely sense objects or phenomena. The active sensors' EMR propagates from the sensor, interacts with the atmosphere, arrives at target objects trees, rocks, buildings, etc., interacts with these objects, and must be reflected in order to travel back through the atmosphere and be recorded at the sensor. Generally there are two types of active sensors:

A. Radar (Radio Detection and Ranging), which utilizes microwave energy, and

B. LiDAR (Light Detection And Ranging), which utilizes near-infrared or visible energy.

Reflectance of Electromagnetic Energy

Remote sensing would be of little use if every object or phenomenon on Earth behaved in exactly the same way when interacting with EMR. Fortunately, different objects reflect portions of the electromagnetic spectrum with differing degrees of efficiency. Similarly, different objects emit previously absorbed EMR with differing degrees of efficiency. In the visible spectrum these differences in reflective efficiency account for the myriad of colors that we see. For example, green plants appear of that color because they reflect greater amounts of green light than of blue or red light. Plotting the spectral reflectance levels of a given object or phenomenon by wavelength yields a spectral reflectance curve, or spectral signature. This signature is the remote sensing key to distinguishing between one type of target and another. For example, the signature of a deciduous tree is entirely different that of an evergreen tree.

Analog or Film-based Sensors

Today we hear the terms analog and digital when referring to a wide range of electronic devices. In general, analog devices operate using dynamic physical properties (e.g., chemical changes) while digital devices operate using numbers (0s and 1s). Remote sensor systems record patterns in incoming EMR using analog detectors. While all remote sensor systems have at least a partial complement of analog components, some sensor systems are completely analog. A prime example of this is a film-based aerial camera. The emulsion of silver halide crystals in film responds chemically to EMR exposure. Further analog processing is used to generate negative and positive transparencies and hardcopy photographs.

In an analog aerial camera, the length of exposure to incoming EMR is controlled through a shutter that opens for just a fraction of a second. While the shutter is open, the incoming light is focused on the film plane at the back of the camera using a high quality lens. With each exposure, the focused image of EMR causes a lasting chemical change to the exposed portion of film and a new unexposed section of film is needed in order to repeat the process.

A film-based camera used for remote sensing differs in a few ways from a typical camera used for photography. For one thing, the film itself is much larger (nine inches wide). For another, the camera's focal length is much longer (about 175 mm). Without delving in detail into the science of photography, these differences allow the aerial camera to take better, larger-scale photographs even from a moving platform. Most cameras designed for this purpose are metric, meaning that their internal dimensions have been precisely calibrated and are reported to the user. This is vital to the practice of photogrammetry or taking detailed measurements on photographic maps.

Digital Sensors

Digital sensors also measure patterns in incoming EMR using analog detectors. However, measurements of EMR taken by each detector element are recorded, not using an analog medium such as film, but using numbers. These measurements are digitized through a process called analog-to-digital (A-to-D) conversion. Possible values are in a pre-defined range, such as 0 to 255. Each recorded numerical value is then stored on some kind of digital medium, such as a hard disk, as part of a raster dataset. The value in each raster cell represents the amount of energy received at the sensor from a particular circular area, instantaneous-field-of-view (IFOV) on the ground. Digital sensors make use of the same basic technology as a computer document scanner or a digital camera. In fact, specialized digital cameras are often used to acquire remote sensor data and professional-grade document scanners are often used to convert analog remote sensing data to digital data.

The detectors in a digital sensor can be arranged in a number of different ways. One method utilizes a single detector for each frequency band. A scanning mirror is then used to capture EMR at each IFOV along a scan line. The forward motion of the sensor allows for additional scan lines and therefore a two dimensional image. This is type of instrument is often referred to as a scanning mirror sensor.

A second method is to have a linear array of detectors for each band. Each detector in an array records EMR for a single IFOV in the cross-track dimension i.e., perpendicular to the direction of flight. The forward motion of the sensor again allows for repeated measurements and two-dimensional imagery. This type of sensor system is often called a linear array push-broom scanner. Push-broom systems have several advantages over scanning mirror sensors. They have fewer moving parts, so they are generally more durable. Also, the process of assigning coordinates to push-broom data is much easier.

A third digital sensor configuration is the one that is most like the operation of analog film-based systems. In this case, an entire area array is placed at the back of the sensor. Energy is focused through a lens onto this bank of detectors. These types of sensors are called digital cameras, or area array sensors. They are often used in similar applications as film-based cameras.

Types of Resolution

Resolution quantifies how distinguishable the individual parts of an object or phenomenon are. When discussing the specifications of remote sensor systems, we generally speak of four different types of resolution.

A. Temporal Resolution

Temporal resolution is how often a sensor visits, or can visit, a particular site to collect data. This is important because many applications depend on observing change in phenomena over time. A remote sensing instrument is mounted on a platform such as a satellite, an aircraft, a hot air balloon. The platform on which a sensor is mounted is the greatest determinant of that sensor's temporal resolution.

Some satellites orbit Earth without ever approaching its shadow - that is, they are in Sun-synchronous orbit. Other satellites maintain a fixed position above the rotating Earth - these are in geo-synchronous orbit. In either case, these satellites have a regular and predictable temporal resolution (every 16 days). Some satellite-based sensors are more flexible than other ones because of their ability to point at various targets near their default field-of-view. These more flexible sensors may have a temporal resolution range (2-3 days). Sensors mounted on aircraft fly ad-hoc or on-demand missions with less predictable but more flexible temporal resolution (every hour).

B. Spatial Resolution

Spatial resolution describes the size of the individual measurements taken by the remote sensor system. This concept is closely related to scale. With an analog sensor, such as film, the spatial resolution is commonly expressed in the same terms as the scale (e.g., 1:500). Since digital sensor records information in raster format the spatial resolution is the cell size (e.g., 3 x 3 meters) in ground units.

C. Spectral Resolution

Spectral resolution describes the sensor systems' ability to distinguish different portions of the EMR spectrum. Some sensors are sensitive to visible light only, while others can also capture near-infrared energy. The portions of the spectrum to which an instrument is sensitive are referred to as its bands. A sensor can have multiple bands, and bands can be of varying widths. Spectral resolution refers both to the number and width of the bands for a given sensor.

A panchromatic band is a wide band that encompasses a large spectral range, often the entire visible spectrum. Commonly we call film that is sensitive to the entire visible range "black and white" film because often we print images from this sort of film in grayscale. However, there are analog and digital sensors that have wide panchromatic bands that also encompass the near infrared portion of the spectrum.

When a sensor records only a few portions of the spectrum i.e., contains only a few, relatively wide bands, it is said to be a multispectral system. A multispectral sensor might have two or three bands in the visible range i.e. red, green, and blue and it might also have a few near-infrared or middle infrared bands. Typical multispectral systems have between 4 and 10 bands.

Hyperspectral sensors have a large number of relatively narrow bands. By definition, hyperspectral sensors have a higher spectral resolution than multispectral sensors. Commonly a sensor is considered hyperspectral when it has at least 20 or 30 bands. Many such sensors have hundreds of bands. In general, a sensor with more spectral bands has a greater ability to distinguish between two objects with similar spectral properties.

Each band in a digital dataset can be thought of as an individual raster layer. Visualize an image in three dimensions, with rows, columns, and bands filling the x, y, and z coordinates of a cube.

D. Radiometric Resolution

Radiometric resolution describes the number of unique values that can be recorded by a sensor system when measuring reflected or emitted EMR. In a digital system this is easily quantified as a number. Since the digital numbers in remote sensor data are stored in a computer, they are often expressed in terms of how many bits are used to store that variety of numbers (Ex., 8-bits, 11-bits). An 8-bit sensor would store a value for each measurement in an integer range from 0 to 255. This range has 28-256 discrete values. With analog, or film-based, systems it is the quality of the film that determines its radiometric resolution.

Converting Remote Sensing Data into Geospatial Data

Remote sensing applications are rarely successful without at least some direct measurements / ground truth being taken within the area. However, "truth" is really a misnomer since there is always at least some error in measurements, even if they are taken directly. "Ground reference" would be a better descriptor. A correct term for measurements taken directly as opposed to remote measurements is in situ data collection. Several types of in situ measurements may be necessary for a given project or application. Almost all remote sensing projects require some amount of in situ data collection in order to perform geometric and radiometric calibration. Additional in situ data may be required to create reference maps of spatial variables, including biophysical properties.

Geometric Correction

When remote sensor data is initially collected it is not geospatial data. In order to make the transition to geospatial data, geometric correction must be applied to make the data into a real-world coordinate system. Beyond having no real-world coordinates assigned, the raw data also contains geometric distortion. This means that all of the objects or phenomena that can be seen in the data are not equally out of place relative to a desired coordinate system. Distortion generally increases away from the point in the data that were acquired at straight down. Distortion is therefore different depending on the sensor configuration (Ex., scanning mirror sensors vs. area array digital cameras). Another source of distortion are variations in the terrain and objects on the terrain. Tall objects and steeply sloping terrain lead to more distortion than flat objects on flat terrain.

A basic method for geometric correction involves the use of a GPS receiver in the field. GPS measurements are taken at locations that are also easily identifiable in the imagery. These types of locations will vary according to the spatial resolution of the remote sensor data. Ideally the smallest possible features that can be visualized in that data should be located in the field and their positions surveyed. These features should also be permanently situated. The recorded locations of these features in the study area are collectively known as control points. Road intersections typically make good control points. Features above the ground surface do not make good control points because they cause distortion. Control points should be collected at locations spaced evenly throughout the remote sensor image. In fact, the relative location of the control points is at least as important as the number of points.

Once enough control points have been collected, they can be used to adjust the data to its approximate spatial position within a coordinate system. Most geospatial software packages provide an interface for doing this. As part of the process, the software package will typically report a number indicating the degree to which the desired transformation was successfully implemented. The success rate depends on the amount of distortion present in the raw data. Once the remote sensor data has undergone this process it is said to be georectified data.

Photogrammetry Correction

In order to create an image that is free from all major distortions, the terrain and sensor-induced distortions must be accounted for explicitly. This is done by using a combination of GPS control points, a digital elevation model (DEM), and a detailed report of the distortion present in the sensor system. When data has been corrected in this manner it is said to be orthorectified. In an orthorectified image, all points are in their proper x, y position and aligned as they would appear if one were looking straight down at them.

The practice of orthorectification is part of photogrammetry — the art of taking direct measurements from photos and other remotely sensed data. Measurements derived using photogrammetric techniques include the height of objects on the terrain, their x, y location, and the ground distance between objects.

Radiometric Correction

In addition to geometric distortion, EMR that is received by the sensor contains radiometric distortions. The source of these distortions is primarily the atmosphere and its dynamic constituents. If there were no atmosphere with which to contend, EMR recorded by the sensor would be a much more perfect representation of EMR reflected or emitted from the target object or phenomena. However, along the path between the target and the sensor, EMR must interact twice with the atmosphere. Some of this energy is scattered and some of it is absorbed. Atmospheric constitutes such as water vapor and pollution vary across space and time, and therefore these distortions make it particularly difficult to compare datasets collected at different times.

There are various ways to minimize this distortion. Between-date radiometric differences can be minimized if the datasets are collected at similar times so that the

TBC Demo Script

Trimble Business Center

January, 2019

Trimble Dealer Confidential

Importing and processing GNSS data

Introduction

This document is prepared to demonstrate how to import GNSS data into TBC, use some of the views and settings available to manipulate the baselines, perform a network adjustment and download CORS data using the Internet download function.

About the demo dataset

The demonstration data has been gathered from the VRS Now portal to simulate a static survey in Victoria. The occupation times and vector lengths are not to be taken as an example of how to perform a survey of this nature. It is purely a data set for software workflow purposes.

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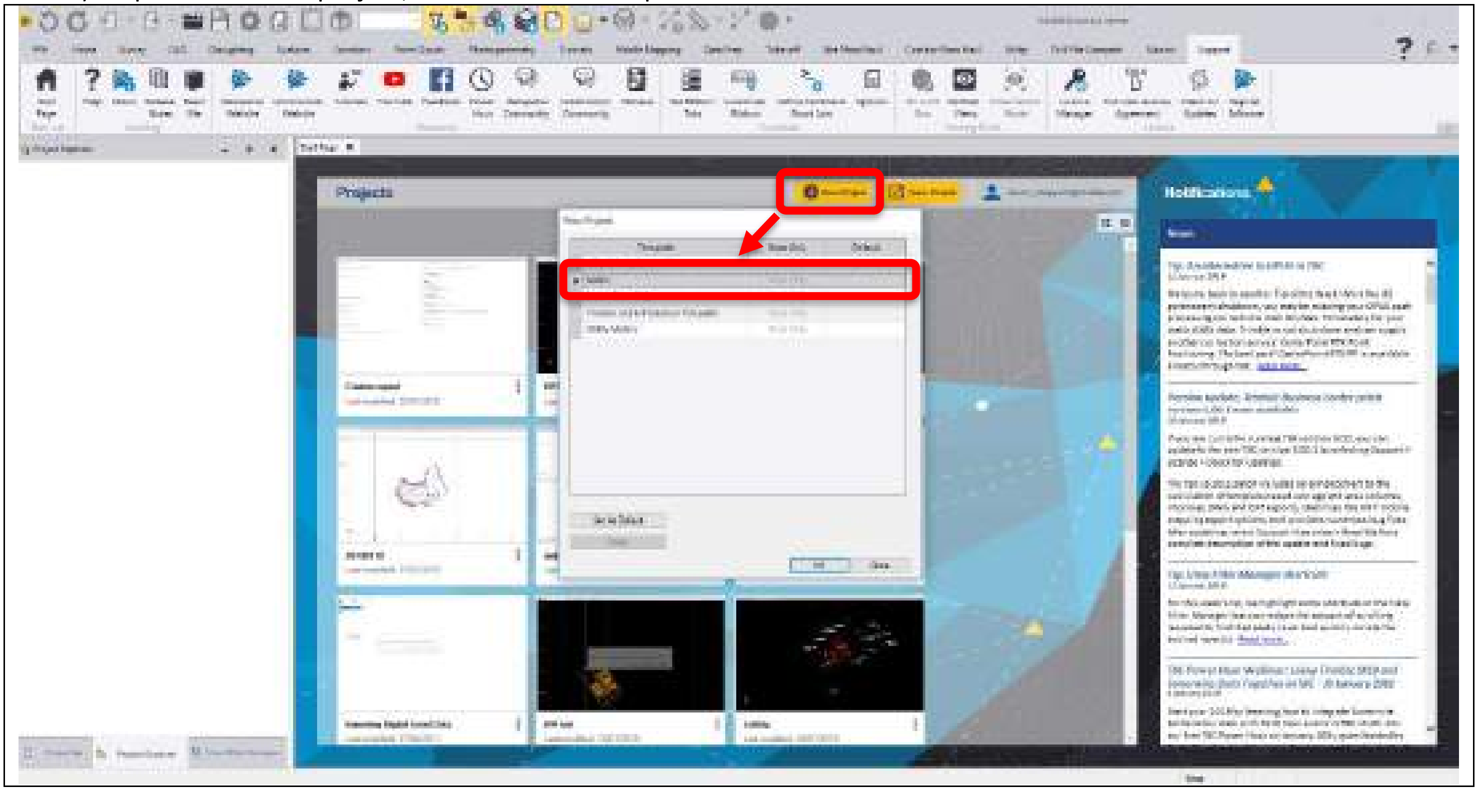
Contents

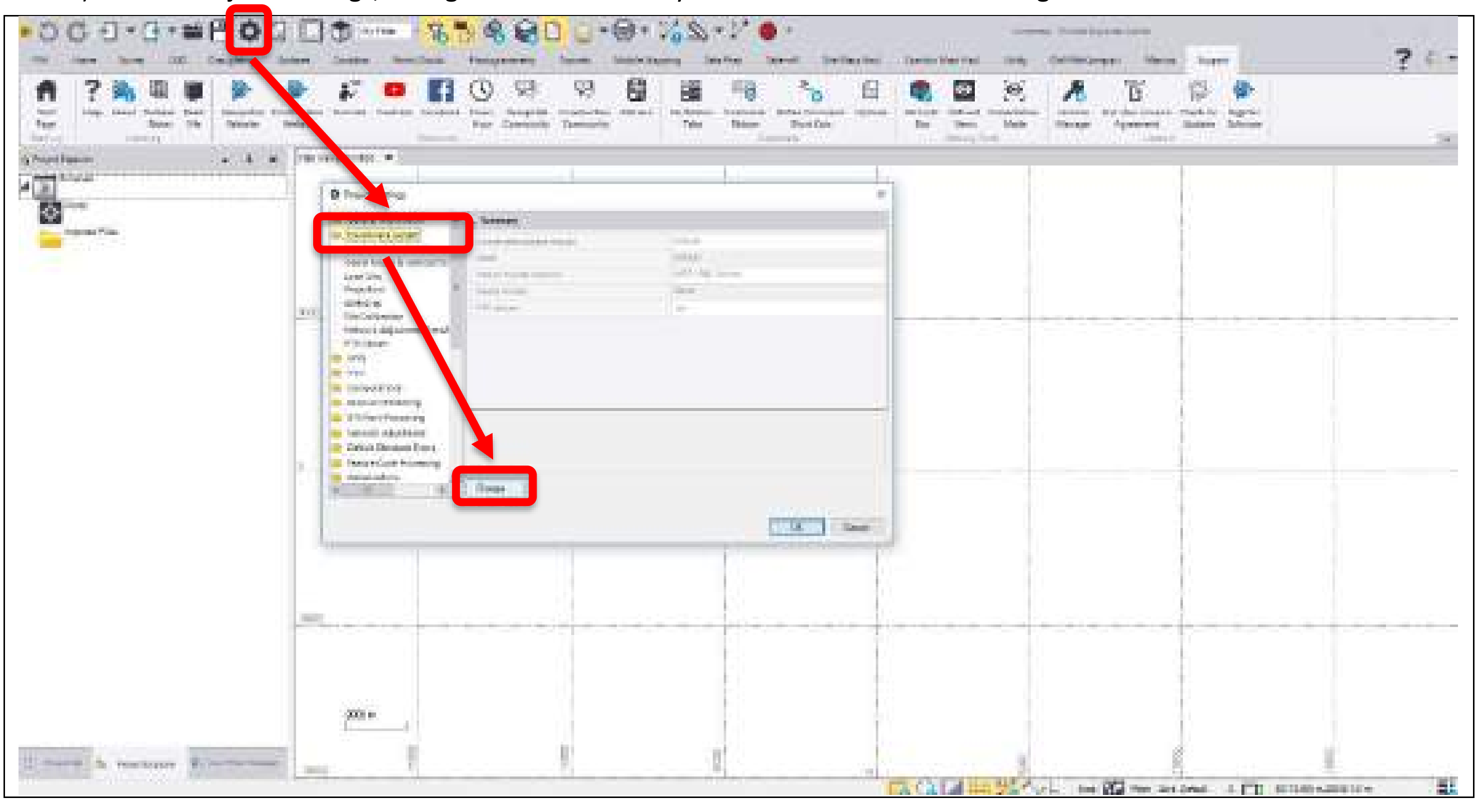
Workflow Steps

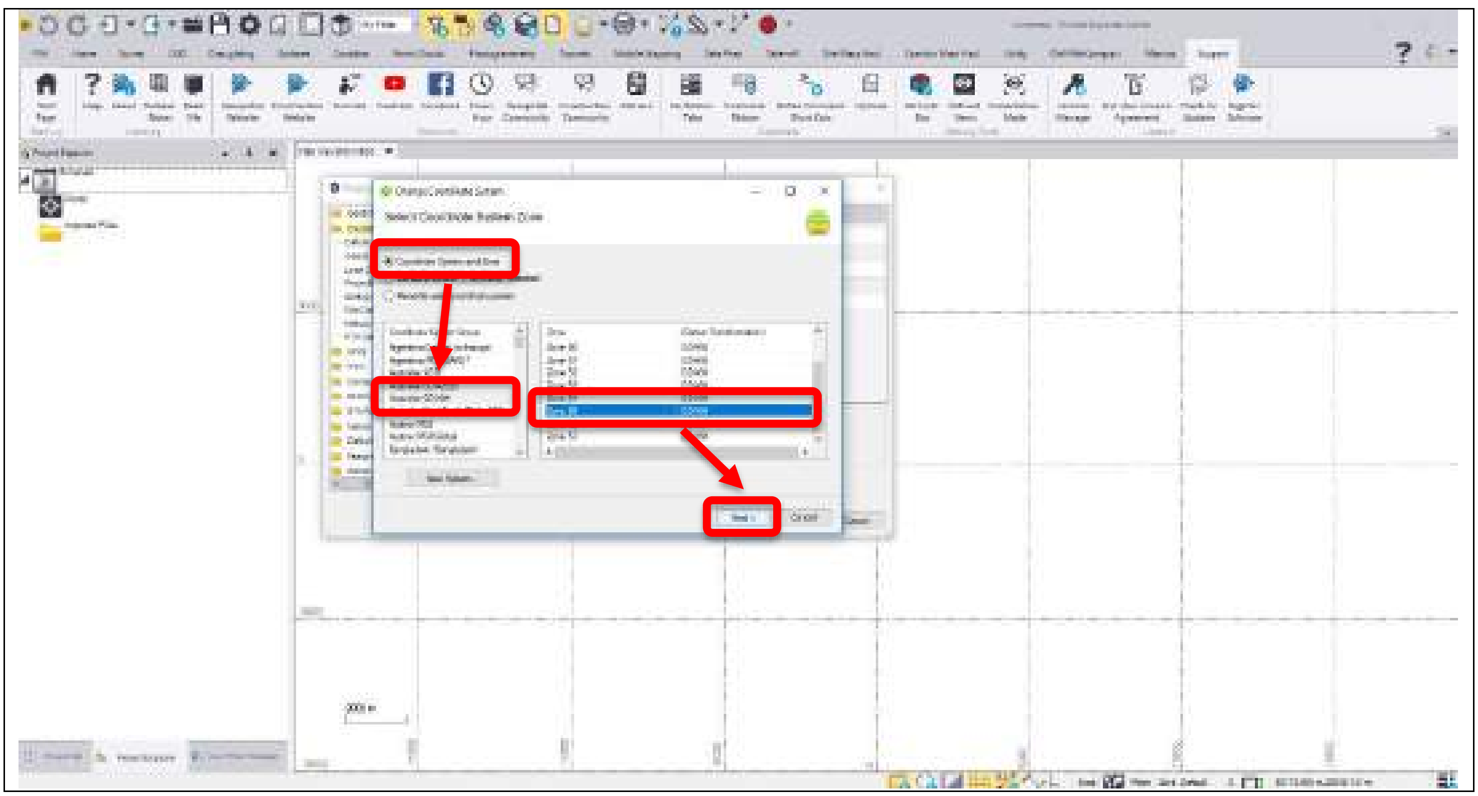
Import Data

1) Open a new TBC project, use the Metric template

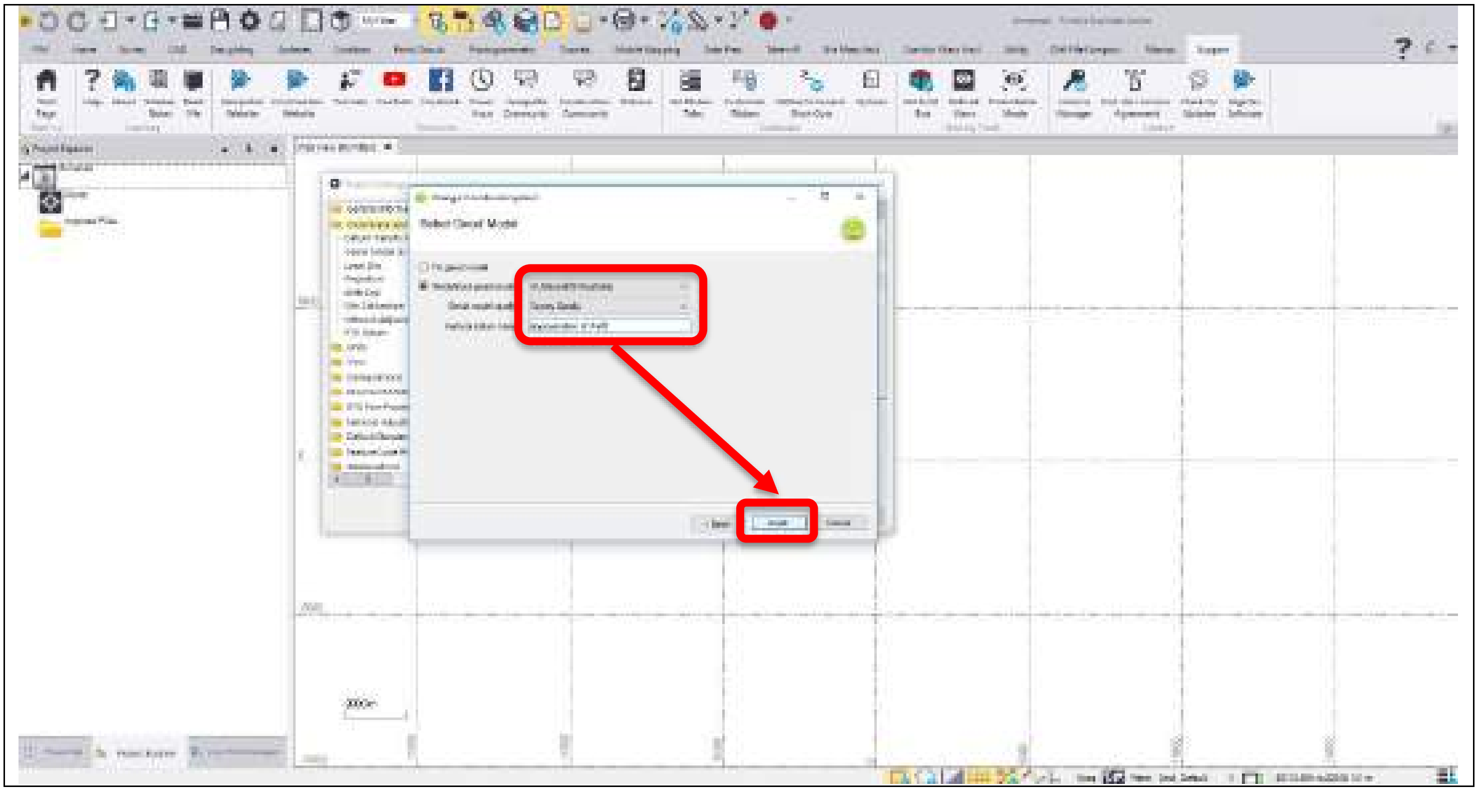


2) Go to Project Settings, change the coordinate system to GDA94. Zone 55. Ausgeoid09.

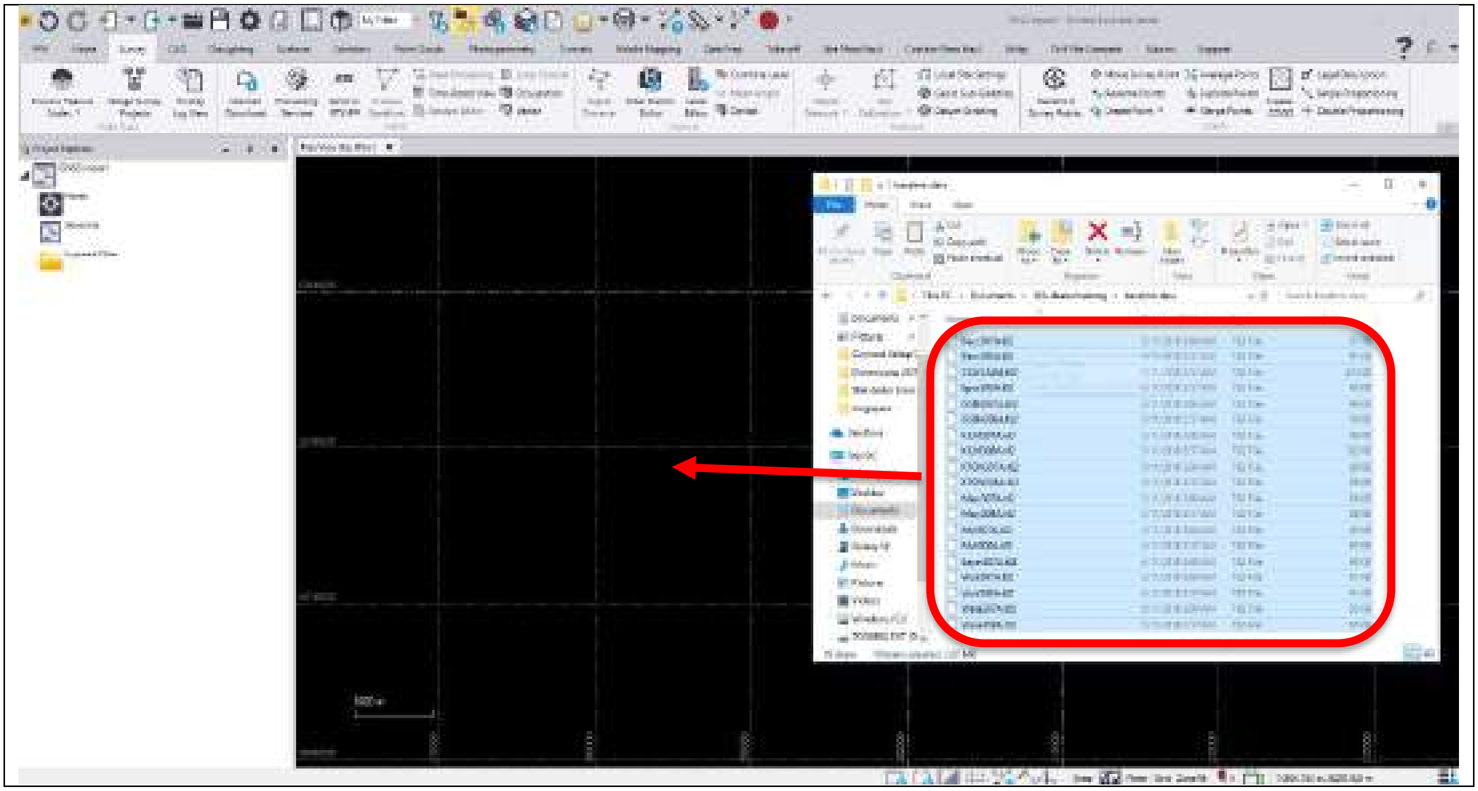




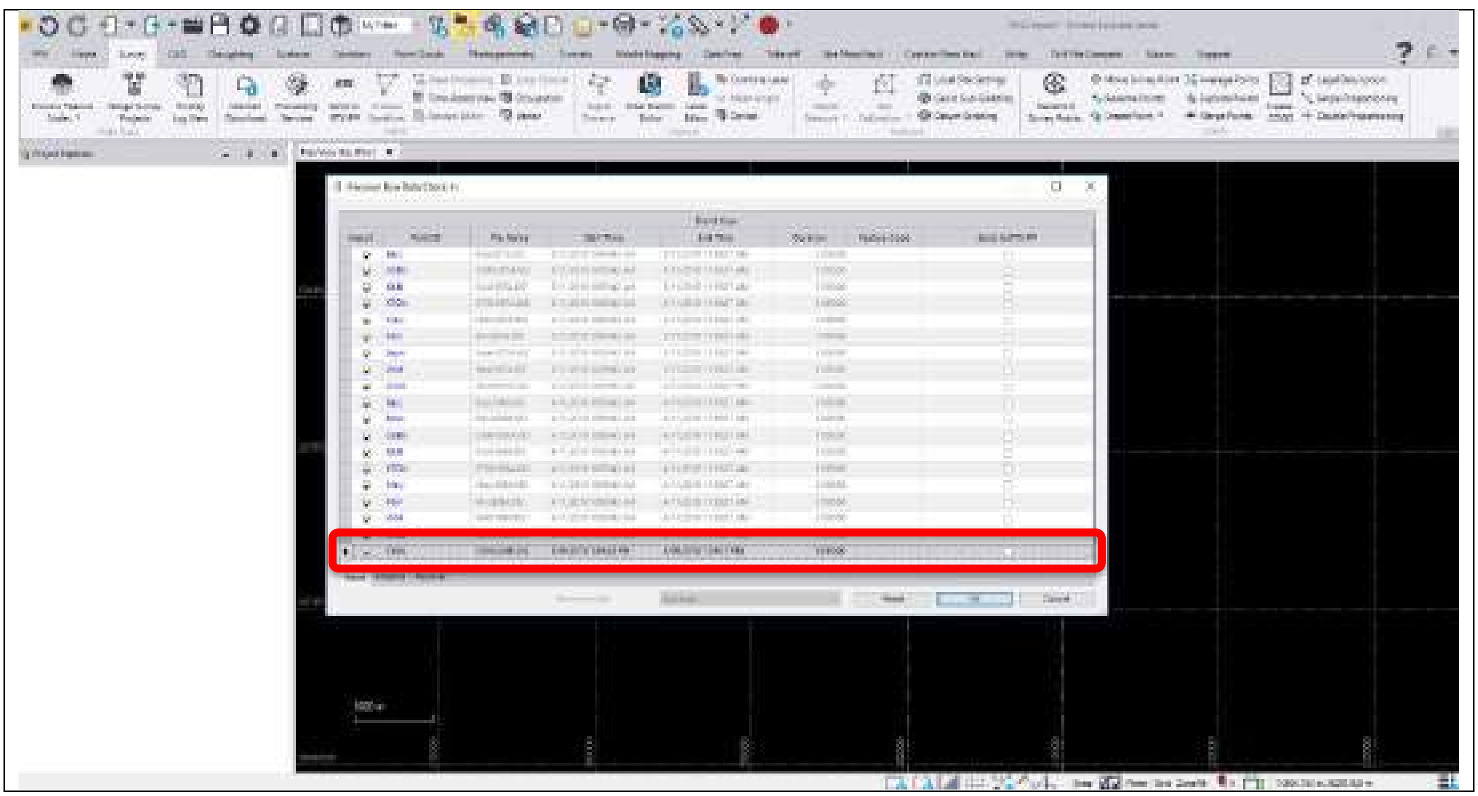
3) Within the geoid selection pane, you have a field for Vertical datum name. This field is optional and will not influence the processing in any way. Once you've finished the selection select Finish and then OK to exit the Project Settings.



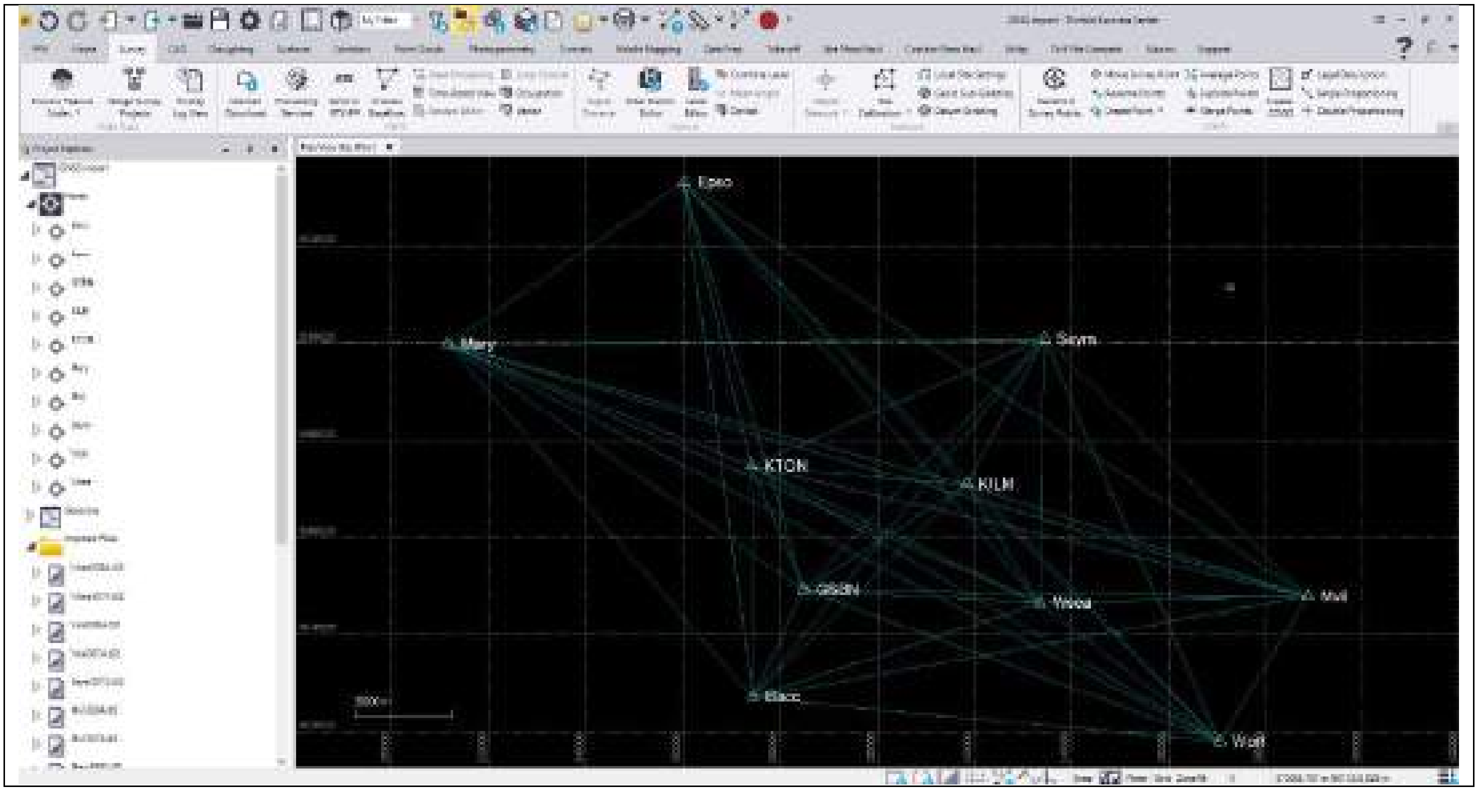
4) Next, select all of the T02 files and drag them into the Plan View in TBC. This will begin the import.



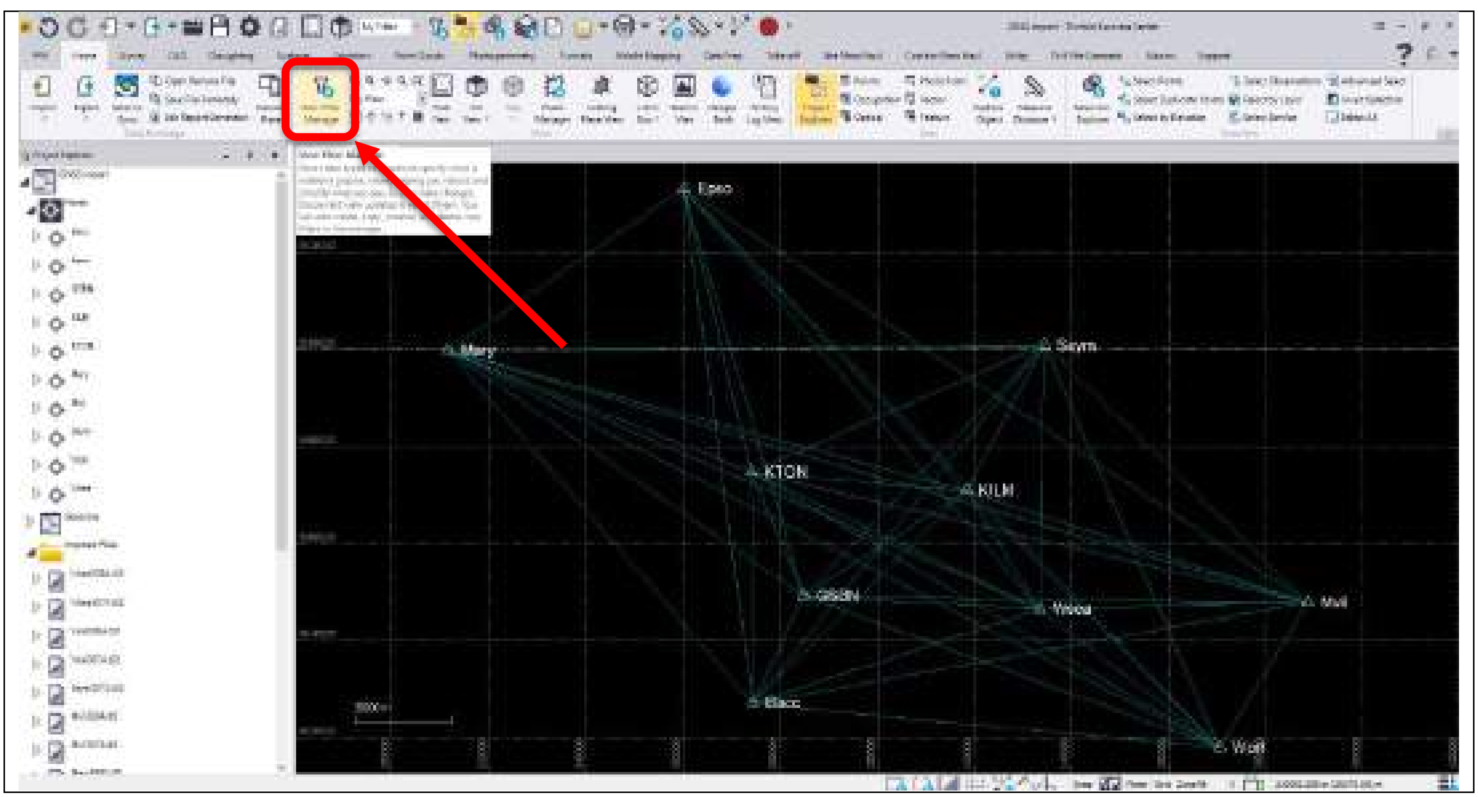
5) From the Receiver Raw Data Check In we can review the data we are going to Import. As you can see below, we have one file that sits outside of our occupation times for all the other stations. Deselect it to prevent its import.



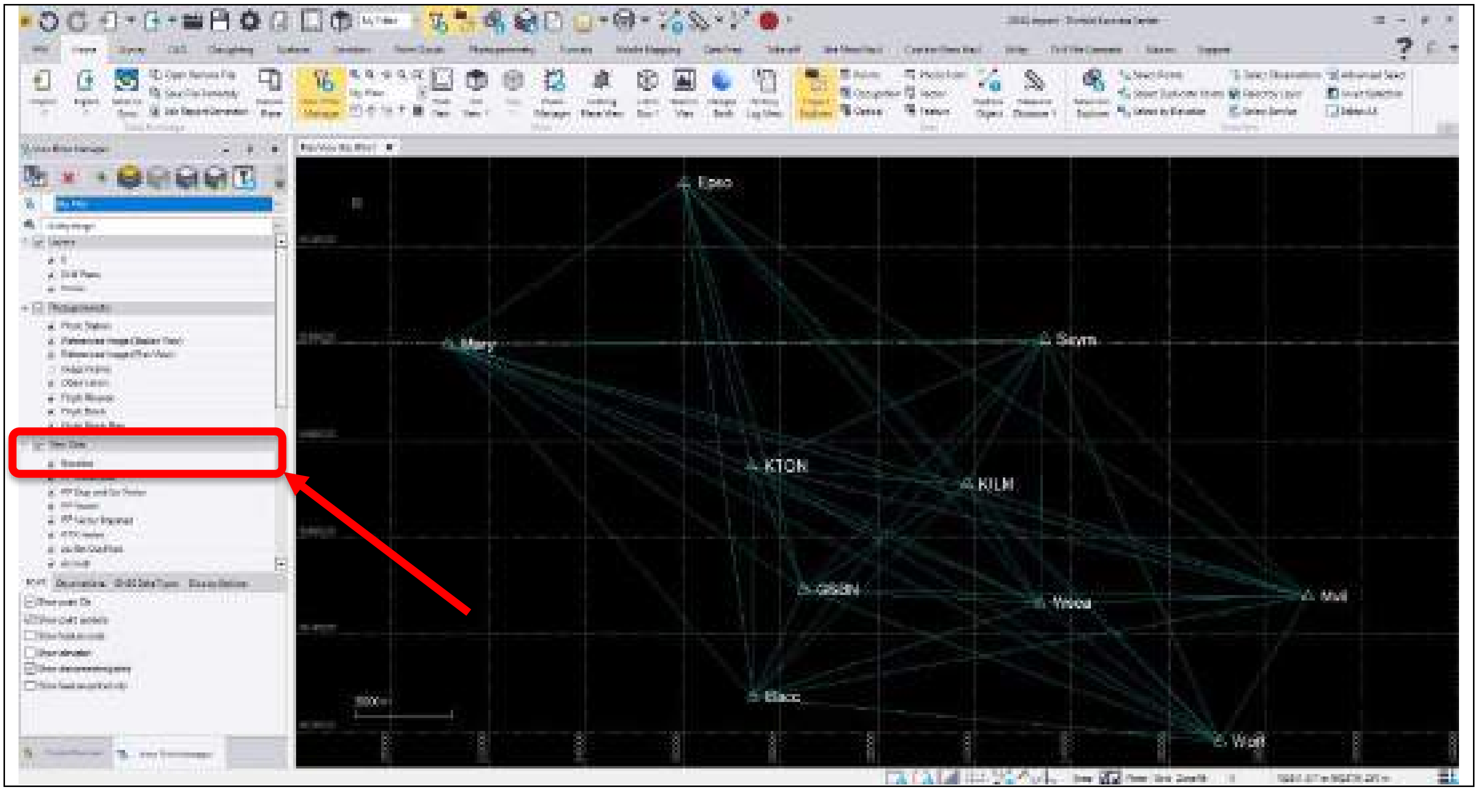
6) As you can see the import has generated a significant amount of baselines between the points.



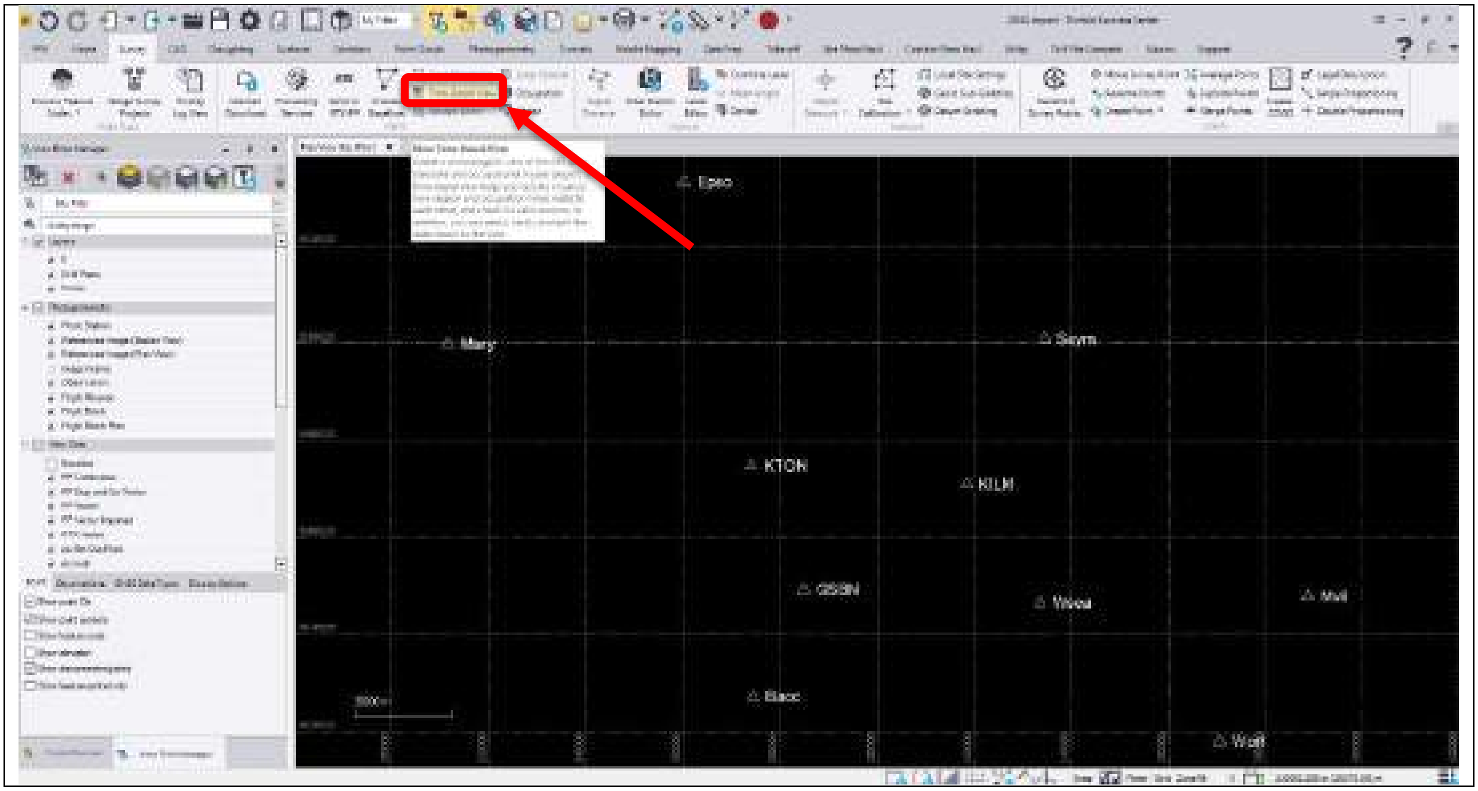
7) If you don't already have the View Filter Manager open, please do so now from the Home tab. This can be docked in the same area as the Project Explorer to make navigating TBC easier.



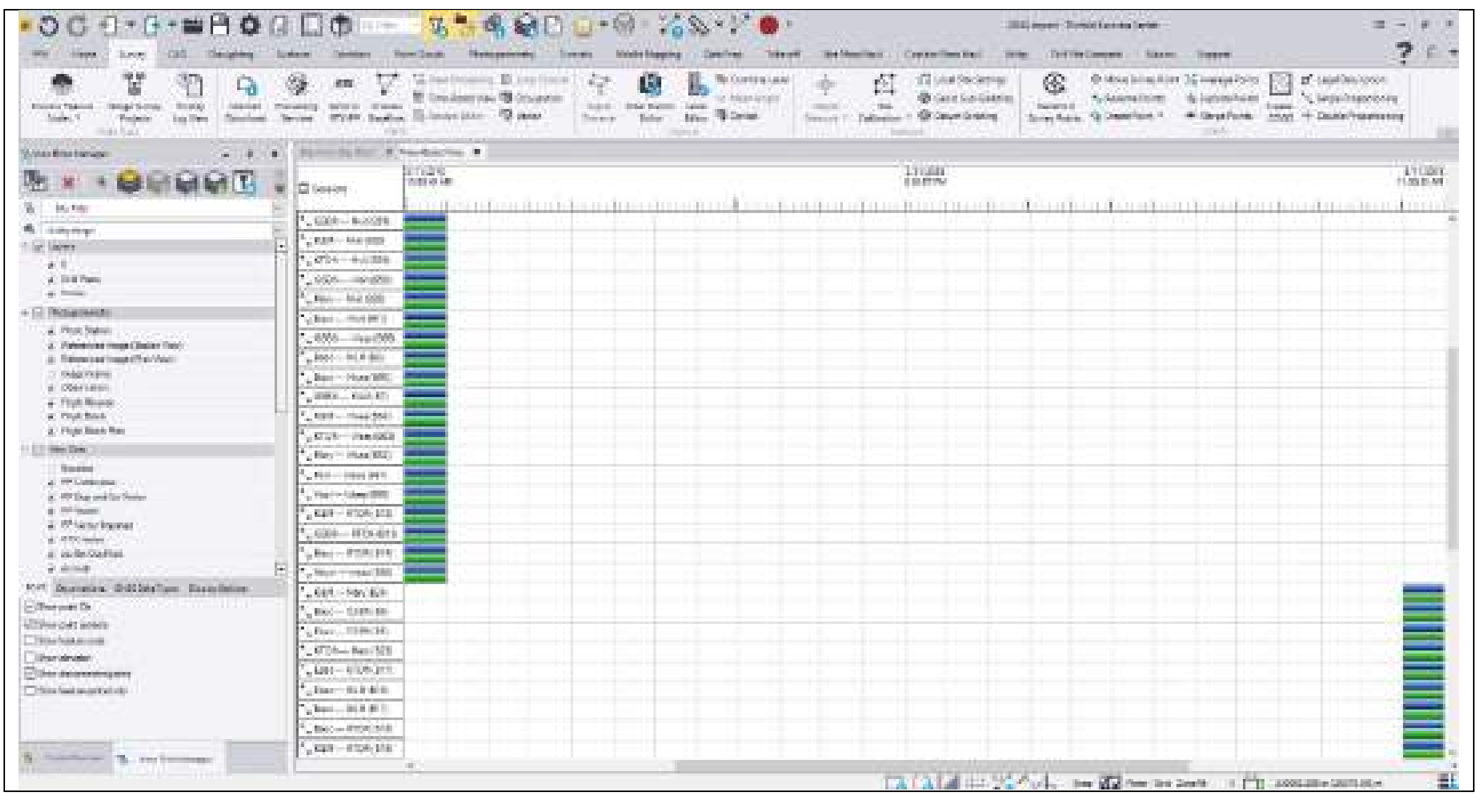
8) If you expand the Raw Data section of the View Filter Manager you can deselect the Baselines and a number of other entities to aid in cleaning up the views until you're ready to deal with a certain data type in TBC. We'll leave them on for now though.



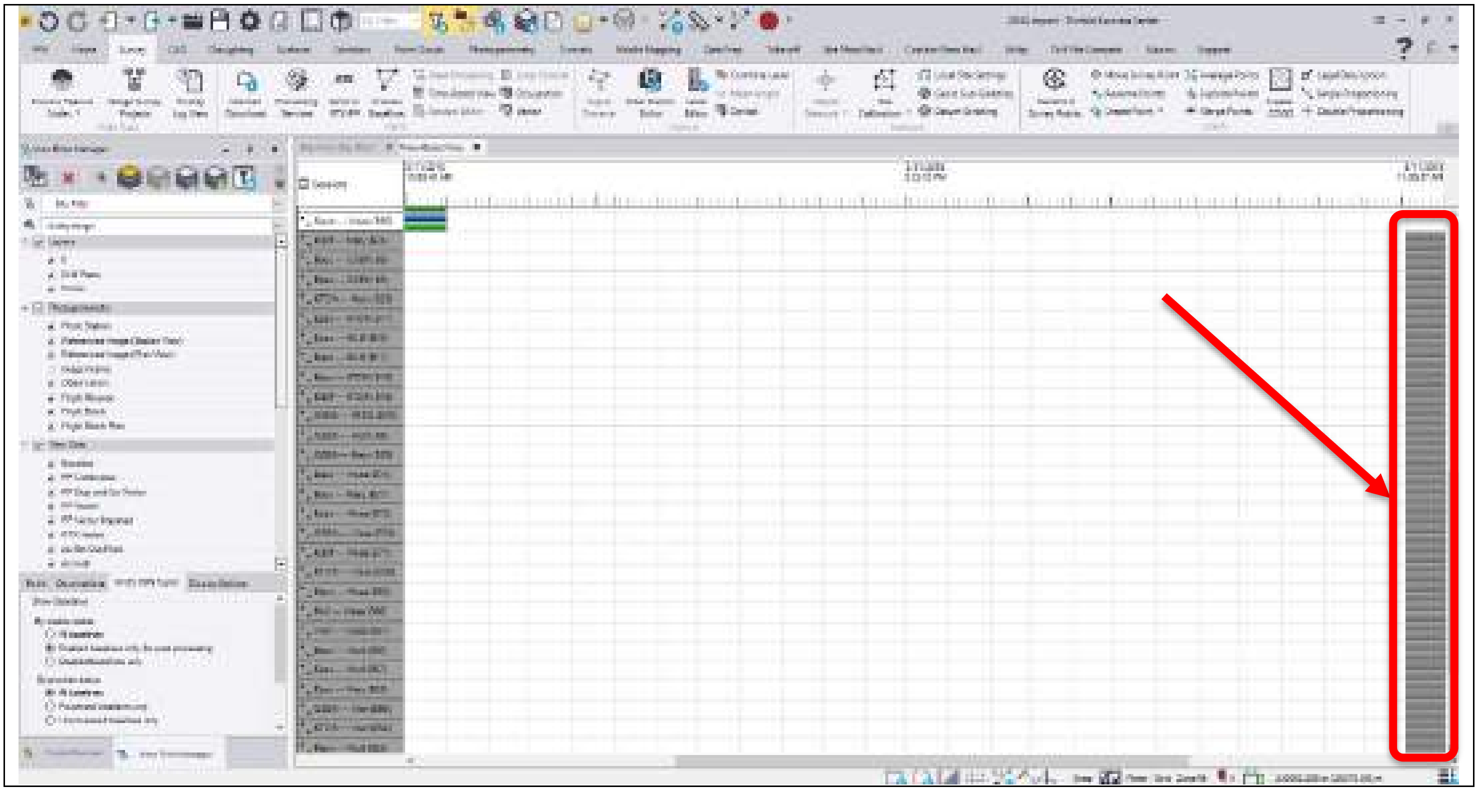
9) Next, select Time-Based View from the Survey tab.



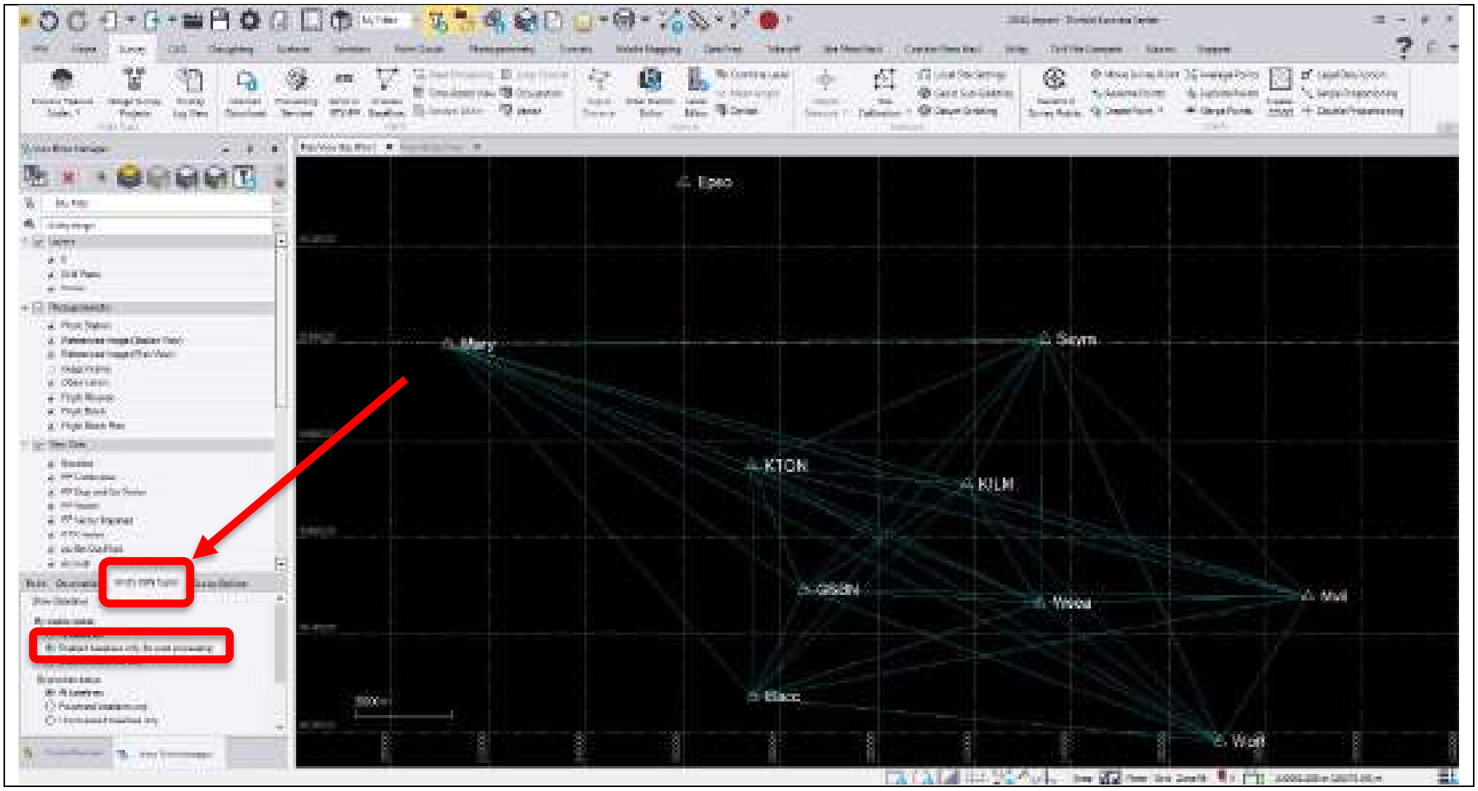
10) Within the Time-Based View it is easier to see the individual baselines, and which session they belong to.



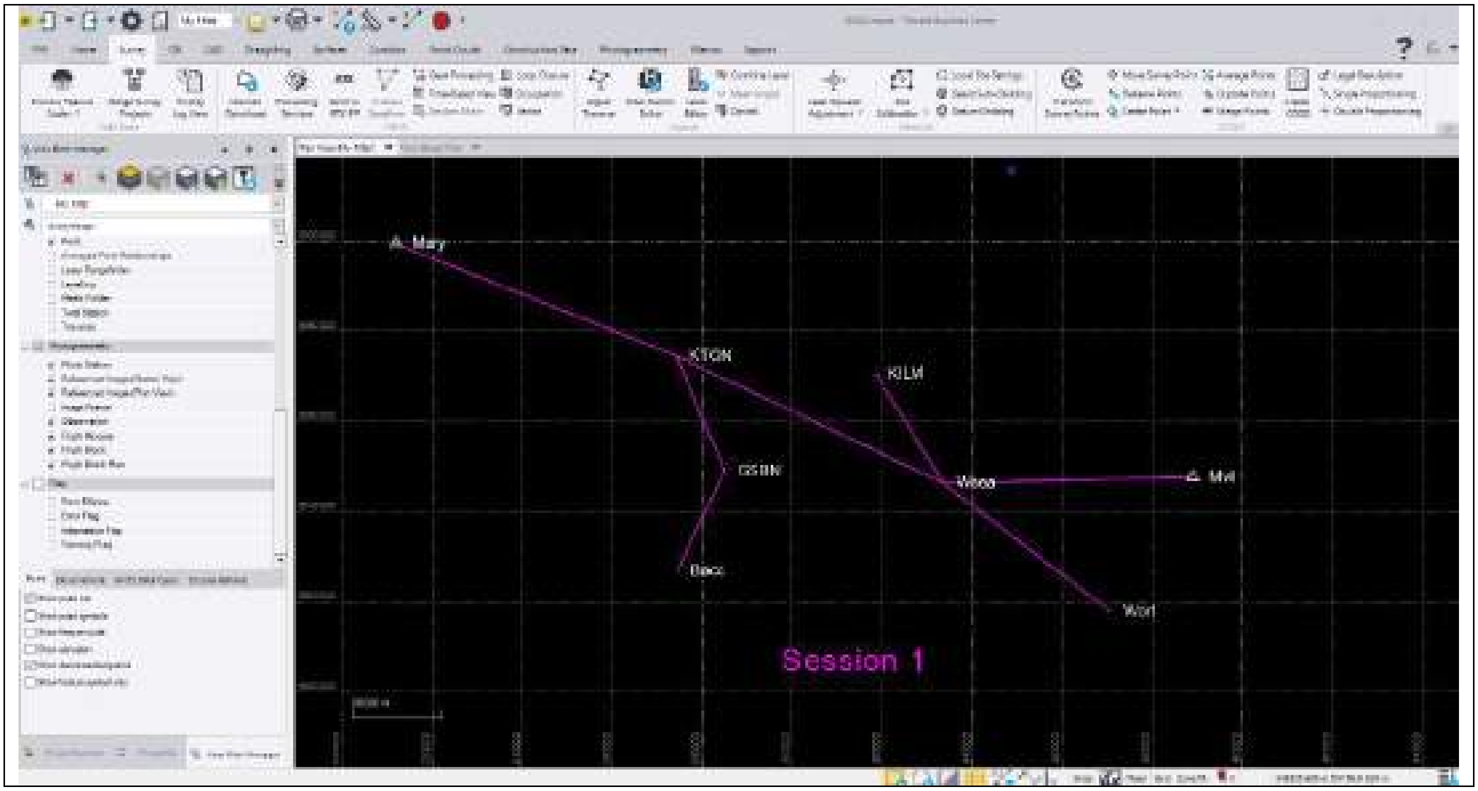
11) So that our statistics are valid when performing a Network Adjustment later in the tutorial we will need to remove a number of baselines from being processed. To begin with, we want to select the entire second session and then right click and select Disable Baselines.



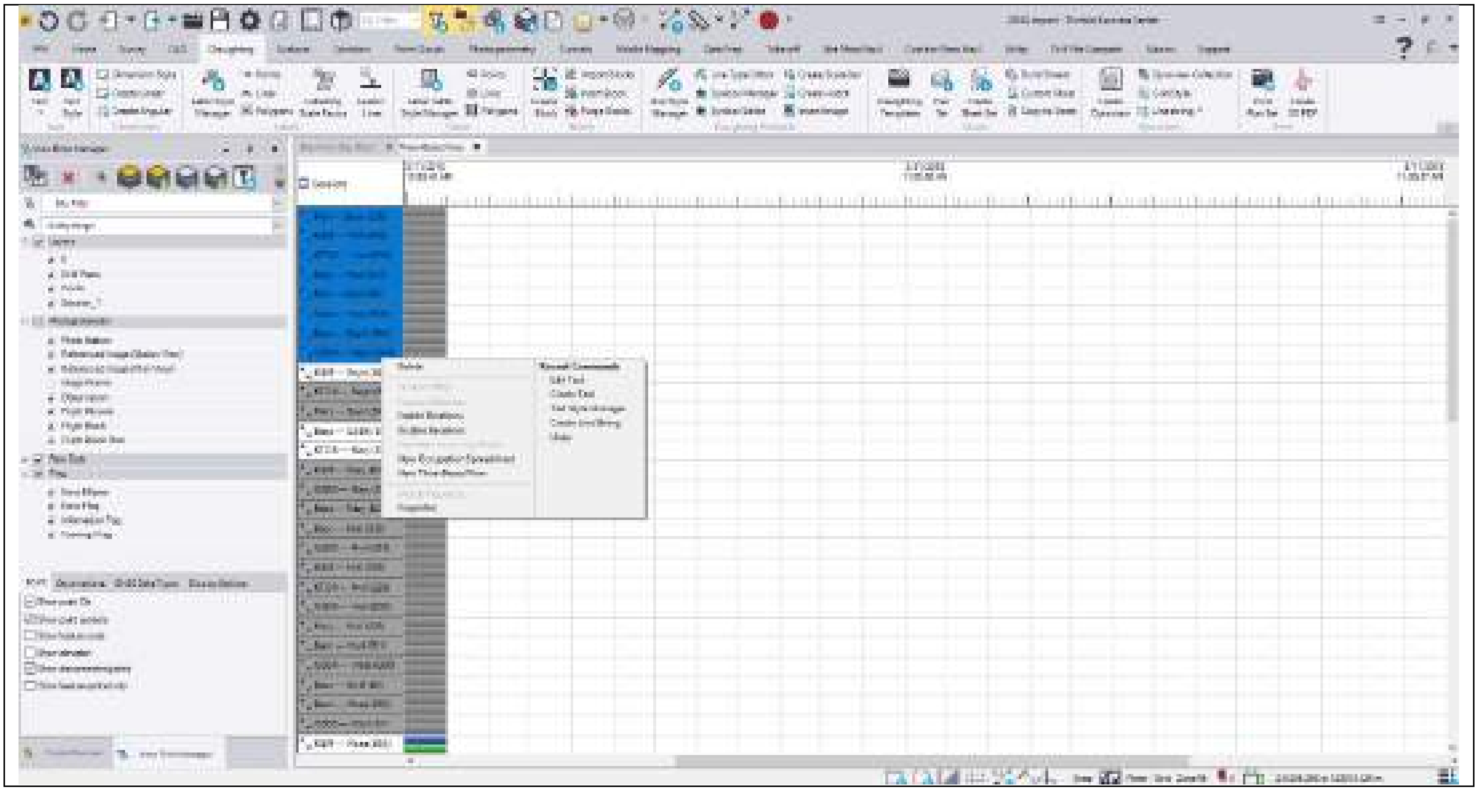
12) In the View Filter Manager you'll find a number of tabs at the bottom. Under the GNSS Data Types, select Enabled baselines only (for post processing). This allows us to easily separate the session visibility.



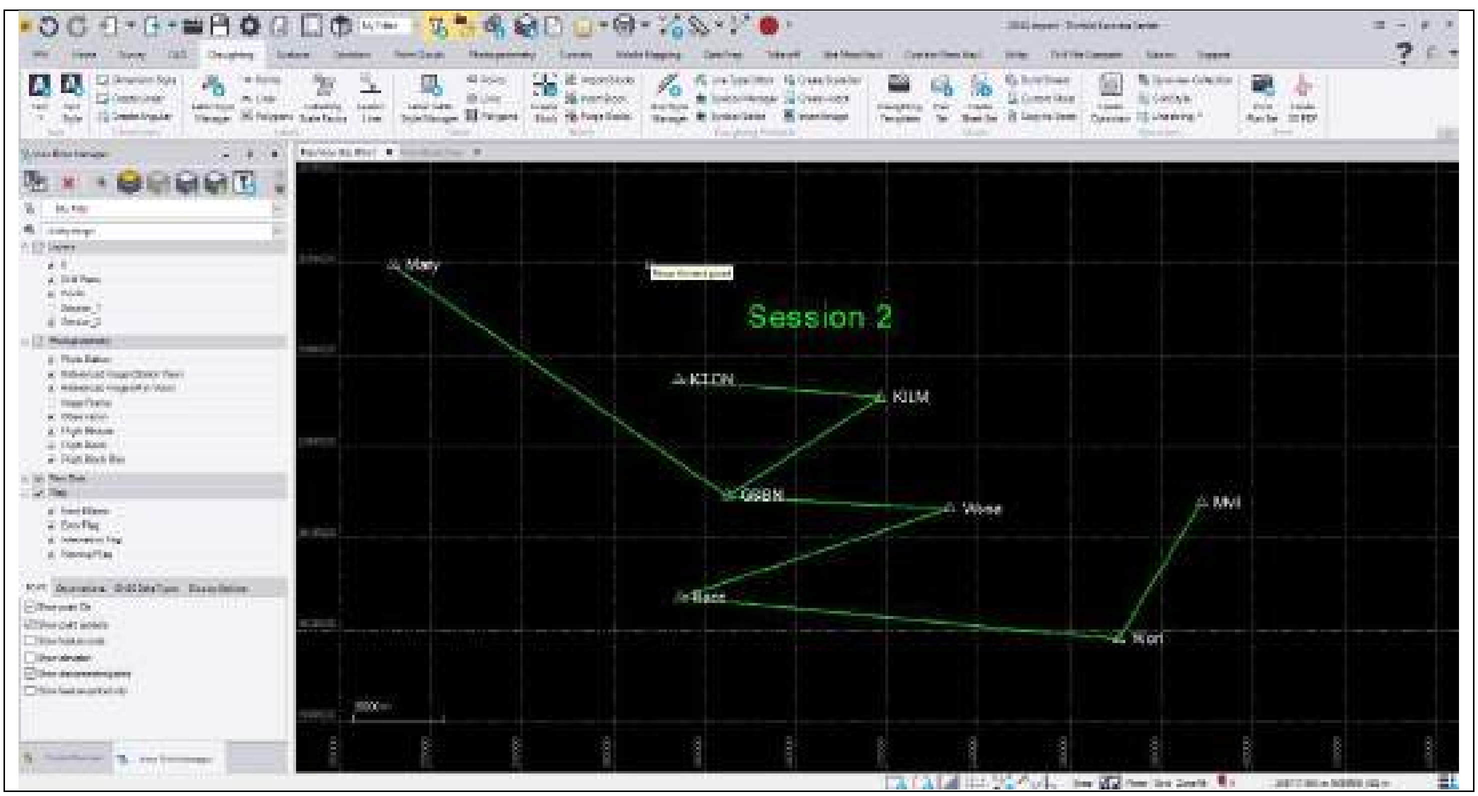
13) For any session of static survey there are only a small number of baselines that are required to determine the geometry of the network. All other baselines are referred to as trivial baselines, In order to remove all trivial baselines, delete all of the baselines except for the ones shown below.



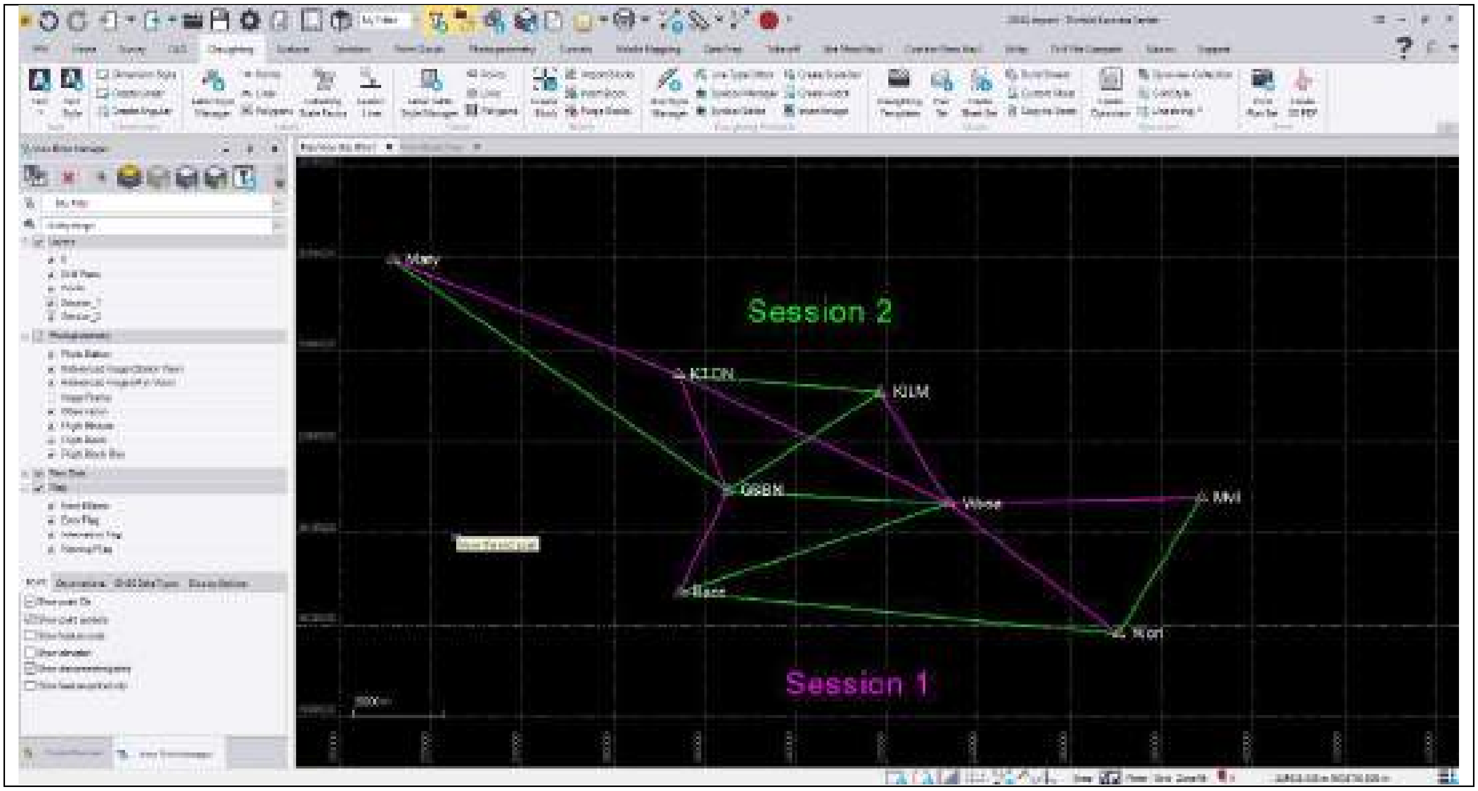
14) Once we've deleted the trivial baselines, we can then disable the baselines in Session 1 and enable the baselines in Session 2, so that only the Session 2 is visible for editing.



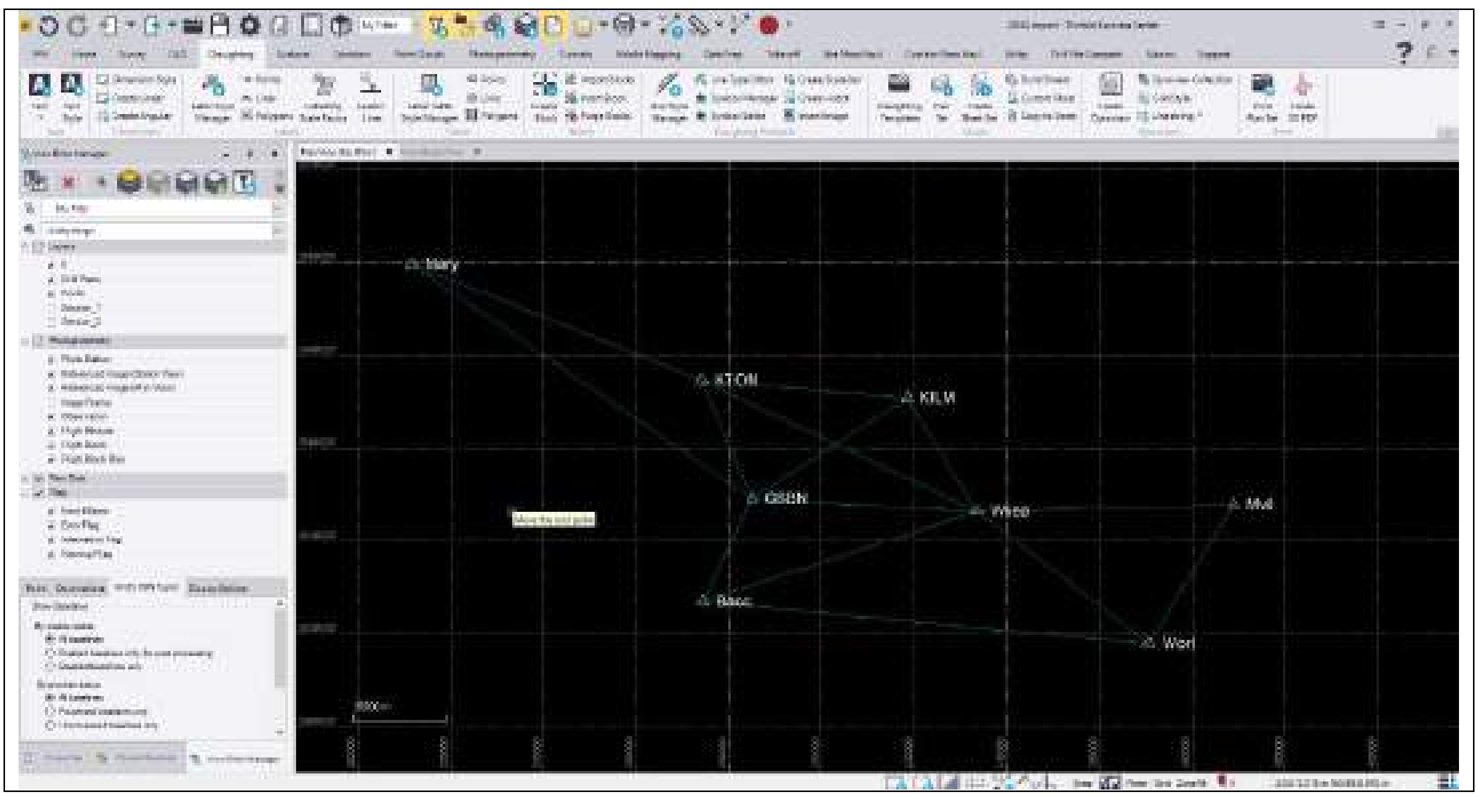
15) For Session 2 we want to achieve a network that appears as the one below.



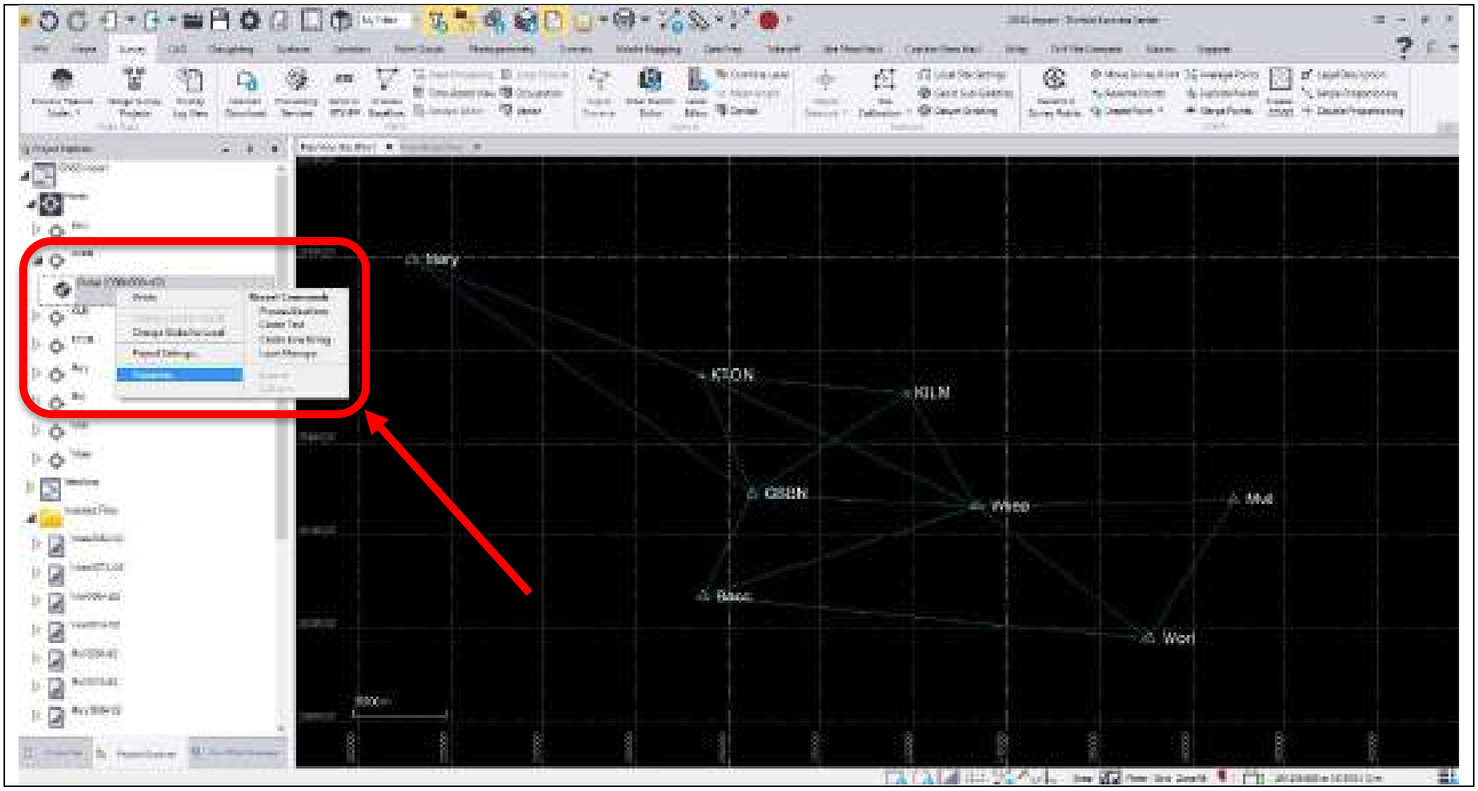
16) Your final network should look like the one shown below.



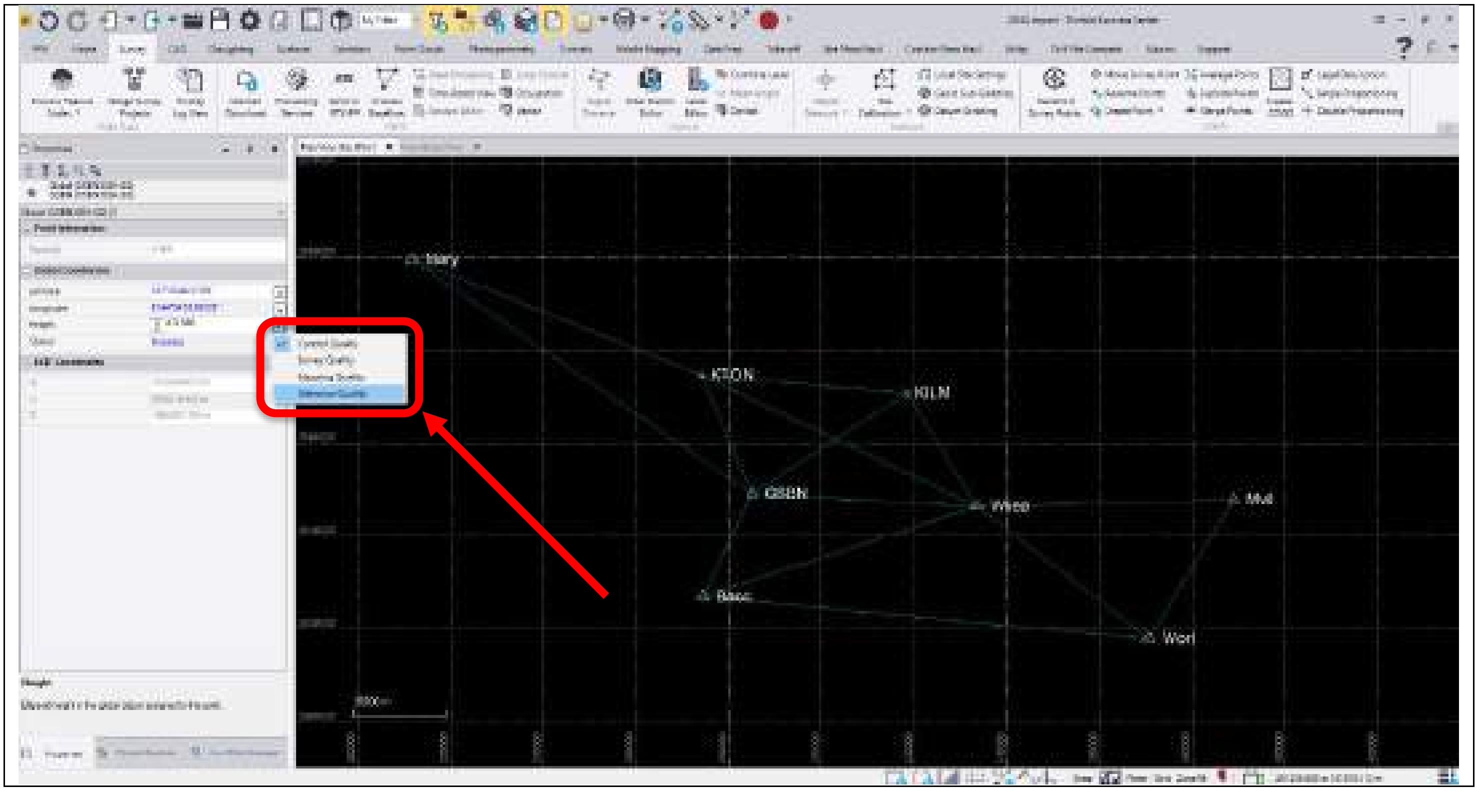
17) Here the network is shown again but, only as the baselines not the CAD lines and text.



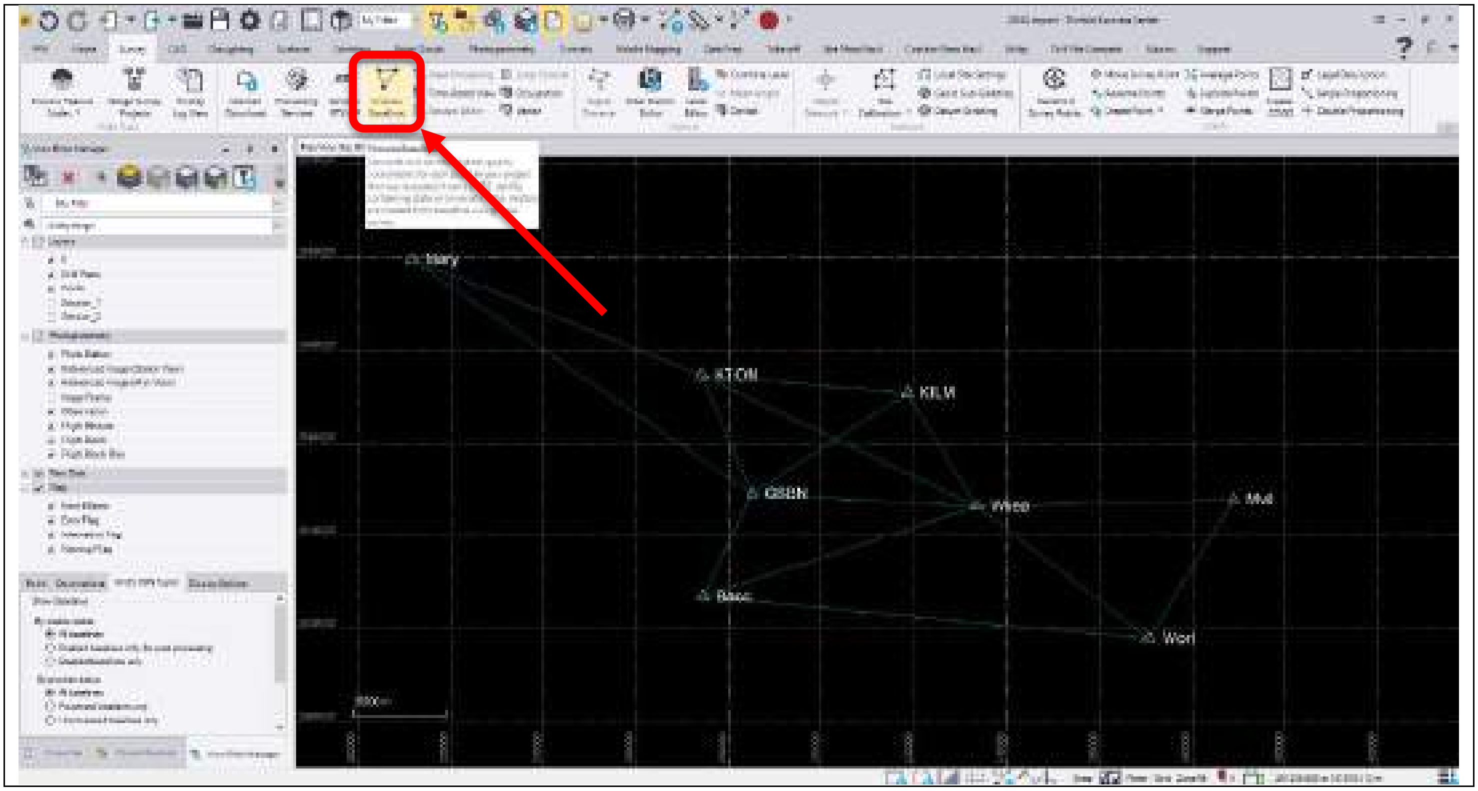
18) Next, expand the point information in the Project Explorer. Select one of the coordinates that is associated with a point and open Properties.



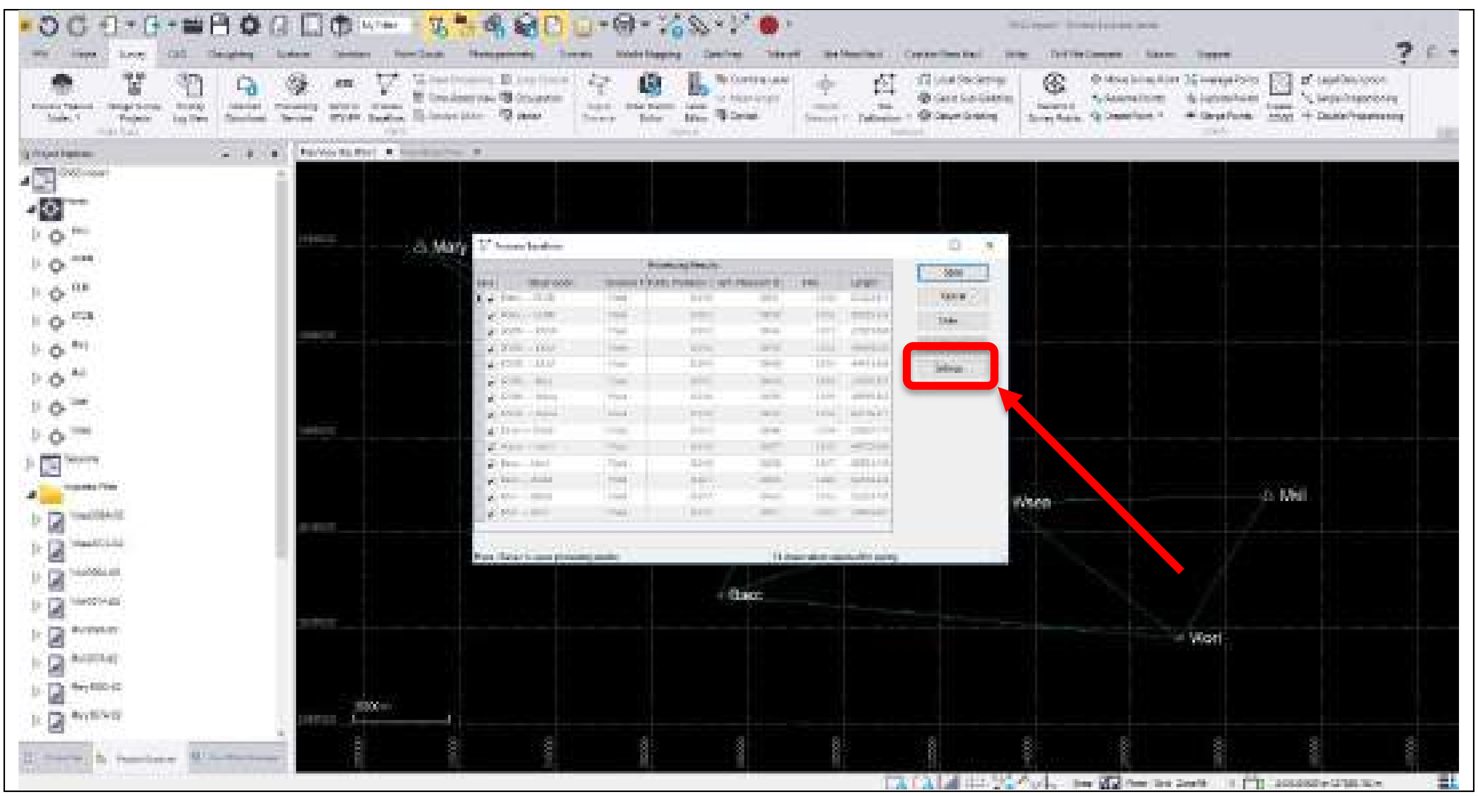
19) Generally, when importing data of this type the coordinate quality will be set to Unknown upon import. In this case because they have come from the CORS network. To maintain the standard workflow, change the coordinate quality for all the station to Unknown expect for Mary and Mvil, these should remain as Control Quality.



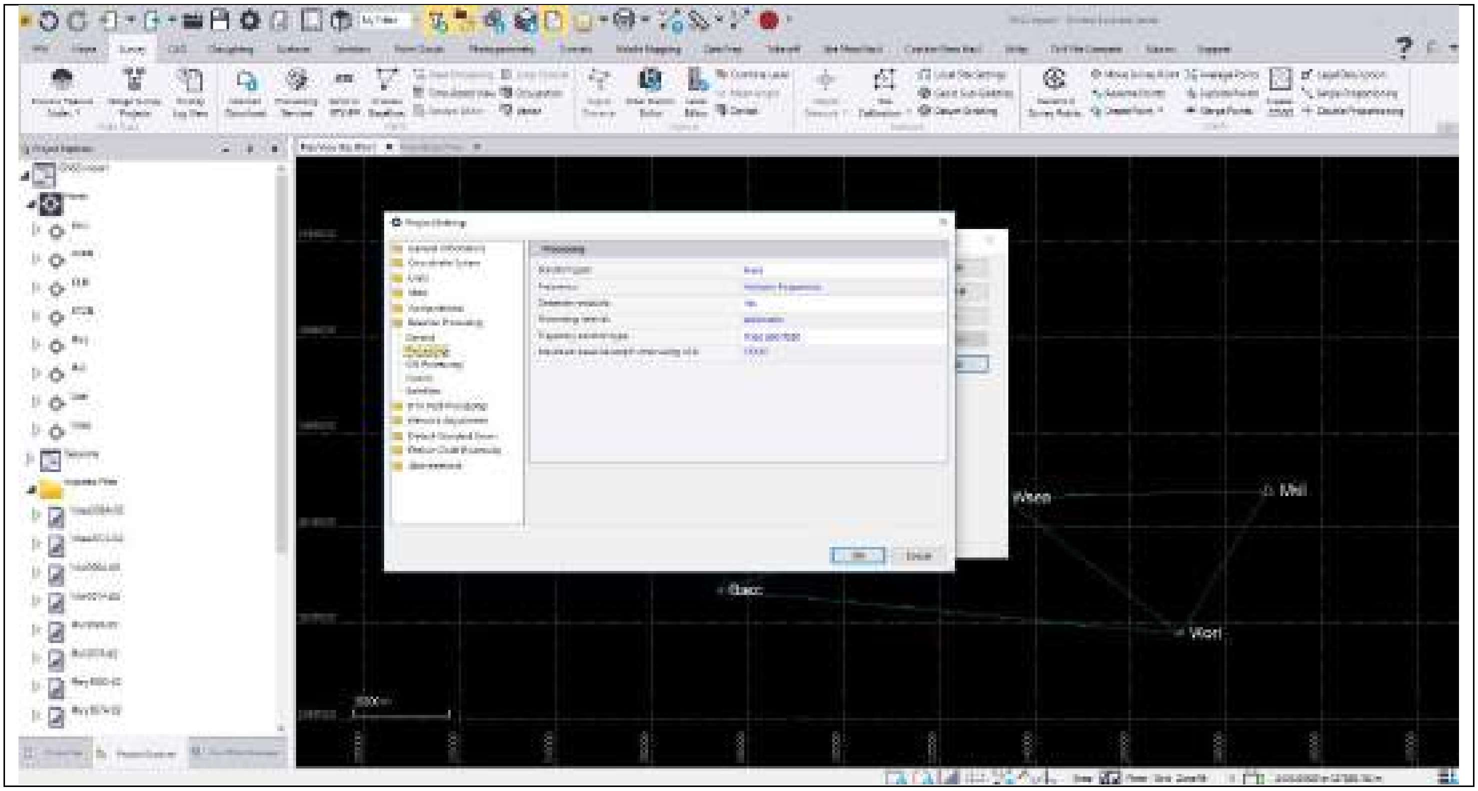
20) We're now ready to process the baselines. Select Process Baselines from the Survey tab.



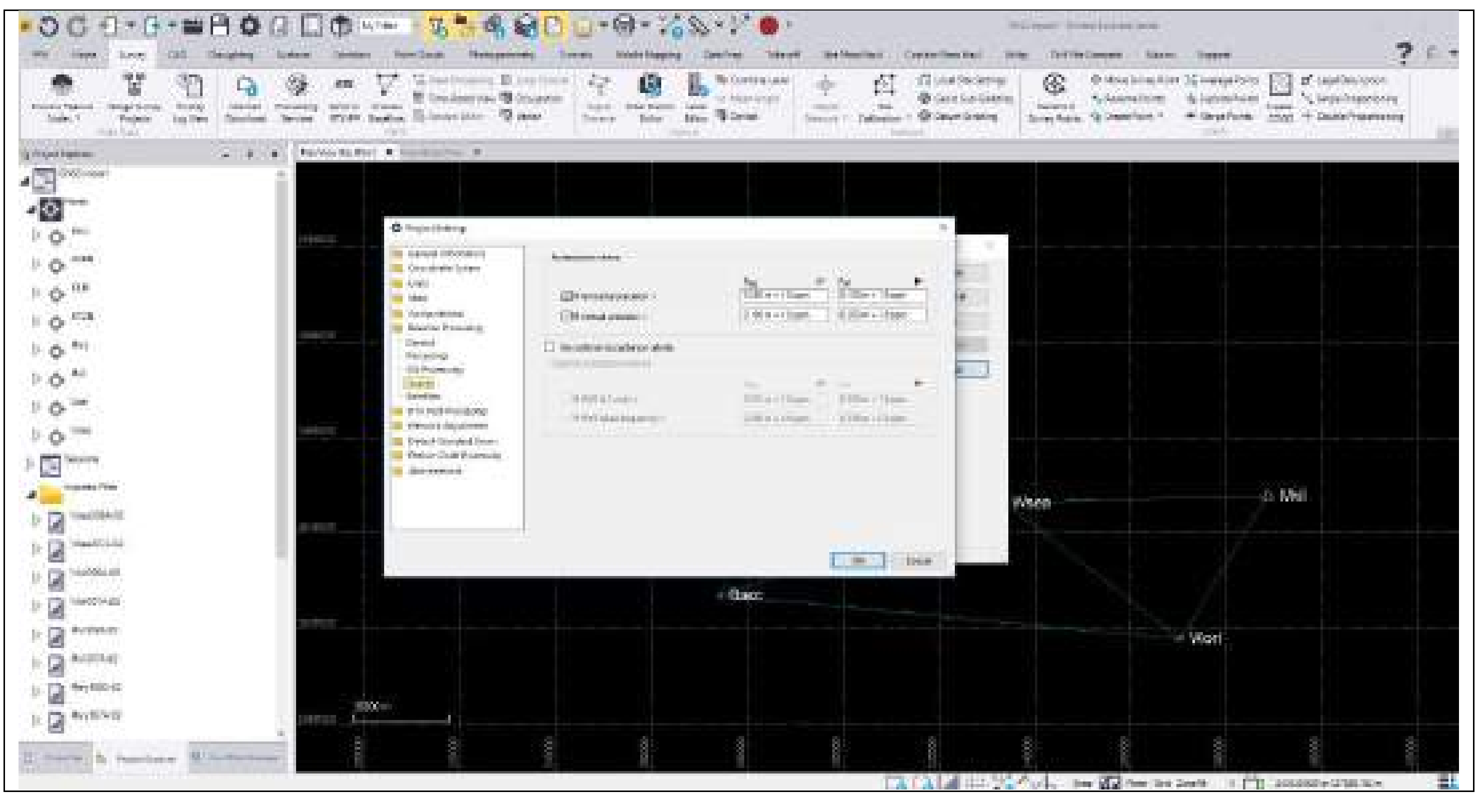
21) If we wanted to change any settings we could access the Project Settings from the Process Baselines menu.



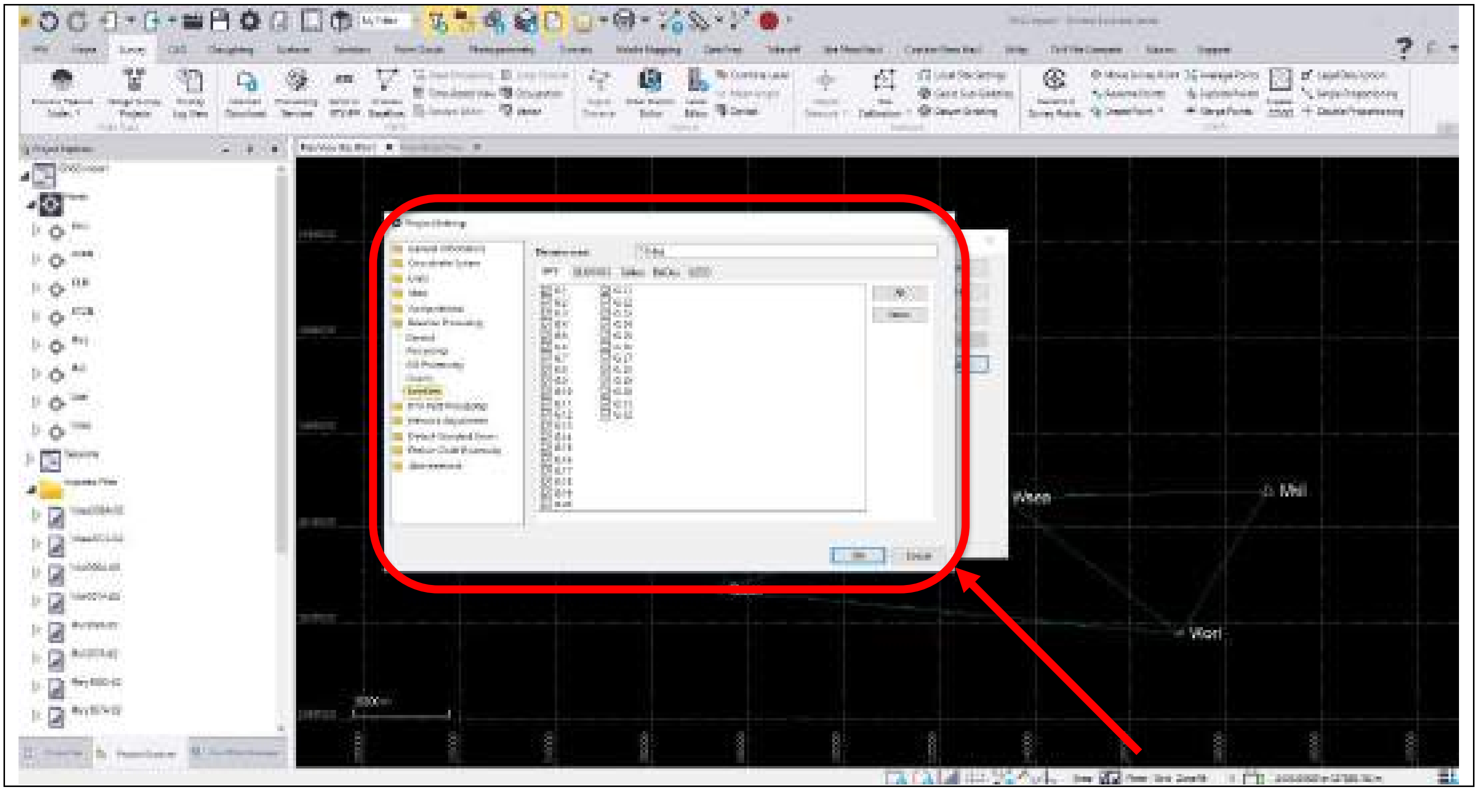
22) The project settings contain a number of different sections dedicated to baseline processing.



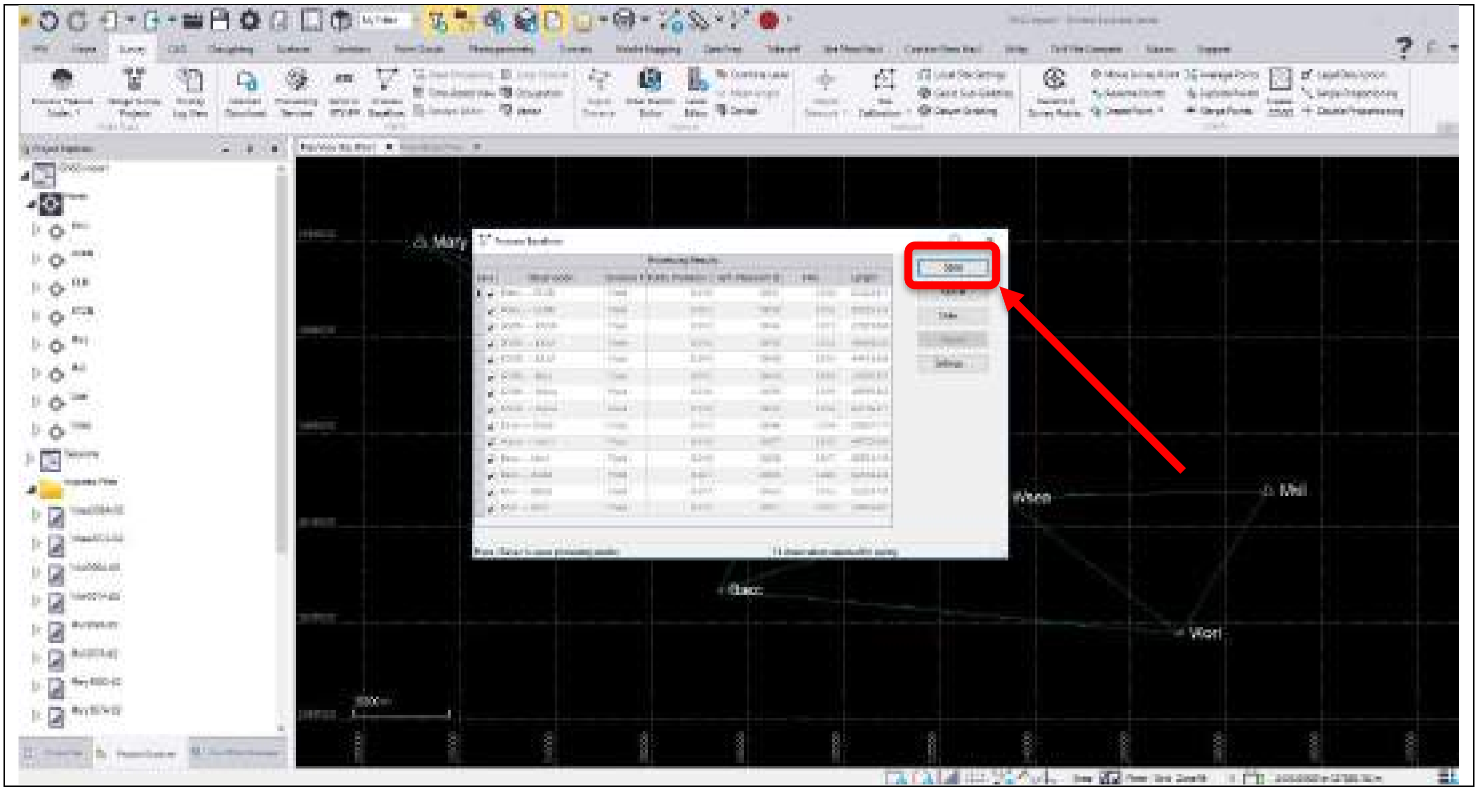
23) One way of identifying baselines that may not be of good quality is to adjust the acceptance criteria to a threshold that will flag outliers. For this project we will leave it as the default settings though.



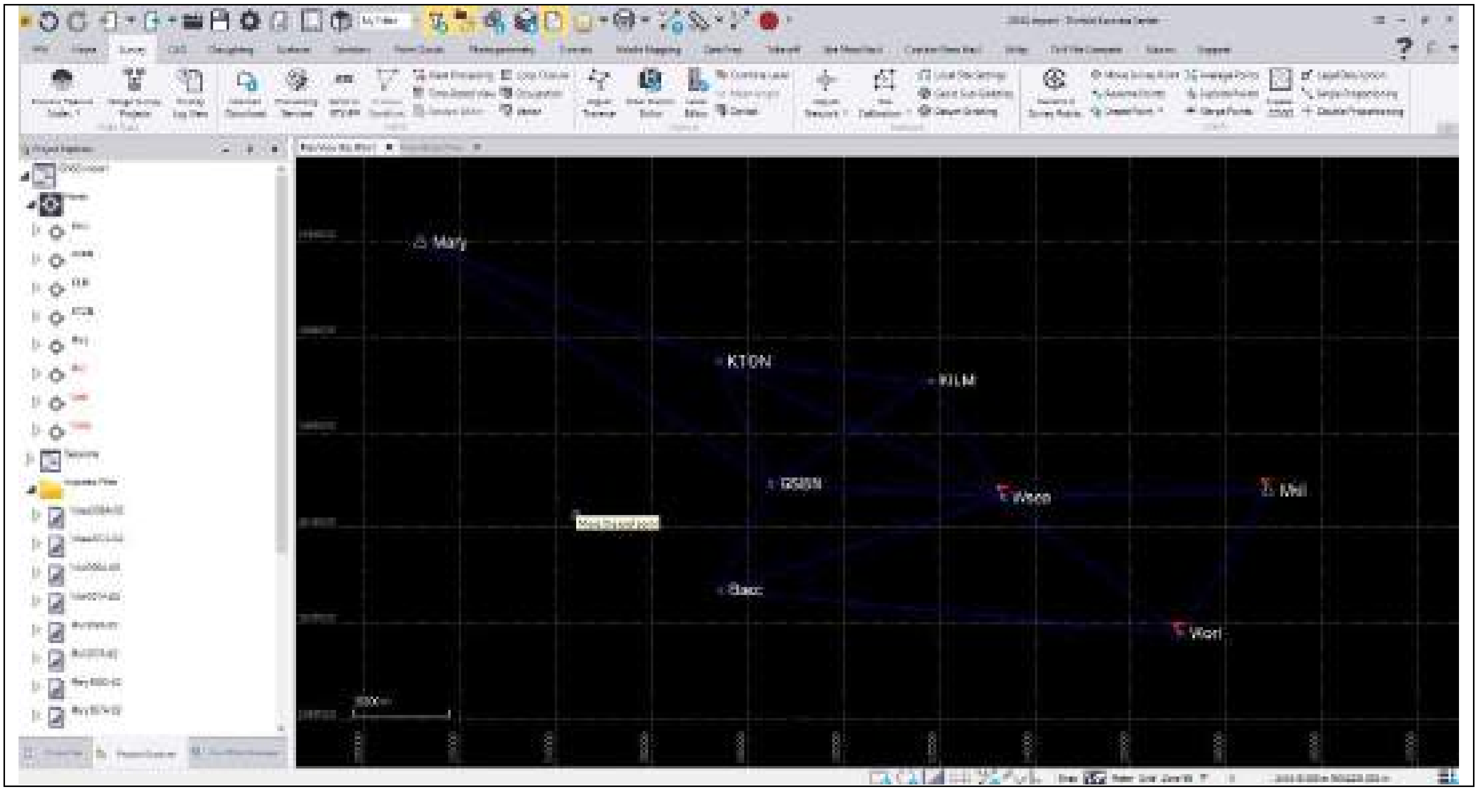
24) Under the Satellites section we are also able to choose which constellation we want to use in our processing and what elevation mask we want to process to. This data set only tracked GPS / GLONASS so there is no need to modify the settings as these default to being on. Select OK to exit.



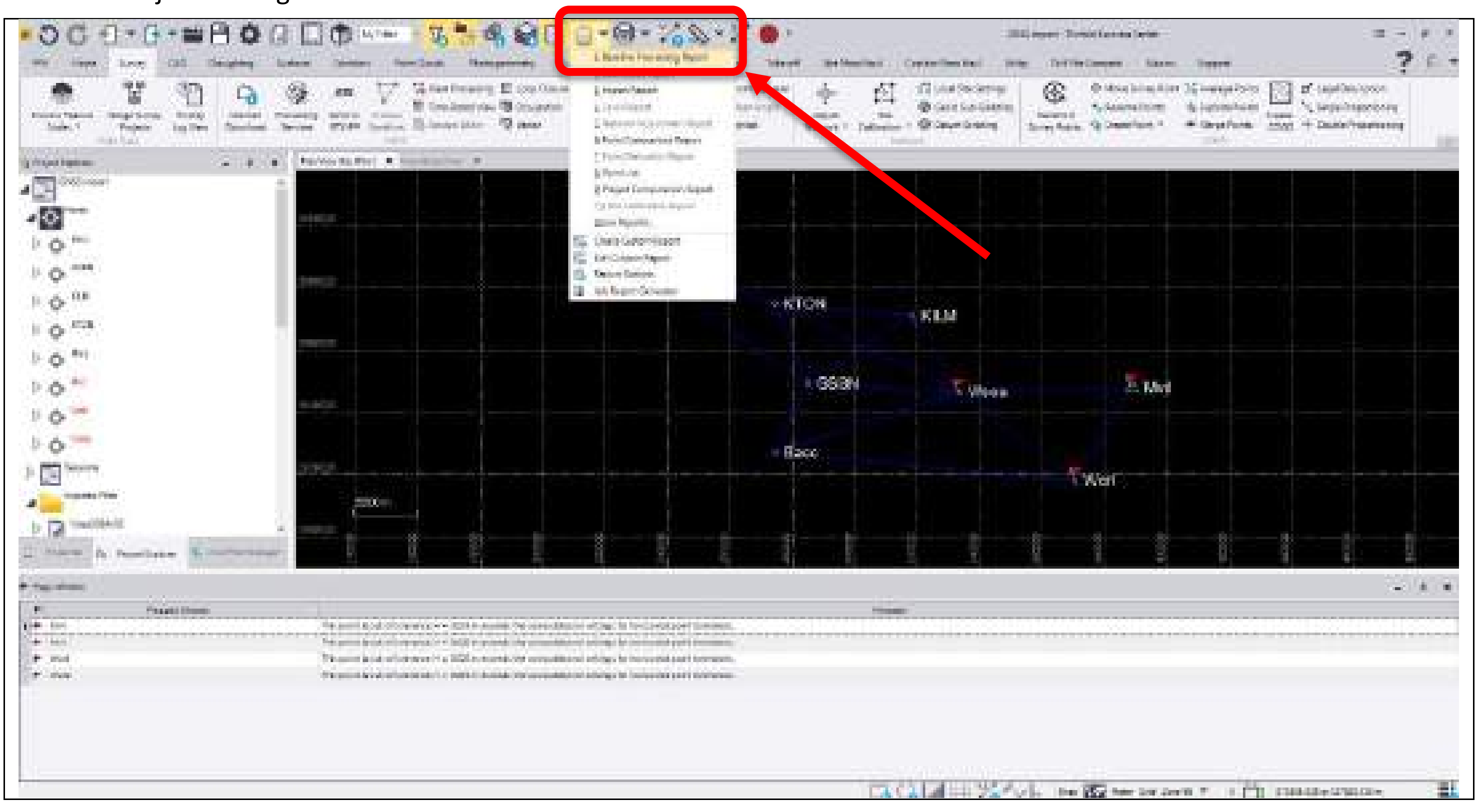
25) Select Save to accept the processing results and close the pane



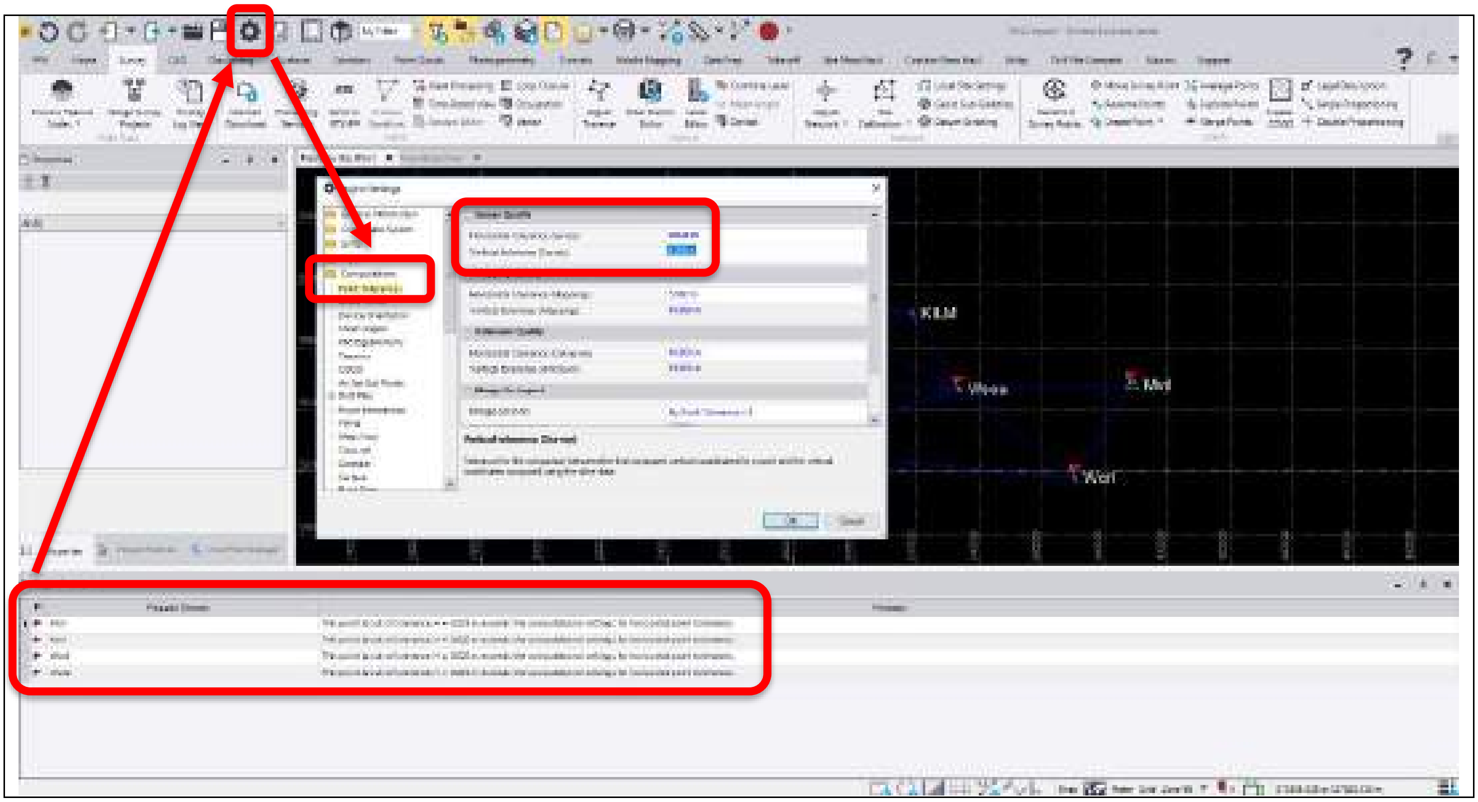
26) Once you save the results you can now see the blue vectors that make up the network. Each of the different raw data types have a specific colour, this helps to identify different data types easily when working with complex data sets.



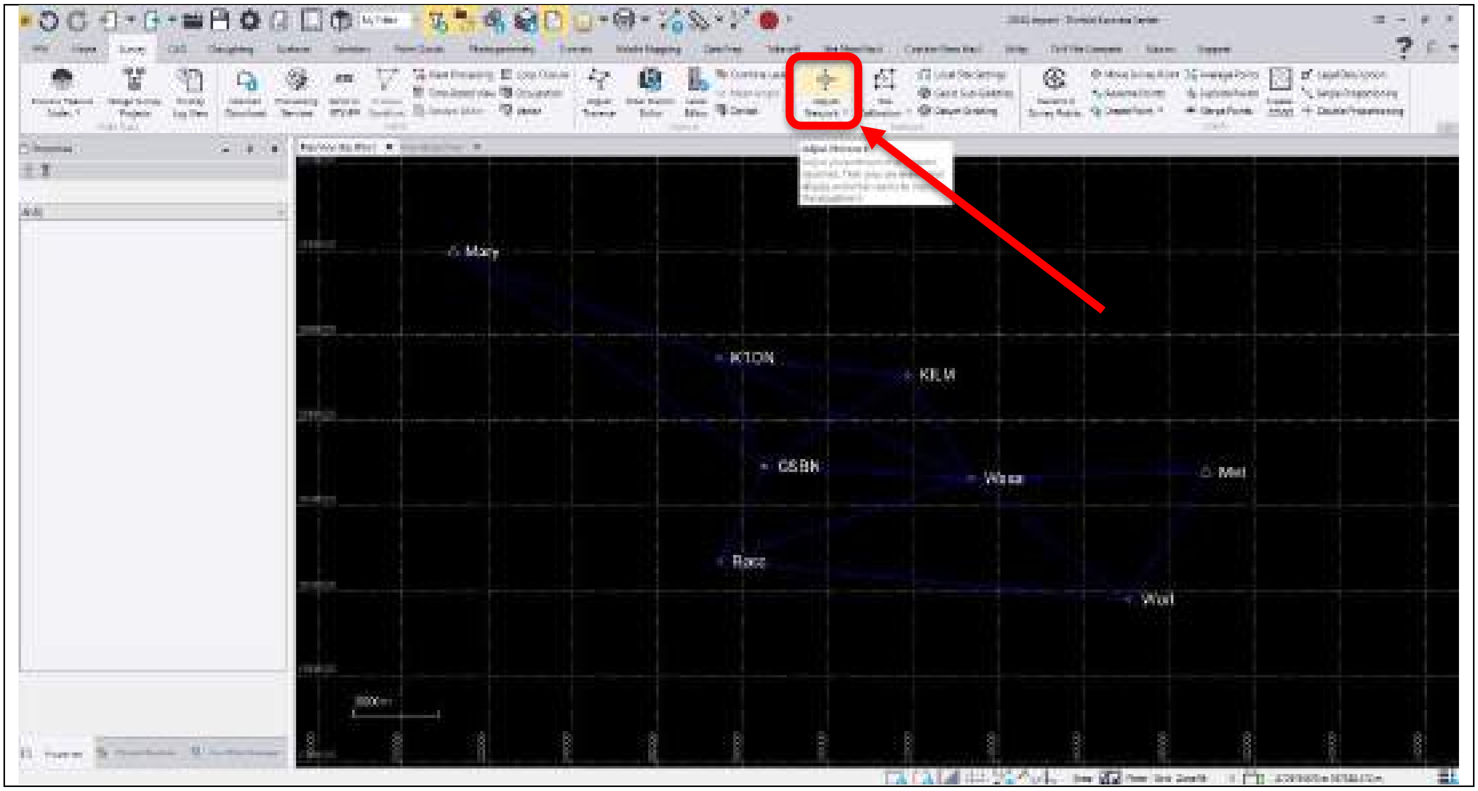
27) If we wanted to generate a Baseline Processing Report to review the processing in more detail we can do so from the Reports button on the Quick Access Tool-Bar.
28) As you can see in the image below, the processing has caused a few error flags to be generated. This is due to the relatively short occupation times, long baselines, and the default settings for the Point Tolerances in the Project Settings.



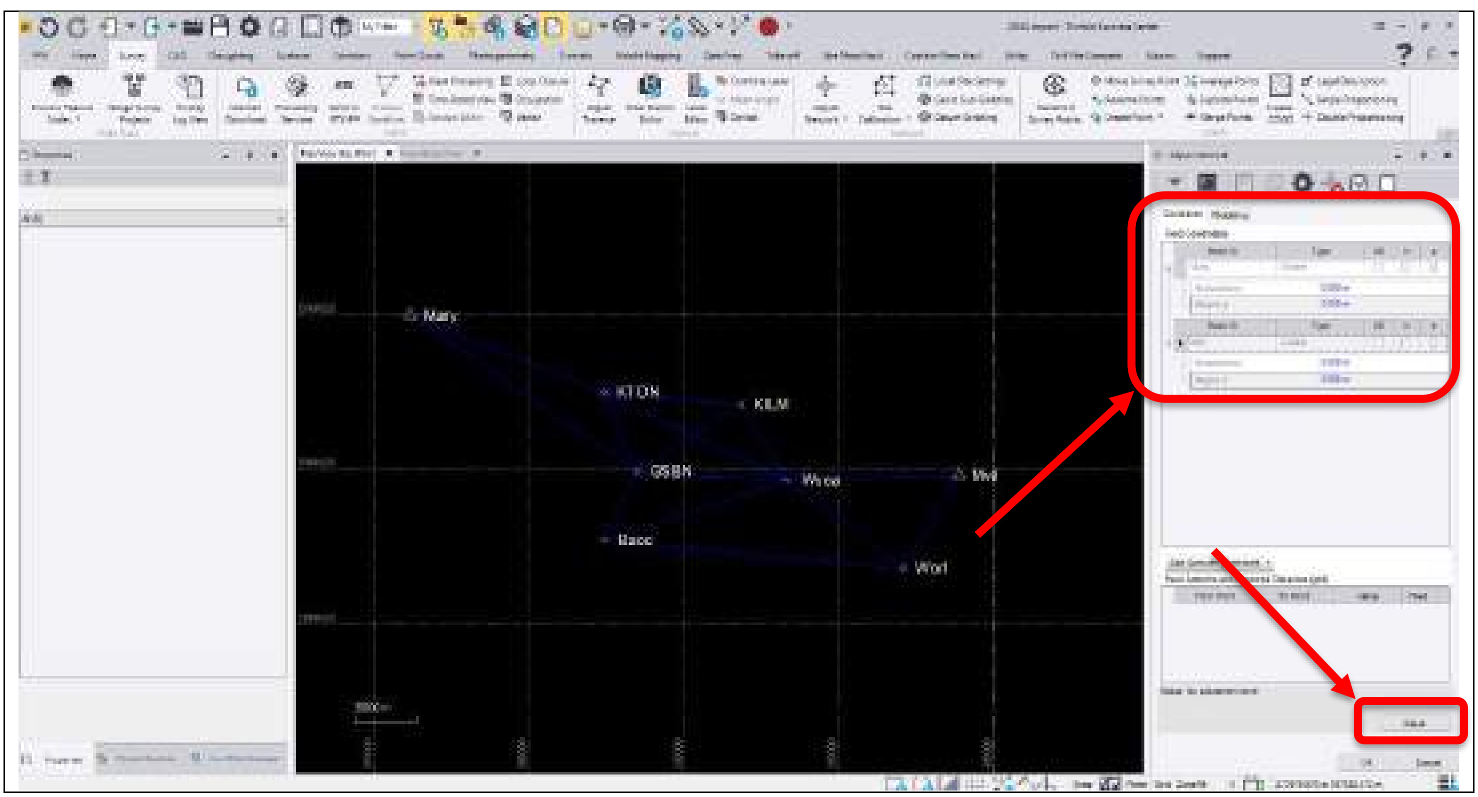
29) If we wanted to quickly remove the flags, we can increase the Point Tolerances to something more reasonable for the project. This is optional and the Network Adjustment won't be influenced if you didn't make changes to the Point Tolerances.



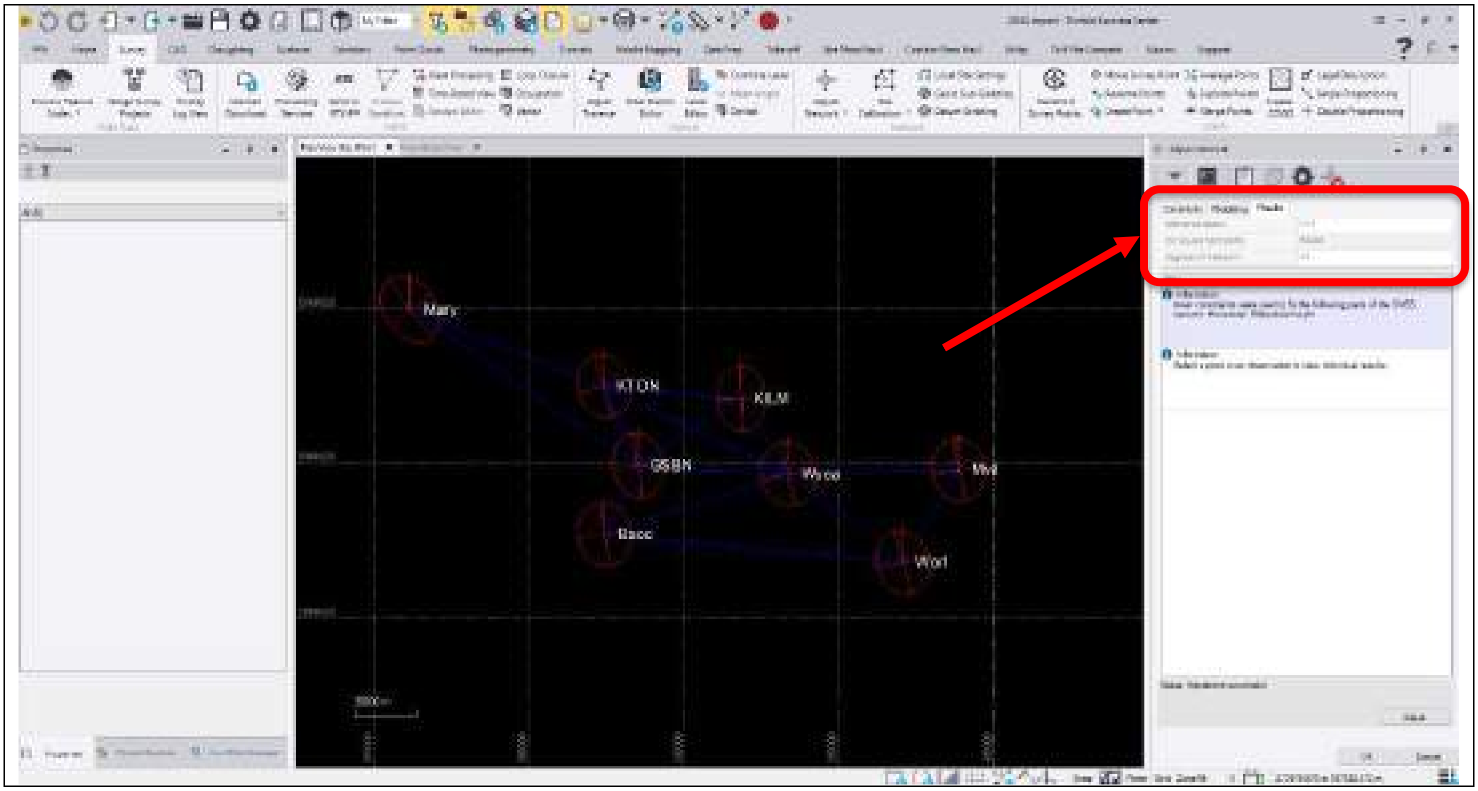
30) Next, select Adjust Network from the Survey tab.



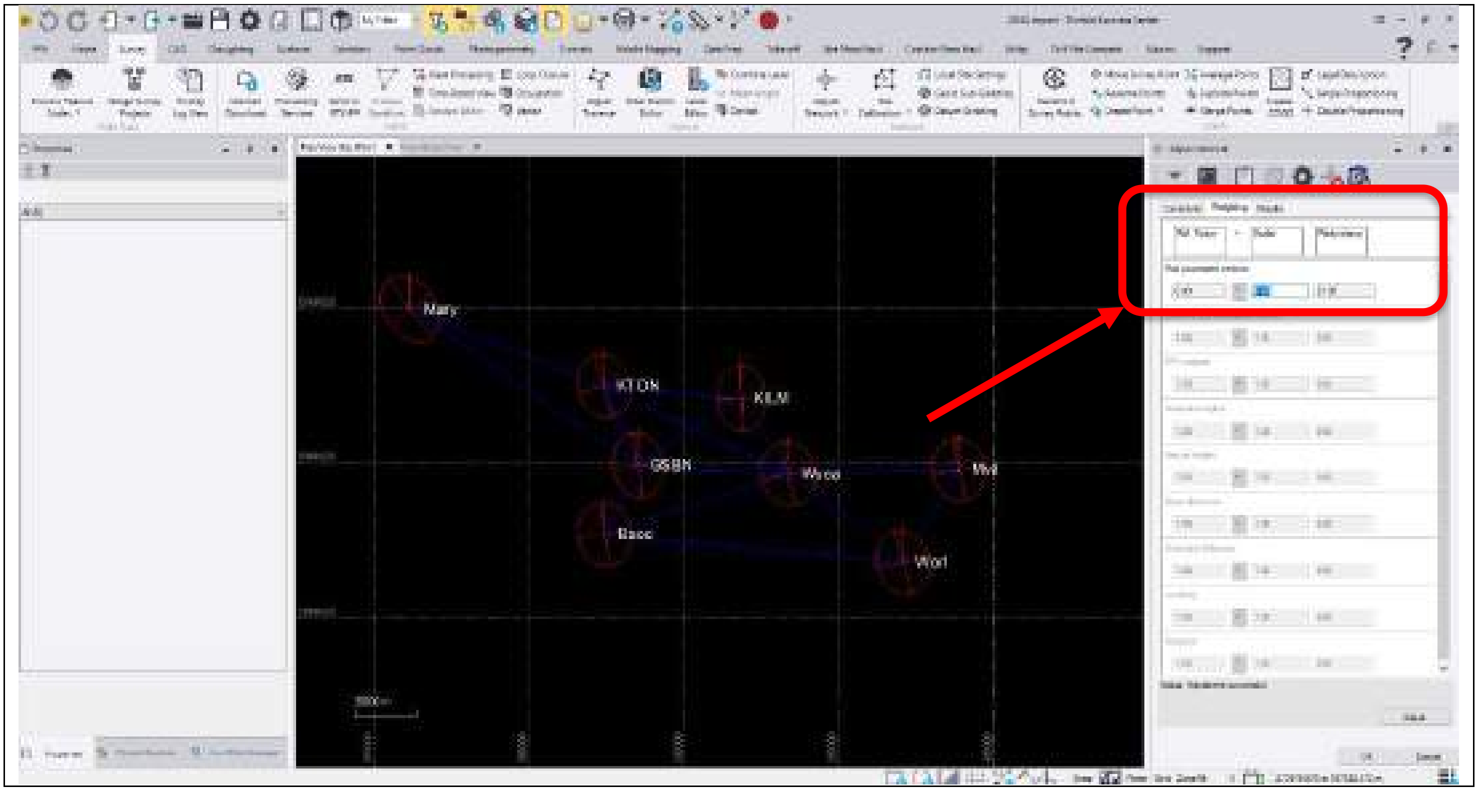
31) To begin with we won't apply any constraints to the Network Adjustment. This allows us to review the quality of the network without bias from constraints influencing the result. Select Adjust.



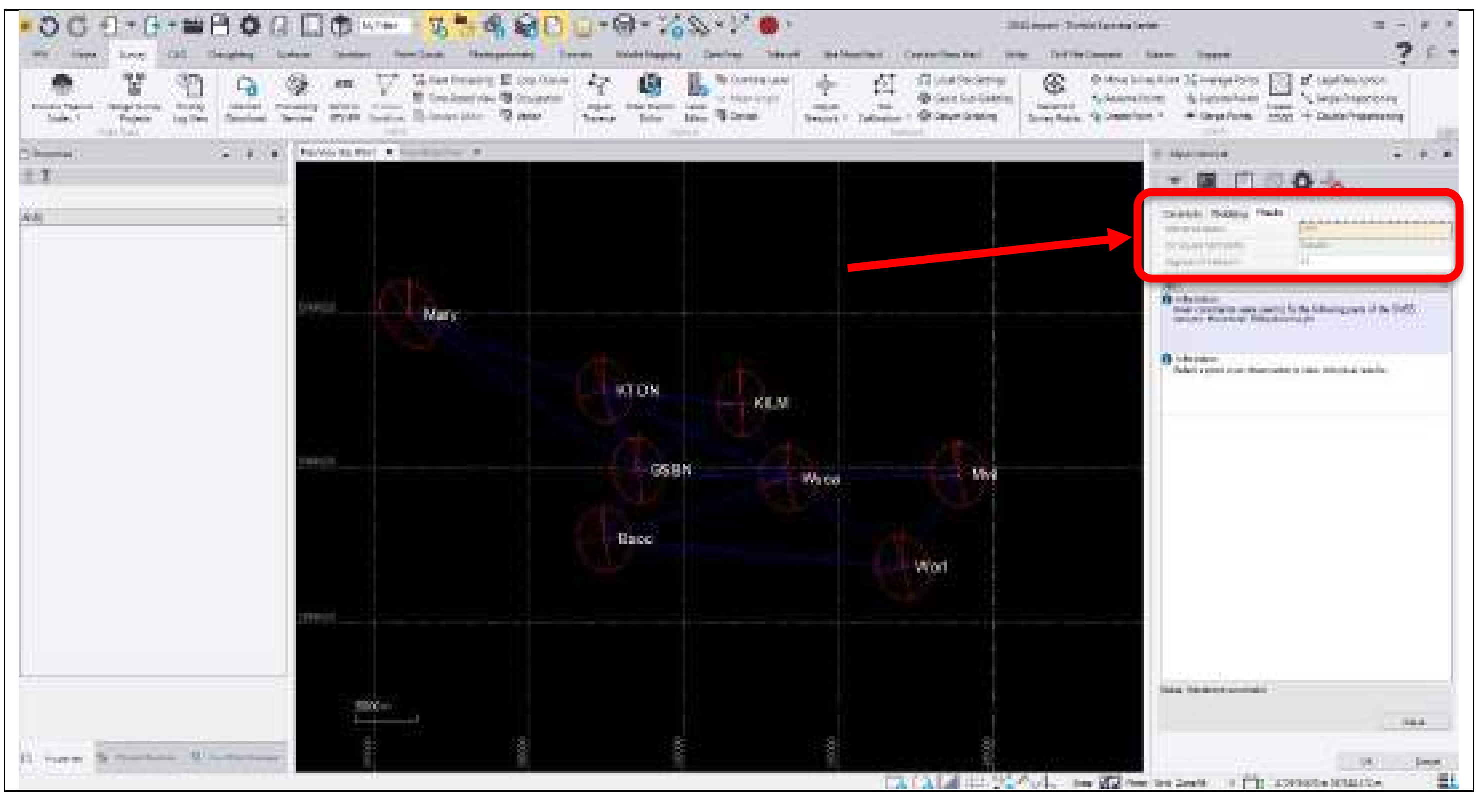
32) As can be seen here the initial Adjustment has resulted in a Chi Square test that Failed. The Chi Squared test is a statistical test to indicate whether the results are reasonable. As can be seen from the Reference factor we have underestimated the quality of our network and achieved smaller residuals than expected.



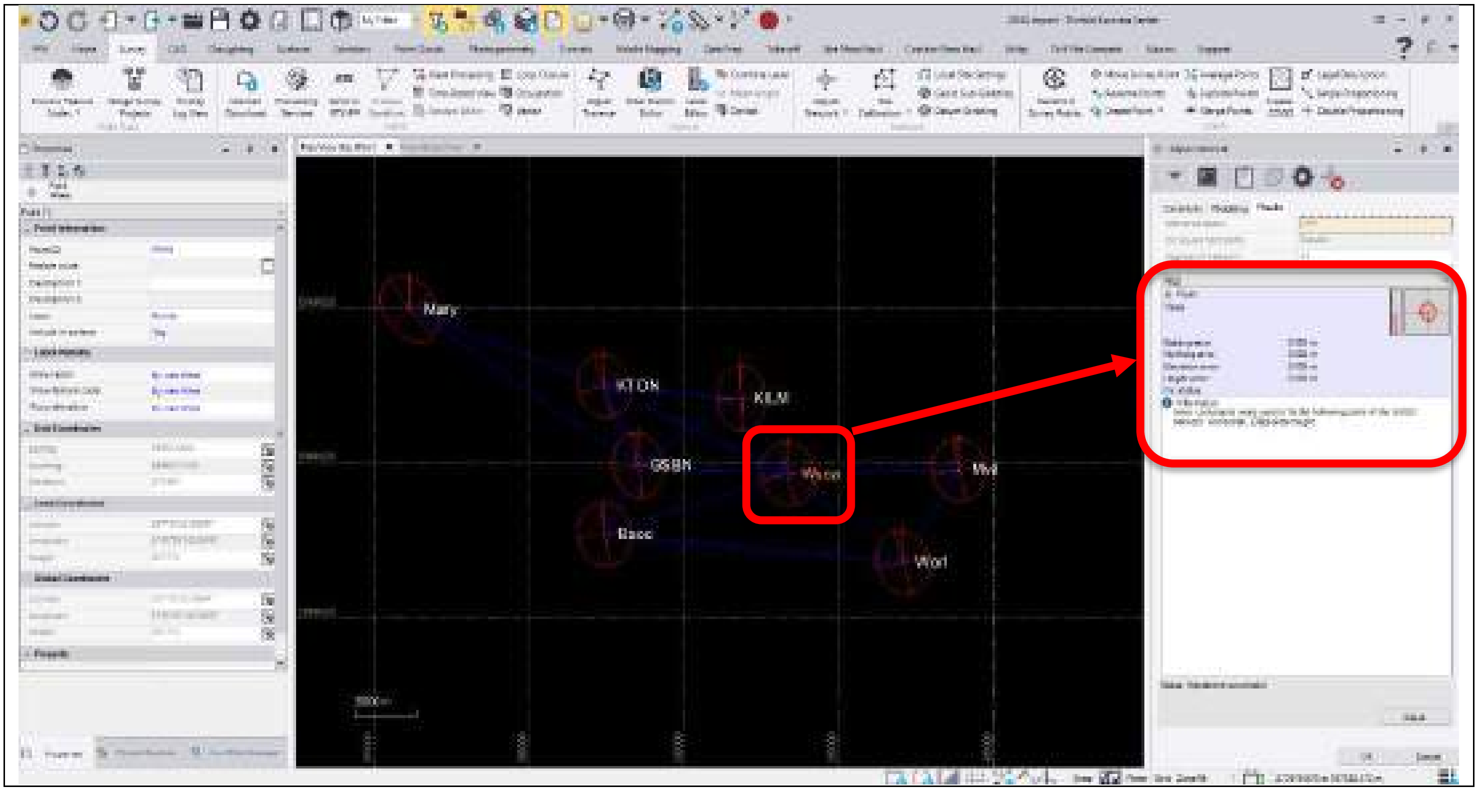
33) To correct the estimates for our network we can apply a scalar value from the adjacent tab.



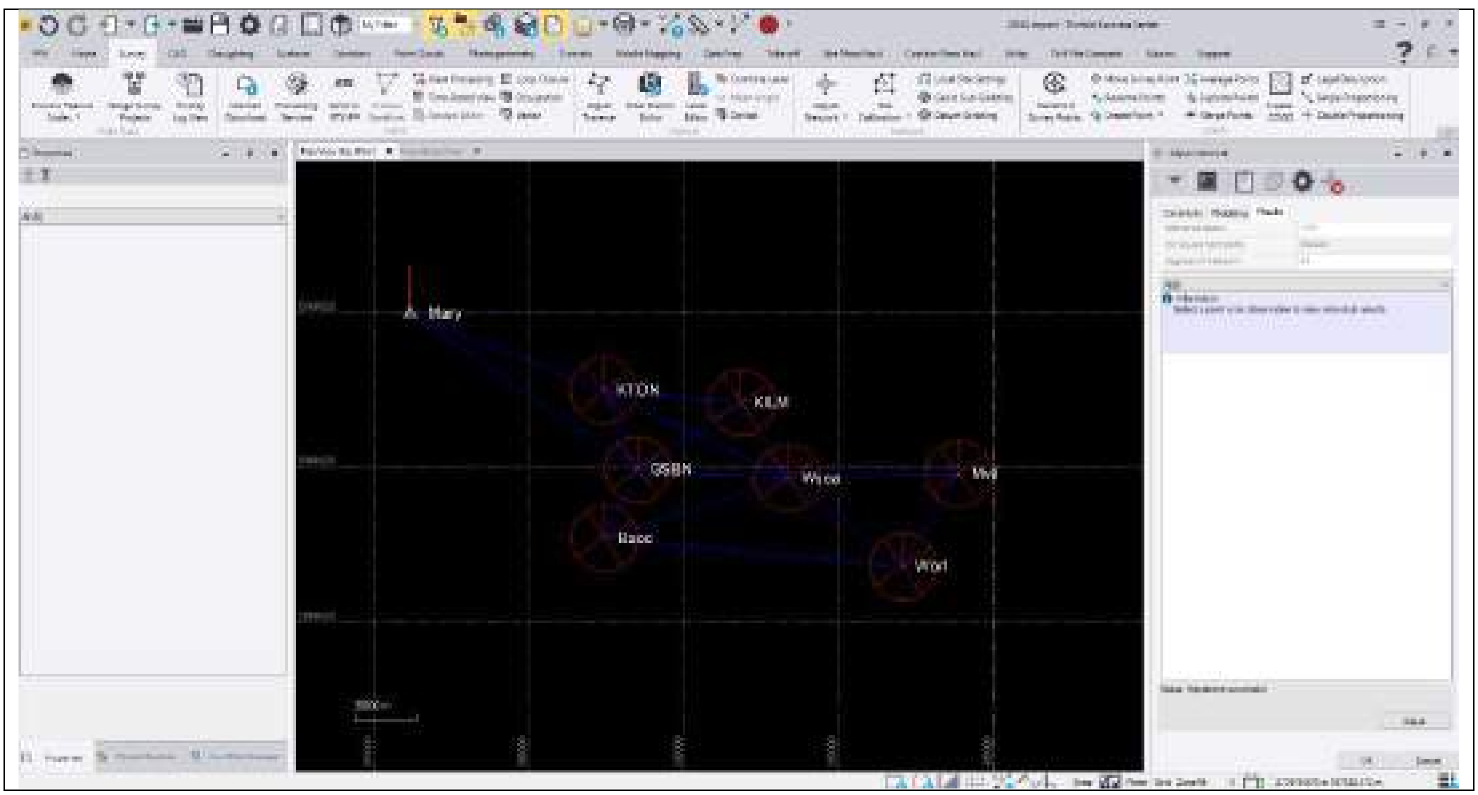
34) Select Adjust again after applying the scalar and you should see the Results pane now has a Reference factor of 1.00. This means the error model is accurate for the network. The Chi Square test has also Passed now too.



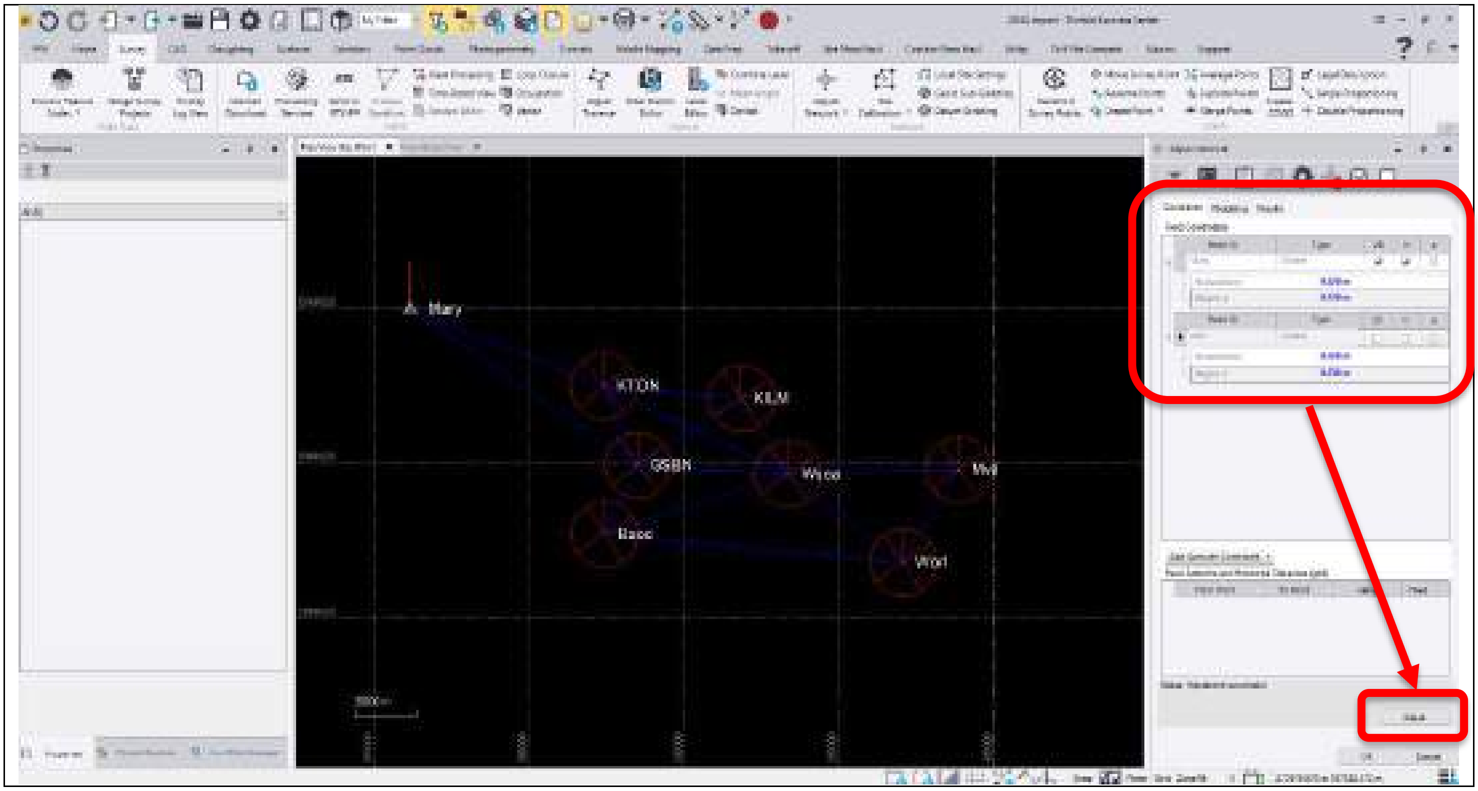
35) If you select any point in the adjustment from the Plan View you will get a detailed break down of the error ellipse components.



36)

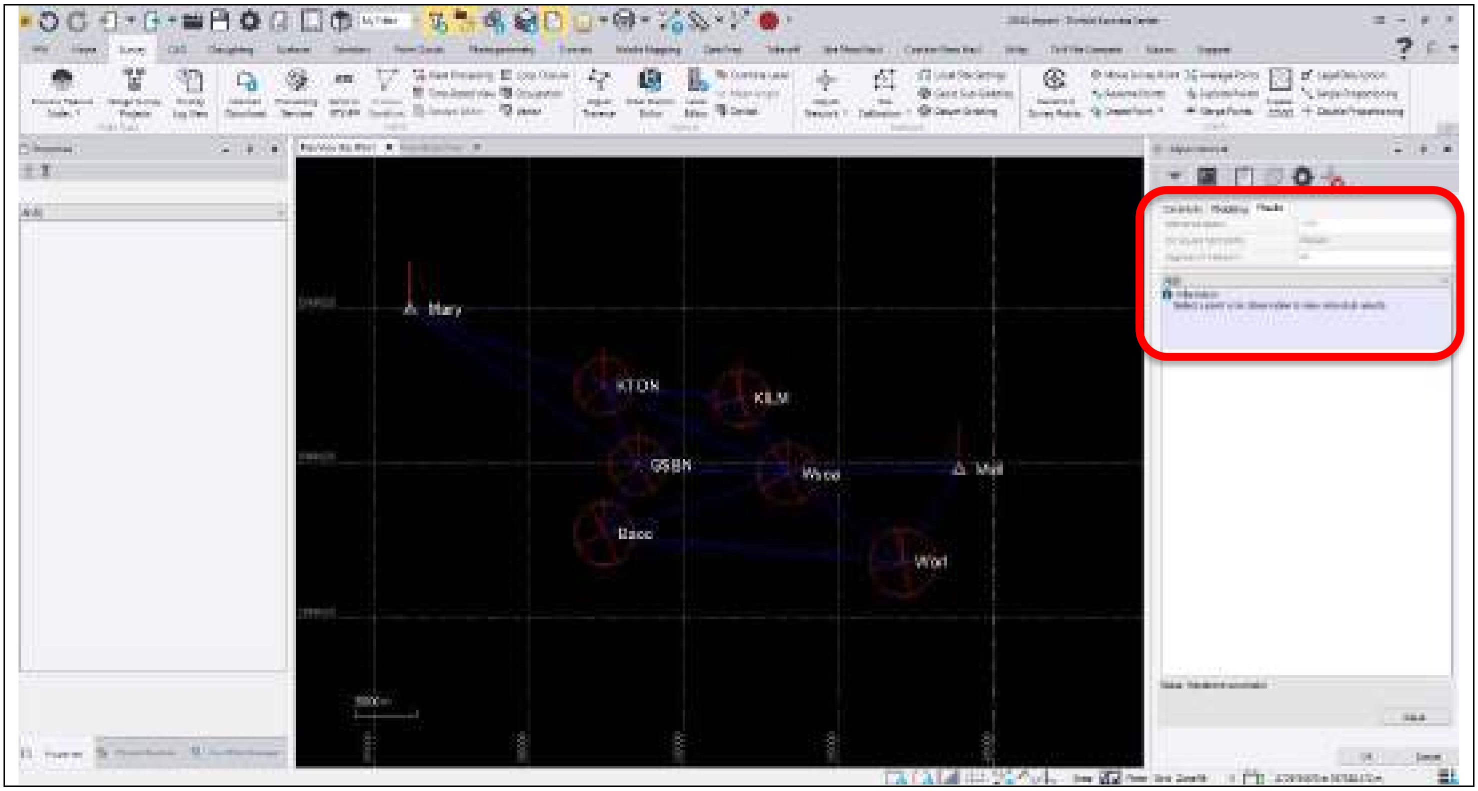


37) We'll now apply constraints to the network and reprocess it. Initially we'll only constrain the *Mary*. When doing so expand the details for *Mary* and input a Horizontal standard deviation 0.02m and a Vertical standard deviation of 0.03m.



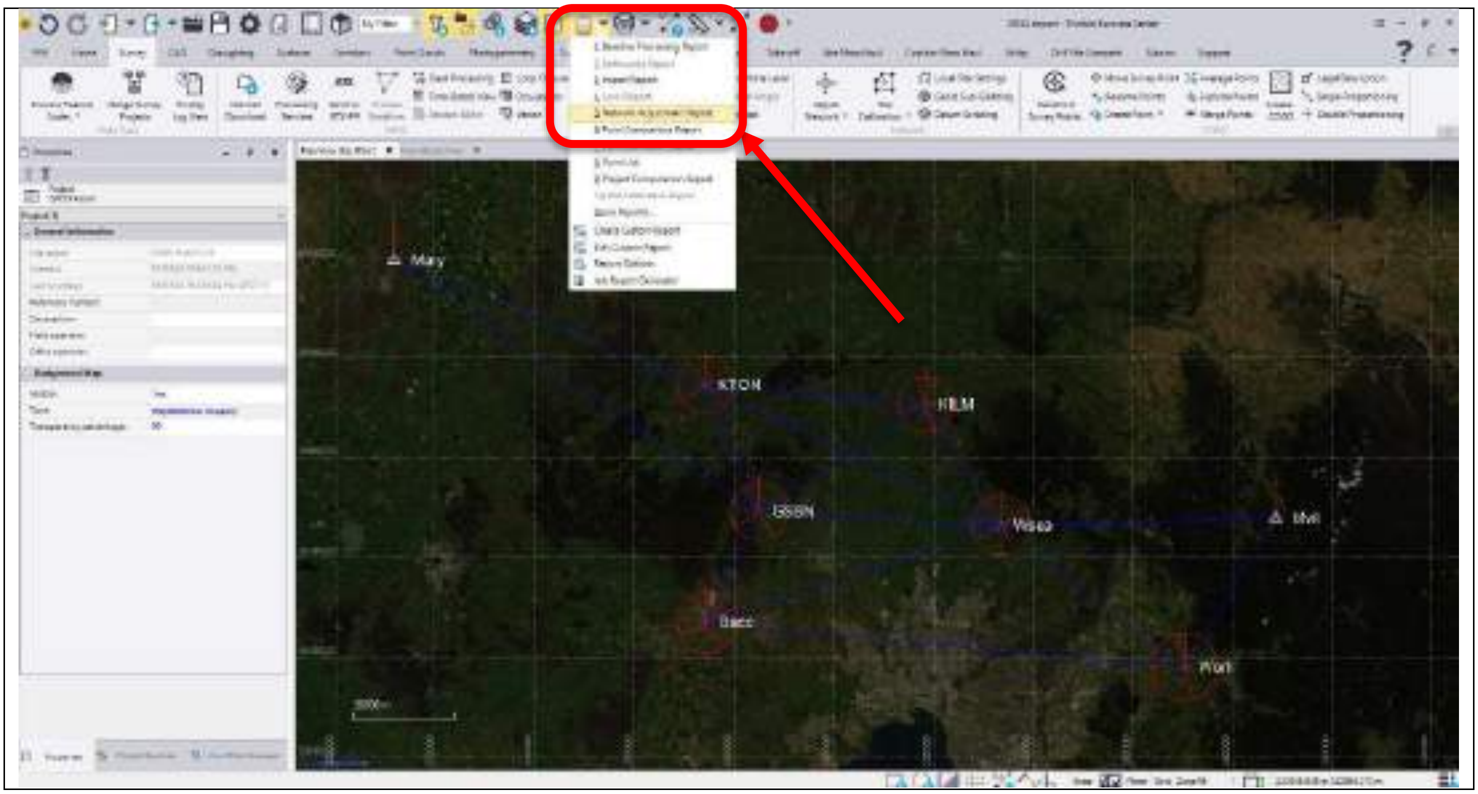
Trimble

38) After reviewing the adjustment, you can then proceed to constrain *Mvil* and select Adjust again. This is now a fully constrained adjustment. You may have noted that as we constrained the network the ellipses became more circular in form. In general, we should expect circular ellipses from GNSS networks.

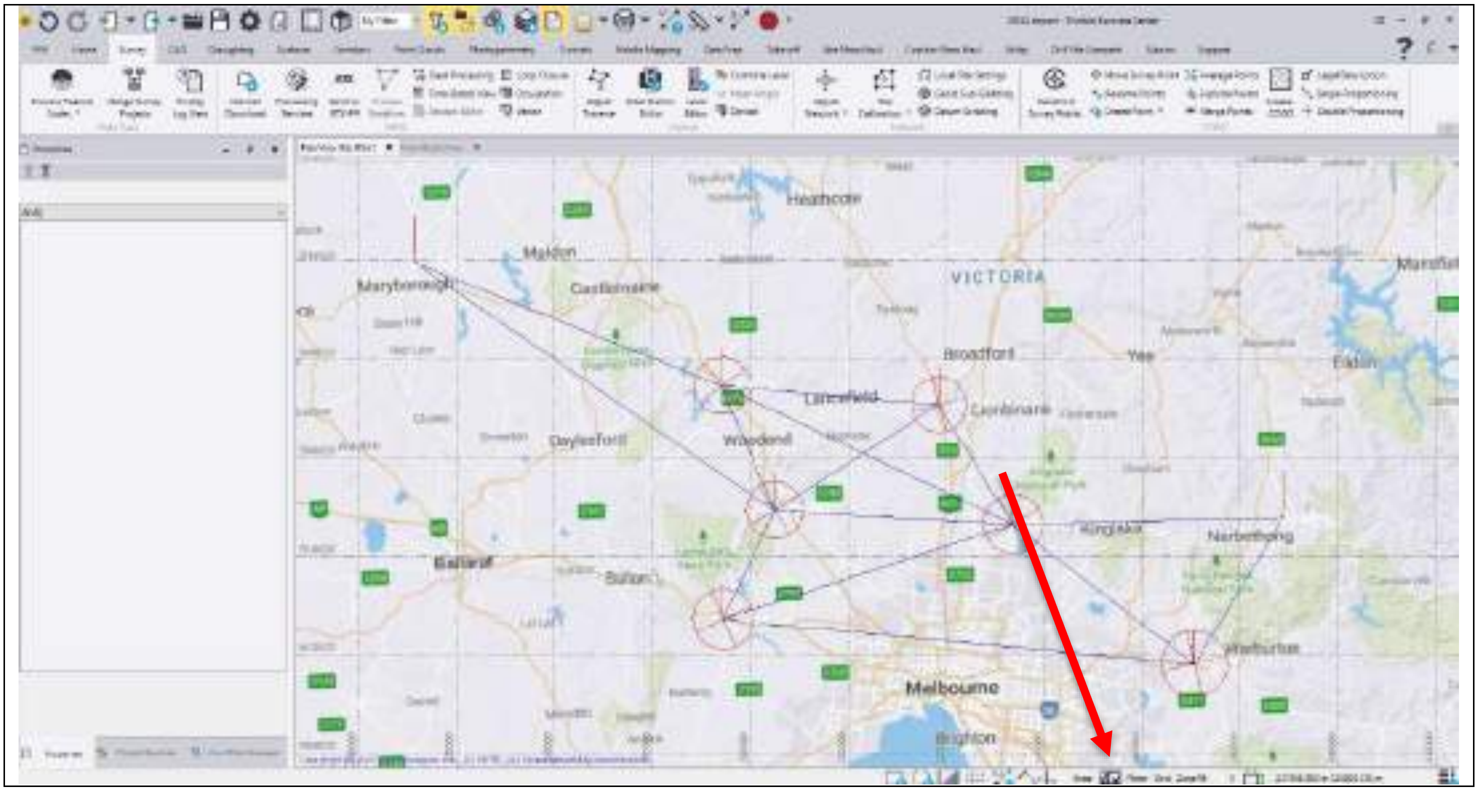


39) Select OK to close Adjust Network.

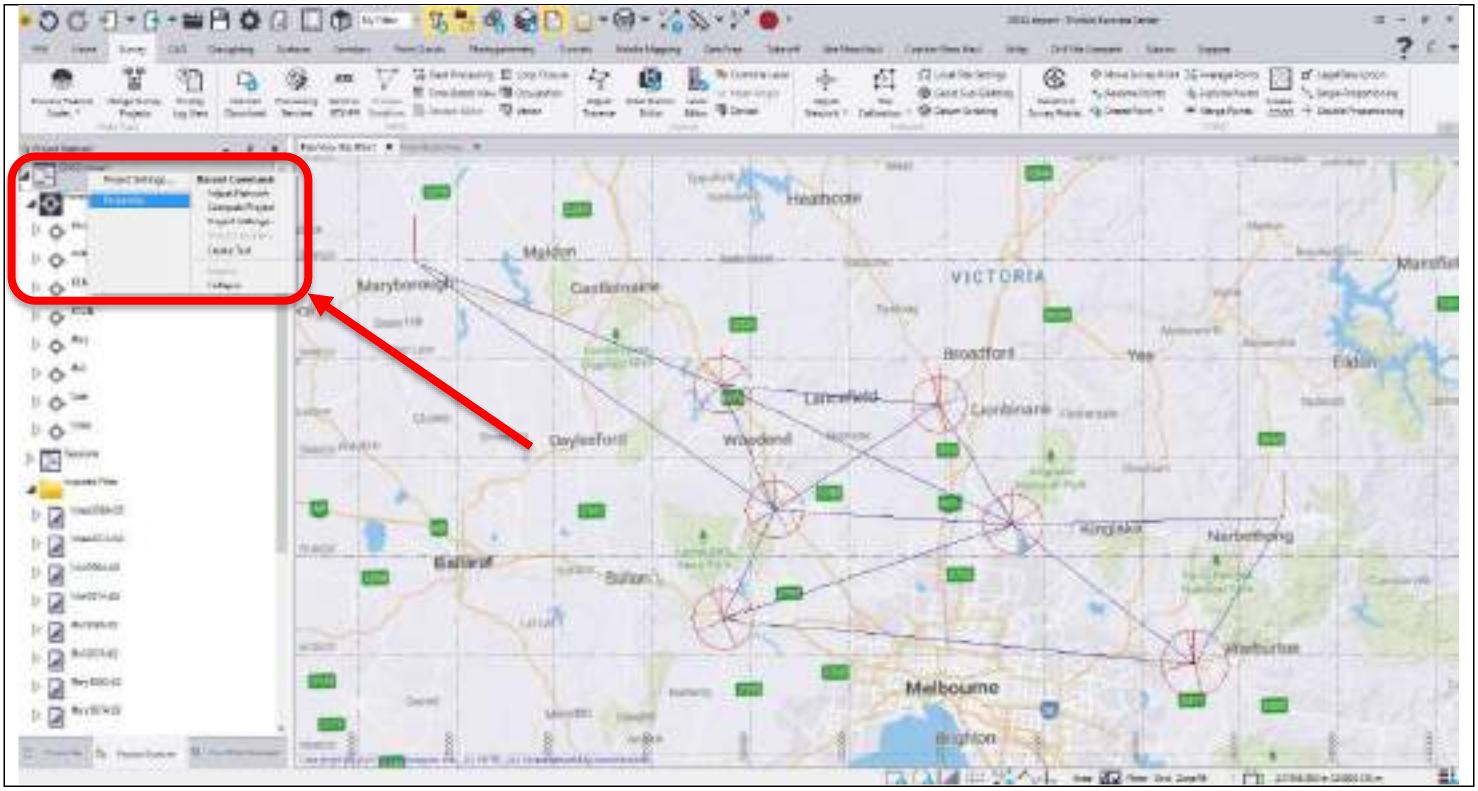
40) If necessary you could also generate a Network Adjustment Report to review the adjustment in more detail.



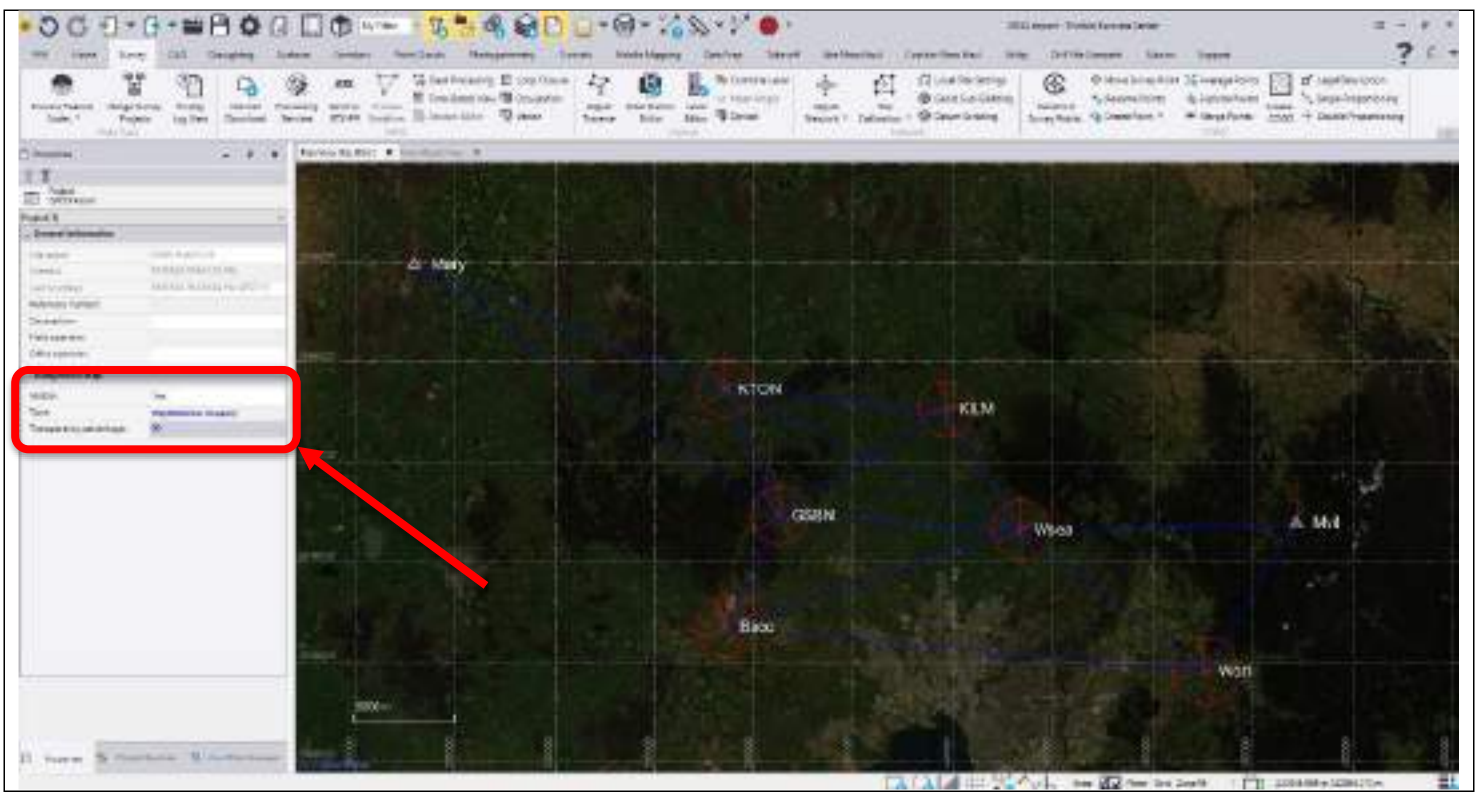
41) Sometimes it is useful to switch on background map information to assist in reviewing the station positions. This can be done easily from the bottom toolbar. You'll need to be logged into Trimble Connect for this service to be available.



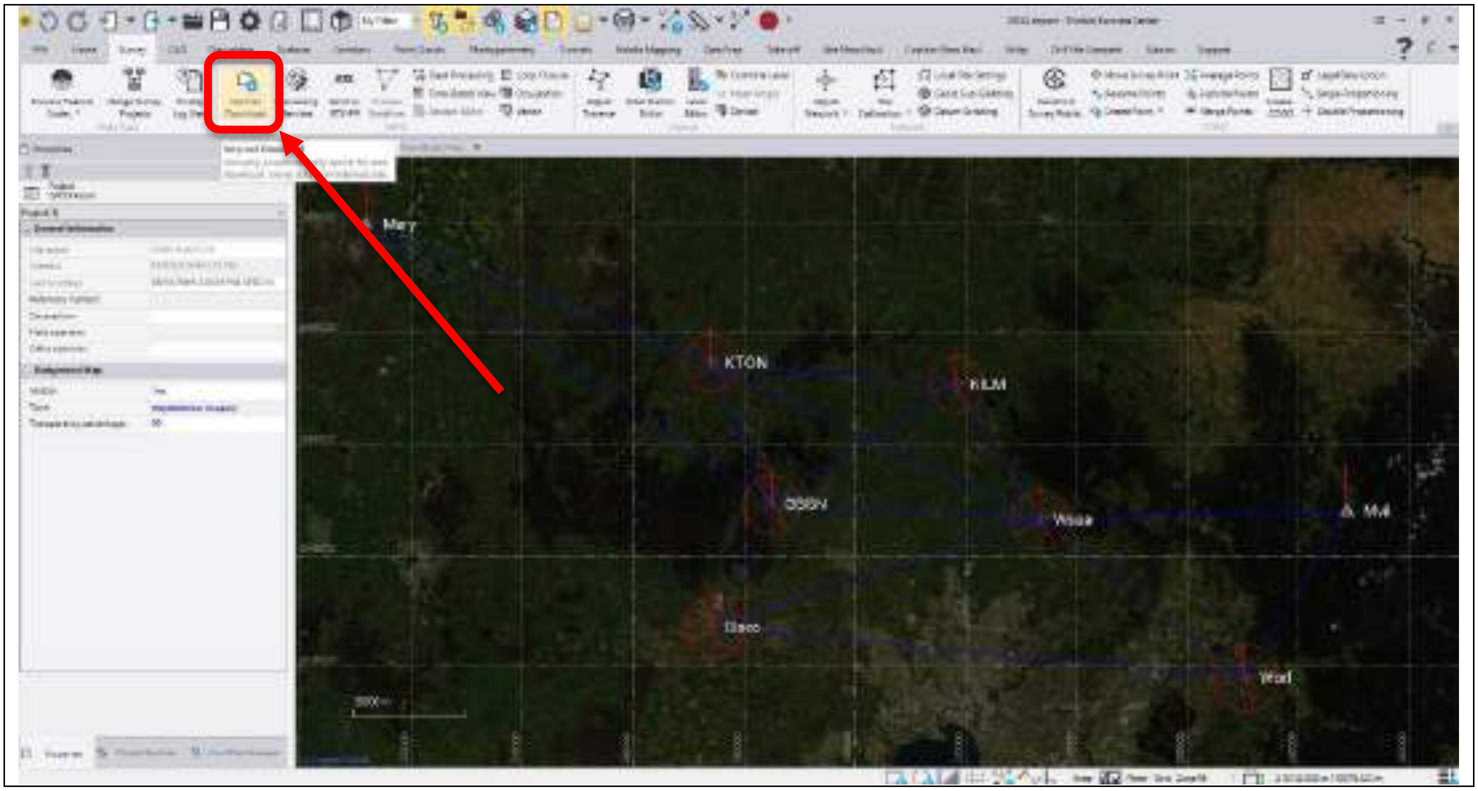
42) If we wanted to switch from a background map to satellite imagery, right click on the Project in the Project Explorer and select Properties.



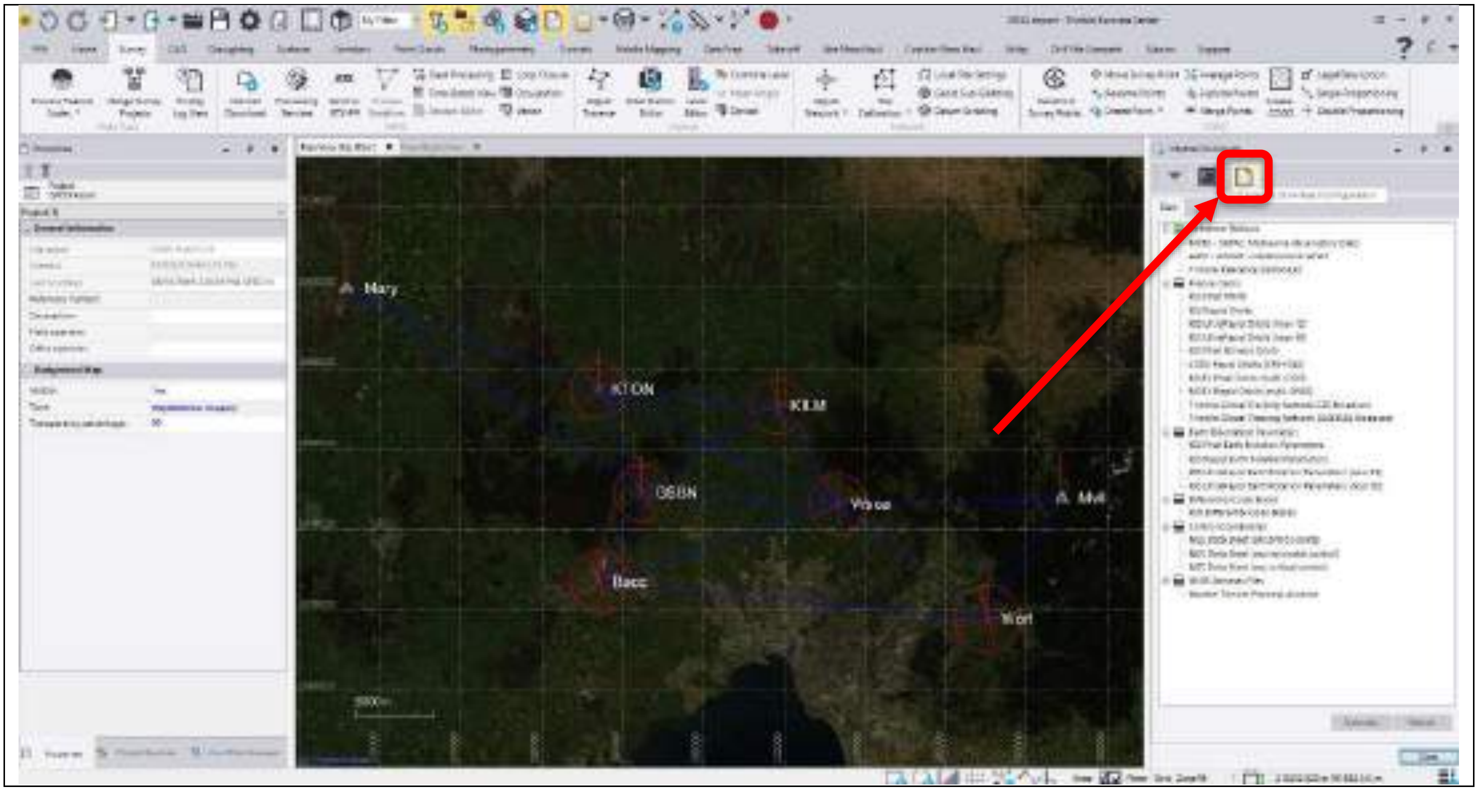
43) From the Properties pane switch the type of Background map to DigitalGlobe Imagery.



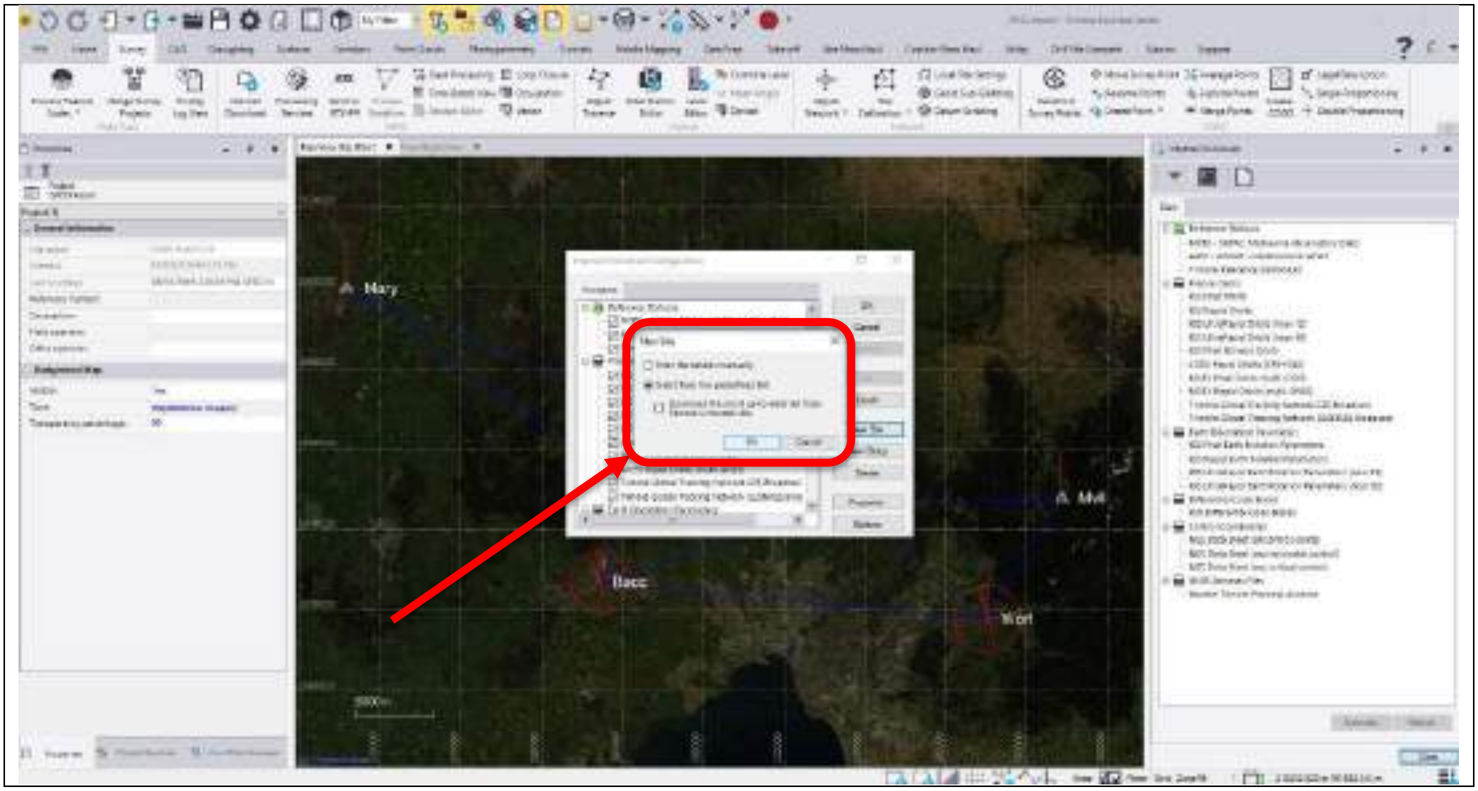
44) In addition to the occupation information that we already have for the network, we may want to include an additional CORS site to further consolidate our network. TBC provides an easy to use tool for bringing CORS data into a project. Select Internet Download from the Survey tab.



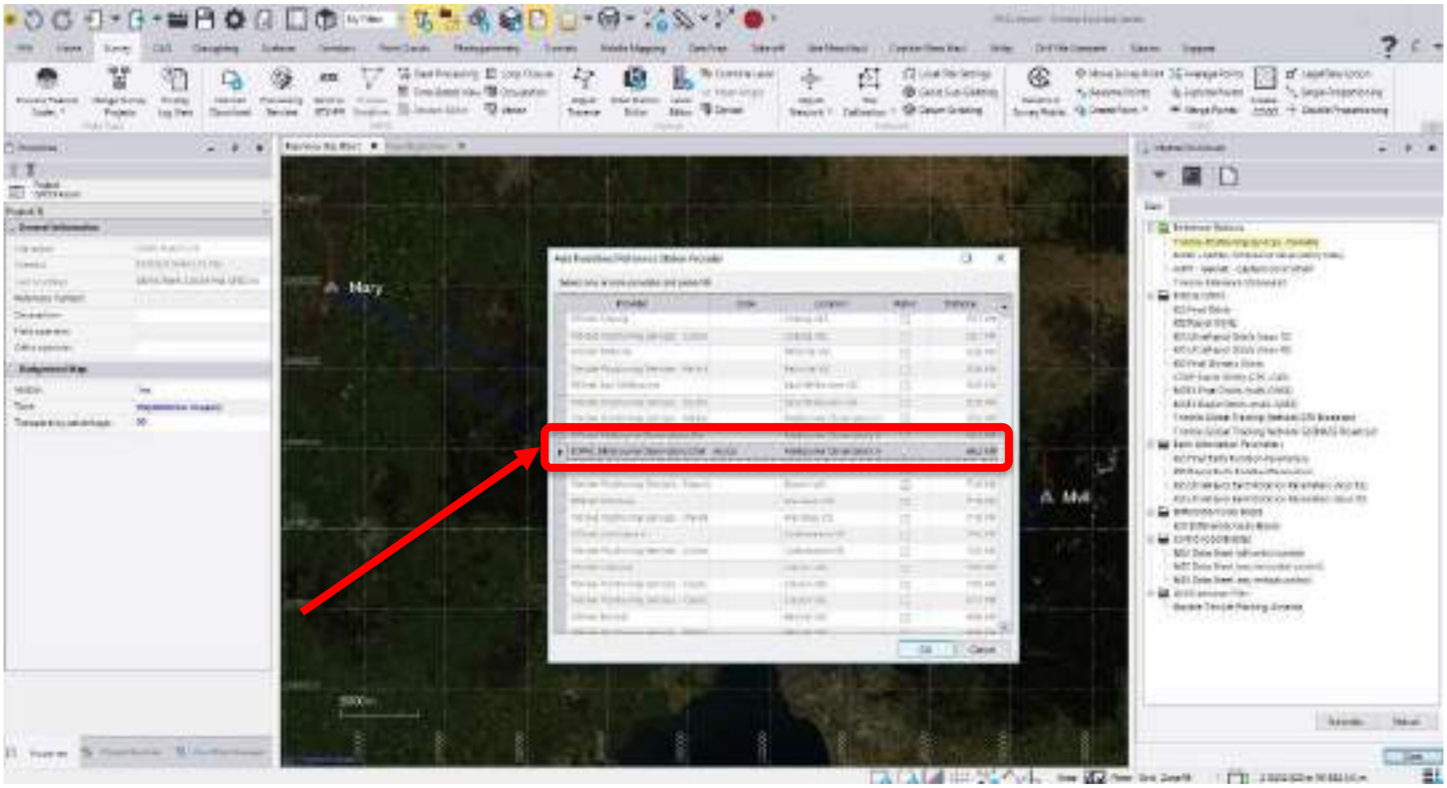
45) First, we need to define where we are going to source the data from. Select the Internet Download Configuration button.



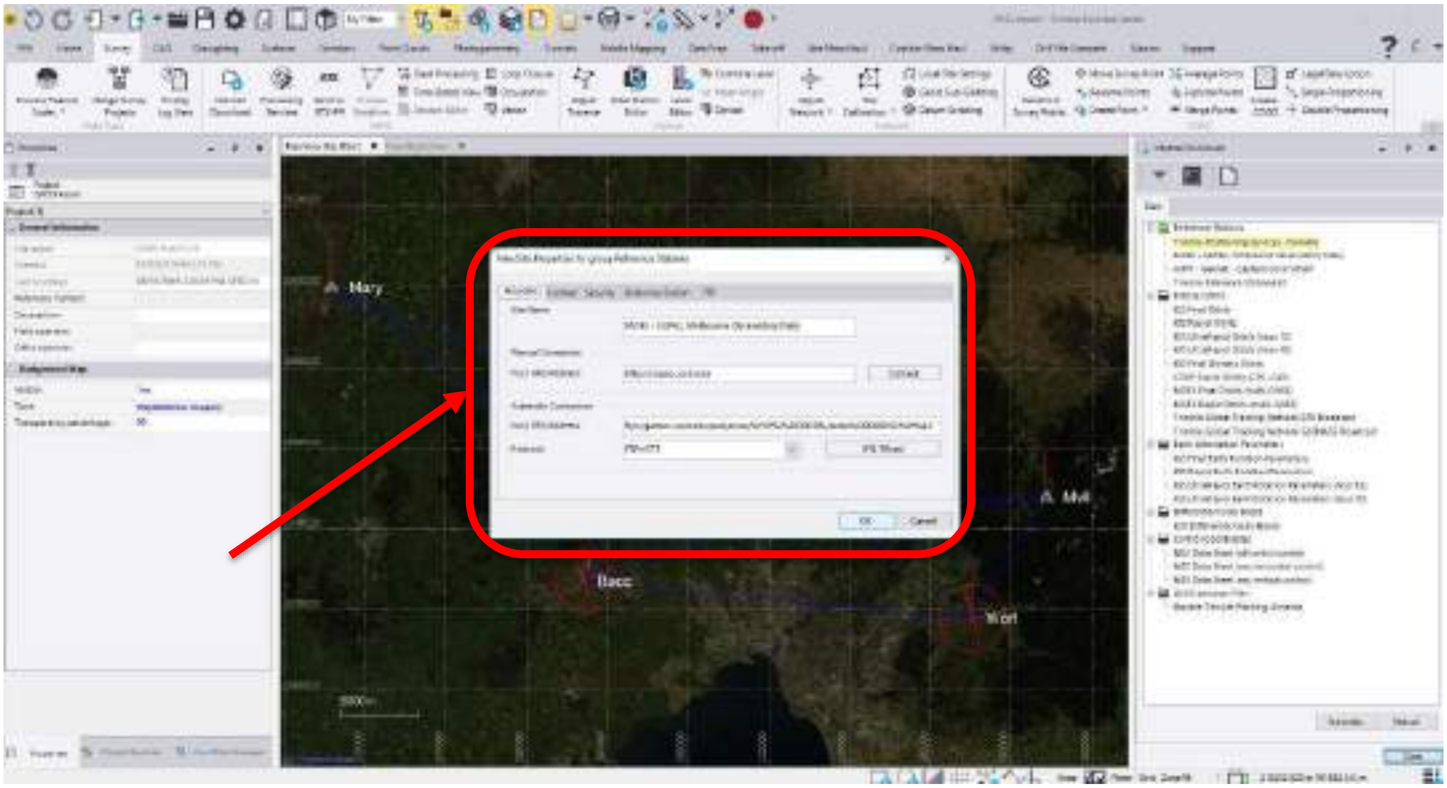
46) Select New Site and then leave the selection in the popup and select OK. If you haven't done this before it will trigger a download of all the available download sites.



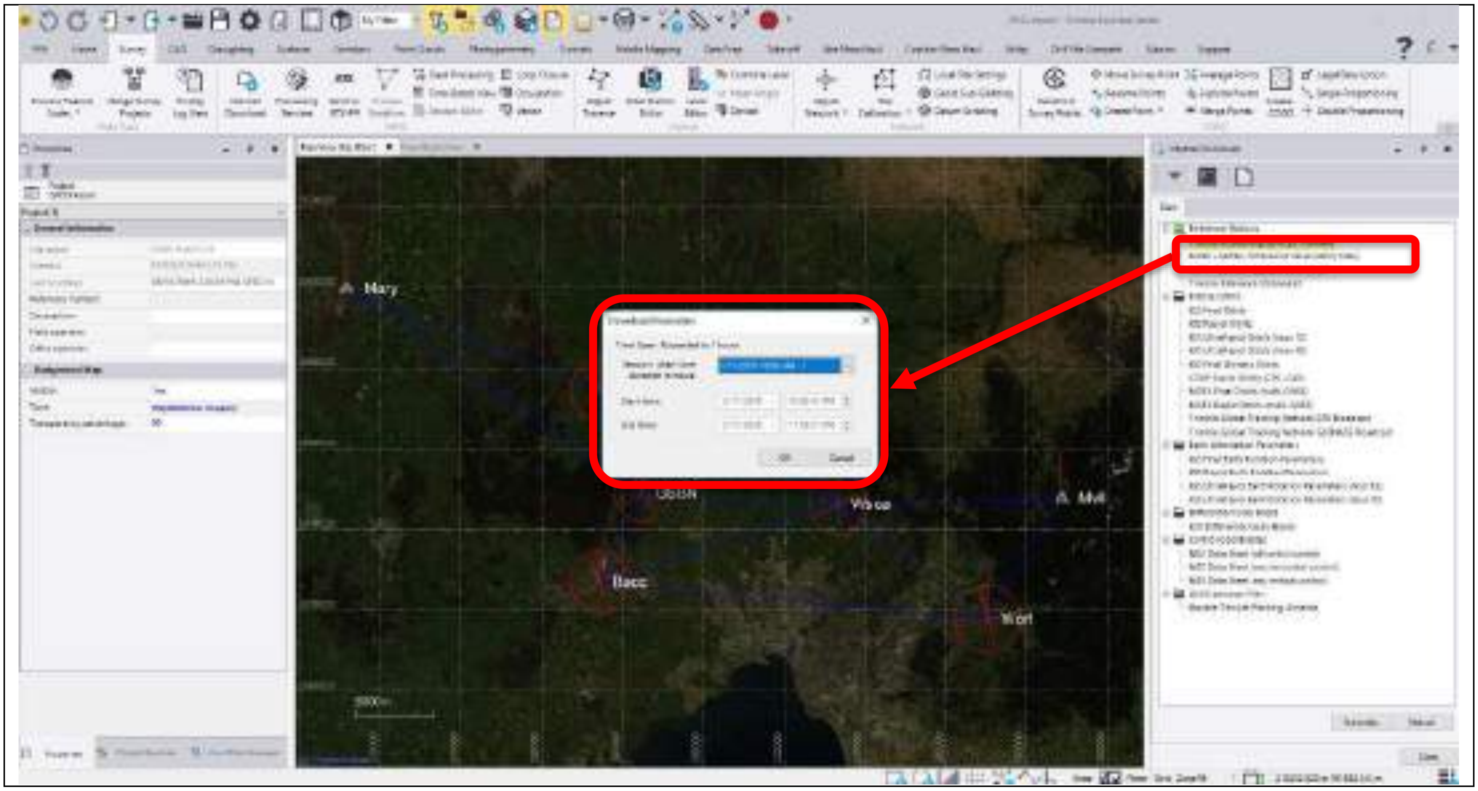
47) Select SOPAC, Melbourne Observatory. This is a Public download site and won't require a subscription. Select OK.



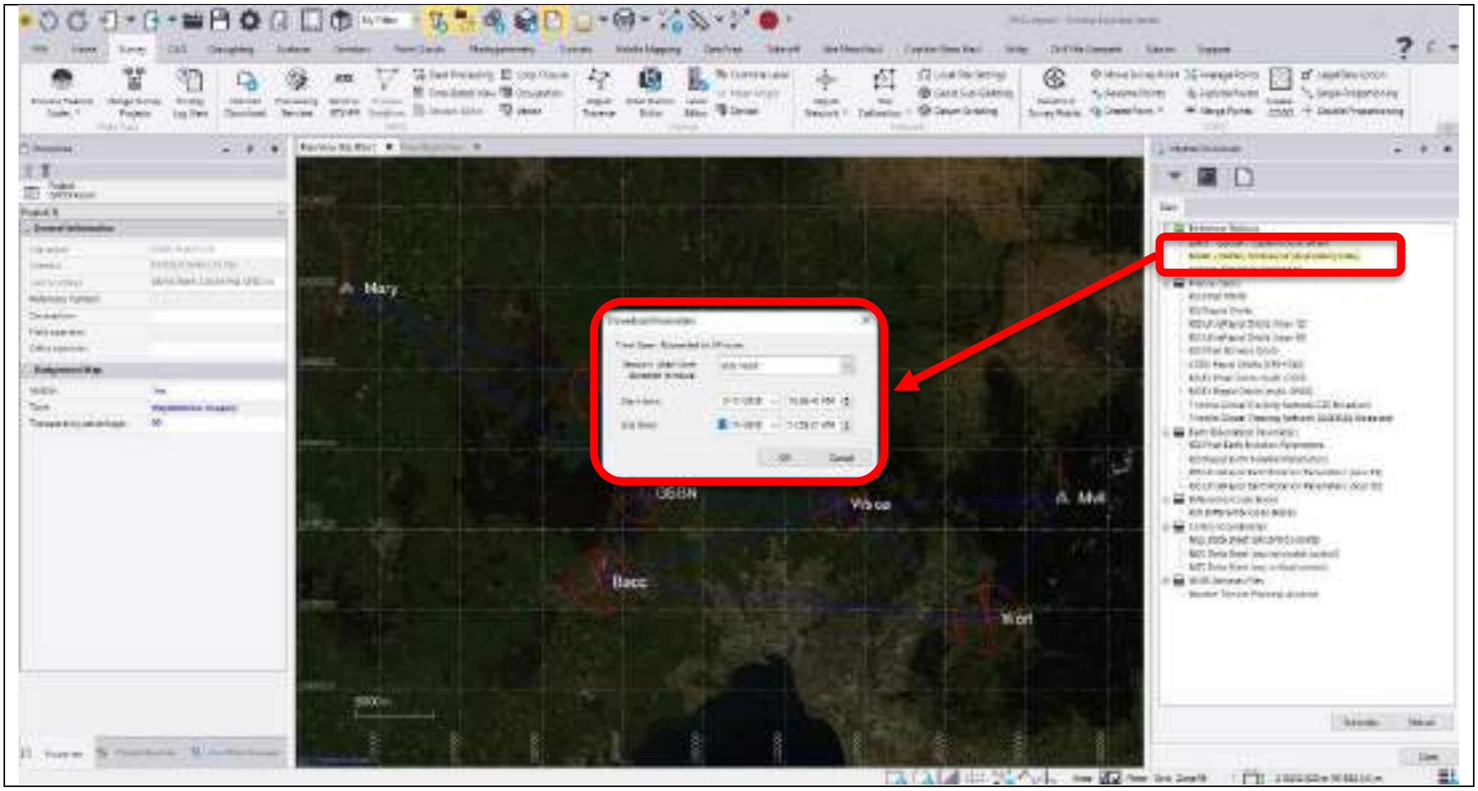
48) Because it is a free download site, we don't need to configure any thing in the New Site Properties. Select OK to exit this pane.



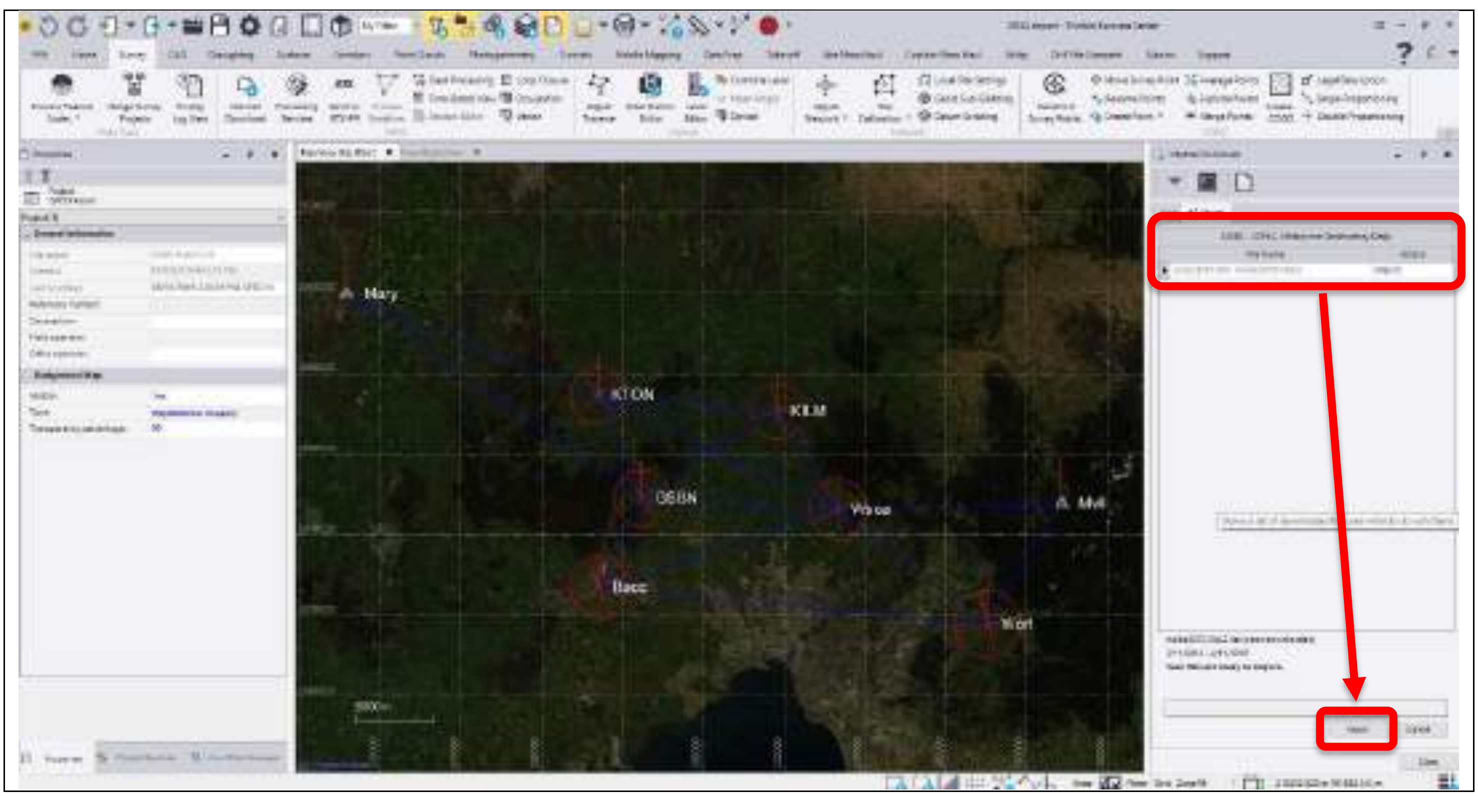
49) Close the Internet Download Configuration and then double-click on the newly defined MOBS – SOPAC Reference Site. A popup should be triggered where you can select the time period.



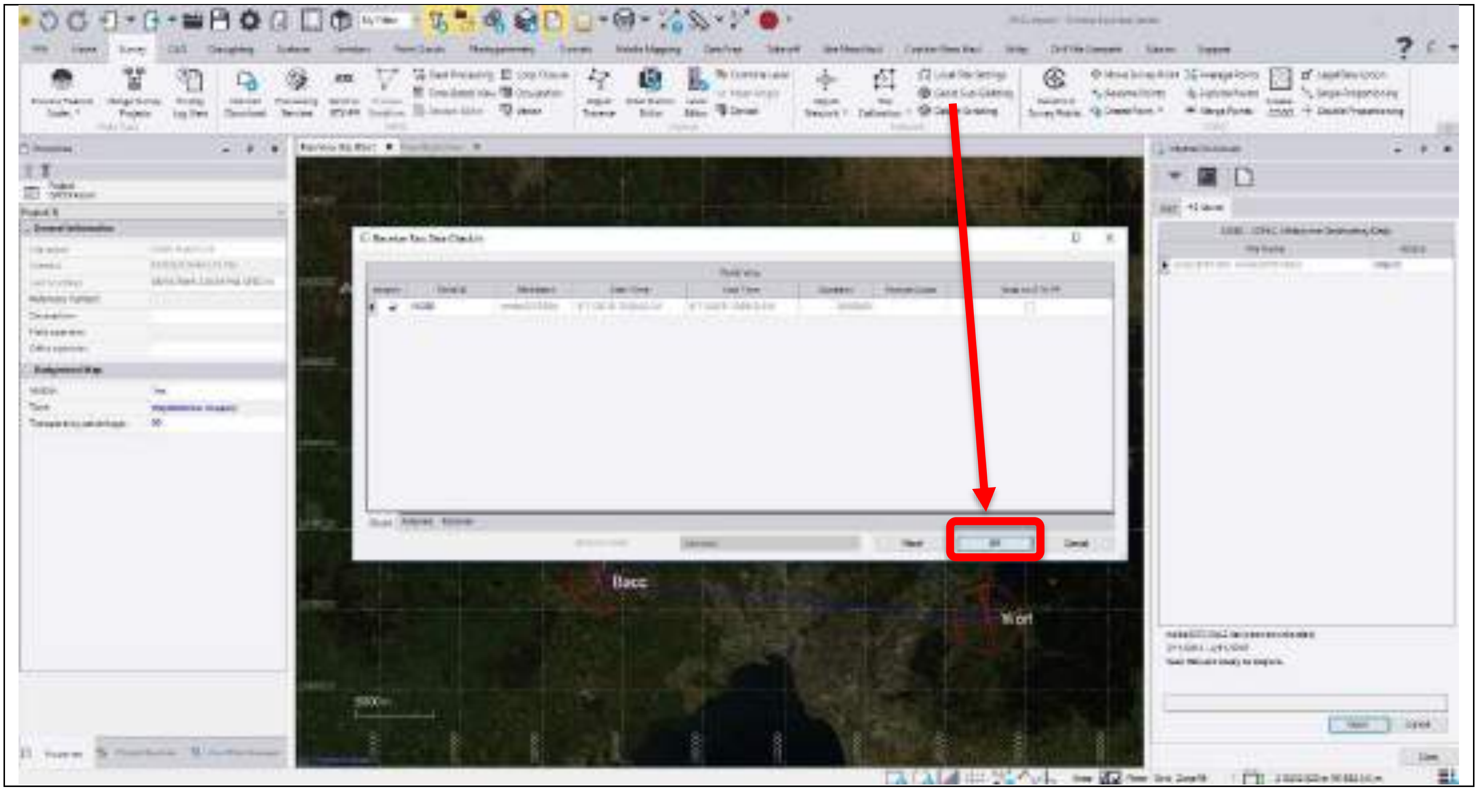
50) Since we don't want to download information across the entire time period for the project from the Session dropdown select User input. Change the finish date to 3/11/2018 and select OK.



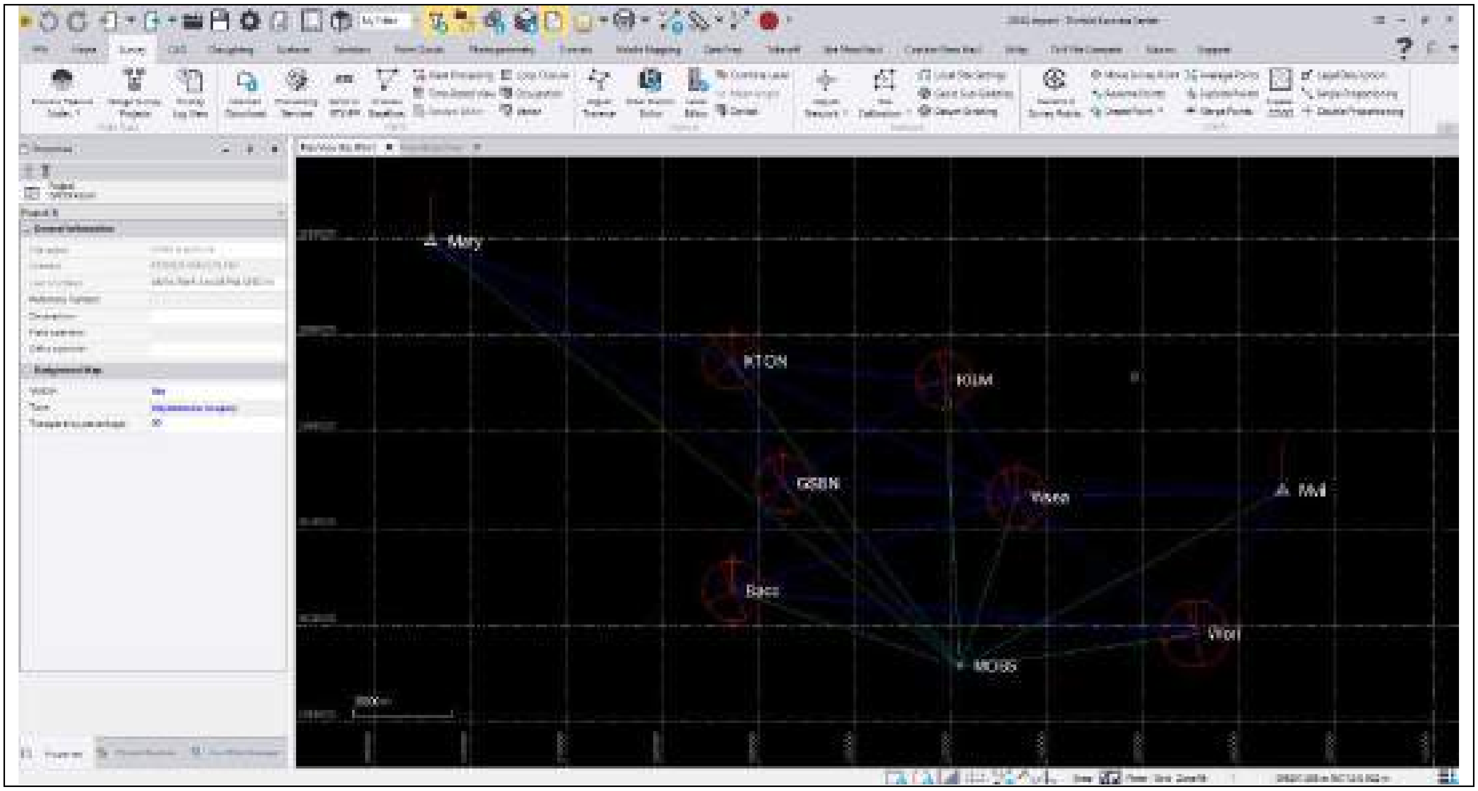
51) Once it has finished downloading select Import.



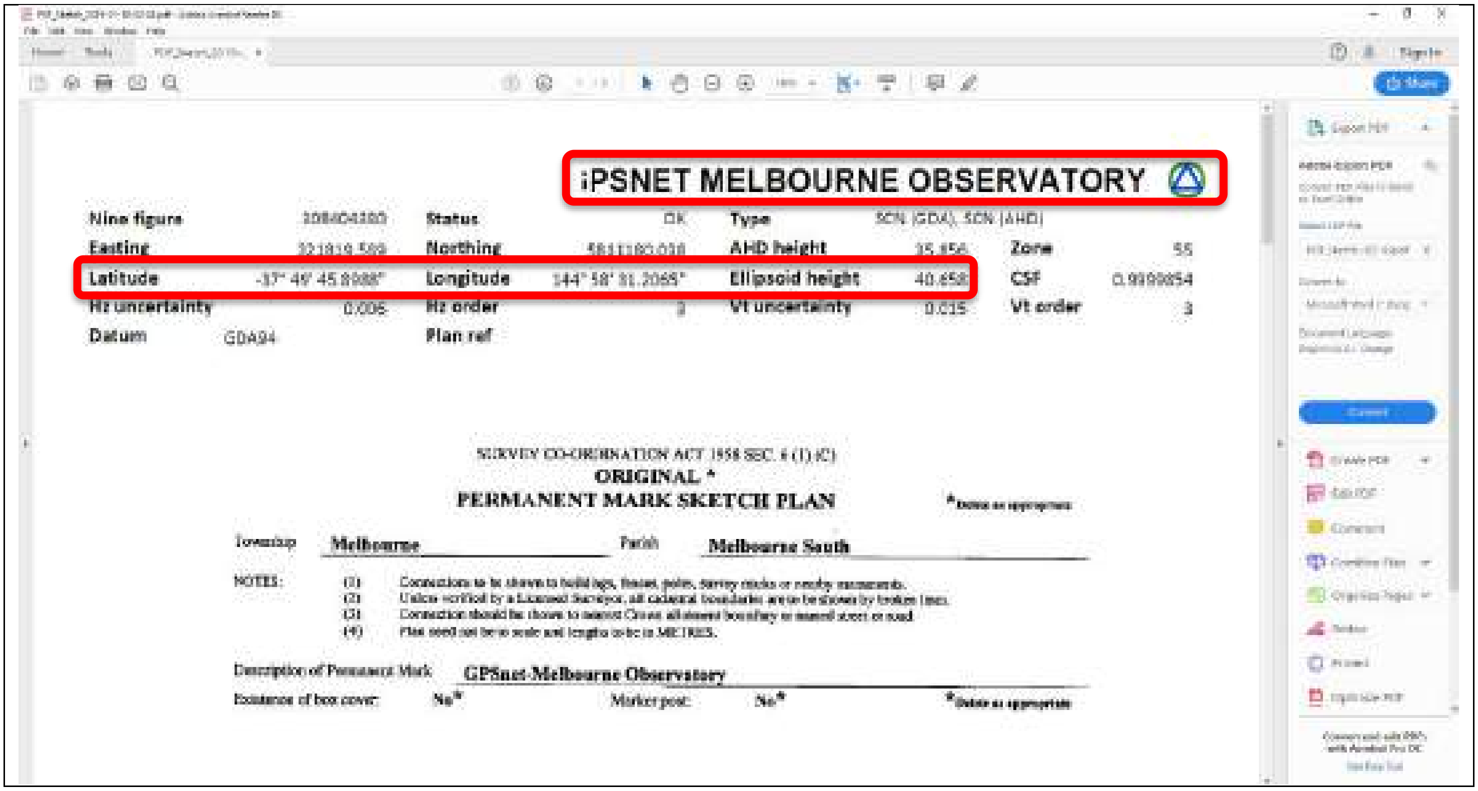
52) The Reciever Raw Data Check In will popup and you can select OK to allow the Import to occur.



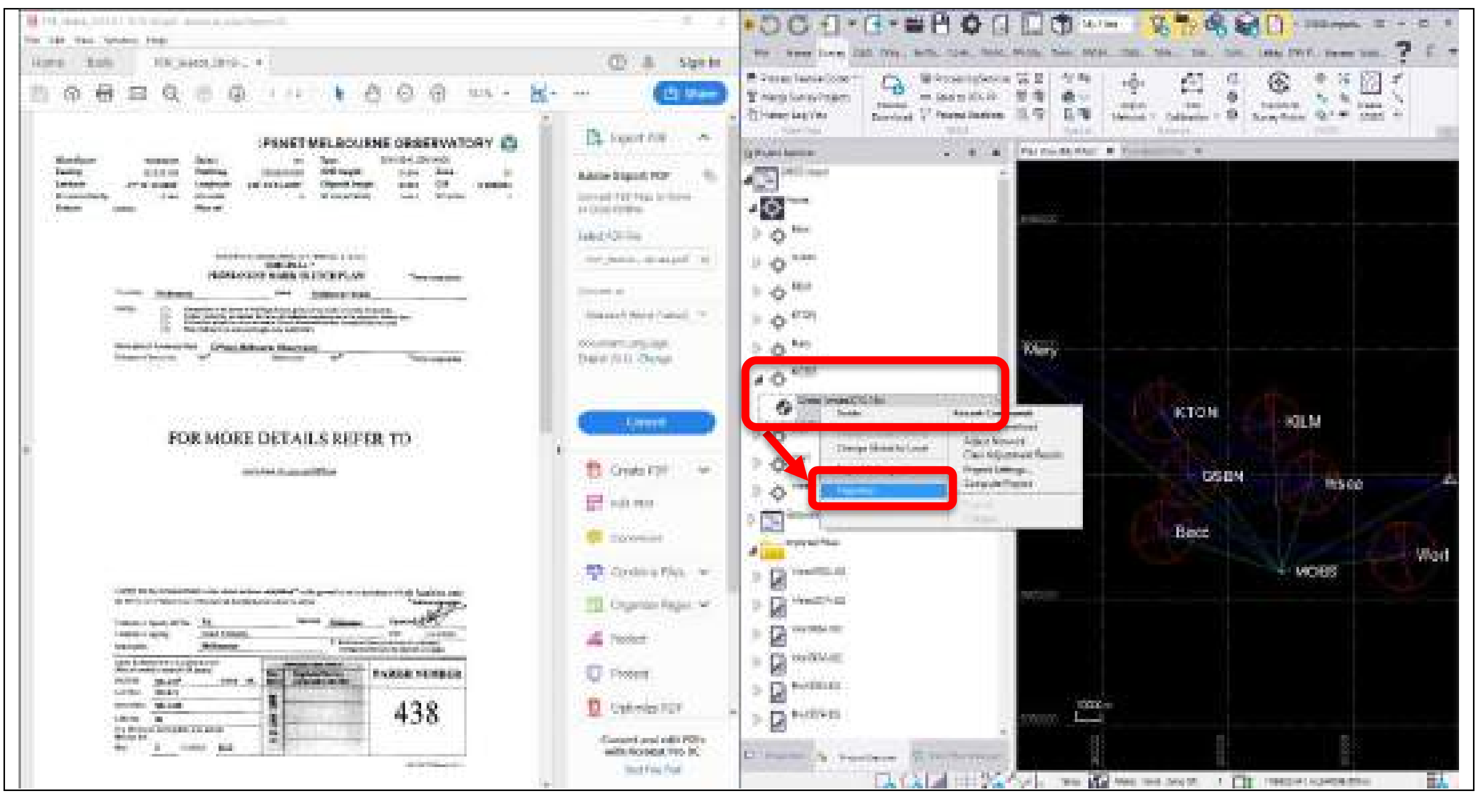
53) You'll need to repeat this process to get the corresponding static session for the second day.
54) Once you have downloaded both days of static logging information you should have some unprocessed baselines visible in the Plan View.



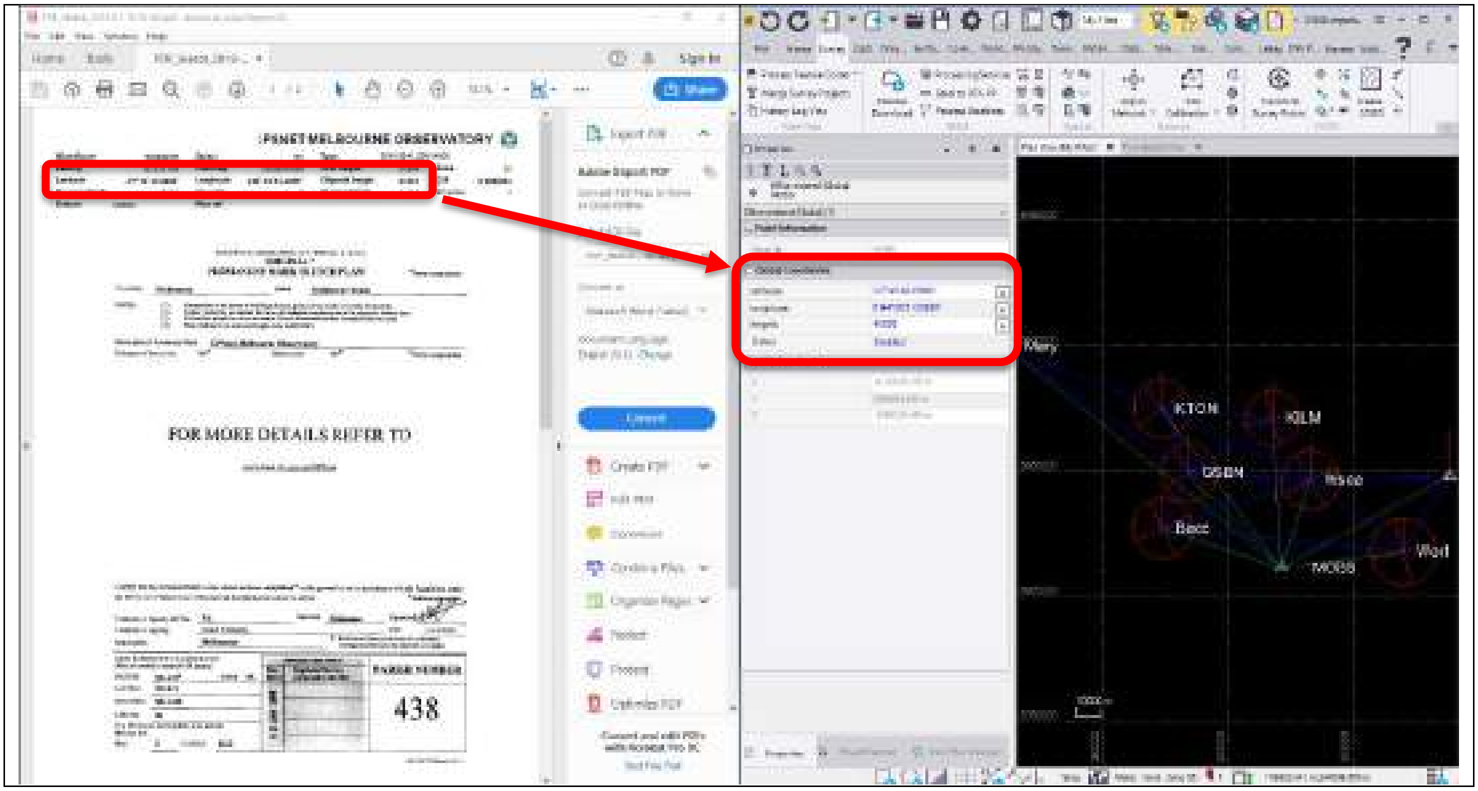
55) Below is the Survey Mark Report for the *MOBS* station.



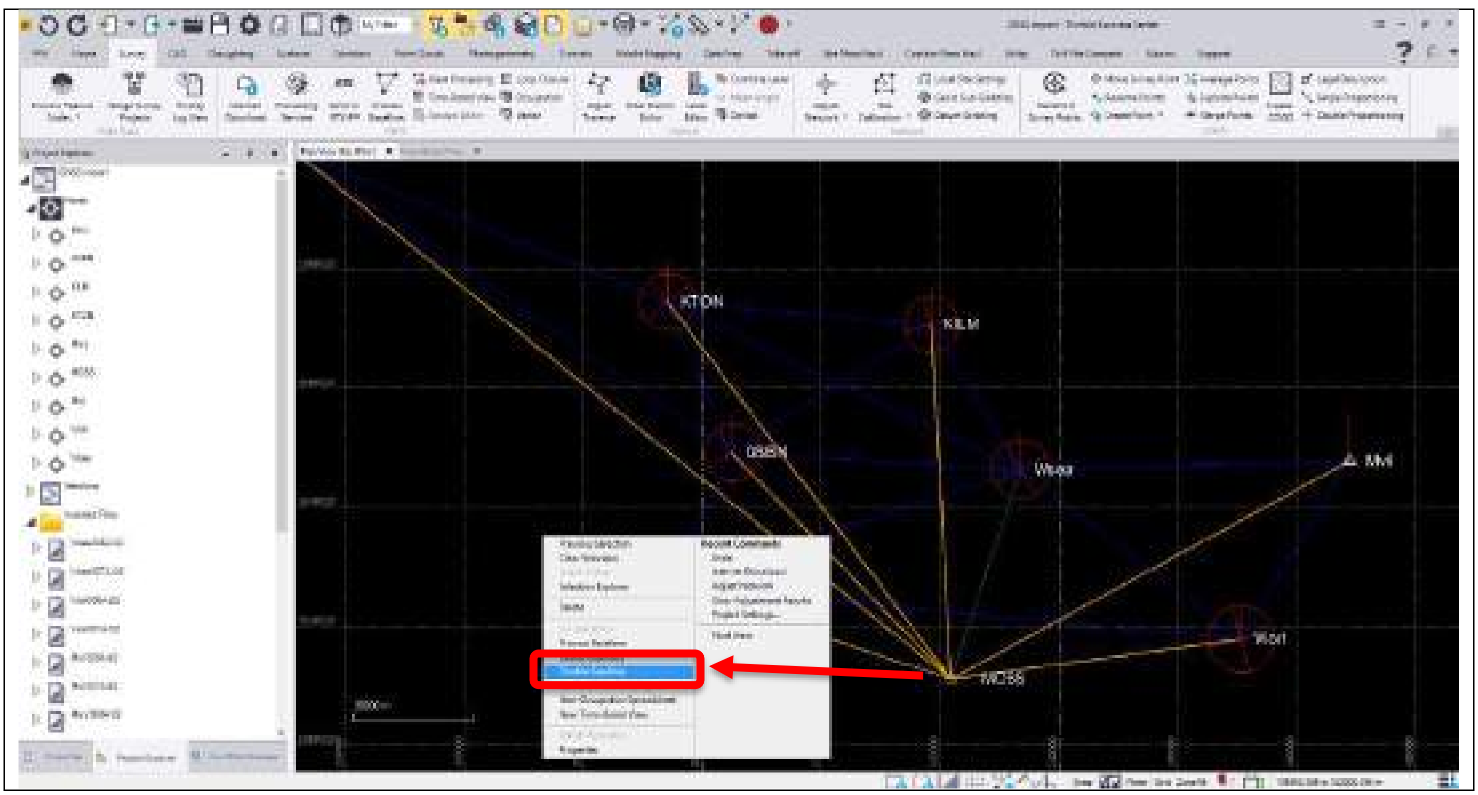
56) If we expand the point information in relation to the station *MOBS* we can select the coordinate properties.



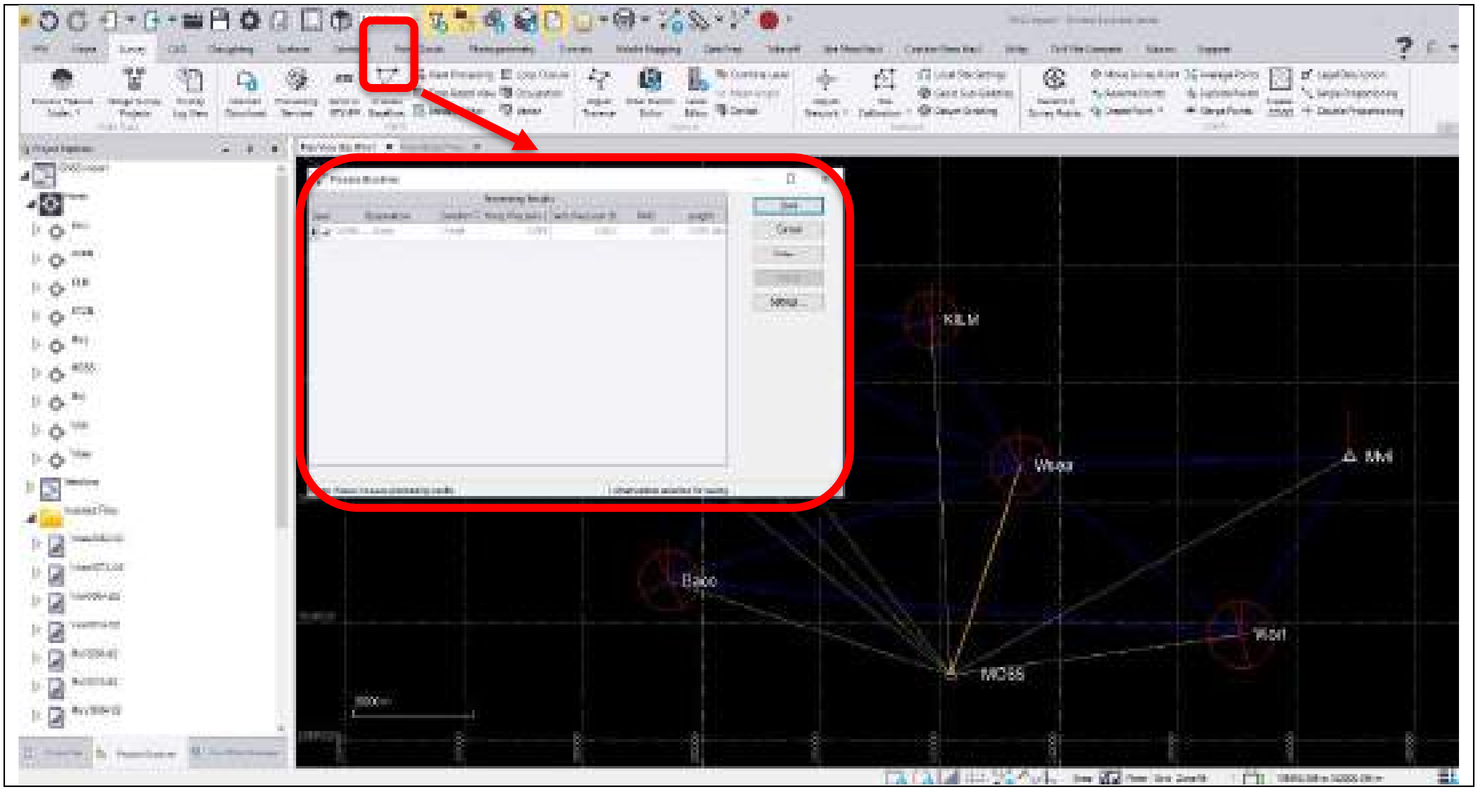
57) Within the coordinate properties, we can amend the coordinates to reflect those in the Survey Mark Report.



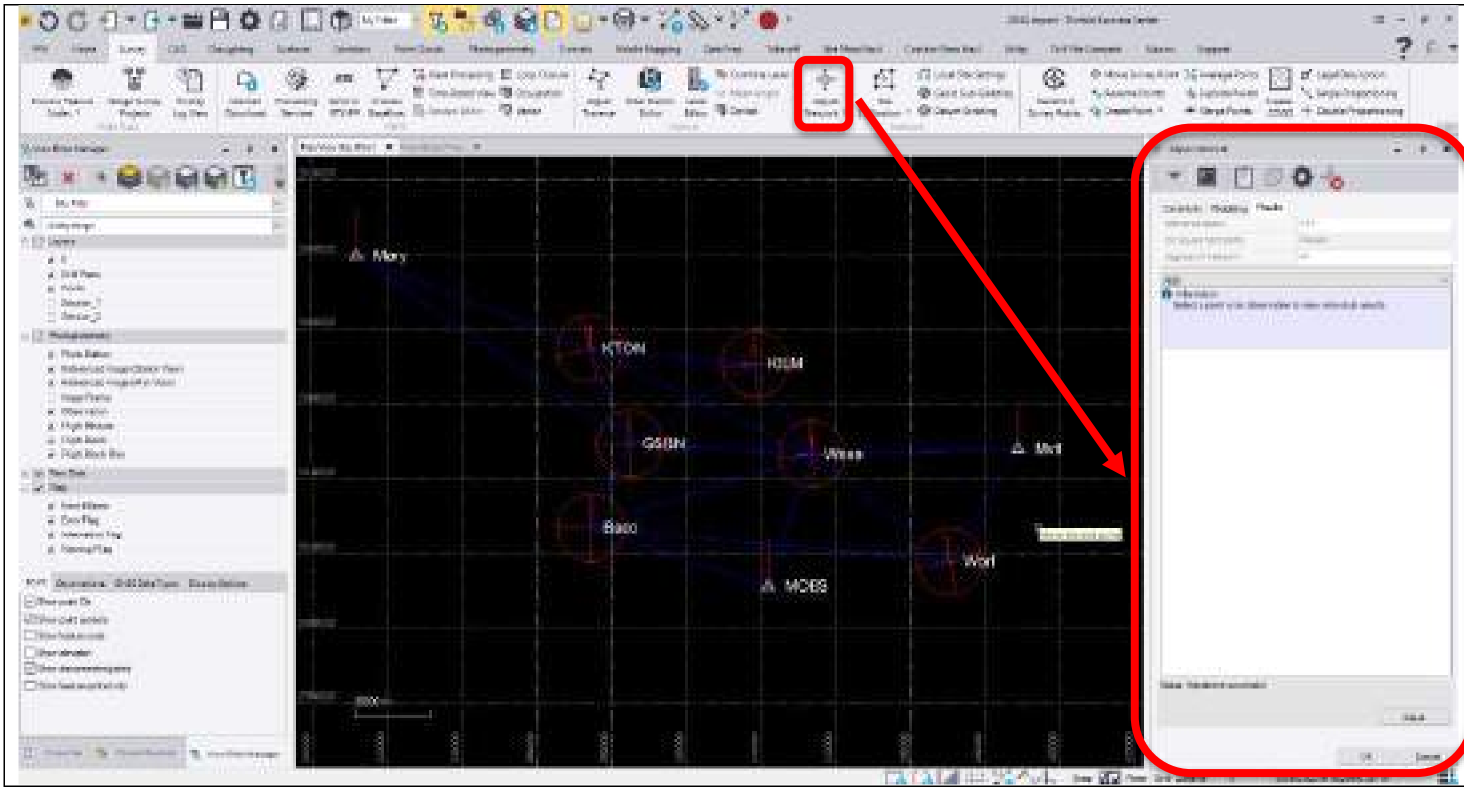
58) Select the baselines connected to *MOBS* and just leave one active per static session as we did earlier in the tutorial.



59) Select the remaining baselines that are active and select Process Baselines from the Survey tab. Select Save once the processing is finished.



60) Constrain the coordinates of *MOBS* to the same standard deviations as used previously for *Mvil* and *Mary*, then select Adjust.



This concludes the tutorial on Importing and processing GNSS data.

STATIC SURVEY FOR TRIMBLE DGPS

BASE

After complete Instrument setup

Open Trimble Access software in Trimble TSC3 controller

Go to general Survey

Then Job

New Job

Input Job name

Template – Last use job

Accept

Measure

Static

Start base receiver

Input Base point name

Input Antenna height

Measure to – centre of bumper

Start

Base start--- ok

ROVER

Then go to Rover

Open Trimble Access software in Trimble TSC3 controller

Go to general Survey

Job

New Job

Input Job name

Template – Last use job

Accept

Measure

Static

Measure Point

Input Rover point name

Input antenna height

Measure to – Bottom of antenna mount

Then measure

Wait for 8 min or you can change time limit in option

Then go to next point after complete 1st point.

Same procedure for all rover points.

RTK SURVEY FOR TRIMBLE DGPS

BASE

After complete Instrument setup

Open Trimble Access software in Trimble TSC3 controller

Go to general Survey

Then Job

New Job

Input Job name

Template – Last use job

Accept

Measure

RTK

Start base receiver

Click on right arrow of base point name

Key in

Click on here

Input point name

Input Antenna height

Start

Base start--- ok

You will see base receiver radio light blinking

Then got o Rover

ROVER

Open Trimble Access software in Trimble TSC3 controller

Go to general Survey

Then Job

New Job

Input Job name

Template – Last use job

Accept

Measure

RTK

Measure point

Input point name

Input Antenna height

Measure to – Bottom of antenna mount

Measure

Wait for 5 sec (if you select auto record in option then point will record automatically otherwise you have record manually after complete 5 sec store option will come)

Same procedure for next all rover points.

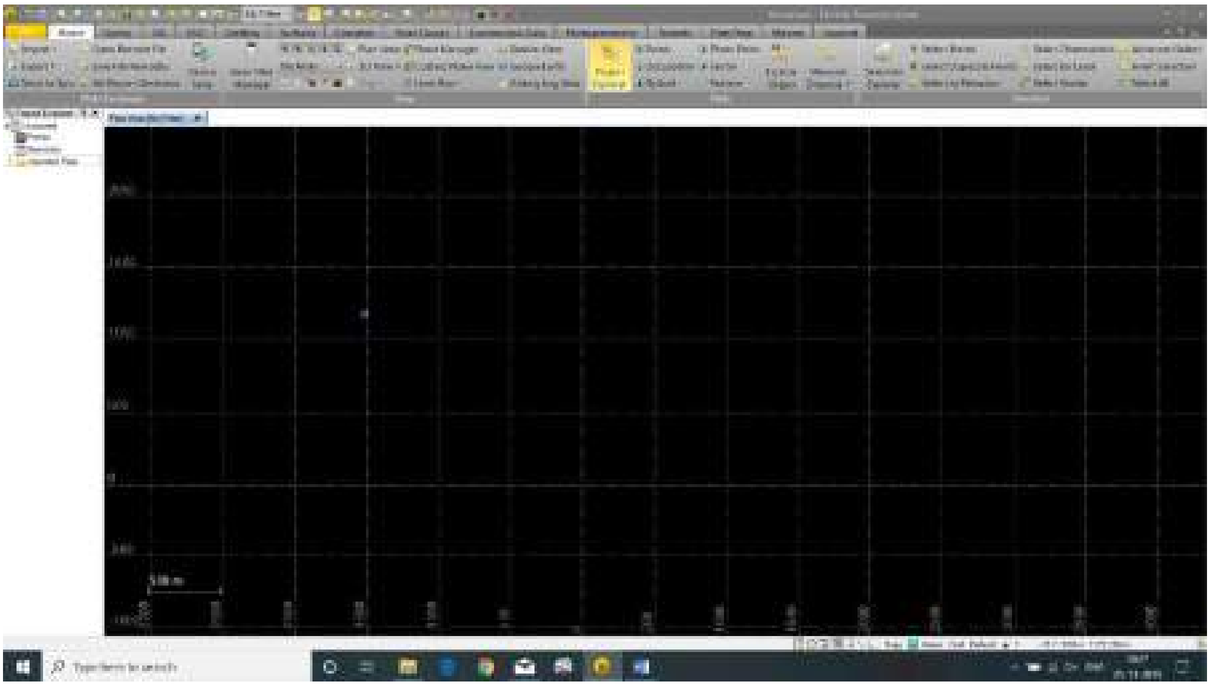
Go to map for see all points

Go to favourite – points manager for see all points coordinates.

Trimble Business Centre

Open TBC Software

New Project

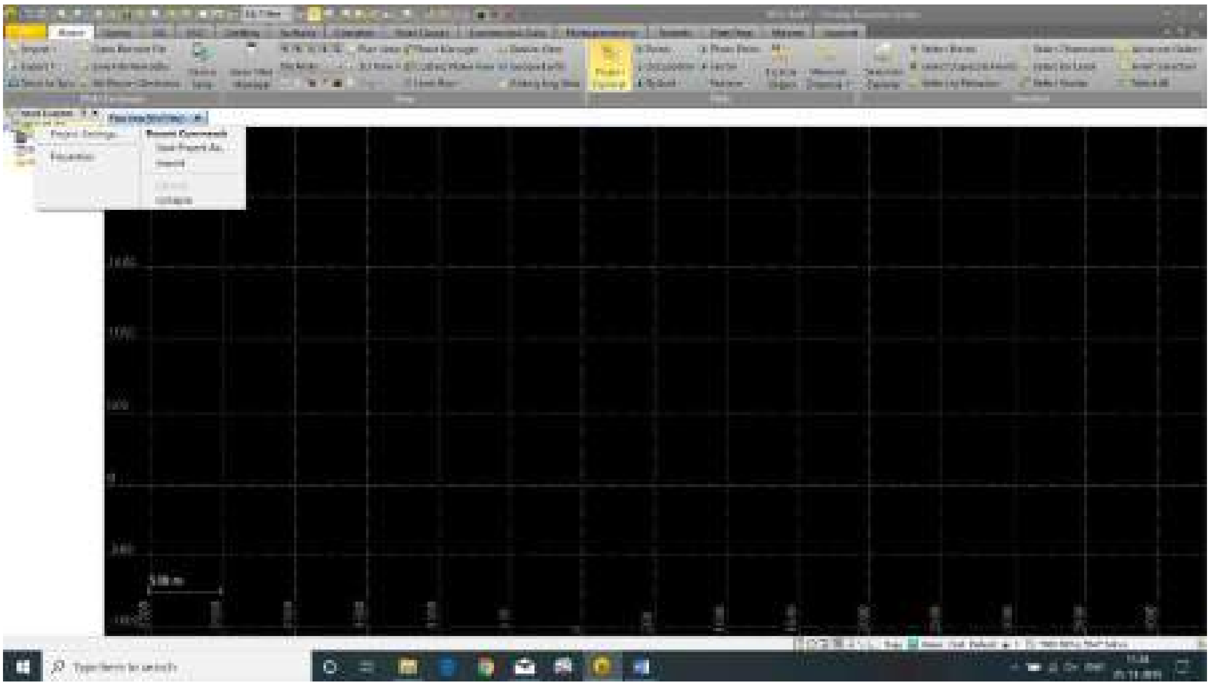


Go to File

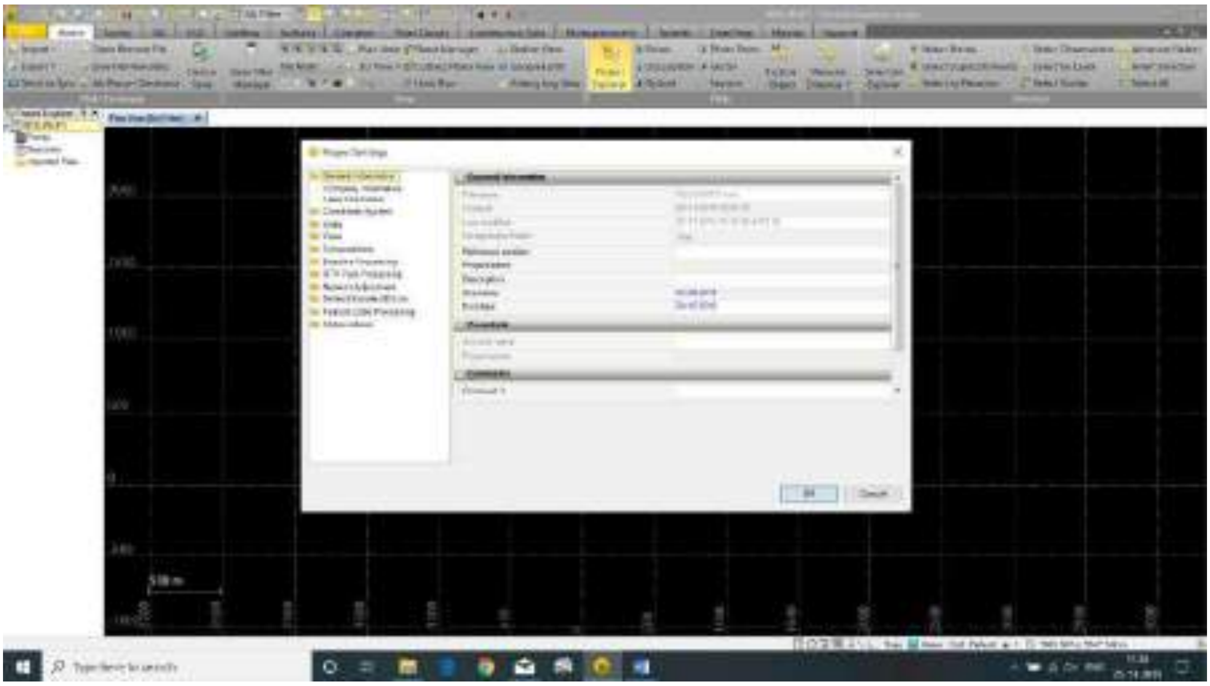
Save AS

Input Project Name and Save

Right Click on Project Nmae

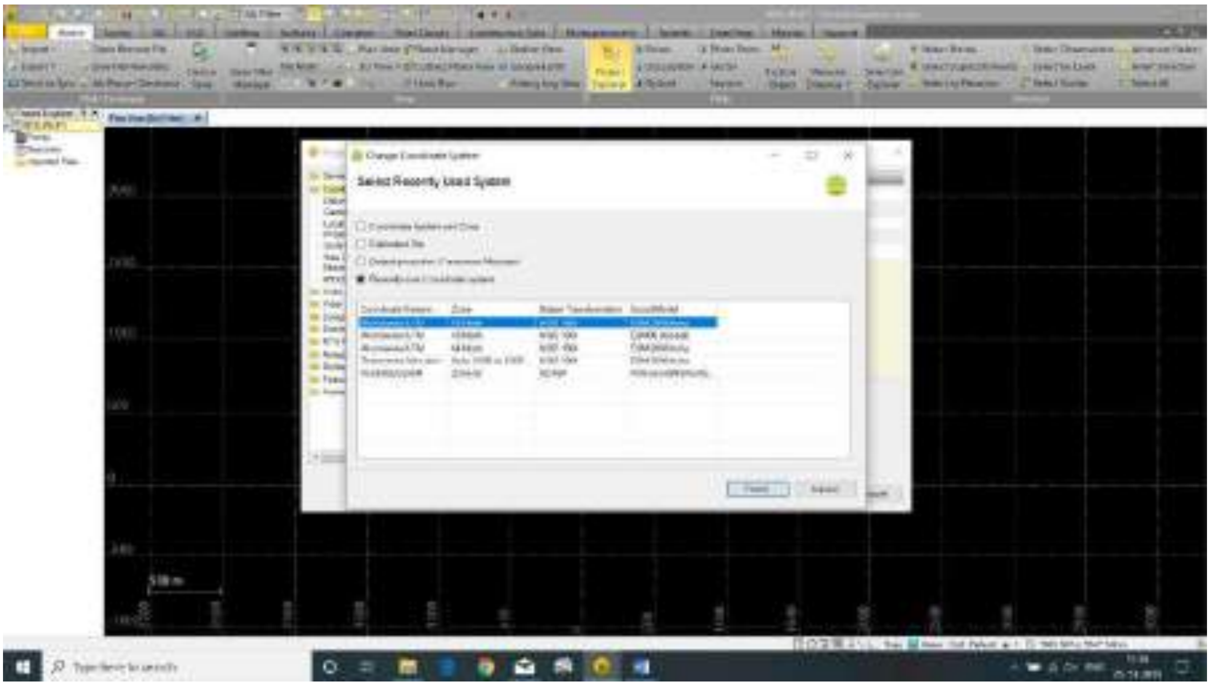


Select Project Setting



Click on Coordinate System

Click on change

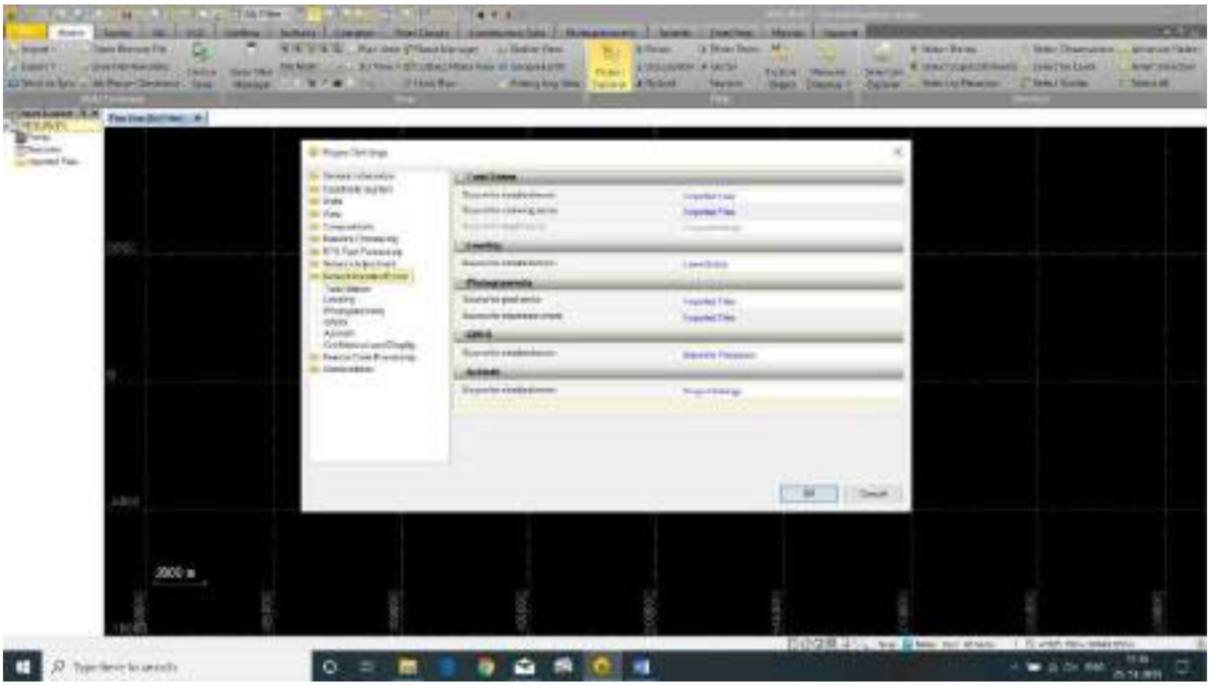


If Coordinate system in your Recently Used List then select which is your Zone and Finish.

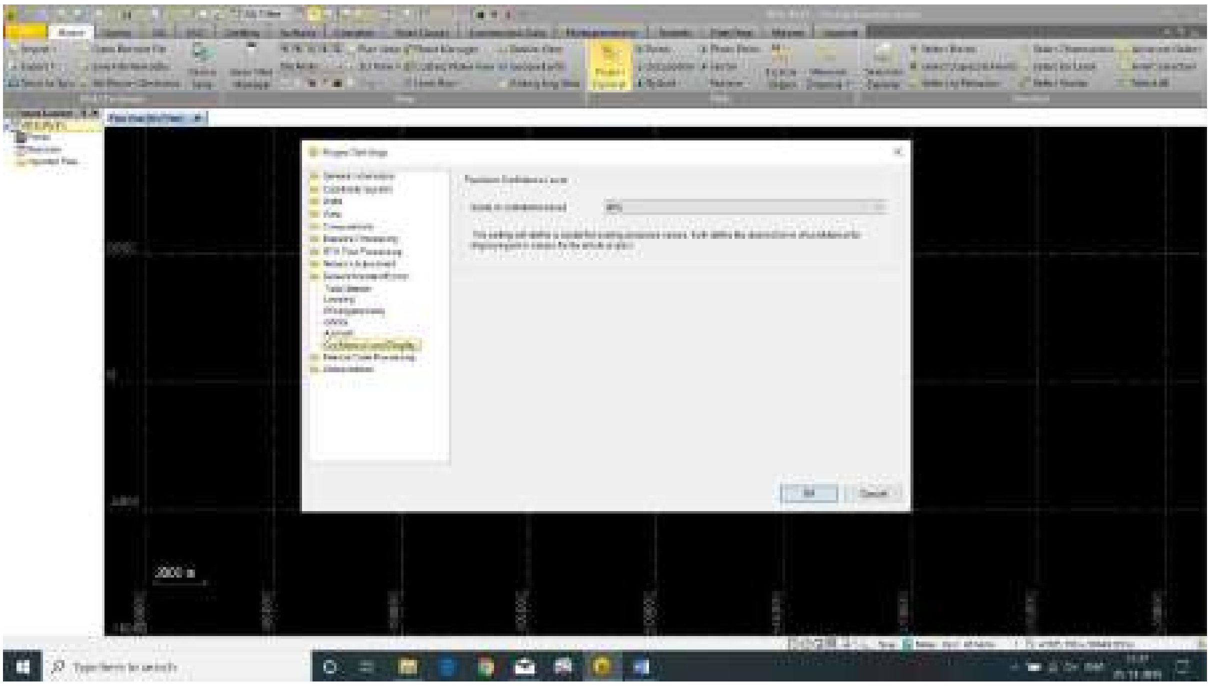
If Coordinate system not in your list then click on Coordinate system and Zone from there you can select which is you site Zone.

I am select UTM45 that is in my Used List

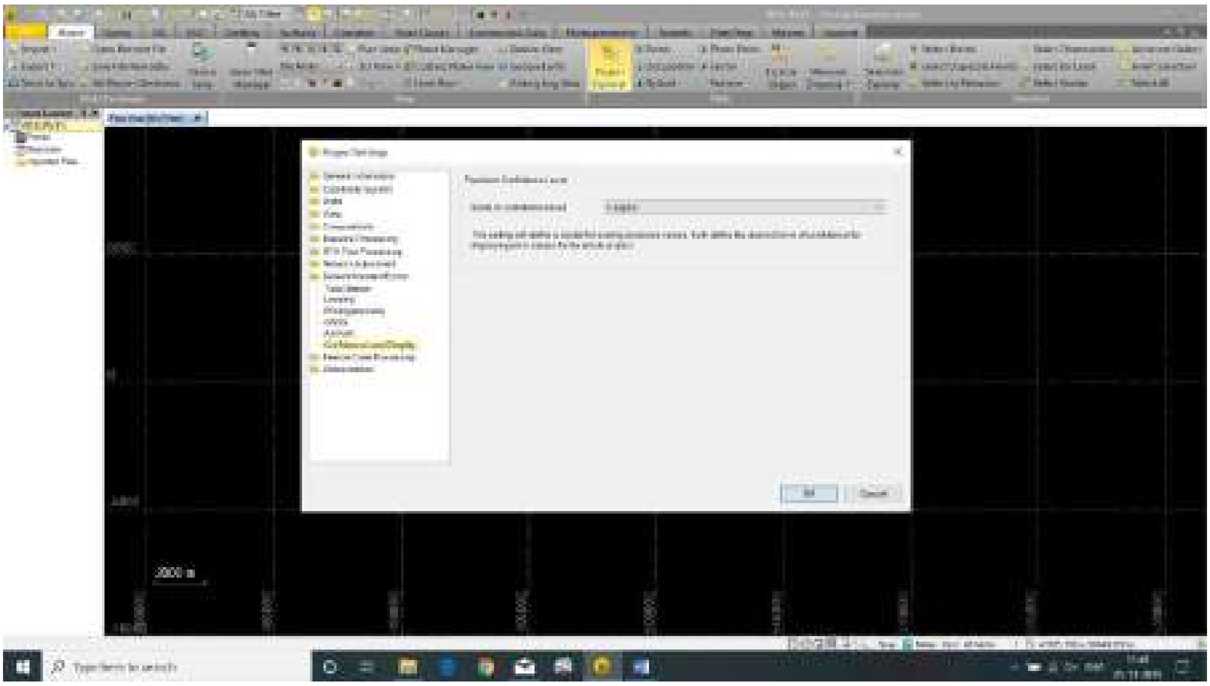
Now click on default standard error



Select Confidence Level Display

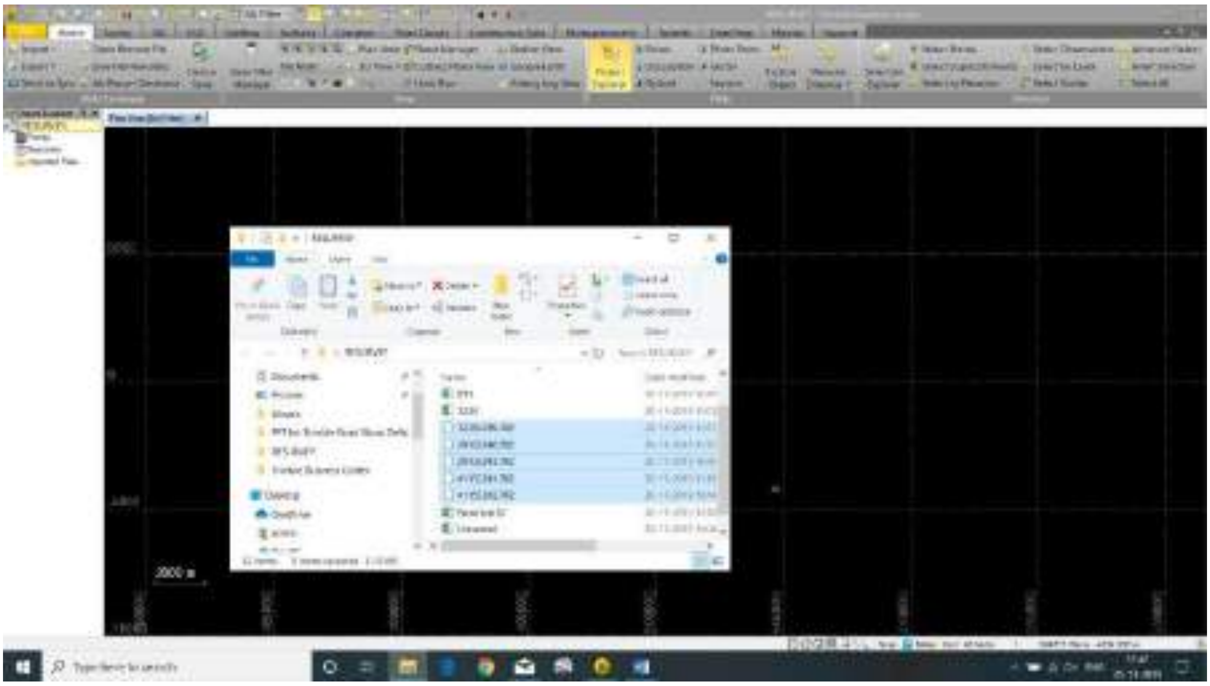


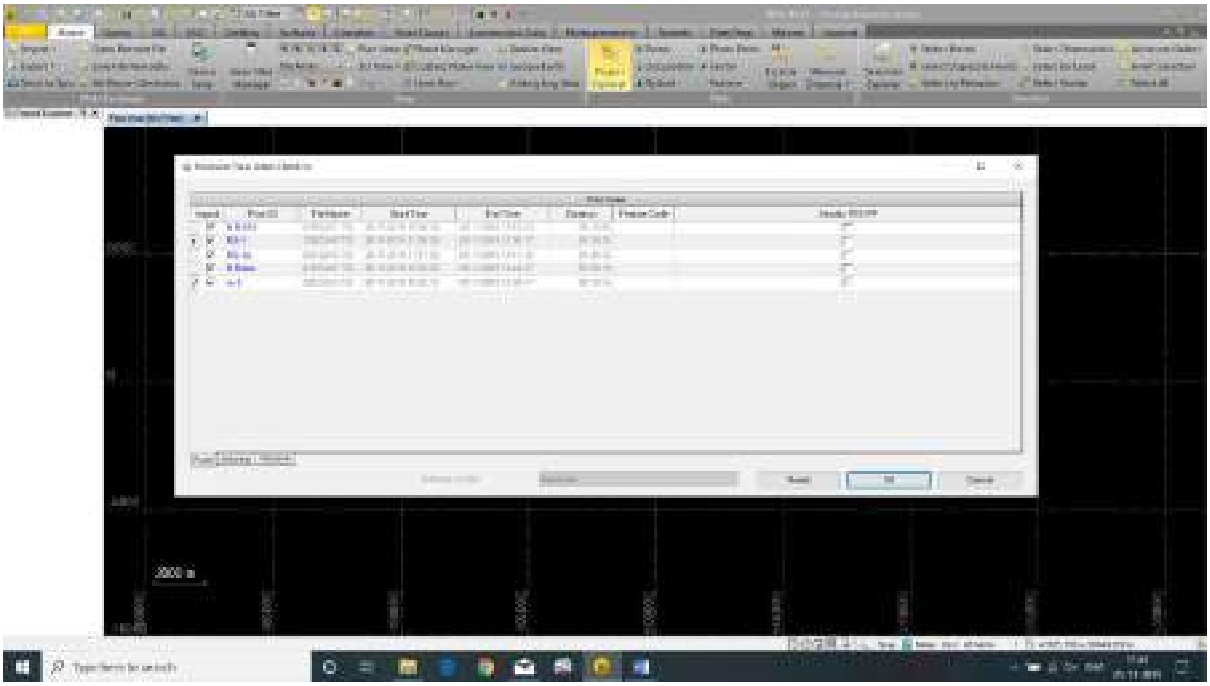
Scale to confidence Level and select 1-sigma



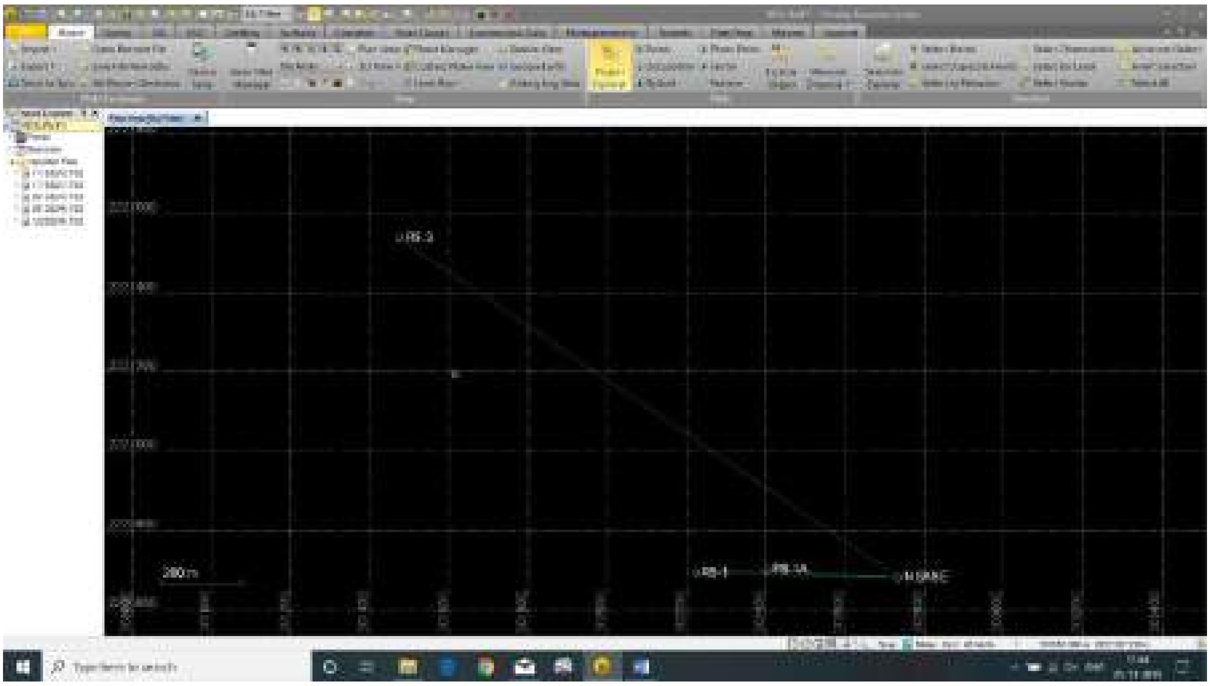
Then press ok

Now open your folder where is your DGPS raw data select point with ext. 01,02,04 or Rinex and drop in TBC.

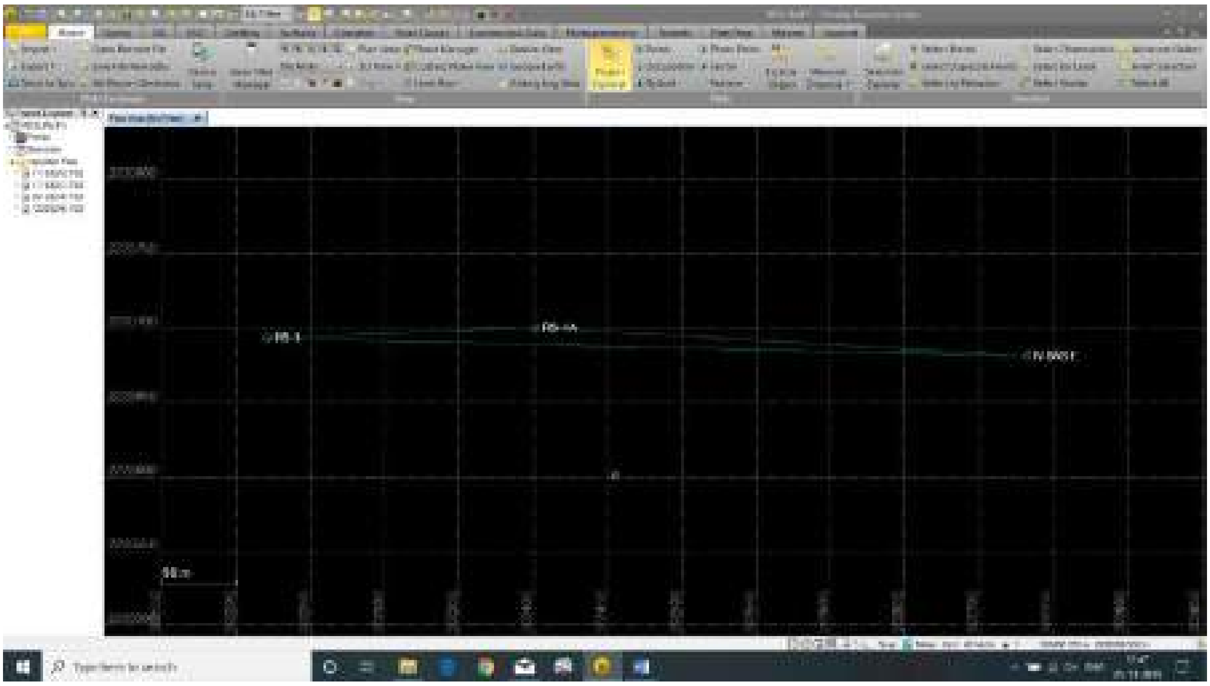




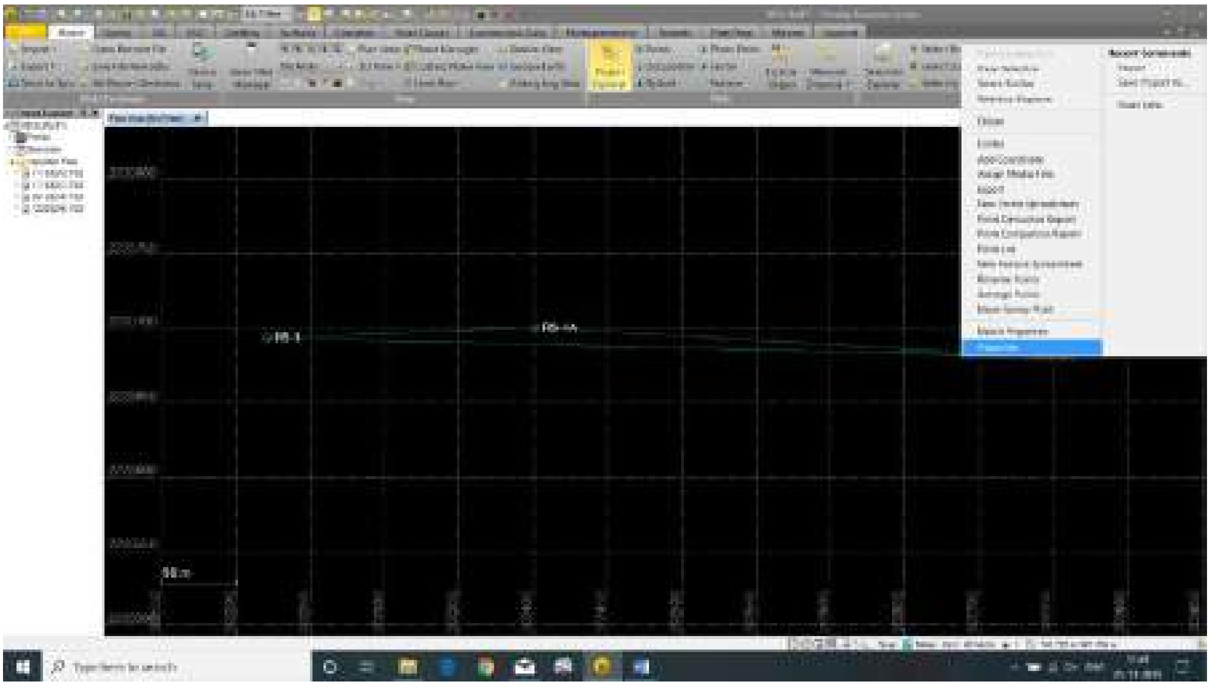
Now press ok.

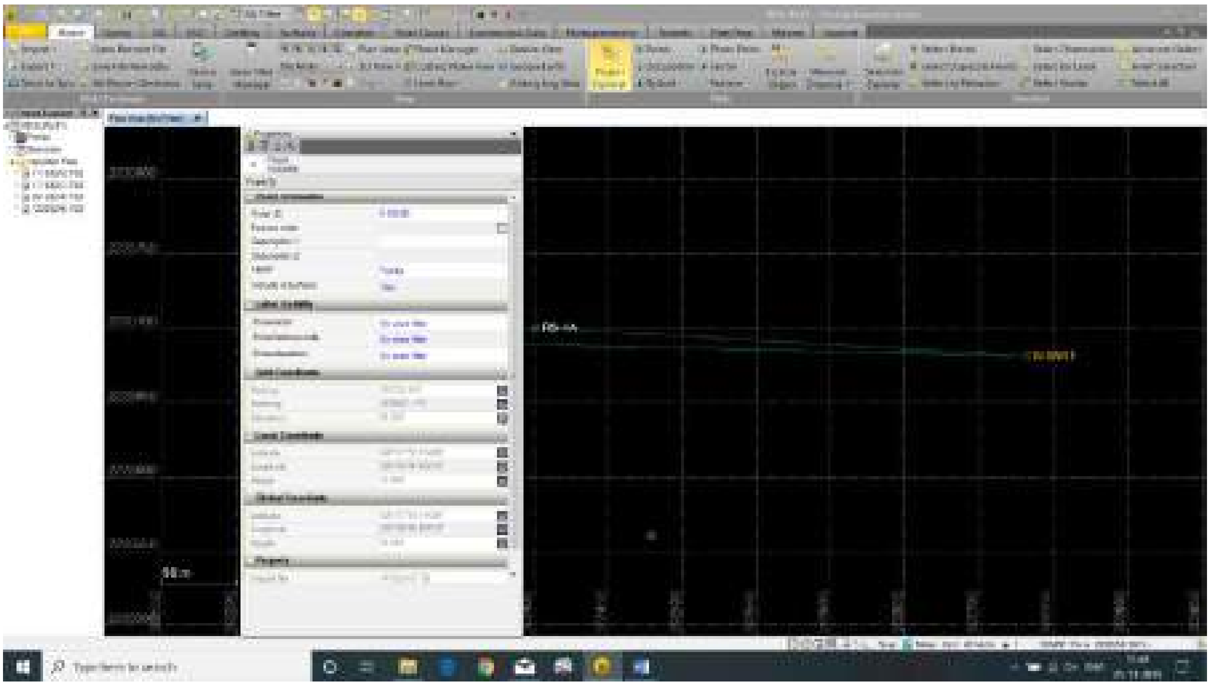


In this display we know RS3 point is wrong so select this point and delete.

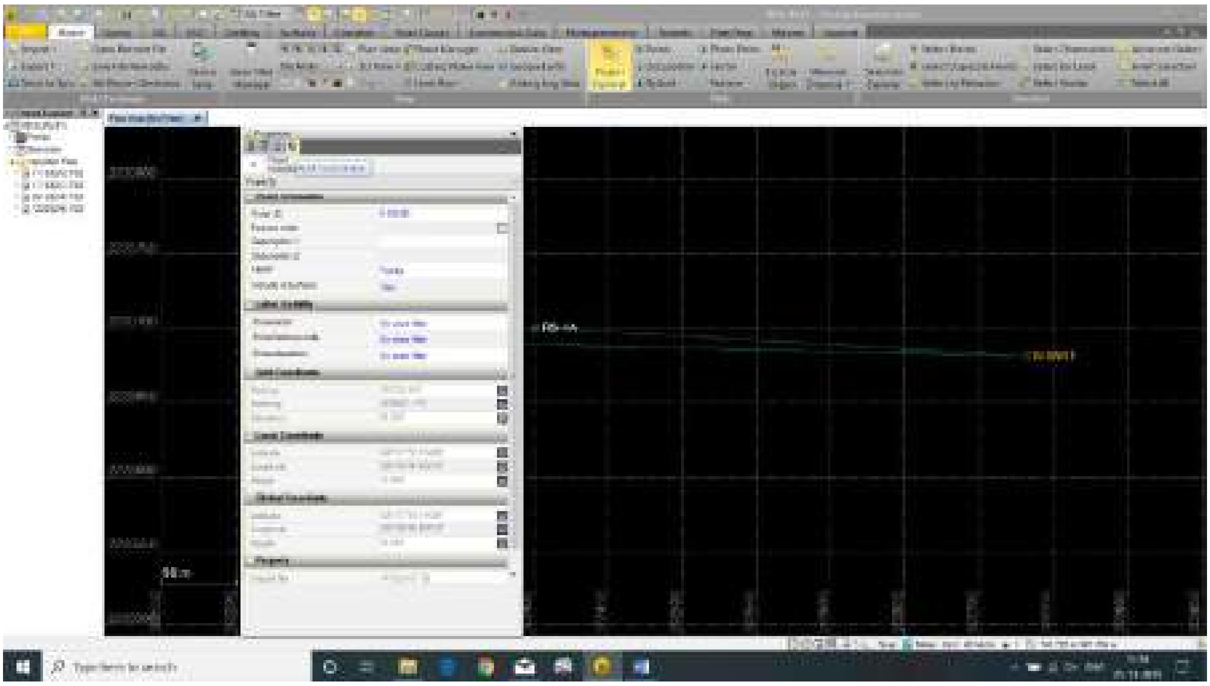


Now right click on N.Base and go to properties



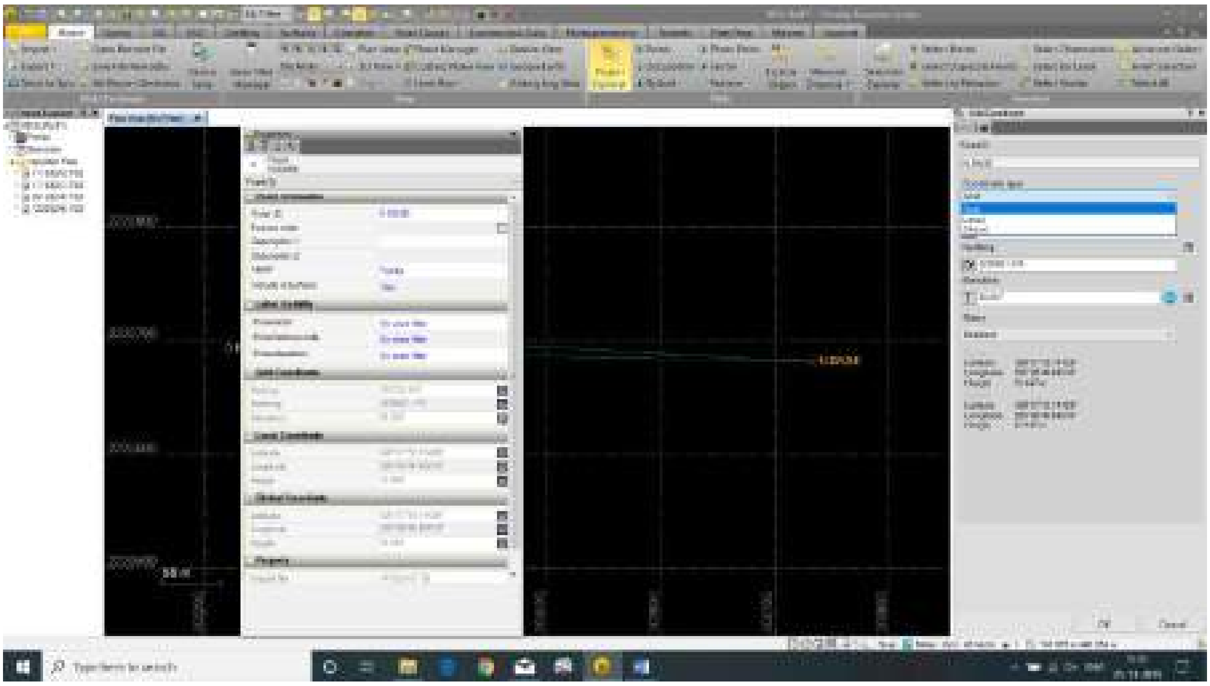


Click on Add coordinate symbol



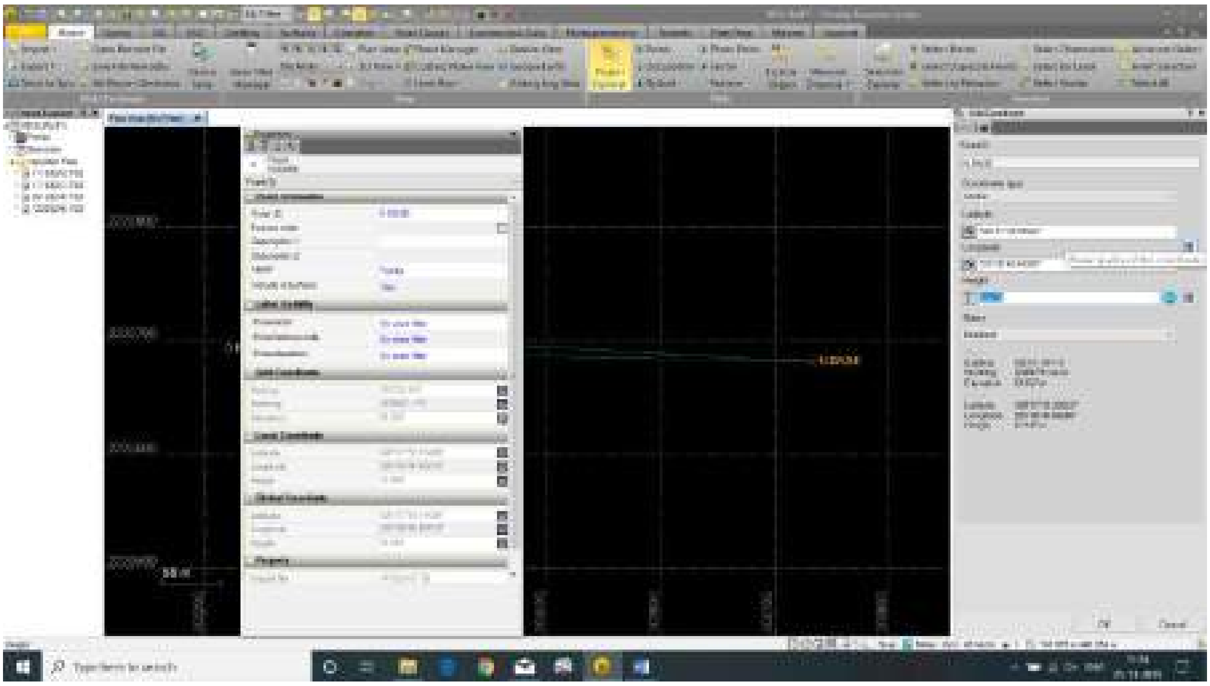
Select Coordinate type

Global



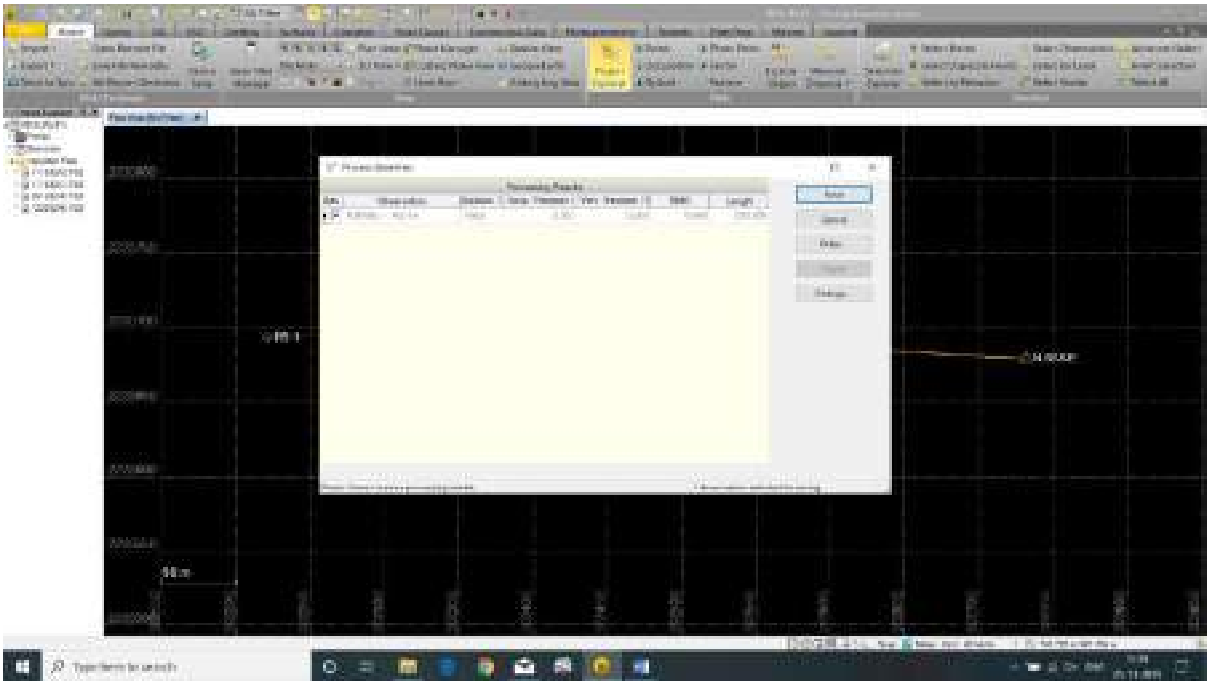
Now input your base corrected Coordinates

Then click on (?) and select Control Quality on both then press ok.

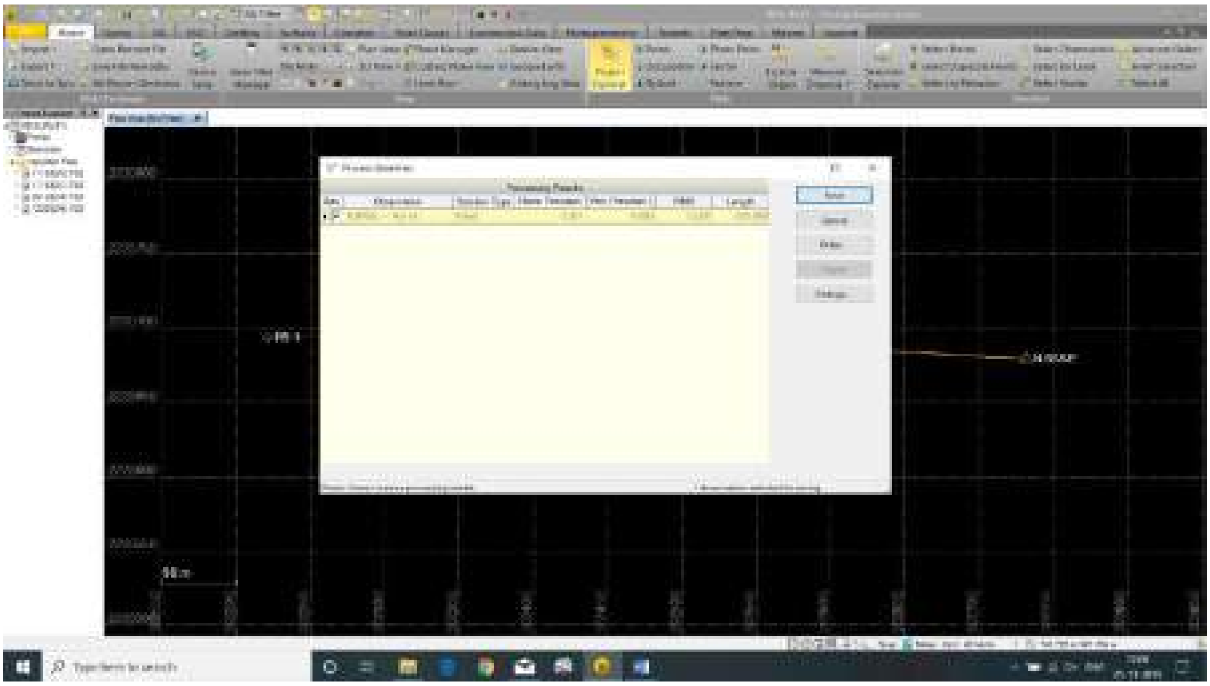


Close the properties

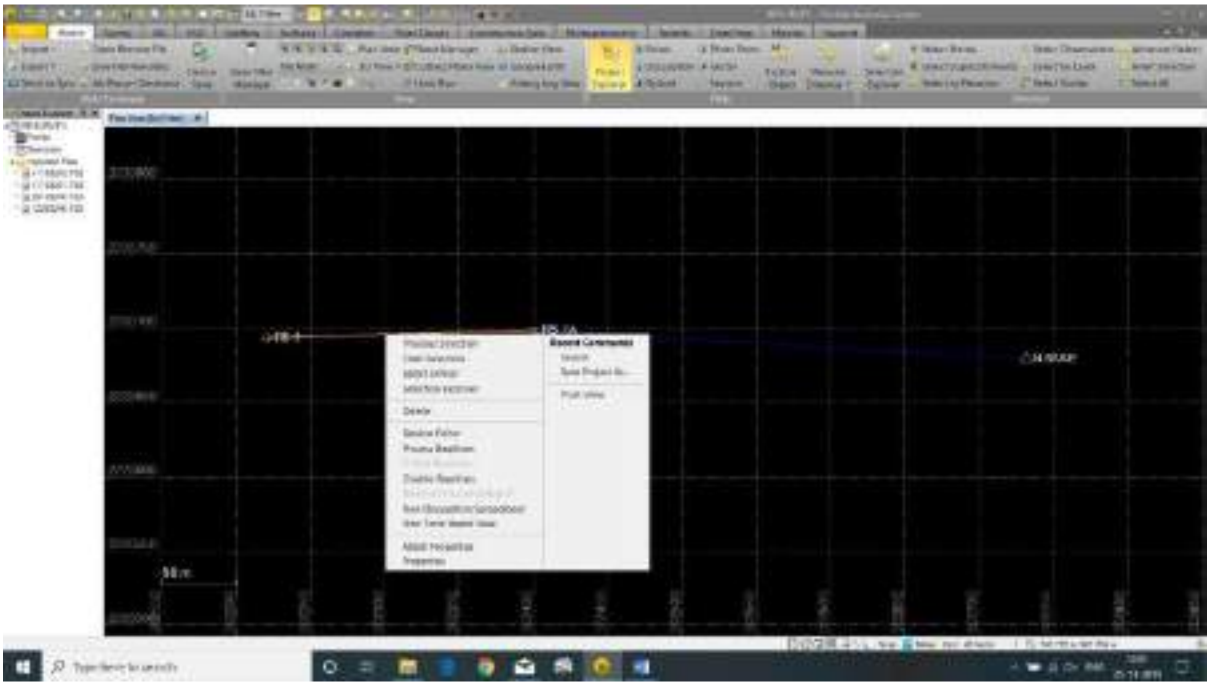
Delete the unwanted line first you process main control point RS1A then from RS1A to Auxiliary point RS1 you process.



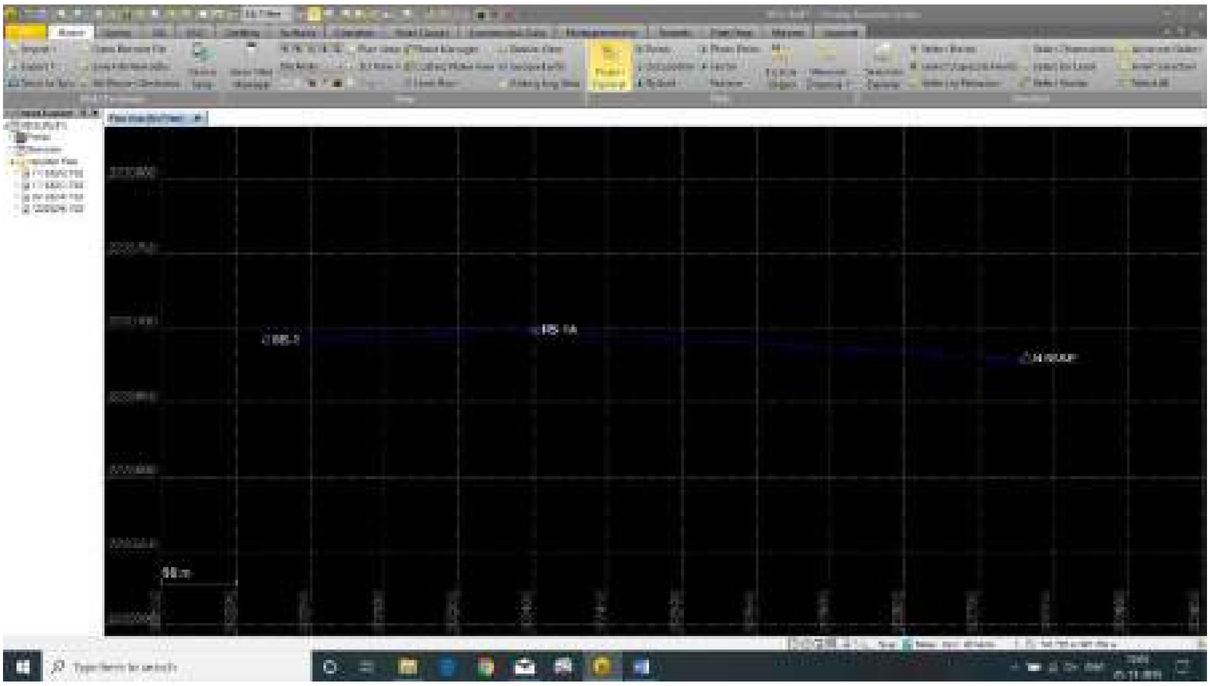
If your Solution Type Fixed and Horizontal and Vertical accuracy in permissible then press Save.



Now select other base line and process



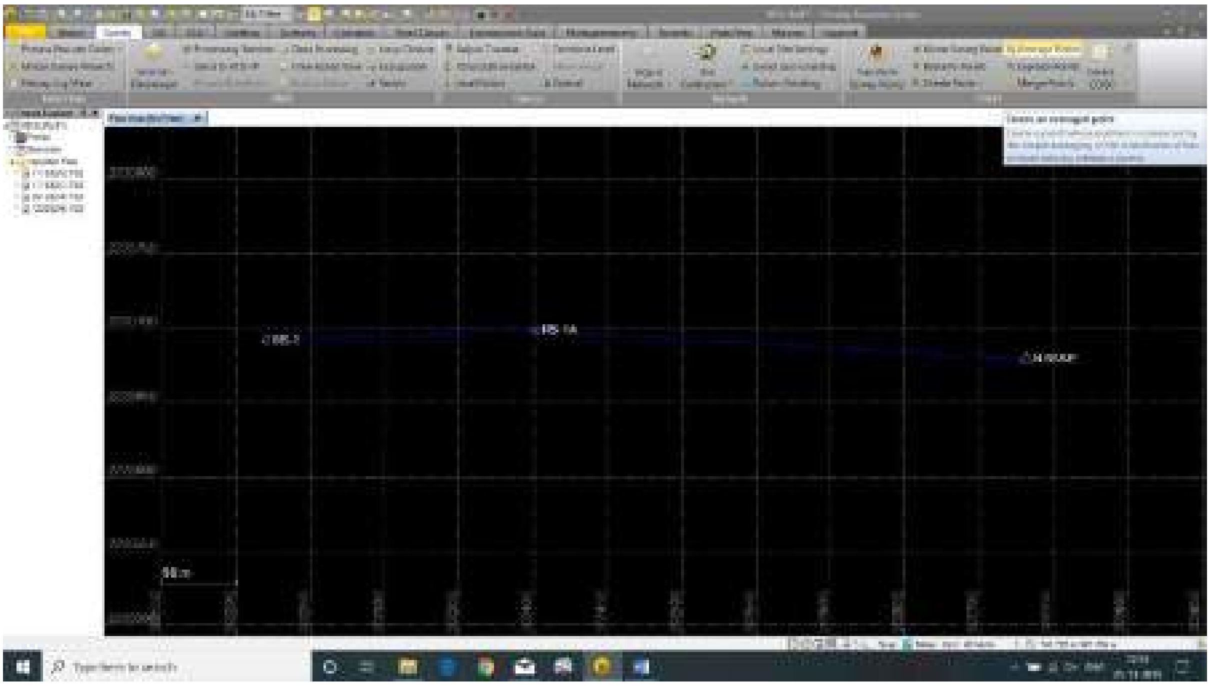
Then Press Save



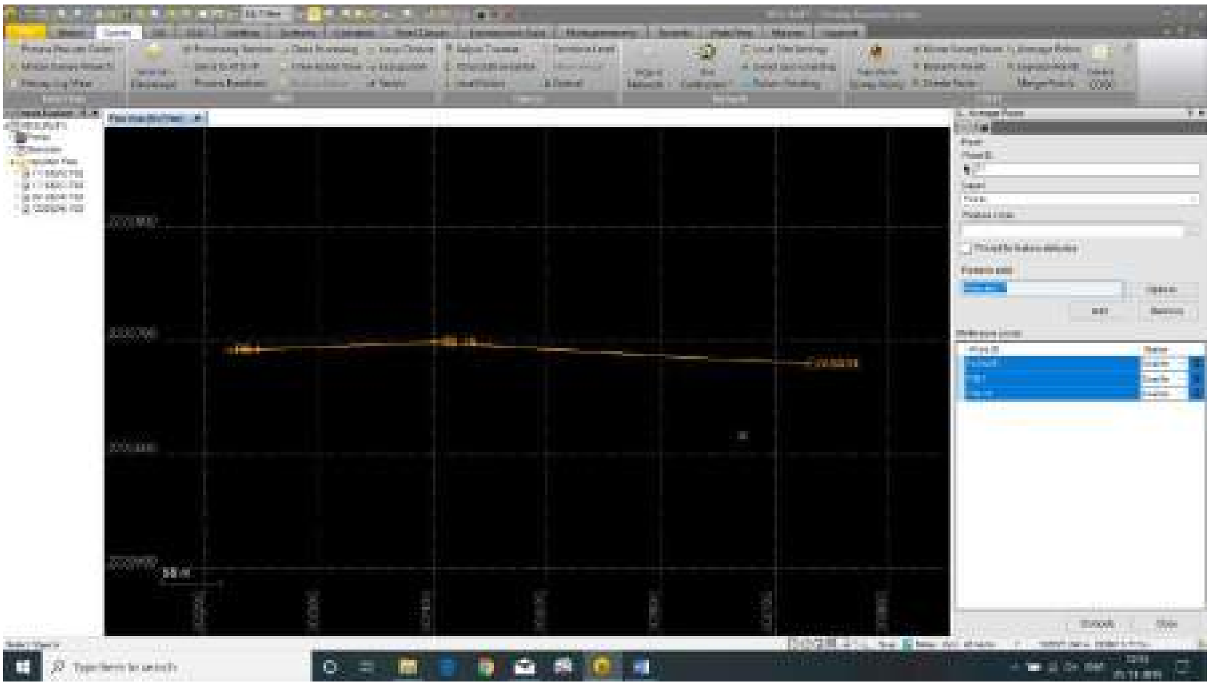
Now Click on Survey Page

And click on average point

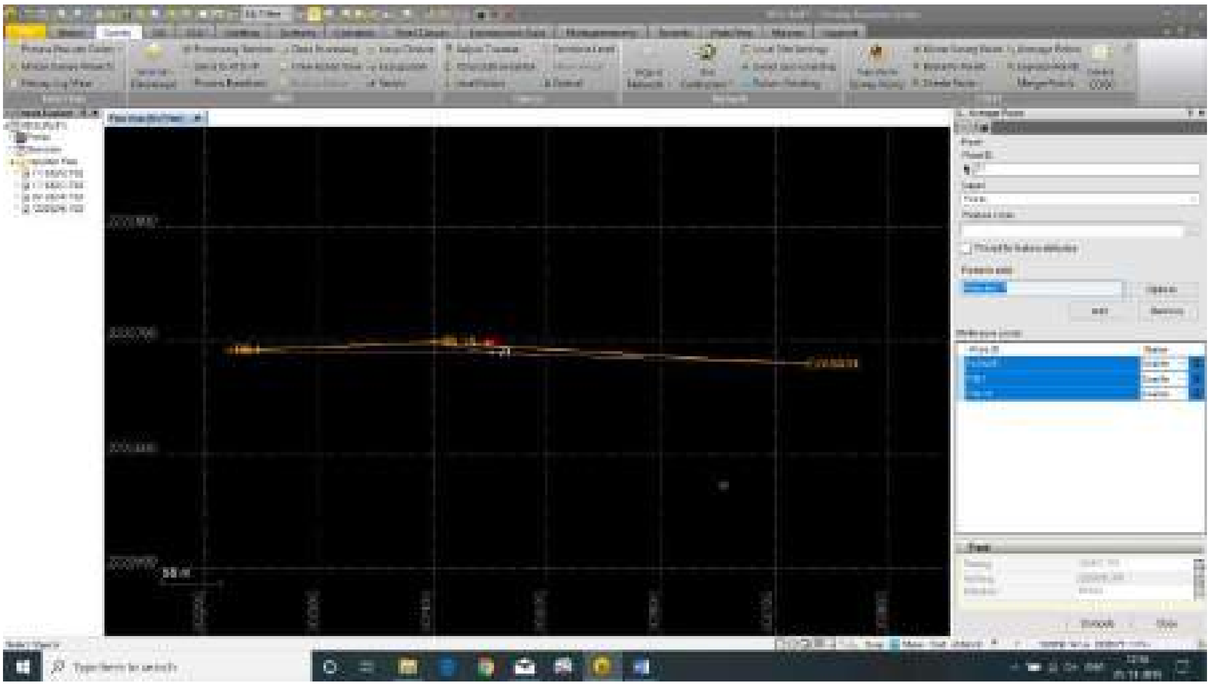
Input Dummy point ID like Z1



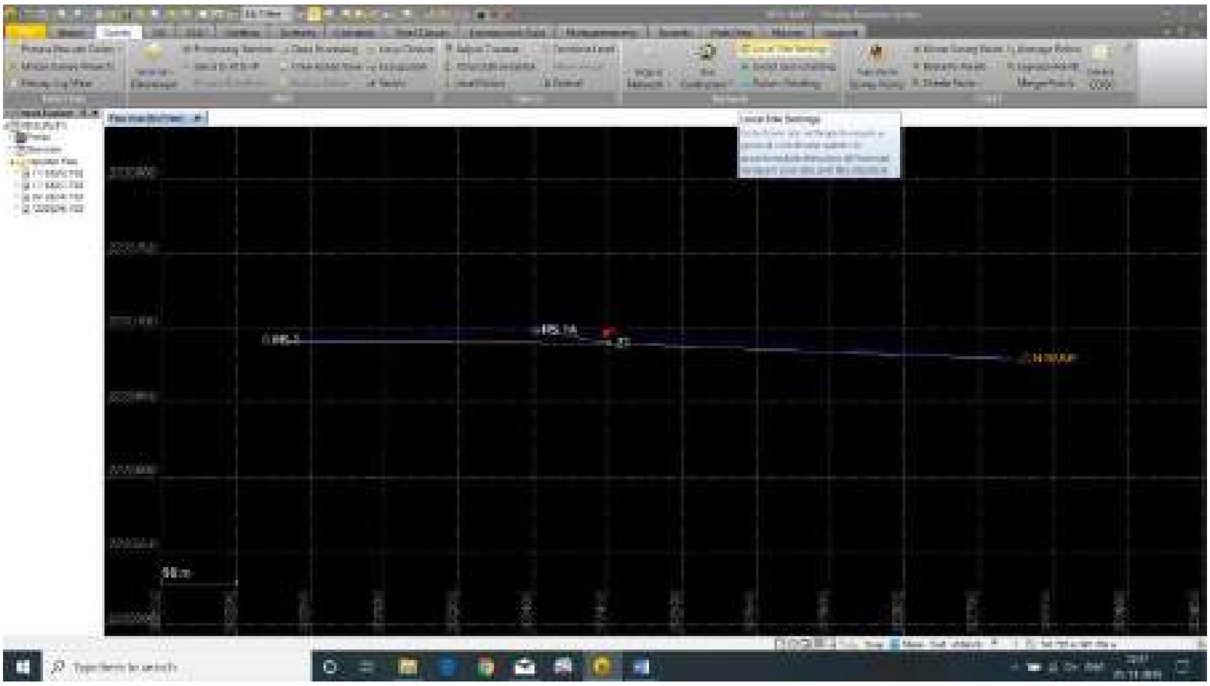
Select all point and Add



Then press Compute

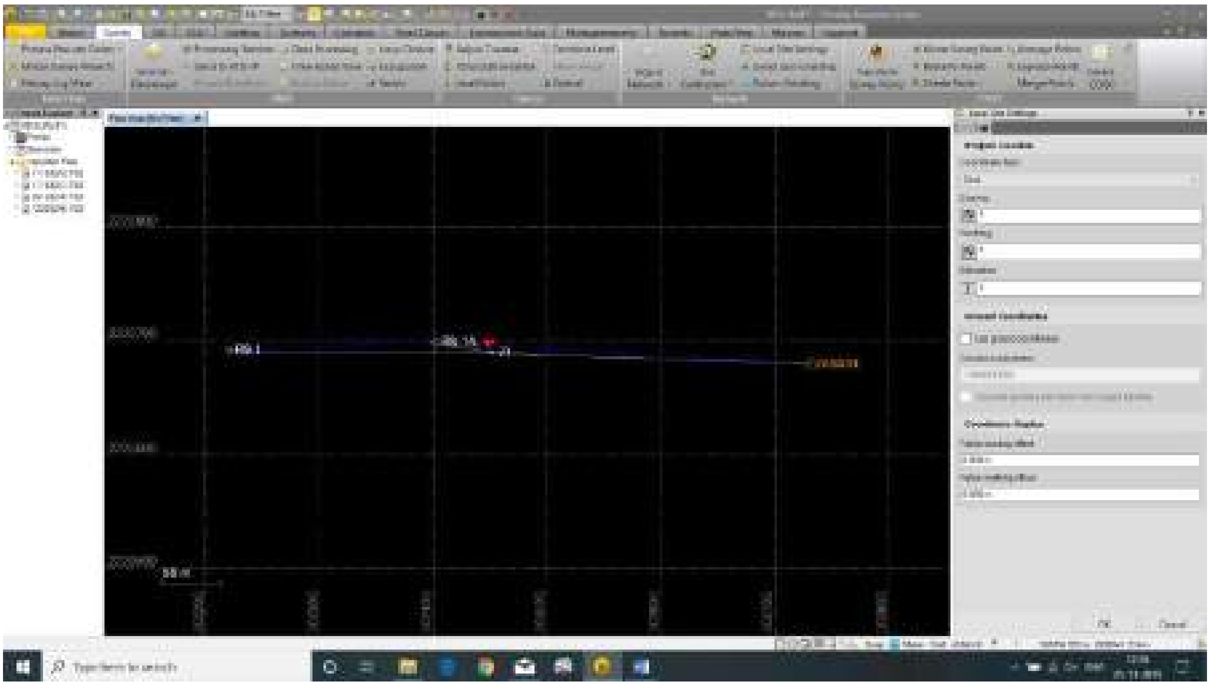


Software create a point Z1 now close Average Point

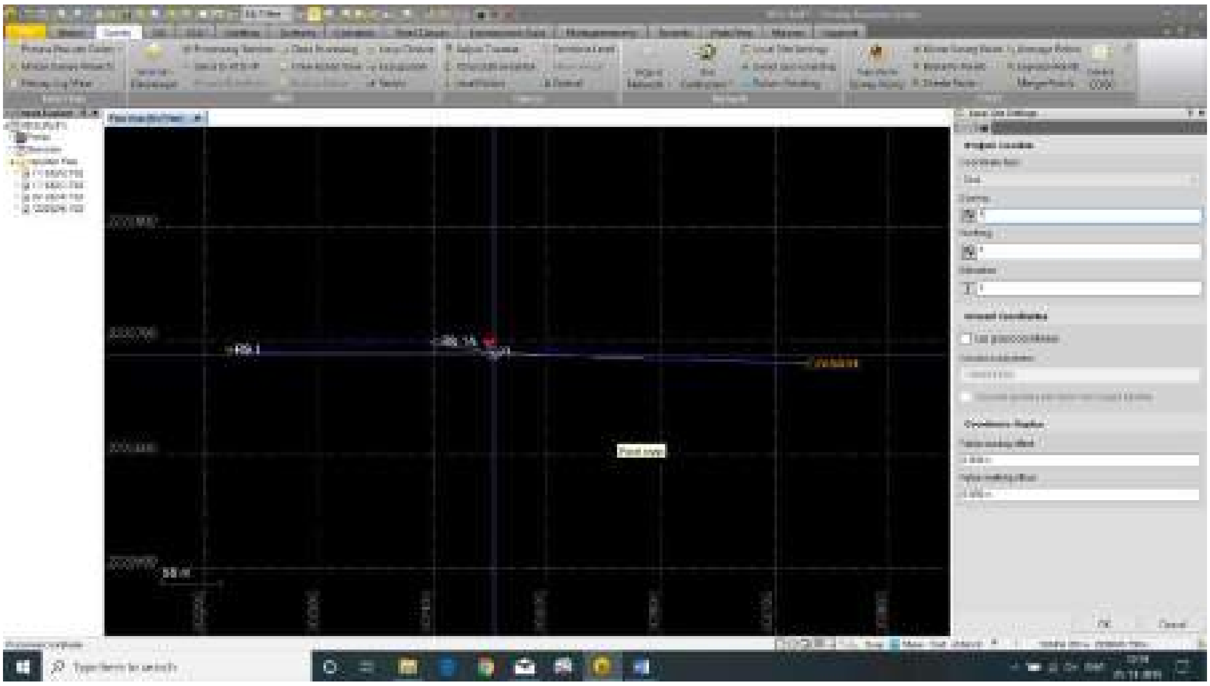


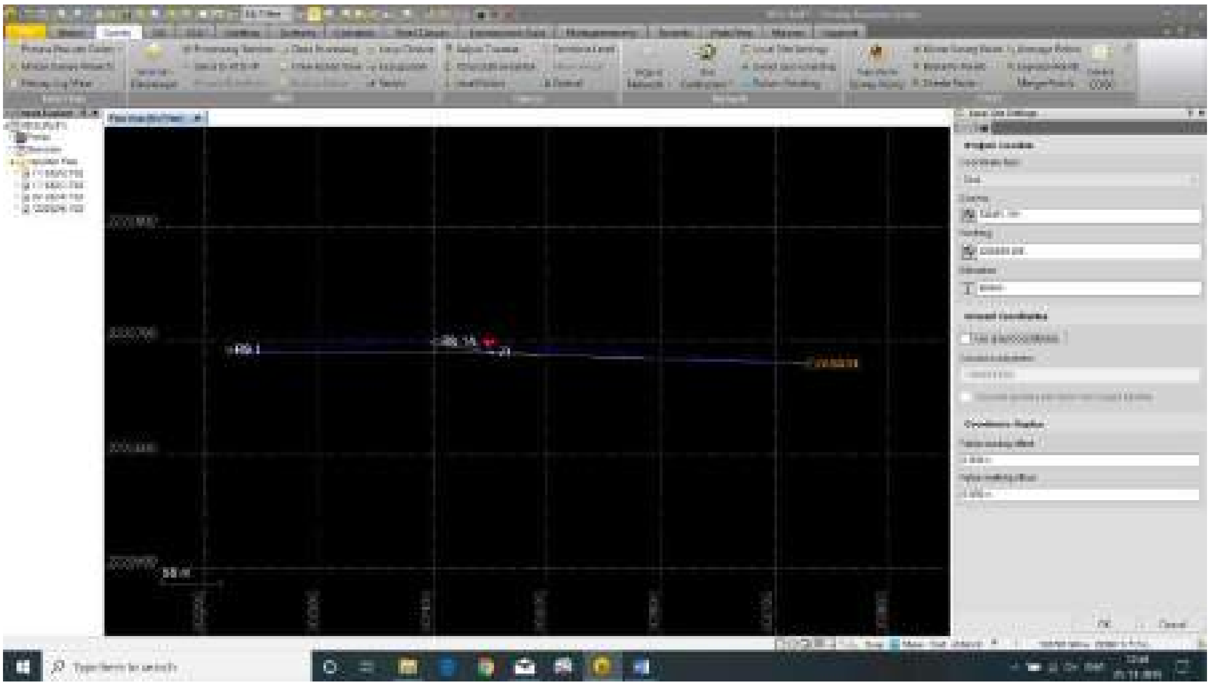
Now click on Local Site Setting

Click in Easting

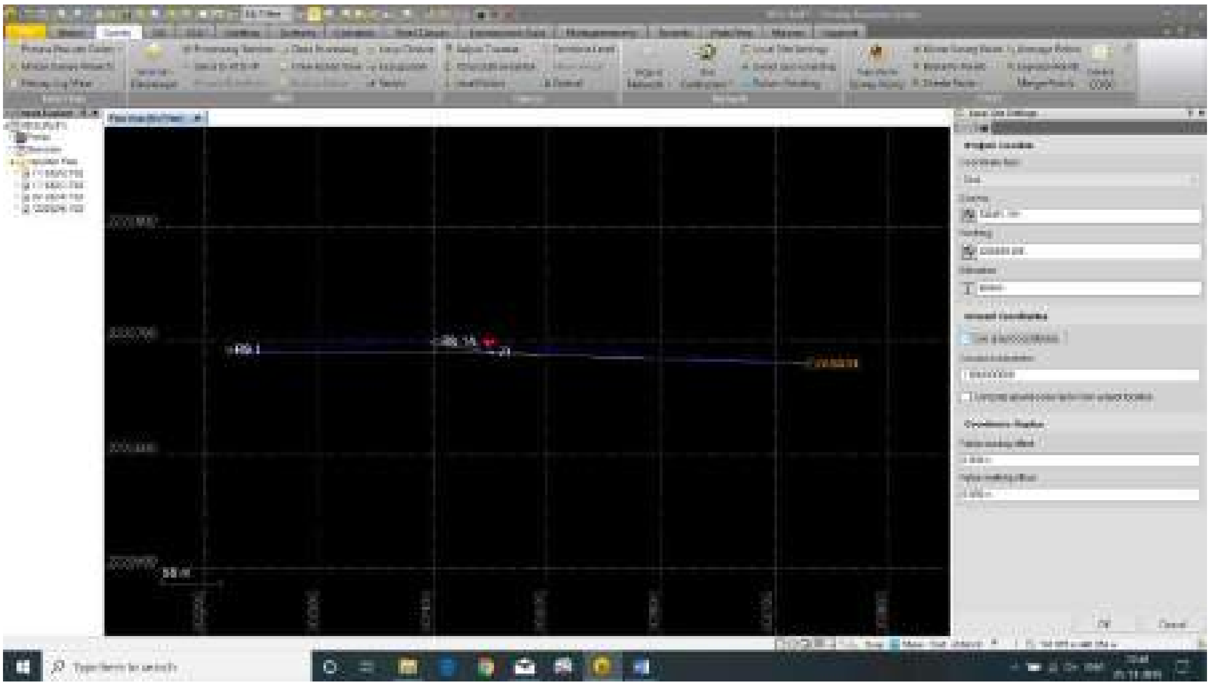


Click Two Time on Z1 Point

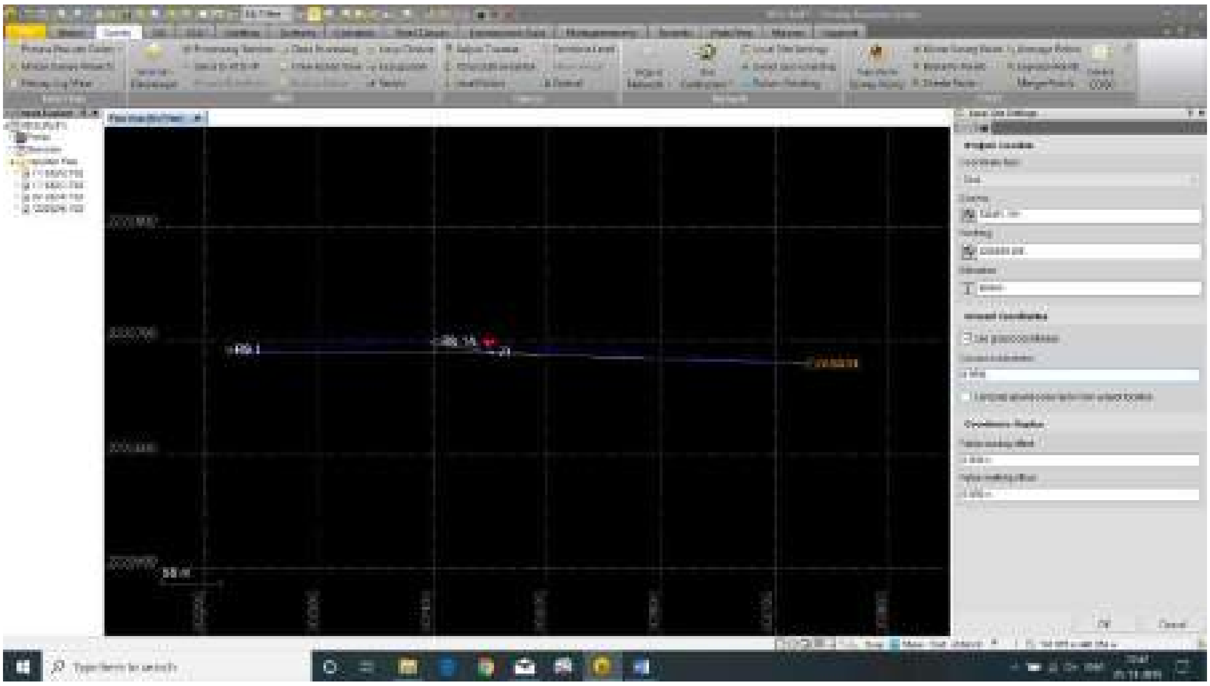


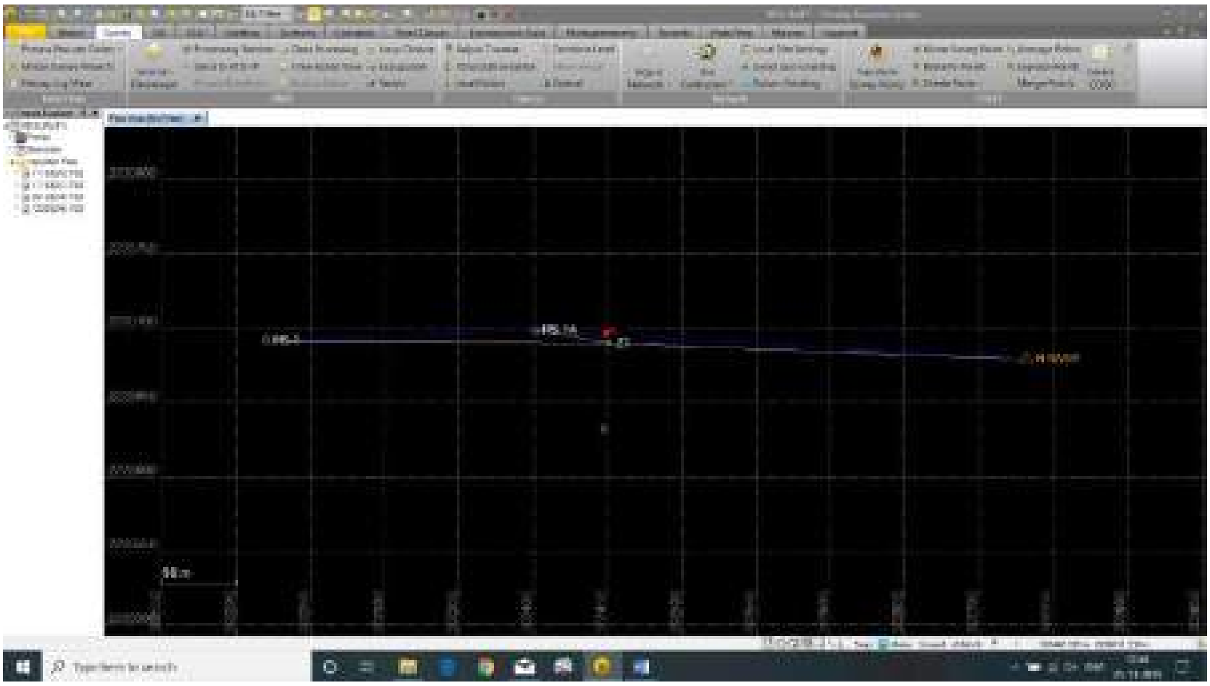


Click on Use Ground coordinate

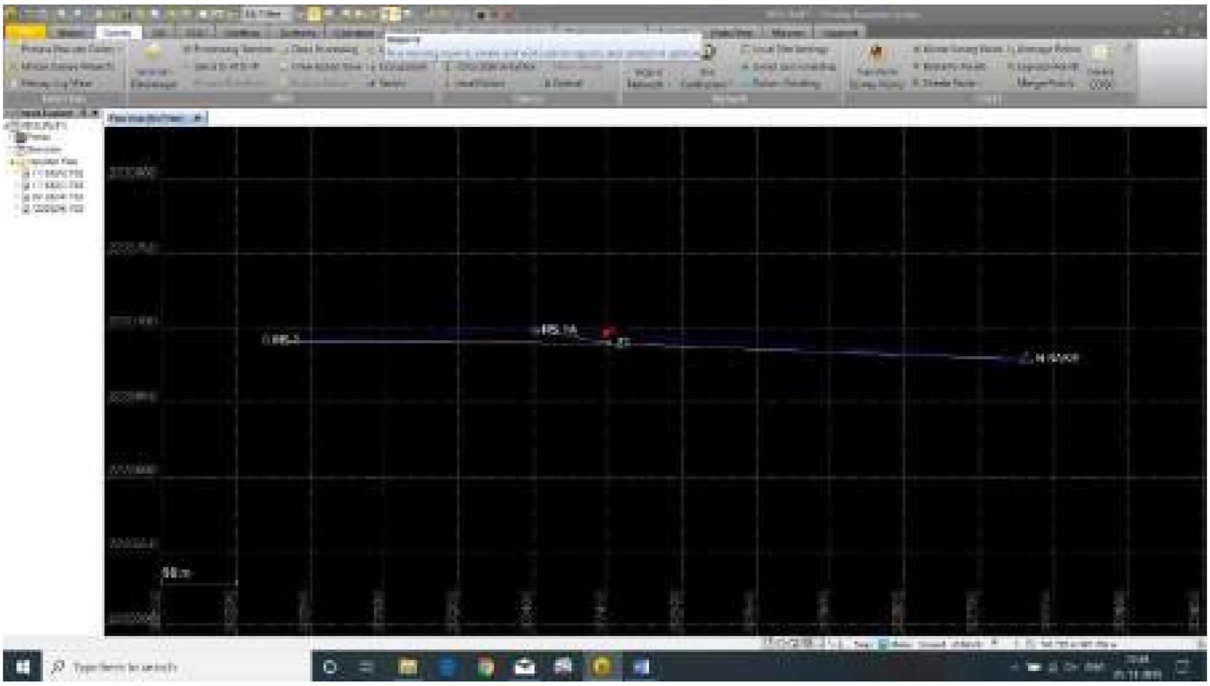


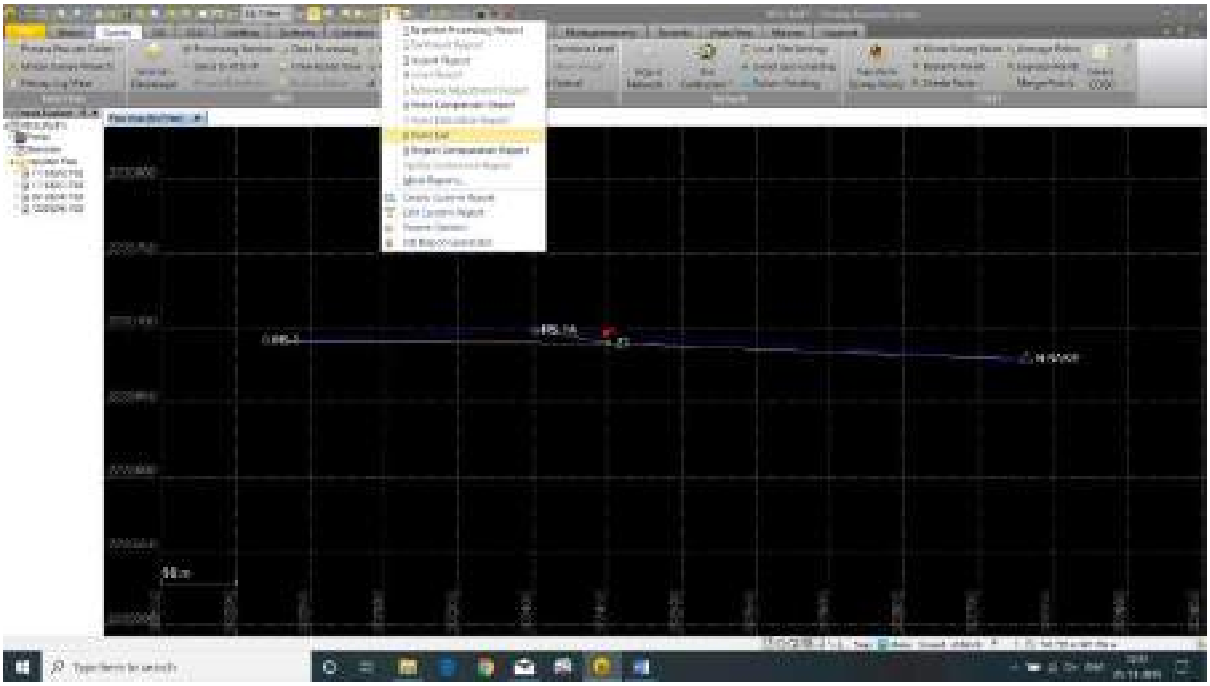
And input scale 0.9996 and press ok

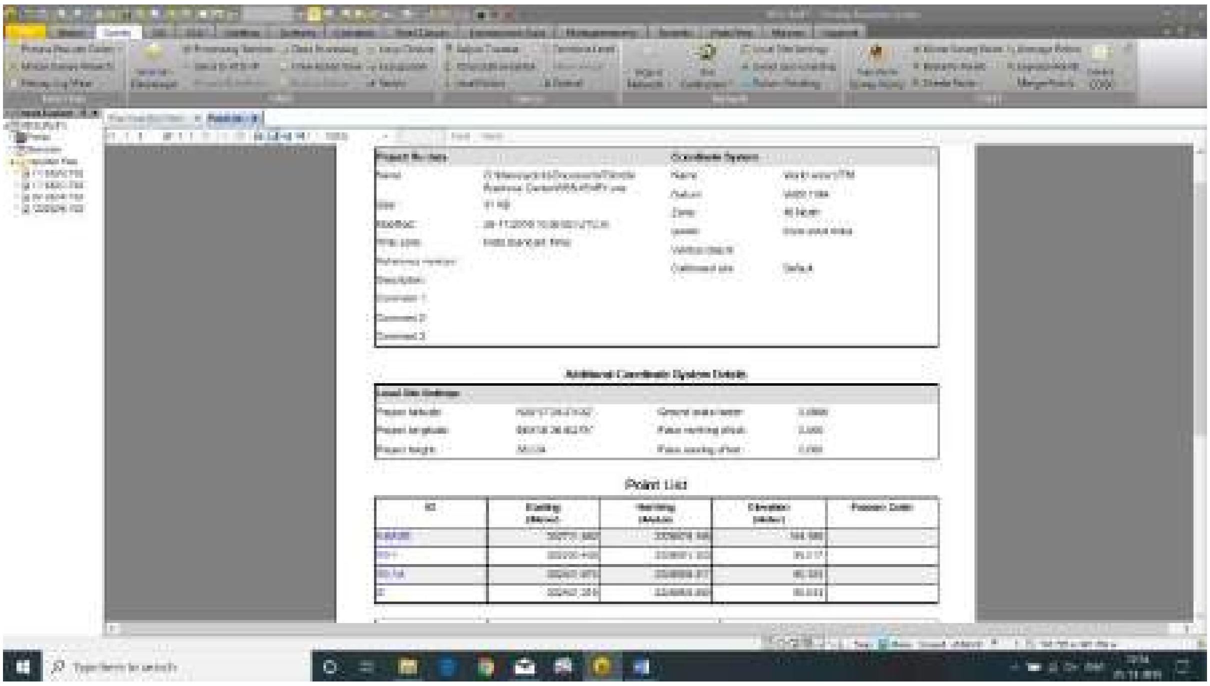




Now Click on Reports and select Point List and use coordinate with total station






Additional Coordinate System Details
Point List