**Date**: 2024-07-29

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**Subject**: Estimating Aquifer Diffusivity using Tidally Influenced Wells

## 1.0 Introduction

Aquifer diffusivity (T/S) values were estimated using the following two equations, the simplified amplitude analysis and the simplified time lag analysis given by (Ferris et al., 1962; Todd, 1980). A total of five tidally influenced groundwater monitoring wells, were selected along with the corresponding nearest tide or hydrometric station.

Simplified Amplitude Equation Time Lag Equation

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Figure 1. Where shore water level is in blue and well water level is in green

## 2.0 Methodology

The following methodology was applied to each of the five observation wells:

1. Obtain groundwater and tide/hydrometric water level data
2. Choose optimal time frame of with a length of100 hours, based on most minimal groundwater level fluctuations
3. Fit groundwater level data with a composite sine curve
4. Simplified Amplitude Analysis:
   1. Calculate well/shore amplitudes
   2. Pair each corresponding well/shore amplitudes together
   3. Compute Hx/h0 for each corresponding well/shore amplitude pair
   4. Compute T/S for each Hx/h0 value
   5. Remove outliers
   6. Compute mean T/S
5. Time Lag Analysis:
   1. Identify time at peaks/troughs for both well/shore
   2. Compute time lags for peaks/troughs
   3. Compute T/S for each time lag
   4. Remove outliers
   5. Compute mean T/S

## 3.0 Results:

In Table 1 the results of the analysis are summarized with the mean aquifer diffusivity values for the aquifers that are correlated to the five groundwater wells were used in the analysis. Estimates for the storativity and transmissivity based on the mean diffusivity value are also listed for reference. Most transmissivity values are well reasonable however, for observation well 473, the transmissivity estimate was only reasonable based off of only the simplified amplitude diffusivity value.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| OW# | Aquifer | Aquifer Type | Mean SA T/S | Mean TL T/S | Mean T/S | Storativity Estimate1 | Transmissivity | |
| [OW511](https://apps.nrs.gov.bc.ca/gwells/well/128292) | [834](https://apps.nrs.gov.bc.ca/gwells/aquifers/834) | 4b2  Quadra Sand | 0.2453 | 0.2453 | 0.2453 | 0.02 | 0.0049 | 423.9 |
| [OW408](https://apps.nrs.gov.bc.ca/gwells/well/44210) | [834](https://apps.nrs.gov.bc.ca/gwells/aquifers/834) | 4b2  Quadra Sand | 0.943 | 0.611 | 0.7770 | 0.02 | 0.0155 | 1342.7 |
| [OW452](https://apps.nrs.gov.bc.ca/gwells/well/109140) | [37](https://apps.nrs.gov.bc.ca/gwells/aquifers/37) | 4a  Sumas Outwash | 4.4521 | 5.358 | 4.9050 | 0.02 | 0.0981 | 8475.9 |
| [OW499](https://apps.nrs.gov.bc.ca/gwells/well/123004) | [566](https://apps.nrs.gov.bc.ca/gwells/aquifers/566) | 4a  Salish Outwash | 7.0553 | 6.7668 | 6.9110 | 0.02 | 0.1382 | 11942.3 |
| [OW473](https://apps.nrs.gov.bc.ca/gwells/well/115134) | [747](https://apps.nrs.gov.bc.ca/gwells/aquifers/747) | 6b  Diorite | 0.6508 | 40.9141 | 0.6361 | 0.00064 | 0.0004 | 35.2 |

Table 1. Shows the results for mean T/S calculated using simplified amplitude and time lag methods with storativity and transmissivity estimates of each aquifer. Mean T/S and transmissivity estimates for OW473 only included the mean SA T/S.

1. Carmichael, V., 2014. Compendium of re-evaluated pumping tests in the Cowichan Regional District, Vancouver Island, British Columbia., Victoria: B. C. Ministry of Environment.
2. Partially confined, used 4a storativity.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| OW# | Tide/hydrometric station | Start Date | End Date | Tidal Period (h) | Distance from shore (m) |
| [OW511](https://aqrt.nrs.gov.bc.ca/Data/DataSet/Summary/Location/OW511/DataSet/GW%20Elevation/MASL/Interval/Latest) | [Mitlenatch](https://www.tides.gc.ca/en/stations/07895) | 2023-01-02 | 2023-01-07 | 12.67 | 155 |
| [OW408](https://aqrt.nrs.gov.bc.ca/Data/DataSet/Summary/Location/OW408/DataSet/GW%20Elevation/MASL/Interval/Latest) | [Mitlenatch](https://www.tides.gc.ca/en/stations/07895) | 2024-03-03 | 2024-03-08 | 12.67 | 306 |
| [OW452](https://aqrt.nrs.gov.bc.ca/Data/DataSet/Summary/Location/OW452/DataSet/GW%20Elevation/MASL/Interval/Latest) | [08MH0047](https://aqrt.nrs.gov.bc.ca/Data/DataSet/Summary/Location/08MH0047/DataSet/Stage/Telemetry/Interval/Latest) | 2024-06-22 | 2024-06-27 | 12.67 | 681 |
| [OW499](https://aqrt.nrs.gov.bc.ca/Data/DataSet/Summary/Location/OW499/DataSet/GW%20Elevation/MASL/Interval/Latest) | [Roberts Creek](https://www.tides.gc.ca/en/stations/07824) | 2024-03-03 | 2024-03-08 | 12.67 | 782 |
| [OW473](https://aqrt.nrs.gov.bc.ca/Data/DataSet/Summary/Location/OW473/DataSet/GW%20Elevation/MASL/Interval/Latest) | [Point Atkinson](https://www.tides.gc.ca/en/stations/06476) | 2023-07-29 | 2023-08-03 | 12.67 | 280 |

Table 2. Lists the constants used for the amplitude and time lag calculations including start/end dates, tidal period, and distance from shore

#### *3.1 OW511*

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Figure 2a. Plot of the water level for OW511 in green and the fitted sine curve plotted in red

In observation well 511, no values were excluded in the final mean diffusivity calculations. The diffusivity values from the simplified amplitude analysis produced similar values with a standard deviation of 0.093. The diffusivity values calculated using the time lag analysis produced values that were more variable with a standard deviation of 0.27.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Well Hours (h) | 25.735 | 49.536 | 73.315 | 97.094 |
| Well Amplitude (m) | 0.035 | 0.034 | 0.033 | 0.032 |
| Shore Hours | 21.384 | 45.937 | 70.490 | 86.598 |
| Shore Amplitude (m) | 0.500 | 0.350 | 0.230 | 1.950 |
|  | 0.070 | 0.098 | 0.111 | 0.017 |
|  | 0.235 | 0.306 | 0.342 | 0.098 |

Table 3a. Displays the calculated diffusivity values along with the values, well and shore amplitudes and at which hours the amplitudes were from

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Well Peak Hours (h) | 25.735 | 49.536 | 73.315 | 97.094 |
| Shore Peak Hours (h) | 21.384 | 45.937 | 70.490 | 86.298 |
| Time Lag Peaks (h) | 4.351 | 3.599 | 2.826 | 10.496 |
| Peaks | 0.355 | 0.519 | 0.843 | 0.0611 |
| Well Trough Hours (h) | 37.636 | 61.415 | 85.194 | 108.973 |
| Shore Trough Hours (h) | 29.121 | 53.819 | 78.480 | 91.211 |
| Time Lag Troughs (h) | 8.515 | 7.596 | 6.713 | 17.762 |
| Troughs | 0.0928 | 0.117 | 0.150 | 0.0213 |

Table 3b. Shows the calculated diffusivity values, time lag values for peaks and troughs, and well/shore hours at peaks/troughs included in calculations

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Figure 2b. Plotted water level for OW511 in green and the tide level at Mitlenatch station

#### 3.2 OW408

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Figure 3a. Plotted water level for OW408 in green and the fitted sine curve plotted in red

In observation well 408, diffusivity values calculated using trough lag times were excluded from the final mean diffusivity calculation. The diffusivity values from the simplified amplitude analysis produced similar values with a standard deviation of 0.05. The diffusivity values calculated using the time lag analysis produced values that were slightly more variable with a standard deviation of 0.1.

|  |  |  |  |
| --- | --- | --- | --- |
| Well Hours (h) | 46.727 | 71.051 | 95.374 |
| Well Amplitude (m) | 0.123 | 0.127 | 0.131 |
| Shore Hours | 40.106 | 64.776 | 89.339 |
| Shore Amplitude (m) | 1.550 | 1.800 | 1.900 |
|  | 0.0796 | 0.0707 | 0.069 |
|  | 1.007 | 0.919 | 0.902 |

Table 4a. Displays the calculated diffusivity values along with the values, well and shore amplitudes and at which hours the amplitudes were from.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Well Peak Hours (h) | 22.404 | 46.727 | 71.051 | 95.374 |
| Shore Peak Hours (h) | 14.853 | 40.106 | 64.776 | 89.339 |
| Time Lag Peaks (h) | 7.551 | 6.621 | 6.275 | 6.035 |
| Peaks | 0.460 | 0.598 | 0.666 | 0.720 |
| Well Trough Hours (h) | 34.577 | 58.900 | 83.223 | \_ |
| Shore Trough Hours (h) | 31.559 | 56.600 | 81.588 | \_ |
| Time Lag Troughs (h) | 3.018 | 2.300 | 1.635 | \_ |
| Troughs | 2.879 | 4.957 | 9.808 | \_ |

Table 4b. Shows the calculated diffusivity values, time lag values for peaks and troughs, and well/shore hours at peaks/troughs included in calculations. T/S values in red were excluded when calculating mean T/S

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Description automatically generated with medium confidence

Figure 3b. Plotted water level for OW408 in green and the tide level at Mitlenatch station

#### 3.3 OW452

A graph of a function

Description automatically generated

Figure 4a. Plotted water level for OW452 in green and the fitted sine curve plotted in red

In observation well 452, one diffusivity value was excluded from the final mean diffusivity calculation for both the simplified amplitude analysis and the time lag analysis and are displayed in red in Table 5a and 5b below. The diffusivity values from the simplified amplitude analysis produced values that were variable with a standard deviation of 2.3. The diffusivity values calculated using the time lag analysis produced values that were also variable with a standard deviation of 3.3. The variation in values may be attributed to the variability in the amplitudes of the water level curve from the Fraser River hydrometric station.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Well Hours (h) | 34.612 | 59.155 | 83.674 | 108.169 |
| Well Amplitude (m) | 0.0044 | 0.0047 | 0.0048 | 0.0050 |
| Shore Hours (h) | 30.993 | 55.986 | 79.493 | 96.010 |
| Shore Amplitude (m) | 0.055 | 0.040 | 0.010 | 0.610 |
|  | 0.0809 | 0.117 | 0.485 | 0.008 |
|  | 5.0510 | 6.9223 | 61.003 | 1.382 |

Table 5a. Displays the calculated diffusivity values along with the values, well and shore amplitudes and at which hours the amplitudes were from. T/S values in red were excluded when calculating mean T/S

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Well Peak Hours (h) | 10.069 | 34.612 | 59.155 | 83.674 | 108.169 |
| Shore Peak Hours (h) | 6.496 | 30.993 | 55.986 | 79.493 | 96.009 |
| Time Lag Peaks (h) | 3.574 | 3.619 | 3.169 | 4.181 | 12.159 |
| Peaks | 10.170 | 9.917 | 12.933 | 7.431 | 0.879 |
| Well Trough Hours (h) | 22.353 | 46.895 | 71.414 | 95.933 | \_ |
| Shore Trough Hours (h) | 15.487 | 42.004 | 64.996 | 89.494 | \_ |
| Time Lag Troughs (h) | 6.866 | 4.891 | 6.418 | 6.439 | \_ |
| Troughs | 2.755 | 5.429 | 3.1536 | 3.133 | \_ |

Table 5b. Shows the calculated diffusivity values, time lag values for peaks and troughs, and well/shore hours at peaks/troughs included in calculations. T/S values in red were excluded when calculating mean T/S

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Figure 4b. Plotted water level for OW452 in green and the water level at 08MH0047 hydrometric station along the Fraser River

#### 3.4 OW499

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Figure 5a. Plotted water level for OW499 in green and the fitted sine curve plotted in red

In observation well 499, two diffusivity values from the time lag calculations using the trough time lags were excluded from the final mean diffusivity calculations and are displayed in red in Table 6b below. The diffusivity values from the simplified amplitude analysis produced values that were similar with a standard deviation of 0.6 The diffusivity values calculated using the time lag analysis produced values that were more variable with a standard deviation of 5.8.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Well Hours (h) | 22.608 | 46.579 | 70.551 | 94.522 |
| Well Amplitude (m) | 0.1305 | 0.130 | 0.130 | 0.129 |
| Shore Hours (h) | 17.219 | 42.2650 | 66.847 | 91.313 |
| Shore Amplitude (m) | 1.300 | 1.450 | 1.600 | 1.700 |
|  | 0.100 | 0.0897 | 0.081 | 0.076 |
|  | 7.972 | 7.243 | 6.667 | 6.338 |

Table 6a. Displays the calculated diffusivity values along with the values, well and shore amplitudes and at which hours the amplitudes were from. T/S values in red were excluded when calculating mean T/S

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Well Peak Hours (h) | 22.608 | 46.579 | 70.551 | 94.522 | \_ |
| Shore Peak Hours (h) | 17.219 | 42.265 | 66.847 | 91.313 | \_ |
| Time Lag Peaks (h) | 5.389 | 4.314 | 3.704 | 3.210 | \_ |
| Peaks | 5.898 | 9.202 | 12.484 | 16.624 | \_ |
| Well Trough Hours (h) | 10.634 | 34.605 | 58.577 | 82.548 | 106.520 |
| Shore Trough Hours (h) | 8.380 | 33.542 | 46.907 | 72.127 | 83.576 |
| Time Lag Troughs (h) | 2.253 | 1.063 | 11.670 | 10.421 | 22.943 |
| Troughs | 33.735 | 151.652 | 1.258 | 1.577 | 0.325 |

Table 6b. Shows the calculated diffusivity values, time lag values for peaks and troughs, and well/shore hours at peaks/troughs included in calculations. T/S values in red were excluded when calculating mean T/S

A graph of a function

Description automatically generated with medium confidence

Figure 5b. Plotted water level for OW499 in green and the tide level at Roberts Creek station

#### 3.5 OW473

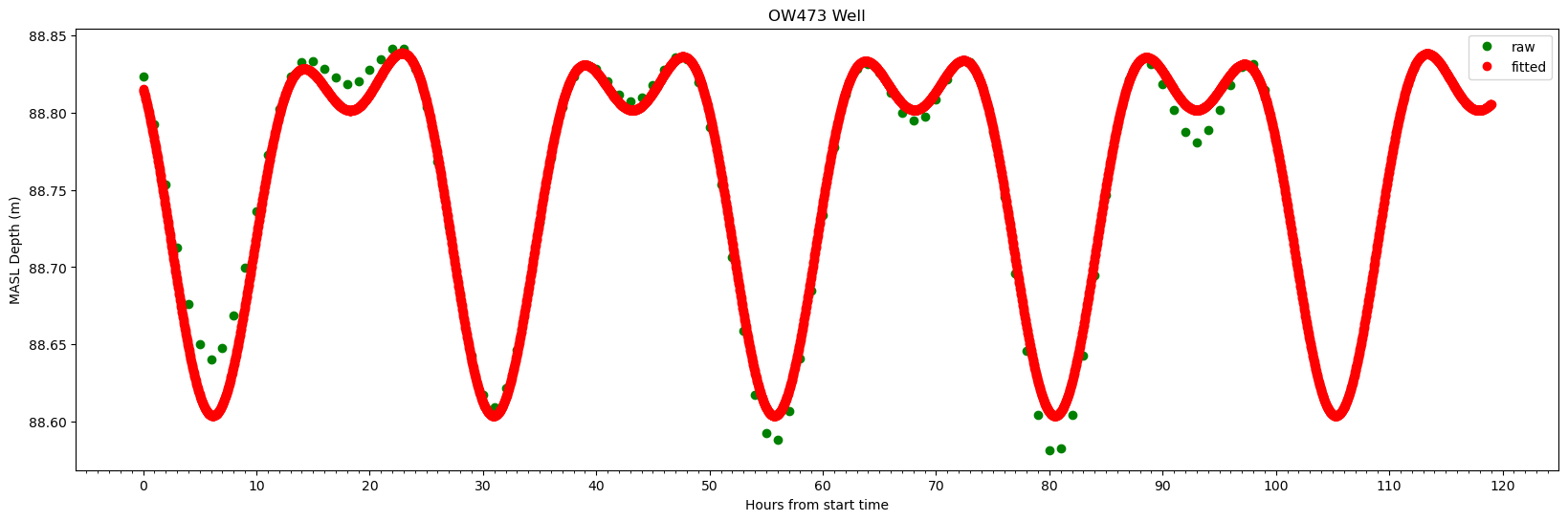


Figure 6a. Plotted water level for OW473 in green and the fitted sine curve plotted in red

In observation well 473, diffusivity values from the time lag calculations using the trough and peak time lags were excluded from the final mean diffusivity calculations and are displayed in red in Table 7b below. The diffusivity values from the simplified amplitude analysis produced values that were similar with a standard deviation of 0.7 The diffusivity values calculated using the time lag analysis produced values that were highly variable with a standard deviation of 21. The final mean diffusivity value produced was particularly high and differed significantly from the diffusivity value produced using the simplified amplitude calculation. The high diffusivity values can be attributed to very short lag times between well peaks and troughs to shore peaks and troughs, with values less than an hour.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Well Hours (h) | 22.866 | 39.000 | 47.638 | 63.772 | 72.432 | 88.567 |
| Well Amplitude (m) | 0.019 | 0.114 | 0.017 | 0.115 | 0.016 | 0.116 |
| Shore Hours (h) | 22.101 | 38.310 | 47.149 | 62.990 | 72.234 | 87.597 |
| Shore Amplitude (m) | 0.250 | 2.000 | 0.250 | 2.150 | 0.350 | 2.200 |
|  | 0.074 | 0.057 | 0.069 | 0.053 | 0.046 | 0.053 |
|  | 0.799 | 0.656 | 0.756 | 0.629 | 0.568 | 0.624 |

Table 7a. Displays the calculated diffusivity values along with the values, well and shore amplitudes and at which hours the amplitudes were from. T/S values in red were excluded when calculating mean T/S

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Well Peak Hours (h) | 14.205 | 22.866 | 39.000 | 47.638 | 63.772 | 72.432 | 88.567 |
| Shore Peak Hours (h) | 13.574 | 22.101 | 38.310 | 47.149 | 62.990 | 72.234 | 87.597 |
| Time Lag Peaks (h) | 0.631 | 0.764 | 0.690 | 0.489 | 0.782 | 0.199 | 0.970 |
| Peaks | 55.132 | 37.582 | 46.087 | 91.924 | 35.892 | 555.955 | 23.339 |
| Well Trough Hours (h) | 18.278 | 30.944 | 43.185 | 55.716 | 68.091 | 80.489 | 92.998 |
| Shore Trough Hours (h) | 17.911 | 30.297 | 42.922 | 55.143 | 67.787 | 79.970 | 92.613 |
| Time Lag Troughs (h) | 0.367 | 0.647 | 0.262 | 0.573 | 0.305 | 0.518 | 0.384 |
| Troughs | 163.135 | 52.517 | 319.225 | 66.846 | 236.542 | 81.824 | 149.035 |

Table 7b. Shows the calculated diffusivity values, time lag values for peaks and troughs, and well/shore hours at peaks/troughs included in calculations. T/S values in red were excluded when calculating mean T/S

A graph of a graph

Description automatically generated with medium confidence

Figure 6b. Plotted water level for OW473 in green and the tide level at Point Atkinson station

## References

Ferris, J.G., D.B. Knowles, R.H. Brown and R.W. Stallman, 1962. Theory of aquifer tests, *U.S. Geol. Surv*. 1536, 174

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