NGS River/Valley Crossing Procedures

Iowa ASCE Meeting
Ames, IA
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by
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Team Members

• Kendall Fancher, Team Leader,
  – Instrumentation Branch Chief
• Steve Breidenbach, Charles Geoghegan
  – Instrumentation Branch
• John Ellingson, Dave Zenk,
  – Advisors in Wisconsin and Minnesota
New Crossing Method APPROVED

• NGS approved a new crossing method on August 24, 2015 !!!
• Based on use of precise theodolites.
• Continues to use traditional targeting.
• Future study to consider retro reflectors.
Outline

- Review of Historical River/Valley Crossing Procedures
- Design of New River Crossing Method
- Design of New River Crossing Equipment
- Initial Test at NGS Instrumentation Branch Corbin Lab
- MNDOT Test Results
- Cautionary Statement
Historical Review

• Chapter 4 of “NOAA Manual NOS NGS 3 GEODETIC LEVELING”, 2001
• Chapter 4 discusses the error theory of River/Valley Crossings and outlines several methods by which such crossings may be conducted.
  – Zeiss River Crossing Method (1970?) Section 4.3
  – Fischer Method (1929) Section 4.4
  – New Procedure (2015) Section 4.6 ????
Zeiss River Crossing Equipment

• 2 identical level instruments each equipped with a rotating wedge device and mounted on a single tripod head.

• Sighting to a target column with 2 targets and a height stud.
Zeiss River Crossing Equipment

- Rotating Wedge Device allowed line of sight to be *angled* (not shifted) upward or downward by up to 200 arc-seconds with an accuracy of 0.2 arc-seconds.

- By carefully measuring the angular deviations to upper and lower targets and accounting for instrument collimations, one could conduct First Order Class 1 River Crossings up to 1 km or more.
Fischer Method

• The Fischer Level was equipped with a precise tilting screw with which the line of sight could be *angled* (not shifted) upward or downward by up to 200 arc-seconds with an accuracy of 0.5 arc-seconds.

• Similar targets as for Zeiss.

• Not recommended for First Order.
Good Results, Slow

• The Zeiss Method and Fischer Method each produced good results when all procedures were followed.
• Complete field observing routines required about 1 day.
Why NGS Needed a New Method

• Existing River/Valley Crossing procedures do not meet customers needs.
• Existing procedures do not include the use of digital leveling systems.
• Required specialized instruments (Zeiss River Crossing Equipment) are no longer commercially available.
• The “Instructions for Ordinary Leveling Instruments” (Fischer level) relies upon an instrument which is no longer commercially available.
• NGS customers have a need to conduct this activity and are looking to us for guidance.
Expected Outcomes for New Method

- Design river/valley crossing data collection/analysis procedures and forms which enable our customers to conduct this type of activity, achieving 1st order precision, while using commercially available instrumentation along with specialized equipment readily fabricated at the average machine shop.
- Field test new procedures, comparing against a standard (Zeiss river crossing procedure) and report on results.
- Publish new river/valley crossing procedures in the form of a technical paper and make available to our customers for use as a viable alternative to current river crossing procedures.
- In future revision of NOS-NGS 3 incorporate the new river/valley crossing procedure into the document as a replacement of the existing procedures.
Design of New Method

• NGS Instrumentation Branch studied the existing methods and adopted the following guiding principles
  – Dual simultaneous reciprocal observations
  – Precise vertical angle measurements
  – Sighting Targets
  – Readily available or easily constructed equipment
Design of New Method

• NGS Instrumentation Branch
  – Adopted the use of modern digital readout theodolites, to replace the leveling tools and their attachments.
  – Designed a set of sighting targets which could be locally constructed.
  – Created a set of field observations and computations procedures.
  – Conducted an initial test at their Corbin Lab Facility.
  – Conducted additional field testing.
  – Received approval of new method on August 24, 2015.
Geometry and Math

Total Station

Side 1

Backsight = 0.566

Foresight = -1.002

Elevation Difference = -0.436 meters

X

+ 58.5"

- 35.0"

Total Station

Y

+ 45.5"

- 42.5"
Calculate by proportion what would the rod reading have been with a total station angle of 0°-00’-00”

\[
\frac{-35.0”}{+58.5” - (-35.0”)} = \frac{X}{0.659 - 0.511}
\]

\[
\frac{-35.0”}{93.5”} = \frac{X}{0.148}
\]

\[
X = (0.148) \frac{-35.0”}{93.5”}
\]

\[
X = 0.055 \text{ m}
\]

\[
\text{Rod} = 0.511 + 0.055
\]

\[
\text{Rod} = 0.566 \text{ meters}
\]

Side 1 – backsight rod
Geometry and Math

• Similarly, compute Side 1 Foresight to opposite bank of river.

• Elevation Difference = backsight – foresight
  – Elevation Difference is affected by Earth’s curvature and atmospheric refraction.
  – Instrument has collimation errors.
Error Control

- Observe all angles with telescope in direct and reversed positions (face 1 / face 2).
  - Eliminates instrument collimation errors.
- Simultaneously observe all angles from both sides of river.
  - Mitigates (or eliminates) effects of curvature and refraction.
- Observe multiple sets of angles
  - Eliminates small random errors of sighting and reading.
Errors Caused by Angular Resolution Limits

River Crossing Wedge & Total Station
Error caused by 0.2” angular error at varying distances

<table>
<thead>
<tr>
<th>Distance to Target (in meters)</th>
<th>Error (in meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 m</td>
<td>0.00003 m = 0</td>
</tr>
<tr>
<td>100 m</td>
<td>0.0001 m</td>
</tr>
<tr>
<td>300 m</td>
<td>0.0003 m</td>
</tr>
<tr>
<td>500 m</td>
<td>0.0005 m</td>
</tr>
<tr>
<td>1000 m</td>
<td>0.0010 m</td>
</tr>
<tr>
<td>2000 m</td>
<td>0.0019 m</td>
</tr>
</tbody>
</table>
Error caused by 0.5” angular error at varying distances

<table>
<thead>
<tr>
<th>Distance to Target (in meters)</th>
<th>Error (in meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 m</td>
<td>0.00007 m = 0</td>
</tr>
<tr>
<td>100 m</td>
<td>0.0006 m</td>
</tr>
<tr>
<td>300 m</td>
<td>0.0007 m</td>
</tr>
<tr>
<td>500 m</td>
<td>0.0012 m</td>
</tr>
<tr>
<td>1000 m</td>
<td>0.0024 m</td>
</tr>
<tr>
<td>2000 m</td>
<td>0.0048 m</td>
</tr>
</tbody>
</table>
Error Budget

Side 1

Total Station
Backsight = 0.566

Foresight = -1.002

Elevation Difference = -0.436 meters
Error Budget

- Assume 0.1 mm error in each target height
- Assume 0.5 second vertical angle error
- Operator error controlled by rejection limit from mean
- C+R will be eliminated by dual-simultaneous observations
- Compute 30 meter BS and 300 meter FS
- Compute 30 meter BS and 1000 meter FS
- Compute 30 meter BS and 2000 meter FS
- All quantities are added/subtracted so error propagates as square root of sum of squares
Error Budget at 300 meters

- Backsight error = sum of 4 errors
  \[= \sqrt{(0.0001^2) + (0.0001^2) + (0^2) + (0^2)}\]
  \[= 0.00014 \text{ m}\]

- Foresight error = sum of 4 errors
  \[= \sqrt{(0.0001^2) + (0.0001^2) + (0.0007^2) + (0.0007^2)}\]
  \[= 0.00100 \text{ m}\]

- dH Error = \[\sqrt{(0.00014^2) + (0.00100^2)}\]
  \[= 0.00101 \text{ m}\]
Error Budget at 1000 meters

• Backsight error = sum of 4 errors
  • = \sqrt{(0.0001^2) + (0.0001^2) + (0^2) + (0^2)}
  • = 0.00014 m

• Foresight error = sum of 4 errors
  • = \sqrt{(0.0001^2) + (0.0001^2) + (0.0024^2) + (0.0024^2)}
  • = 0.00340 m

• dH Error = \sqrt{(0.00014^2) + (0.00340^2)}
  • = 0.00340 m
Error Budget at 2000 meters

- Backsight error = sum of 4 errors
  - \( = \sqrt{(0.0001^2) + (0.0001^2) + (0^2) + (0^2)} \)
  - \( = 0.00014 \text{ m} \)

- Foresight error = sum of 4 errors
  - \( = \sqrt{(0.0001^2) + (0.0001^2) + (0.0048^2) + (0.0048^2)} \)
  - \( = 0.00679 \text{ m} \)

- \( dH \) Error = \( \sqrt{(0.00014^2) + (0.00679^2)} \)
  - \( = 0.00679 \text{ m} \)
Operator error = inability to sight the target, read the instrument, and record the angle.

For digital theodolites the error is in the sighting, since the instrument reads the angle.

Transcription errors are eliminated by recording the angles to a data collector.
Error Budget

- If operator can sight target within $\sigma = 2''$, then if 16 sets are turned:
  - $\sigma_{\text{mean}} = 2'' / [\sqrt{16}]$
  - $\sigma_{\text{mean}} = 0.5''$

- If operator can sight target within $\sigma = 1''$, then if 4 sets are turned:
  - $\sigma_{\text{mean}} = 1'' / [\sqrt{4}]$
  - $\sigma_{\text{mean}} = 0.5''$
Combined Effect of C+R

Assume a 300 meter imbalance of BS and FS
300 meters = 0.300 km = 984 feet = 0.186 miles

Combined (c+r) Equations (from textbooks):

c+r = 0.574 M²
   M is distance in miles
   \[ c+r = 0.574 \times (0.186)^2 = 0.019 \text{ feet} \]

c+r = 0.0206 F²
   F is distance in thousands of feet
   \[ c+r = 0.0206 \times (0.984)^2 = 0.020 \text{ feet} \]

c+r = 0.0675 K²
   K is distance in kilometers
   \[ c+r = 0.0675 \times (0.300)^2 = 0.006 \text{ meters} \]
Combined Effect of C+R

So, for a 300 meters imbalance in BS and FS distances, we should expect a measured difference in height to be affected by 0.006 meters in each direction. Example – consider known BM “A” is 99.000 meters, and known BM “B” is 98.00 meters.

\[
\text{dH} = \text{BS} - \text{FS}
\]

- For BS = 1.000 and FS = 2.006:
  \[
  \text{dH} = 1.000 - 2.006 = -1.006 \text{ meters}
  \]

- For BS = 1.006 and FS = 2.000:
  \[
  \text{dH} = 2.000 - 1.006 = +0.994 \text{ meters}
  \]
Overall Leveling / River Crossing Diagram

All lines are double-run leveling
Limits and Tolerances

• Limits and Tolerances
  • Examination of:
    – “FGCS Specifications and Procedures to Incorporate Electronic Digital/Bar-Code Leveling Systems” and
    – “Standards and Specifications for Geodetic Control Networks”
  • shows several limits and tolerances that could be applied to the new procedure, including:
    – Least count of theodolite
    – Number of repeat measurements
    – Rejection limits from mean
    – Loop closure
Limits and Tolerances

Rejection Limits from Mean by Order/Class of Leveling

<table>
<thead>
<tr>
<th>Order/Class</th>
<th>Limit (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>(3mm) * sqrt(km)</td>
</tr>
<tr>
<td>1/2</td>
<td>(4mm) * sqrt(km)</td>
</tr>
<tr>
<td>2/1</td>
<td>(6mm) * sqrt(km)</td>
</tr>
<tr>
<td>2/2</td>
<td>(8mm) * sqrt(km)</td>
</tr>
<tr>
<td>3</td>
<td>(12mm) * sqrt(km)</td>
</tr>
</tbody>
</table>

Note: at least 2mm will be tolerated for shorter lines

See Table 3.1 on page 3-7 of NOAA Manual NOS NGS 3 Geodetic Leveling
Limits and Tolerances

Loop Closures by Order/Class of Leveling

<table>
<thead>
<tr>
<th>Order/Class</th>
<th>Closure (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>(4mm) * sqrt (km)</td>
</tr>
<tr>
<td>1/2</td>
<td>(5mm) * sqrt (km)</td>
</tr>
<tr>
<td>2/1</td>
<td>(6mm) * sqrt (km)</td>
</tr>
<tr>
<td>2/2</td>
<td>(8mm) * sqrt (km)</td>
</tr>
<tr>
<td>3</td>
<td>(12mm) * sqrt (km)</td>
</tr>
</tbody>
</table>

Note: at least 4mm will be tolerated for shorter loops

See Table 3.1 on page 3-7 of NOAA Manual NOS NGS 3 Geodetic Leveling
Limits and Tolerances

The least count (L.C.) and standard deviation (S.D.) of the optical total station must be capable of delivering the tolerances as specified for the Order and Class of the leveling in which the crossing will be included (see Table 3-1).

Example:
What least count and standard deviation would be needed for a 290 meter crossing in a second order, class 1 leveling survey?

Table 3-1 requires 6mm \( \times \sqrt{K} \)
The total tolerance for error would be \( 6 \times \sqrt{.290} = 3.23 \text{ mm} \)
The error occurs due to angles to bottom and top targets, so each error can be \( \frac{1}{2} \) of the total error. Therefore, each angle must be measured to achieve 1.6 mm of error.
The angular error \( \theta = \tan^{-1}(0.0016/290) = 1.1 \text{ seconds} \)
Because each angle is to be measured 8 times, then the instrumental precision may be estimated from the following equation: \( \sigma_{\text{mean}} = \sigma_{o}/\sqrt{n} \)
1.1 seconds = \( \sigma_{o}/\sqrt{8} \)
\[
\sigma_{o} = 1.1 \times \sqrt{8} \\
\sigma_{o} = 3.1 \text{ seconds}
\]
The required standard deviation of the measured angles should therefore be +/- 3.1 seconds.
## Limits and Tolerances

### Required Standard Deviation (S.D.) by Order/Class and Width

<table>
<thead>
<tr>
<th>Crossing Width (meters)</th>
<th>Item</th>
<th>1/1</th>
<th>1/2</th>
<th>2/1</th>
<th>2/2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 300</td>
<td>S.D. seconds</td>
<td>1.4</td>
<td>2.2</td>
<td>3.1</td>
<td>3.9</td>
<td>6.2</td>
</tr>
<tr>
<td>300 - 600</td>
<td>S.D. seconds</td>
<td>1.1</td>
<td>1.4</td>
<td>2.3</td>
<td>2.8</td>
<td>4.2</td>
</tr>
<tr>
<td>600 - 1000</td>
<td>S.D. seconds</td>
<td>0.8</td>
<td>1.1</td>
<td>1.7</td>
<td>2.3</td>
<td>3.4</td>
</tr>
<tr>
<td>1000 - 1500</td>
<td>S.D. seconds</td>
<td>0.7</td>
<td>0.8</td>
<td>1.4</td>
<td>2.0</td>
<td>2.8</td>
</tr>
<tr>
<td>1500 - 2000</td>
<td>S.D. seconds</td>
<td>0.6</td>
<td>0.7</td>
<td>1.1</td>
<td>1.7</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Recommended Least Count (L.C.) by Order/Class and Width

<table>
<thead>
<tr>
<th>Crossing Width (meters)</th>
<th>Item</th>
<th>1/1</th>
<th>1/2</th>
<th>2/1</th>
<th>2/2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 300</td>
<td>L.C. seconds</td>
<td>0.1</td>
<td>0.5</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>300 - 600</td>
<td>L.C. seconds</td>
<td>0.1</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>600 - 1000</td>
<td>L.C. seconds</td>
<td>0.1</td>
<td>0.1</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>1000 - 1500</td>
<td>L.C. seconds</td>
<td>0.1</td>
<td>0.1</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>1500 - 2000</td>
<td>L.C. seconds</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Corbin Baseline Test

- Setup 2 marks 300 meters apart
  - OBSERVATORY and MITCHELL
- Ran levels between them
  - elevation difference = 1.01319 m
- Setup theodolites and observed 20 sets of D+R angles on target sets.
- Computed elevation differences from angular measurements
  - OBSERVATORY to MITCHELL = 1.01298 m
  - compared to leveling difference = 0.00021 meters
- See diagram and tables to follow
Forward Run from Side A to Side B

SIDE A

Total Station

SIDE B

OBSERVATORY

K

k

j

j

T1 = 1.53051

0.50021

Height Diff = ?

T2 = 0.50432

0.50038

MITCHELL
SIDE A  Backward Run from Side B to Side A  SIDE B

Total Station

T1 = 1.53051
T2 = 0.50432

Height Diff = ?

0.50021
0.50038

K  k  M
J  j  n

OBSERVATORY  MITCHELL

NOAA's National Geodetic Survey Positioning America for the Future
geodesy.noaa.gov
Forward Run from Side A to Side B
OBSERVATORY to MITCHELL
Compute vertical angles j, k, m, n
from the zenith angles.
Compute distances J, K, M, N
by proportion.

Angles (for Set 15)
j = 0° -52'-48.2”
k = 4° -17'-46.0”
m = 0° -05'-05.8”
n = 0° -01'-21.4”

Distances (for Set 15)
J = 0.50021 (j) / (j + k) = 0.08505 m
K = 0.50021 (k) / (j + k) = 0.41516 m
M = 0.50038 (m) / (m + n) = 0.39519 m
N = 0.50038 (n) / (m + n) = 0.10519 m

Plate-to-Plate = J – N = -0.02014 m
Height Diff = T1 + J – N – T2 = 1.00605 m

Average Height Difference from OBSERVATORY to MITCHELL = 1.01298 m
Leveled Height Difference = 1.01319 m

Backward Run from Side B to Side A
MITCHELL to OBSERVATORY
Compute vertical angles j, k, m, n
from the zenith angles.
Compute distances J, K, M, N
by proportion.

Angles (for Set 15)
j = 0° -05'-10.8”
k = 0° -01'-14.0”
m = 0° -54'-40.0”
n = 4° -09'-01.6”

Distances (for Set 15)
J = 0.50021 (j) / (j + k) = 0.40402 m
K = 0.50021 (k) / (j + k) = 0.09619 m
M = 0.50038 (m) / (m + n) = 0.09007 m
N = 0.50038 (n) / (m + n) = 0.41031 m

Plate-to-Plate = N – J = 0.00629 m
Height Diff = T2 + N – J – T1 = -1.01990 m
General Recon Recommendations

• Careful Recon and Setup will make the River Crossing easier.
River Crossing Diagram

All lines are double-run leveling

300 m
General Recon / Setup Pointers

Lines of Sight as high as practical

LOWER TARGET A to LOWER TARGET B should be about 15-30 cm

Height Diff = ?

Height Diff should be about 15-30 cm
Target Construction

• NGS has adopted a recommended target
• MNDOT has modified it for local construction and materials
NGS Adopted Targets

6"

12"

6"
MNDOT Adopted Targets

Cut at 3” width

Available for $12 each at Fast Signs in Minnetonka, MN or nationwide

Dibond material – metal faces sandwiched on 1/16” plastic center. Durable in outdoor exposure. Available in any color combinations.
**MNDOT Adopted Targets**

Permanently mount the 3” piece

Add angle clip to back of 9” piece and clamp on if needed

**Mount 2 Targets per column**

80/20 Inc. T-Slotted Extrusions Clear Anodized Aluminum Alloy Framing
1530-LITE-97
1.5” x 3.0” x 72” $125
http://www.8020.net/Product-Catalog_2012.asp

Also available from Graingers, Inc.
catalog pages 250-252
1.5” x 3” Mfg #1530
Grainger # 5JTC1  72” $123.40
Angle Clip – 1.5” x 1.5” x 5.5” with 2 holes 0.375” diameter. Corners to be radiused and edges smoothed for safe handling.

Hilman #11356
48” length
$6.50 at Lowe’s

T-Nut & Flanged
Button Head Socket Cap Screw, Pkg. of 15.
$15.98 at Grainger.
Grainger #2RCT7
80/20 Inc #3320-15
MNDOT Adopted Targets

Make a hole or a slot in target column. Insert thermometer probe cable within center hollow. Protect thermometer probe cable from abrasion with foam wrap.

Springfield 90817
$9.45 at Amazon
MNDOT Adopted Targets

- **Leveling Rod Level**
  SECO #7321-050

- **Heads-Up Rod Level**
  SECO #5001-21

- **Standard Rod Level**
  SECO #5001-10

- **Post Level**
  JOHNSON #175-O

Need to have one well-adjusted rod leveling device per target column.
MNDOT Adopted Targets

Short Target mounts on Tripod

Tall Target rests directly on benchmark

Need 2 Tall Target Sets and 2 Short Target Sets
Total Cost about $550

Target Columns $450
Arrow Targets $100
Bottom of Short Target Rod

5/8” x 11 Thread
Adapts to any tripod
Bottom of Tall Target Rod

Not flat - Use leveling plug
Top of Target Rod

5/8” x 11 Thread
Attach accessories
Thermometer Attachment

![Thermometer Attachment](image-url)
Measuring Target Separations

Zero-in on target by carefully raising and lowering the level instrument. Read adjacent bar code rod. Repeat several times to get average. Measure both targets and bottom plate. Subtract to get target separations.

Example Readings Upper Target:
1.83927 m
1.83904 m
1.83905 m
Average = 1.83912 m

Example Readings Lower Target:
0.65961 m
0.65968 m
0.65940 m
Average = 0.65956 m

Target Separation = 1.27956 m
Measuring Target Separations
Adjust Optical/Digital Line of Sight

Setup 1 – Optically sight an exact bottom or top edge of a specific stripe or block on the digital bar-code rod. Obtain digital reading.

Setup 2 – Invert the rod. Optically sight the same exact edge of the specific stripe or block on the digital bar-code rod. Obtain a second digital reading.

Calculate the discrepancy by subtracting the digital rod readings. Any discrepancy should be adjusted by moving the crosshair reticle up or down slightly and repeating the test.
Correct for Temperature

- DL = L (\(\alpha\)) (T2 − T1)
  - L = length
  - Aluminum \(\alpha = 0.000023 \text{ m/m C}\)
  - T1 = standard temperature (C)
  - T2 = actual temperature (C)
  - DL = change in length (m)
Correct for Temperature

• Example:
  – Length = 1.27956 m at 80°F (27°C)
  – Correct to length at 68°F (20°C)

\[ DL = 1.27956 \times 0.000023 \times (27 - 20) \]
\[ DL = 0.00021 \text{ m} \]

Length = 1.27935 m at 68°F (20°C)
### Detailed Notes for MNDOT Rods

#### TALL WHITE ROD

<table>
<thead>
<tr>
<th>UPPPER TARGET</th>
<th>LOWER TARGET</th>
<th>BOTTOM PLATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.83927</td>
<td>0.65961</td>
<td>0.12797</td>
</tr>
<tr>
<td>1.83923</td>
<td>0.65950</td>
<td>0.12798</td>
</tr>
<tr>
<td>1.83921</td>
<td>0.65957</td>
<td>0.12787</td>
</tr>
<tr>
<td>1.83904</td>
<td>0.65968</td>
<td>0.12783</td>
</tr>
<tr>
<td>1.83902</td>
<td>0.65955</td>
<td>0.12787</td>
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<td>1.83900</td>
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</tr>
<tr>
<td>1.83901</td>
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</tr>
<tr>
<td>1.83905</td>
<td>0.65949</td>
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</table>

UPPER TO LOWER = 1.17956
LOWER TO BOTTOM = 0.53162

Corrected to 68F
UPPER TO LOWER = 1.17937
LOWER TO BOTTOM = 0.53154

NOTE:
Rods measured at 80 degrees F (27C)
Corrected to 68 degrees F (20C)
Coeff of Expansion for Aluminum = 0.000023 m/m C

#### UPPPER PRISM

<table>
<thead>
<tr>
<th>UPPPER PRISM</th>
<th>LOWER PRISM</th>
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</tr>
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<tr>
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UPPER TO LOWER = 1.00909
LOWER TO BOTTOM = 0.56871

Corrected to 68F
UPPER TO LOWER = 1.00893
LOWER TO BOTTOM = 0.56862

NOTE:
Rods measured at 80 degrees F (27C)
Corrected to 68 degrees F (20C)
Coeff of Expansion for Aluminum = 0.000023 m/m C
## Detailed Notes for MNDOT Rods

<table>
<thead>
<tr>
<th>TALL YELLOW ROD</th>
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<th>BOTTOM PLATE</th>
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<tbody>
<tr>
<td>UPPER TARGET</td>
<td>1.84309</td>
<td>0.62774</td>
</tr>
<tr>
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<td>0.62771</td>
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<td>LOWER TO BOTTOM</td>
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Corrected to 68F

<table>
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<td>AVERAGE</td>
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<tr>
<td>UPPER TO LOWER</td>
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</tr>
<tr>
<td>LOWER TO BOTTOM</td>
<td>0.53436</td>
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Corrected to 68F

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</tr>
<tr>
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</tr>
<tr>
<td>LOWER TO BOTTOM</td>
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Corrected to 68F

<table>
<thead>
<tr>
<th>TALL YELLOW ROD</th>
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<th>BOTTOM PLATE</th>
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<td>LOWER TO BOTTOM</td>
<td>0.53436</td>
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</tbody>
</table>

Corrected to 68F

**NOTE:**

- Rods measured at 80 degrees F (27C)
- Corrected to 68 degrees F (20C)
- Coeff of Expansion for Aluminum = 0.000023 m/m C
# Target Separations @68F

<table>
<thead>
<tr>
<th>Arrow Targets</th>
<th>Tall White Rod</th>
<th>Tall Yellow Rod</th>
<th>Short White Rod</th>
<th>Short Yellow Rod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Target</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.17937 m</td>
<td>1.21515 m</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Lower Target</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.53154 m</td>
<td>0.49985 m</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Bottom Plate</td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Prism Targets</th>
<th>Tall White Rod</th>
<th>Tall Yellow Rod</th>
<th>Short White Rod</th>
<th>Short Yellow Rod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Prism</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00893 m</td>
<td>1.04236 m</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>Lower Prism</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.56862 m</td>
<td>0.53427 m</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Bottom Plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>
MNDOT River Crossing Validation

• Hastings Bridge Area
  – Plan for new BM’s (July 2014)
  – Conduct leveling (July 2014)
  – Conduct 3 River Crossings (July- August 2014)
    • 2 across the Mississippi River
    • 1 along the south shore (verify w/ double-run leveling)
Hastings Bridge Area Leveling

Control Leveling Plan
1001 to 1003 double-run leveling on same bank of river
1003 to 1007 double-run leveling across bridge

River Crossings Plan
1002 to 1008 use new River Crossing Procedure
1008 to 1004 use new River Crossing Procedure
1004 to 1002 use new River Crossing Procedure

Verification Plan
Summation of 3 River Crossings should = 0.000 m
Comparison of River Crossings to 2/1 Leveling
Hastings Bridge Crossings
Hastings Bridge Crossings
River Crossing Point Naming

- There are measurements on 2 benchmarks, 2 instruments, 2 rods, 2 setups, 4 targets, and 4 prisms to manage.
- Need to create a reasonable method to keep all the data correct.
- A sketch with filenames and point numbers is needed.
- Avoid 1000-series numbers (reserved for regular level line bench marks).
River Crossing Point Naming

2000 low series

Yellow Rod
2301 - 2324
2401 - 2424

White Rod
2101 - 2124
2201 - 2224

3000 low series

Yellow Rod
3101 - 3124
3201 - 3224

White Rod
3301 - 3324
3401 - 3424

Setup # 1 – Triangle Targets
River Crossing Point Naming

Setup # 2 – Triangle Targets

Yellow Rod
2701 - 2724
2801 - 2824

White Rod
2501 - 2524
2601 - 2624

Yellow Rod
3501 - 3524
3601 - 3624

White Rod
3701 - 3724
3801 - 3824

2000 high series

3000 high series
River Crossing Point Naming

4000 low series

5000 low series

Setup # 1 – Prism Targets
River Crossing Point Naming

4000 high series

Yellow Rod
4701 - 4724
4801 - 4824

White Rod
4501 - 4524
4601 - 4624

5000 high series

Yellow Rod
5501 - 5524
5601 - 5624

White Rod
5701 - 5724
5801 - 5824

Setup # 2 – Prism Targets
River Crossing Observations

NOAA's National Geodetic Survey Positioning America for the Future

godesy.noaa.gov
Effectiveness of Dual-Simultaneous Observations

• If the air refracts the forward sight down by 0.002 m, it also refracts the backward sight down by 0.002 m.
• The effect on the height differences is equal, but opposite.
• Therefore, the average eliminates the error.
• A plot of the individual results should show the effect.

Effectiveness of Dual-Simultaneous Observations
Effectiveness of Dual-Simultaneous Observations

Figure 1

Series 1
Average = 903.1094 m
Std Dev = 0.0080 m

Figure 2

Series 1
Average = 274.744 m
Std Dev = 0.0070 m

Figure 3

Series 1
Average = -0.3746 m
Std Dev = 0.0012 m
Example Data from Hastings River Crossing

<table>
<thead>
<tr>
<th>YELLOW Setup 1</th>
<th>WHITE Setup 1</th>
<th>Diff = 2x(c+r)</th>
<th>Average Ht Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.56282</td>
<td>0.53316</td>
<td>-0.02966</td>
<td>-0.54799</td>
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<tr>
<td>-0.56265</td>
<td>0.53294</td>
<td>-0.02971</td>
<td>-0.54779</td>
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<tr>
<td>-0.56365</td>
<td>0.53611</td>
<td>-0.02754</td>
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<tr>
<td>-0.56388</td>
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<td>-0.56412</td>
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<td>-0.56355</td>
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<td>-0.56350</td>
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<td>-0.56422</td>
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<td>-0.03041</td>
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<td>-0.56373</td>
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<td>-0.02857</td>
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<td>-0.56361</td>
<td>0.53424</td>
<td>-0.02938</td>
<td>-0.54893</td>
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</table>

Note: C+R formula predicts 0.0137 meters, Therefore expect 2 x 0.0137 = 0.0274 meters
Example Data from Hastings River Crossing

**YELLOW Setup 1**

- Series1

**WHITE Setup 1**

- Series1

**Check for Outliers**

**Average Ht Diff**
## Example Data from Hastings River Crossing

### Lower Target to Lower Target

<table>
<thead>
<tr>
<th></th>
<th>Forward</th>
<th>Backward</th>
<th>Ave</th>
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<tbody>
<tr>
<td>Run 1</td>
<td>0.56364</td>
<td>0.53424</td>
<td>0.54894</td>
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<td>Run 2</td>
<td>0.56345</td>
<td>0.53317</td>
<td>0.54831</td>
</tr>
<tr>
<td></td>
<td>diff</td>
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<td>-0.00063</td>
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</tbody>
</table>

### Bench Mark to Bench Mark

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</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>0.59533</td>
<td>0.56593</td>
<td>0.58063</td>
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<tr>
<td>Run 2</td>
<td>0.59514</td>
<td>0.56486</td>
<td>0.58000</td>
</tr>
<tr>
<td></td>
<td>diff</td>
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<td>-0.00063</td>
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### Allowable 1/1

```
3mm (sqrt KM) = 0.00222
```

### DISTANCES (m)

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<tr>
<td>Yellow BS</td>
<td>12.880</td>
<td>12.880</td>
</tr>
<tr>
<td>Yellow FS</td>
<td>440.919</td>
<td>440.579</td>
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<tr>
<td>White BS</td>
<td>20.728</td>
<td>20.745</td>
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<tr>
<td>White FS</td>
<td>432.441</td>
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### RUNNING LENGTHS

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<tr>
<td>Yellow</td>
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<td>453.459</td>
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<tr>
<td>White</td>
<td>453.169</td>
<td>453.319</td>
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Hastings Bridge Crossing Results

River Crossing 1 (8-06-2014)

<table>
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<th>Backward</th>
<th>Average</th>
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<tr>
<td>Run 1</td>
<td>0.42591</td>
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<td>0.44374</td>
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<td>0.42699</td>
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<td>0.44476</td>
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<tr>
<td>diff</td>
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2/1 Leveling

<table>
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<th>Backward</th>
<th>Average</th>
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</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>0.44861</td>
<td>-0.44664</td>
<td>0.44762</td>
</tr>
<tr>
<td>Run 2</td>
<td>0.4460</td>
<td>-0.4459</td>
<td>0.44595</td>
</tr>
</tbody>
</table>

Allowable 1/1 = 3mm(√.450 km) = 0.00201 m
Actual = 0.0017 m  OK

Note: * = suspect data
Hastings Bridge Crossing Results

River Crossing 1 (8-06-2014)

<table>
<thead>
<tr>
<th></th>
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<th>Backward</th>
<th>Average</th>
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<tbody>
<tr>
<td>Run 1</td>
<td>0.42768</td>
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<td>0.44440</td>
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<td>0.42825</td>
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2/1 Leveling

<table>
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<th>Average</th>
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<td>-0.44664</td>
<td>0.44762</td>
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<tr>
<td>Run 2</td>
<td>0.4460</td>
<td>-0.4459</td>
<td>0.44595</td>
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</table>

Allowable 1/1 = 3mm(√.450km) = 0.00201 m
Actual = 0.0012 m  OK

River Crossing 2 (8-13-2014)

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<th>Average</th>
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<tbody>
<tr>
<td>Run 1</td>
<td>-0.14922</td>
<td>0.12538</td>
<td>-0.13730</td>
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<tr>
<td>Run 2</td>
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<td>-0.13837</td>
</tr>
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<td>0.00107</td>
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2/1 Leveling

<table>
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<th>Backward</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td></td>
<td>-0.1340</td>
<td></td>
</tr>
<tr>
<td>Run 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Allowable 1/1 = 3mm(√2.572 km) = 0.0048 m
Actual = 0.0031 m  OK

River Crossing 3 (8-20-2014)

<table>
<thead>
<tr>
<th></th>
<th>Forward</th>
<th>Backward</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>-0.59421</td>
<td>0.56710</td>
<td>-0.58065</td>
</tr>
<tr>
<td>Run 2</td>
<td>0.59816 *</td>
<td>0.56739</td>
<td>-0.58277</td>
</tr>
<tr>
<td>diff</td>
<td></td>
<td></td>
<td>0.00212</td>
</tr>
</tbody>
</table>

2/1 Leveling

<table>
<thead>
<tr>
<th></th>
<th>Forward</th>
<th>Backward</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>0.44861 *</td>
<td>-0.44664</td>
<td>0.44762 *</td>
</tr>
<tr>
<td>Run 2</td>
<td>0.4460</td>
<td>-0.4459</td>
<td>0.44595</td>
</tr>
</tbody>
</table>

Allowable 1/1 = 3mm(√1.312 km) = 0.00343 m
Actual = 0.00086 m  OK

Note: * = suspect data

Using Prism Targets
Autolock pointings

Note: This slide contains data that is suspect due to malfunctioning autolock (caused by operator error).

Allowable 1/1 = 3mm(√1.312 km) = 0.00343 m
Actual = 0.00086 m  OK
Hastings Bridge Crossing Results

River Crossing 1 (8-27-2014)

<table>
<thead>
<tr>
<th>Run</th>
<th>Forward</th>
<th>Backward</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>0.42875</td>
<td>-0.46052</td>
<td>0.44463</td>
</tr>
<tr>
<td>Run 2</td>
<td>0.42782</td>
<td>-0.46206</td>
<td>0.44494</td>
</tr>
<tr>
<td>diff</td>
<td></td>
<td></td>
<td>-0.00031</td>
</tr>
</tbody>
</table>

2/1 Leveling

<table>
<thead>
<tr>
<th>Run</th>
<th>Forward</th>
<th>Backward</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>0.44861</td>
<td>-0.44664</td>
<td>0.44762 *</td>
</tr>
<tr>
<td>Run 2</td>
<td>0.4460</td>
<td>-0.4459</td>
<td>0.44595</td>
</tr>
</tbody>
</table>

Allowable 1/1 = 3mm(√.450 km) = 0.00201 m
Actual = 0.00116 m        OK

Allowable 1/1 = 3mm(√2.572 km) = 0.0048 m
Actual = 0.0025 m         OK

Note: * = suspect data
Hastings Bridge Crossing Results

Using Prism Targets Autolock pointings

<table>
<thead>
<tr>
<th>River Crossing 1 (8-27-2014)</th>
<th>Forward</th>
<th>Backward</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>0.4298</td>
<td>-0.4651</td>
<td>0.4474</td>
</tr>
<tr>
<td>Run 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2/1 Leveling

<table>
<thead>
<tr>
<th>Forward</th>
<th>Backward</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>0.44861</td>
<td>-0.44664</td>
</tr>
<tr>
<td>Run 2</td>
<td>0.4460</td>
<td>-0.4459</td>
</tr>
</tbody>
</table>

Allowable 1/1 = 3mm(√.450km) = 0.00201 m
Actual = 0.00145 m OK

Note: * = suspect data

<table>
<thead>
<tr>
<th>River Crossing 1 (9-2-2014)</th>
<th>Forward</th>
<th>Backward</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>0.4301</td>
<td>-0.4629</td>
<td>0.4465</td>
</tr>
<tr>
<td>Run 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2/1 Leveling

<table>
<thead>
<tr>
<th>Forward</th>
<th>Backward</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>0.44861</td>
<td>-0.44664</td>
</tr>
<tr>
<td>Run 2</td>
<td>0.4460</td>
<td>-0.4459</td>
</tr>
</tbody>
</table>

Allowable 1/1 = 3mm(√.450km) = 0.00201 m
Actual = 0.00055 m OK
All data were measured on January 22, 2015

<table>
<thead>
<tr>
<th>Method</th>
<th>Forward</th>
<th>Reverse</th>
<th>Difference</th>
<th>Allowable (1/1)</th>
<th>Average</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levelling</td>
<td>0.0773 m</td>
<td>0.0781 m</td>
<td>0.0008 m</td>
<td>+/- 0.00506 m</td>
<td>0.0777 m</td>
<td>8 hours</td>
</tr>
<tr>
<td>Arrows</td>
<td>0.0755 m</td>
<td>0.0805 m</td>
<td>0.0050 m</td>
<td>+/- 0.00506 m</td>
<td>0.0780 m</td>
<td>1 hour</td>
</tr>
<tr>
<td>Prisms</td>
<td>0.0750 m</td>
<td>0.0792 m</td>
<td>0.0042 m</td>
<td>+/- 0.00506 m</td>
<td>0.0771 m</td>
<td>1 hour</td>
</tr>
<tr>
<td>Rounds</td>
<td>0.0787 m</td>
<td>0.0795 m</td>
<td>0.0008 m</td>
<td>+/- 0.00506 m</td>
<td>0.0791 m</td>
<td>15 minutes</td>
</tr>
</tbody>
</table>
Lake Calhoun Water Crossing

Distance = 1497 meters (0.93 miles)

All data were measured on April 29, 2015

<table>
<thead>
<tr>
<th>Method</th>
<th>Forward</th>
<th>Reverse</th>
<th>Difference</th>
<th>Allowable (1/1)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levelling</td>
<td>0.1885 m</td>
<td>0.1918 m</td>
<td>0.0033 m</td>
<td>0.0037 m</td>
<td>0.1902 m</td>
</tr>
<tr>
<td>Arrows</td>
<td>0.1898 m</td>
<td>0.1908 m</td>
<td>0.0010 m</td>
<td>0.0037 m</td>
<td>0.1903 m</td>
</tr>
<tr>
<td>Prisms</td>
<td>0.1894 m</td>
<td>0.1900 m</td>
<td>0.0006 m</td>
<td>0.0037 m</td>
<td>0.1897 m</td>
</tr>
<tr>
<td>Rounds</td>
<td>0.1895 m</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.1895 m</td>
</tr>
</tbody>
</table>
## Dresbach Bridge Crossing

Distance = 480 meters (0.30 miles)

All data were measured on June 28, 2015

<table>
<thead>
<tr>
<th>Method</th>
<th>Forward</th>
<th>Reverse</th>
<th>Difference</th>
<th>Allowable (1/1)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levelling</td>
<td>- - -</td>
<td>- - -</td>
<td>- - -</td>
<td>- - -</td>
<td>- - -</td>
</tr>
<tr>
<td>Arrows</td>
<td>0.9477 m</td>
<td>0.9469 m</td>
<td>0.0008 m</td>
<td>0.0021 m</td>
<td>0.9473 m</td>
</tr>
<tr>
<td>Prisms</td>
<td>0.9466 m</td>
<td>0.9444 m</td>
<td>0.0022 m</td>
<td>0.0021 m</td>
<td>0.9455 m</td>
</tr>
<tr>
<td>Rounds</td>
<td>0.9473 m</td>
<td>0.9463 m</td>
<td>0.0010 m</td>
<td>0.0021 m</td>
<td>0.9468 m</td>
</tr>
</tbody>
</table>
The new total station-based procedure HAS been officially adopted and approved by NGS.

Users MAY submit results of surveys using these procedures to NGS as part of Bluebook surveys.

Celebratory Statement
Intended Use of Results

• I intend to use the results of these tests to design, test, and propose a River Crossing Method using the ROBOTIC function of modern theodolites.
• This will increase efficiency, allow less skilled personnel, and permit winter work on colder days (when you can actually get to the riverside!)
Rods are carefully calibrated to 0.0001 meter. Theodolites make a series of robotic, automated measurements of angles and distances. Can do about 1 set of measurements per minute. Do 12 sets of measurements per setup. Do 2 setups of each theodolite for check. About 30 minutes total for measuring.
The End

• Questions