Median Hydraulic Gradient Calculation to Support Development of Soil Screening Levels and Preliminary Remediation Goals in the 100 Area

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

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Approved for Public Release; Further Dissemination Unlimited
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T. B. Hammond
INTERA

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By Lee Ann Snyder at 12:32 pm, Apr 16, 2014

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**Basis of Qualification:** Education & experience

**Checker:** N Hasan  
**Basis of Qualification:** Education & experience

**Senior Reviewer:** TJ Budge  
**Basis of Qualification:** Education & experience

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<thead>
<tr>
<th>Revision No.</th>
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<th>Date</th>
<th>Affected Pages</th>
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</tr>
</tbody>
</table>

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**Signature**  
**Date:** 4/14/14

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**APPLICABLE IF CALCULATION IS A RISK ASSESSMENT OR USES AN ENVIRONMENTAL MODEL**

**Responsible Manager:** AH Aly / Risk & Modeling Integration Manager (CHPRC)  
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Median Hydraulic Gradient Calculation to Support Development of Soil Screening Levels and Preliminary Remediation Goals in the 100 Area

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**Terms**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWLN</td>
<td>Automated Water Level Network</td>
</tr>
<tr>
<td>CRBG</td>
<td>Columbia River Basalt Group</td>
</tr>
<tr>
<td>ECF</td>
<td>environmental calculation file</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>HEIS</td>
<td>Hanford Environmental Information System (database)</td>
</tr>
<tr>
<td>PRG</td>
<td>preliminary remediation goal</td>
</tr>
<tr>
<td>RUM</td>
<td>Ringold Upper Mud unit</td>
</tr>
<tr>
<td>SSL</td>
<td>soil screening level</td>
</tr>
<tr>
<td>STOMP</td>
<td>Subsurface Transport Over Multiple Phases (software)</td>
</tr>
<tr>
<td>TIN</td>
<td>Triangulated Irregular Network</td>
</tr>
</tbody>
</table>
1 Purpose

Groundwater flow gradient calculation is required for generation of the gradient values to be applied as inputs to numerical vadose zone flow and transport models used to calculate soil-screening level (SSSL) and preliminary remediation goal (PRG) values. Specifically, the models implemented the Subsurface Transport Over Multiple Phases (STOMP) modeling code for SSL and PRG calculation (SGW-50776, Model Package Report: Vadose Zone Model for the River Corridor) require a gradient value for each cell in order to estimate the amount of saturated flow through aquifer cells for the purpose of calculating aquifer dilution. The purpose of this environmental calculation file (ECF) is to explain the steps involved in generation of groundwater flow hydraulic gradient values to be used in STOMP models for the source operable units in the 100-D, 100-H and 100-N areas of the Hanford Site.

2 Background

Groundwater flow gradient is a dimensionless ratio of the change in water level over change in distance \( \frac{\Delta h}{\Delta l} \) and is an important parameter used in the determination of groundwater flow velocity. A simple gradient can be determined between two well locations by \( \frac{\Delta h}{\Delta l} \) but for determination of the gradient of a potentiometric surface, triangulation from at least three water level measuring points is required. Triangulation using the three-point-problem approach determines the slope direction and magnitude (gradient) of a potentiometric surface by taking the water level elevation at three measurement points (wells) and interpolating potentiometric surface elevations along the distances represented by the sides of a triangle made by the points. Computational methods using geographic information systems (GIS) and spreadsheets greatly reduce time and improve efficiency when calculating gradients of potentiometric surfaces with many water level measuring points.

Gradient calculations provided in this ECF were based on water level data available via the Hanford Site’s Automated Water Level Network (AWLN). Because of the large number of monitoring points, and the large amount of data associated with those points, it was necessary to utilize a computational approach for gradient calculations to be used in the numerical flow models for the source operable units in the 100-D, 100-H and 100-N areas. This approach used well data dating back several years from the AWLN. After data acquisition, a triangulated irregular network (TIN) was created using GIS for creation of triangulation areas for gradient calculation (Figure 1). TIN nodes (AWLN wells representing water level measuring points) were then extracted and the necessary connections of those nodes to the triangles created by them for calculating the gradients in Excel® were made. In Excel®, the gradients were calculated for each day, per triangle using the above-mentioned three-point-problem approach. The mean, median, minimum and maximum gradient for each triangle was then calculated. The median gradient is used because it represents the gradient most likely to occur at any given time based on the observed data. Next, an area-weighted and time weighted average gradient value was calculated for use in the 100 Area vadose zone models. Thus, the resulting gradient value is weighted, based both on the area of each triangle and by the number of days in each month in order to minimize the effect of a spatial or temporal bias that may exist in the observed data.

---

1 Excel® is a registered trademark of Microsoft Corporation in the United States and other countries.
3 Methodology

Computational gradient calculations involved three main steps. The first step was to access AWLN and obtain all of the water level data for all wells in the 100-D, 100-H and 100-N areas. Pumping wells, injection wells, and wells open to confined aquifers (CRBG’s and RUM) were identified and omitted from this data set. In order to ensure the greatest accuracy in the median gradient estimation, the entire period of record for each well was used. Next, a TIN was created using GIS from the water level measuring point locations to provide a triangulation platform for the gradient calculations. The final major step was to use the triangular areas with their associated nodes, in Excel® in conjunction with the water level data to calculate median gradients for each triangle and ultimately an area and temporally weighted gradient value for each of the 100-D, 100-H and 100-N areas.

Figure 1. Example of a Triangulated Irregular Network (TIN); nodes (yellow) and corresponding wells (white) are labeled

1. Data acquisition
   a. Access the AWLN on the Hanford Environmental Information System (HEIS) through the virtual library.
   b. Select the desired OU for the data to be downloaded and download the average daily water level values from the most recent going back to 01/01/2004. The output is a comma separated values (.csv) file with columns for well name, date/time, average elevation, minimum elevation, maximum elevation, standard deviation and number of values averaged.
c. Filter the data for wells that are pumping, injection or open to confined aquifers and remove from the dataset.

d. Create an additional column titled “Day” to contain a text formatted version of the water level elevation measurement date by converting the “Date/Time” column using the “=TEXT(C2,"yyyymmdd")” Excel® function (Table 1). This column will be used later by the Visual Basic script in the creation of the individual triangle sheets.

e. Save the final dataset in an Excel® workbook (.xls etc. format).

### Table 1. Example of Data Table Formatted to be Used in Excel® for Gradient Calculations

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Day</th>
<th>Date/Time</th>
<th>Average Elevation (m)</th>
<th>Minimum Elevation (m)</th>
<th>Maximum Elevation (m)</th>
<th>Standard Deviation</th>
<th>Number of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>199-N-14</td>
<td>20040114</td>
<td>1/14/04 0:00</td>
<td>118.147437</td>
<td>118.1307</td>
<td>118.169</td>
<td>0.012561252</td>
<td>24</td>
</tr>
<tr>
<td>199-N-14</td>
<td>20040115</td>
<td>1/15/04 0:00</td>
<td>118.130187</td>
<td>118.0857</td>
<td>118.1531</td>
<td>0.017083435</td>
<td>24</td>
</tr>
<tr>
<td>199-N-14</td>
<td>20040116</td>
<td>1/16/04 0:00</td>
<td>118.094654</td>
<td>118.0787</td>
<td>118.1093</td>
<td>0.008371379</td>
<td>24</td>
</tr>
<tr>
<td>199-N-14</td>
<td>20040117</td>
<td>1/17/04 0:00</td>
<td>118.0562</td>
<td>118.0379</td>
<td>118.0754</td>
<td>0.011065576</td>
<td>24</td>
</tr>
<tr>
<td>199-N-14</td>
<td>20040118</td>
<td>1/18/04 0:00</td>
<td>118.01437</td>
<td>117.9923</td>
<td>118.0365</td>
<td>0.013509078</td>
<td>24</td>
</tr>
</tbody>
</table>

2. **TIN Construction in ArcMap®**

   a. Import a well list derived from the previously mentioned dataset that contains well names, x-coordinates and y-coordinates. Assign a value of “0” for each wells’ z-coordinate. Save as a shape file.

   b. Create a TIN in ArcMap® with the wells shape file using the following sequence: 3D Analysts Tools, Data Management, TIN, Create TIN.

   c. Create the TIN triangles by with the previously generated TIN using the following sequence: 3D Analysts Tools, Conversion, From TIN, TIN Triangle.

   d. Create the TIN nodes by with the previously generated TIN using the following sequence: 3D Analysts Tools, Conversion, From TIN, TIN Nodes.

   e. Add a reference value for associating the Nodes with the triangles by creating an x-coordinate column. Use the “calculate geometry” function to populate the x-coordinate column with the x-coordinate of each node.

   f. Join the attributes of the wells shape file with the nodes shape file. This association will be made using the x-coordinate of both. Be sure to add the “Node_Index” column in the join to the well shape file attributes.

3. **Gradient Calculation in Excel®**

---

2 *ArcMap®* is a registered trademark of Esri in the United States, the European Community, or certain other jurisdictions.
a. In the Excel® workbook created in step 1, create a second sheet for the nodes extracted from the TIN. Include columns for Node Index, x-coordinate, y-coordinate, well name and start and end columns identifying the beginning and end rows in the data sheet for each well/node. This is facilitated by using the "=MATCH" Excel® function (Figure 2).

b. Create a third sheet for the triangles created from the TIN. Include columns for triangle ID, Node 1, Node 2, Node 3, Node Well Name 1, Node Well Name 2, Node Well Name 3 and triangle area (Figure 3). The first four columns would represent the output triangle/node association. Populate the node well name columns by using the "=VLOOKUP" function for the well names associated with each node in the nodes sheet. Populate the triangle area column by copying the areas from the triangles shape file attributes table in GIS and pasting them into Excel®.

c. Create blank summary sheets for median, mean, minimum and maximum gradient with columns for the triangle number; mean, median, minimum or maximum (depending on the specific summary sheet); and columns for each month starting with January; and finally an area column.

d. Write a Visual Basic script using an algebraic solution from three wells in an aquifer with horizontal flow (see Calculation section and Attachment A) to perform the gradient calculations for each triangle for each day of water level data. Include in the script operations to calculate the mean, median, minimum and maximum gradients for each triangle. There should be one spreadsheet for each triangle’s gradient calculations. See the Calculation section for details of the gradient calculation equation used in the Visual Basic script. Also include in the script operations to populate the summary sheets with triangle number and median, mean, minimum or maximum gradient columns. Gradients can also be calculated manually using an algebraic solution from three wells in an aquifer with horizontal flow (see Calculations section and Attachment A).

e. Run the script.

f. On the Summary page, make another column for the areas of each triangle and populate this column by using the "=VLOOKUP" function for the areas in the triangles sheet.

g. Calculate the area weighted mean, median, minimum or maximum gradients for each month by using the "=SUMPRODUCT" function with all of the individual triangle values for that month as the primary array and all of the triangle areas as the secondary array (Figure 4). Divide the sum product by the sum of the triangle areas. Average the previously calculated weighted values.

h. Calculate the temporally weighted value by using the "=SUMPRODUCT" function with all of the monthly area weighted values as the primary array and the number of days in each month as the secondary array. This value for median gradient was used the numerical model gradient input parameter.
Figure 2. Nodes Worksheet

Figure 3. Triangles Worksheet
Conceptual assumptions include:

Two groups of assumptions exist that are involved with the gradient calculations discussed here in. Data assumptions include:

- All water level elevations acquired from AWLN are correct and that the vertical datum used to calculate those elevations are correct in each instance.
- Water level measurement locations (coordinates) are correct.

Conceptual assumptions include:

- The water table for which the gradients were calculated for each operable unit is a spatially and temporally continuous potentiometric surface over the entire data range.
- Horizontal groundwater flow is assumed.
- The three point method for calculating a gradient is sufficiently accurate to approximate the true direction of groundwater flow given any variability that may exist at the site.

4 Assumptions and Input

4.1 Assumptions

Two groups of assumptions exist that are involved with the gradient calculations discussed here in. Data assumptions include:

- All water level elevations acquired from AWLN are correct and that the vertical datum used to calculate those elevations are correct in each instance.
- Water level measurement locations (coordinates) are correct.

Conceptual assumptions include:

- The water table for which the gradients were calculated for each operable unit is a spatially and temporally continuous potentiometric surface over the entire data range.
- Horizontal groundwater flow is assumed.
- The three point method for calculating a gradient is sufficiently accurate to approximate the true direction of groundwater flow given any variability that may exist at the site.
4.2 Inputs

Inputs for the GIS TIN creation included the well locations used to create the TIN and subsequent node and triangle generation. The outputs from this process included the node numbers, triangle numbers and triangle areas. These outputs along with the daily average water level data, well locations and water level measurements from AWLN, were the inputs used in Excel® for the gradient calculations. The number-of-days-in-each-month was used in Excel® to temporally weight the area-weighted gradient values.

5 Software Applications

Software used in these calculations comply with PRC-PRO-IRM-309, Controlled Software Management (CH2M HILL Plateau Remediation Company, 2009), software applications and fit one of two categories, spreadsheets, or utility calculation.

5.1 Approved Software

The following software was used to perform the calculations and was approved and compliant with PRC-PRO-IRM-309. This software is managed under the following documents consistent with the procedure:

5.2 Description

Required software descriptions are provided in the subsections that follow:

5.2.1 Microsoft Excel® 2010 (Spreadsheet Software)

- Software title: Microsoft Excel® 2010
- Software Version: 2010
- Site licensed software managed by the IRM service provider, and hence exempt as a software tool, although the application of this software is reviewed as part of this calculation.
- Workstation type and property number (from which software is run): Dell Laptop (non-HLAN), Dell Service Tag #BX9MMQ1

5.2.2 ArcMap® (Utility Calculation Software)

ArcMap® was used for TIN creation to generate nodes and triangles using the spatial analyst tool and 3D analyst tools.

- Software Title: ArcMap®
- Version: 10.2.1
- Workstation type and property number (from which software is run): Dell Laptop (non-HLAN), Dell Service Tag #BX9MMQ1

5.2.3 Statement of Valid Software Application

- Microsoft Excel® 2010 spreadsheet software identified was used consistent with intended use for CHPRC and is a valid use of this software for the problem addressed in this application.
ArcMap® was used for to support the use of Excel® and this use was consistent with the purposes of this commercial, off-the-shelf software package applied for a utility calculation.

6 Calculation

Gradients were calculated using an algebraic solution from three wells in an aquifer with horizontal flow. When a plane \( h(x, y) \) is fitted through points \( h_A = h(x_A, y_A), h_B = h(x_B, y_B), h_C = h(x_C, y_C) \) the linear approximation for the differential \( \Delta h \) is:

\[
\Delta h = \frac{\partial h}{\partial x} \Delta x + \frac{\partial h}{\partial y} \Delta y
\]

Within any triangle created by three points, we assume the partial derivatives \( \frac{\partial h}{\partial x} \) and \( \frac{\partial h}{\partial y} \) are constant. Given the points A and B the equation above can be written as:

\[
h_B - h_A = \frac{\partial h}{\partial x} (x_B - x_A) + \frac{\partial h}{\partial y} (y_B - y_A)
\]

The same can be done between points C and A:

\[
h_C - h_A = \frac{\partial h}{\partial x} (x_C - x_A) + \frac{\partial h}{\partial y} (y_C - y_A)
\]

This leaves us with a set of two equations and two unknowns, \( \frac{\partial h}{\partial x} \) and \( \frac{\partial h}{\partial y} \). By substitution the set of equations can be solved algebraically and the final magnitude of the hydraulic gradient can be determined based on the equation below:

\[
| \frac{\partial h}{\partial t} | = \sqrt{\left( \frac{\partial h}{\partial x} \right)^2 + \left( \frac{\partial h}{\partial y} \right)^2}
\]

Proof of reproducibility of this calculation serves as its reference. See Attachment A for an example of a manual solution to the above equation and its computational analog calculated using the Visual Basic script in Excel®.

7 Results/Conclusions

Hydraulic gradient values obtained from these calculations were based on data collected over several years of water level monitoring using the AWLN. Seasonally occurring fluctuations of the water table level in the 100 Area has introduced considerable temporal variability into the AWLN dataset. Therefore,
current gradient calculations are based on several years’ worth of data, in order to estimate hydraulic gradients during times of greatest stability. Table 2 lists the calculated hydraulic gradients. The median values listed in Table 2 are the temporally weighted average of all of the weighted monthly averages. These median values represent the hydraulic gradient that is applicable for use in the STOMP one-dimensional fate and transport models used to calculate SSL and PRG values for the corresponding area. Values for minimum, maximum and arithmetic average were also calculated to gauge the scope of the datasets used in gradient calculations (Table 2).

Table 2. Calculated Hydraulic Gradients by Area

<table>
<thead>
<tr>
<th>Source Area</th>
<th>Number of TIN Triangles</th>
<th>Hydraulic Gradient (m/m)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td>Median</td>
</tr>
<tr>
<td>100-D</td>
<td>28</td>
<td>0.00016</td>
<td>0.037</td>
<td>0.0014</td>
</tr>
<tr>
<td>100-H</td>
<td>19</td>
<td>0.0011</td>
<td>0.0086</td>
<td>0.0035</td>
</tr>
<tr>
<td>100-N</td>
<td>17</td>
<td>0.00025</td>
<td>0.0098</td>
<td>0.0020</td>
</tr>
</tbody>
</table>

a. Mean and Median are spatially and temporally weighted values. The median was applied to STOMP models.

The hydraulic gradient values listed in Table 2 differ from previously calculated gradients used in SSL and PRG calculations. The previously calculated hydraulic gradients were based only on data from a single month that was selected to be representative of hydraulic conditions midway between high and low river stage periods. The difference between median hydraulic gradients calculated previously from a single month of hydraulic data, and the median hydraulic gradients calculated here based on data collected over several years of water level monitoring data, is summarized in Table 3.

Table 3. Comparison of Hydraulic Gradients from Prior Calculations (Single Month Basis) and This Calculation (Longer-term Basis)

<table>
<thead>
<tr>
<th>Source Area</th>
<th>Long-term Basis</th>
<th>Single-Month (March) Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median Hydraulic Gradient (m/m)a</td>
<td>Median Hydraulic Gradient (m/m)</td>
</tr>
<tr>
<td>100-D</td>
<td>0.0014</td>
<td>0.0011b</td>
</tr>
<tr>
<td>100-H</td>
<td>0.0035</td>
<td>0.0020b</td>
</tr>
<tr>
<td>100-N</td>
<td>0.0020</td>
<td>0.00101c</td>
</tr>
</tbody>
</table>

a. Mean and Median are spatially and temporally weighted values. The median was applied to STOMP models.
b. Source: ECF-HANFORD-11-0063, Rev. 5.
c. Source: ECF-100NR1-12-0017, Rev. 1.
Uncertainties involved with the hydraulic gradient calculations described herein are primarily based upon the quality of the datasets used. Monthly field verification measurements are taken to identify potential issues with the AWLN such as drifting in automated pressure transducer readings. If issues are found, automated results are adjusted to account for those errors. However, the most recently collected data is subject to change as monthly verification measurements are used to validate weekly processed data.

The methodology used in the current hydraulic gradient calculations is implicit in providing higher quality gradient parameters for use in numerical fate and transport modeling. Larger datasets spanning longer time periods are handled efficiently with the current method, allowing for more accurate and timely gradient calculations.

8 References

ECF-100NR1-12-0017, 2012, STOMP 1-D Modeling for Determination of Soil Screening Levels and Preliminary Remediation Goals for the 100-NR-1 Source Operable Unit, Rev. 2, CH2M HILL Plateau Remediation Company, Richland, Washington.


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Attachment A

Example of Comparison of Manual and Computational Gradient Calculations
It was necessary to compare the computational gradient calculation in Excel® with the manual calculation of the same gradient in order to demonstrate the consistency and reproducibility of the chosen gradient equation. The 100 D gradient calculation for TIN triangle 35, measurement date 01/01/2009, was chosen at random for this demonstration. Figure A-1 shows the result as calculated in Excel® using the equations derived in the Calculations section of this document. The manual calculation of the same gradient is presented after Figure A-1. Comparison of these two calculations shows identical gradients of 0.001674.

Figure A-1. Gradient Calculation for 100 D TIN Triangle 35, Measurement Date 01/01/2009.

Note: The gradient value of 0.001674 is highlighted in yellow.
Continued at 35 of 100 D T1 V data from 01/01/2003

\[
\begin{array}{cccccc}
\text{Node} & \Delta X & \Delta Y & \Delta T & \Delta X & \Delta Y \\
199 & 05-18.2 & 57330.3 & 151347.2 & 51 & 1.1 \\
197 & 05-3.2 & 55330.4 & 151354.1 & -59.8 & 0.8 \\
197 & 04-3.1 & 57330.3 & 151257.3 & 130 & -59.8 \\
15 & 0.1 & 0.2 & & & \\
\end{array}
\]

\[
h_B-h_A = \frac{\mathcal{H}_0}{\mathcal{V}} (X_B^2 - Y_B^2) + \frac{\mathcal{H} \Delta t}{\mathcal{V}} (X_B - Y_B)
\]

\[
h_A-h_A = \frac{\mathcal{H}_0}{\mathcal{V}} (X_A^2 - Y_A^2) + \frac{\mathcal{H} \Delta t}{\mathcal{V}} (X_A - Y_A)
\]

\[
h_B-h_A = \frac{0.155 \times 10^{-3}}{100} = -59.78 \frac{\Delta t}{\mathcal{V}} + 24.2 \frac{\Delta t}{\mathcal{V}}
\]

\[
h_C-h_A = \frac{0.2175 \times 10^{-3}}{100} = 130 \frac{\Delta t}{\mathcal{V}} + 49.7 \frac{\Delta t}{\mathcal{V}}
\]

* End of table for \( \Delta h_A, \Delta h_B = (\Delta h_A - \Delta h_B) \frac{\Delta t}{\mathcal{V}} + \)

\[
\Delta h_A, \Delta h_B = (\Delta h_A - \Delta h_B) \frac{\Delta t}{\mathcal{V}}
\]

\[
\Rightarrow 6.3737 - 0.1875 \frac{\Delta t}{\mathcal{V}} + 8.54.77.87 \frac{\Delta t}{\mathcal{V}}
\]

\[
\Rightarrow \frac{\Delta h_A}{\mathcal{V}} = \left( \frac{6.3737 - 25.1.77.87 \frac{\Delta t}{\mathcal{V}}}{79.1875} \right)
\]

\[
\frac{\Delta t}{\mathcal{V}} = 0.00537 - 3.63.83.1451 \frac{\Delta t}{\mathcal{V}}
\]

* Display of \( h_B-h_A \) for \( \frac{\Delta t}{\mathcal{V}} 
\]

\[
\Rightarrow 0.153 \times 10^{-3} = -59.78 \frac{\Delta t}{\mathcal{V}} + 24.2 \frac{\Delta t}{\mathcal{V}}
\]

\[
= -421.9 \frac{\Delta t}{\mathcal{V}}
\]

\[
\frac{\Delta h_A}{\mathcal{V}} = 0.00537 + 0.3185 \frac{\Delta t}{\mathcal{V}}
\]

\[
\frac{\Delta t}{\mathcal{V}} = 0.0271.28502
\]
\[
\Delta \theta: \quad \frac{\Delta \theta}{\Delta x} = \frac{0.0257 - 3.3023}{51} \times 0.00124552 \\
= 0.0018428
\]

* Gradient: \[
\left| \frac{\partial y}{\partial x} \right| = \sqrt{\left( \frac{\partial y}{\partial x} \right)^2 + \left( \frac{\partial y}{\partial y} \right)^2}
\]

\[
\left| \frac{\partial y}{\partial x} \right| = \sqrt{\left(0.0018428\right)^2 + \left(0.00124552\right)^2}
\]

\[
\frac{\partial y}{\partial x} = 0.00184232
\]