3 Method of Data Collection

3.1 General Site Information

The contamination site is located in the town of Oneida, Tennessee and owned by the Norfolk Southern Railway Company. Figure 3.1 is a site map showing locations of piezometers and monitoring wells used in this study as well as relative locations of the trees, interception trench, railroad tracks, and Pine Creek. Figure 3.1 also delineates the area used for the water budget in Chapter 4. The site is bordered to the east and north by Pine Creek. An active rail-yard borders the site to the west and south. The area of interest for remediation is approximately 1.7 acres. Hybrid poplar trees (1036) were planted over a span of two years beginning in the spring of 1997, and 927 hybrid poplar trees remain. The trees cover 0.7 acres. Shale bedrock lies 9 to 12 feet below the ground surface throughout the site (Loftis, 1999).

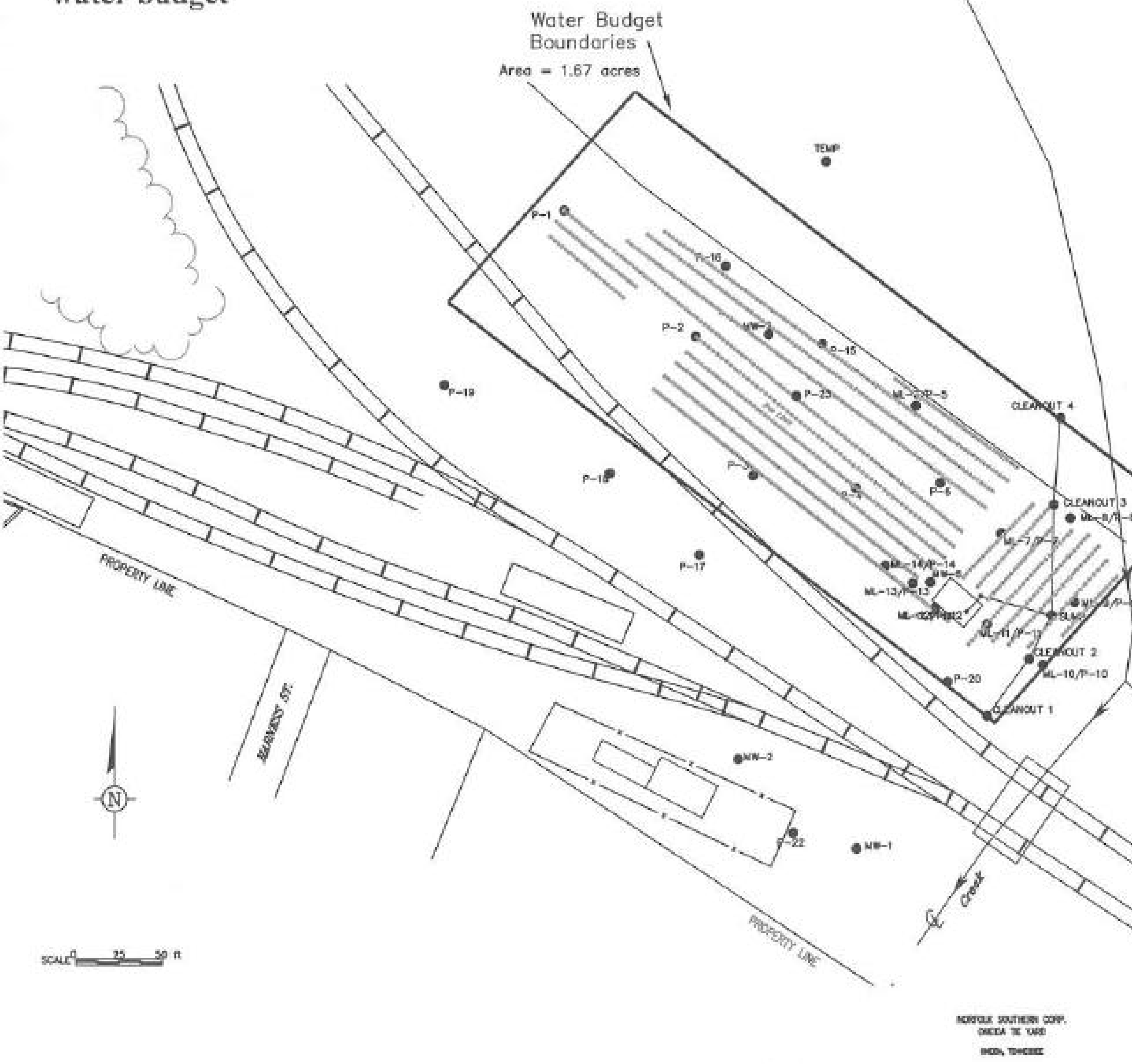
There are seven monitoring wells, twenty-two multi-level samplers, and twenty-seven piezometers located at the site. Four multi-level samplers (ML22 – ML25) were installed during the March 2000, site visit, and two piezometers (P22 and P23) were installed during the August 1999 site visit. The TEMP piezometer shown in Figure 3.1 was also installed in August 1999 to obtain a water level reading and then immediately removed. All new wells were surveyed for location and elevation. Based on data collected in August 1999, two piezometers were found to have incorrect Top of Casing (TOC) elevations. The TOC elevation for P1 was corrected to 1436.79 ft from 1435.90 ft and P2’s TOC elevations was corrected to 1436.96 ft from 1435.02 ft.

3.2 Materials and Methods

Data used in this study is derived from several sources of information and site instrumentation:

- Weather Station located at the site
- ARCADIS Geraghty & Miller
  - rainfall data
  - interception trench
  - bedrock data
- National Weather Service website in Morristown, Tennessee
- Knoxville, TN and Somerset, KY airport weather information
- Water Level Measurements
  - continuous monitoring using pressure transducers
  - discrete water level measurements

Figure 3.1: Oneida, Tennessee Tie Yard Site showing locations of piezometers and monitoring wells used in data collection, interception trench, tree rows as well as the delineated boundary used to determine the water budget



Source: *www.maps.yahoo.com*

The data obtained from the above sources is used throughout this report. Rainfall data and interception trench data is used in the water budget. Barometric pressure data is used to correct the Solinst Leveloggers. The bedrock data is used in the groundwater flow model. The data obtained from the pressure tranducers is used to calculate tree water use as well as water level conditions at the site. The discrete water level measurements are used to calculate flow directions and hydraulic gradients.

3.2.1 The Weather Station

The GroWeather weather station, manufactured by Davis Scientific, is located on the eastern most part of the site near the creek between ML8 and ML9. The weather station was originally powered directly from an electrical source installed at the site. Unfortunately, data was not collected initially due to an inadequate electrical supply. A solar panel was installed in August 1999 to serve as the main power source because the electrical source was unreliable. The weather station records rainfall data, barometric pressure, temperature, and humidity. Plotted rainfall data from the weather station for the period of August 1999 through March 2000 is shown in Figure 3.2. Rainfall and barometric pressure from the weather station can be found in Appendix A.

3.2.2 Other Weather Data Sources

Although the weather station was not operational from June through mid-August 1999, barometric pressure data was still required to correct P4 and P6 water level data. The need for barometric pressure correction is described is section 3.2.3. Therefore, the data was obtained from the websites for the Knoxville, Tennessee airport (http://weather.noaa.gov/weather/current/KTYS.html), and the Somerset, Kentucky airport (http://weather.noaa.gov/weather/current/KSME.html). Knoxville is located approximately 50 miles to the southeast of Oneida and Somerset is located 40 miles to the north. Barometric pressure is posted at 2-hour intervals at these websites and the two readings are averaged to obtain the approximate barometric pressure at Oneida.

The National Weather Service website for Morristown, Tennessee (http://www.srh.noaa.gov/mrx/) was used for general weather data monitoring. Morristown is located approximately 60 miles east-southeast of Oneida. Climate data such as average rainfall

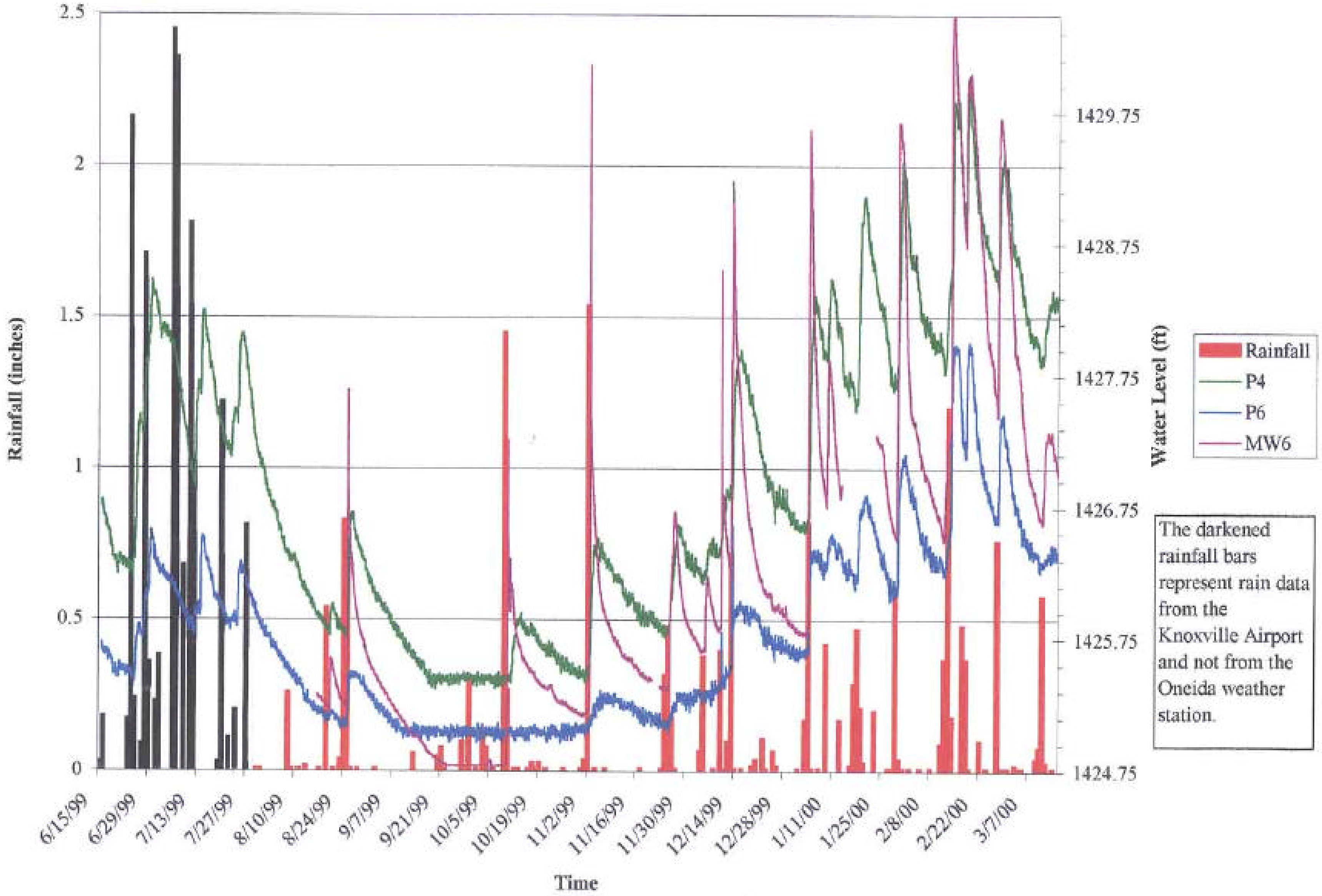


Figure 3.2: Plot of Rainfall Data and Pressure Transducer Data for P4, P6, and MW6 from June 15, 1999, to March 15, 2000, at Oneida, Tennessee

and average temperature also aided in data collection and analysis. Average temperature data was used in the Thornthwaite Method and average rainfall was used for comparing actual rainfall data. Rainfall data at the website was also used to help plan the best time to make site visits for water level measurement and sampling.

3.2.3 Continuous Water Level Monitoring

Three pressure transducers are used for measuring water levels over time. The pressure transducers located in P4 and P6 are Solinst Leveloggers (Model 3001). The Solinst transducers were installed in June 1999. The Solinst transducers have enough data storage for approximately six months of data collection based on a sampling rate of 15 minutes. The devices are located approximately 6 to 12 inches above the bottom of the wells. The Solinst Leveloggers measure total pressure which is to say they measure the water column in the piezometer above the probe plus the air column in the atmosphere. To get accurate water levels these devices must be corrected for air pressure changes. Barometric pressure data is recorded by the weather station. The initial water level must be known to have a reference water level and any subsequent rise or fall of the water table is added or subtracted from this initial level. The water level is taken using the water level indicator described in section 3.2.4. The same procedure in data analysis is applied to barometric pressure changes for the Solinst Leveloggers.

The pressure transducer located in MW6 is an INW (Instrumentation Northwest, Inc.) PS9104 Passive mV Transducer and is connected to a Campbell Scientific Data Logger. The INW transducer was installed in July 1999 although data collection was not achieved until August 1999. The Campbell Scientific Data Logger has enough data storage for approximately eight weeks worth of data based on a sampling rate of 15 minutes. The INW pressure transducer measures the height of the water column above the probe.

The pressure transducer data for the period of June 15, 1999 through March 15, 2000 is shown in Figure 3.2. Water levels in P4 are consistently the highest and water levels in P6 are consistently the lowest. Water levels (P4, P6, and MW6) from approximately mid-September through mid-October fell below the recording devices, resulting in data that appears as a horizontal line. During site visits, the water levels were checked to make sure the devices were recording accurately. The time series data will be used in Chapter 5 for calculating water use by trees and in Chapter 7 for calibrating the groundwater model. More information about the pressure transducers is located in Appendix B.

3.2.4 Discrete Water Level Measurements

During site visits, water level measurements of the piezometers and a few of the monitoring wells were taken. Water level measurements from ARCADIS Geraghty & Miller is also used. The water level indicator is manufactured by the Slope Indicator Company. The measurements are taken by inserting the water level probe into the well which sounds upon reaching the water table. Readings are taken from the marked cord to which the probe is attached relative to the top of the casing. After each measurement, the probe is cleansed with soapy water and rinsed with deionized water to prevent cross contamination of wells. These values are then subtracted from the known casing elevation to obtain a water level. The data allows for direction of groundwater flow and hydraulic gradients to be determined for the aquifer. The data is discussed and analyzed in Chapter 6.

3.2.5 Bouwer and Rice Slug-Test

On June 15, 1999, the Bouwer and Rice Slug-Test was conducted on MW6 to gain an estimate of hydraulic conductivity of the aquifer using the Solinst pressure transducer. The test was developed for unconfined aquifers and can be performed on open boreholes or screened wells (Fetter, 1994, pg. 251). The Bouwer and Rice equation is:

$$K = \frac{r_c^2 \ln(R_e/R)}{2L_e}\frac{1}{t}\ln\left(\frac{H_0}{H_t}\right) \qquad (3.1)$$

where:

K = Hydraulic Conductivity (ft/day)
r_c = radius of the well casing (ft)
R = radius of the gravel envelope (ft)
R_e = effective radial distance over which head is dissipated (ft)
L_e = length of the screen or open section of the well (ft)
H_0 = drawdown at time t = 0, or any initial time (ft)
H_t = drawdown at time t = t (ft)
t = time since $H = H_0$ (day)

L_w is the length of the well to the bottom of the screen that is below the water table and h is the saturated thickness of the aquifer. If L_w = h (as in the case at Oneida) then:

$$ln\frac{R_e}{R} = \left[\frac{1.1}{ln(L_w/R)} + \frac{C}{L_e/R}\right]^{-1} \qquad (3.2)$$

C is a dimensionless number that is determined from Figure 3.3. Values of C are plotted against L_e/r_w.

Parameters for MW6 are shown below:

r_c = 0.083 ft
R = 0.167 ft
L_w = 6.71 ft
L_e = 5 ft
C = 2 (determined from Figure 7.23 on pg. 253, Fetter, 1994)
$ln(R_e/R)$ = 2.75 (determined from Equation 3.2)

Water levels were measured using a Solinst Model 3001 Levelogger. Two tests were completed on MW6. For the first test, t1 = 100 sec (0.00116 days), t2 = 600 sec (0.00694 days), H_0 = 0.865 ft, and H_t = 0.474 ft. For the second test, t1 = 0.00116 days, t2 = 0.00694 days, H_0 = 0.739 ft, and H_t = 0.367 ft. Inserting all parameters into Equation 3.1 yields K_1 = 0.20 ft/day and K_2 = 0.23 ft/day. See Appendix E for more information on the Bouwer and Rice Slug-Test.

3.2.6 Interception Trench

Data of trench discharge was obtained from ARCADIS Geraghty & Miller (personal communication). Data is obtained from a flow meter attached to the 6000 gallon above ground storage tank. The trench operates intermittently by a float-activated electrical pump. Interception trench data can be found in Appendix F.

3.3 Discussion of White's Equation

As discussed before, fluctuations in a water table result from evapotranspiration, changes in barometric pressure, temperature changes, recharge, and inflow/outflow of the aquifer can all create fluctuations in a water table. It is desirable to distinguish which parameter is responsible for a given fluctuation. Evapotranspiration fluctuations are generally diurnal in nature and show a water table rise during the nighttime hours and a decline during the daylight hours. Figure 3.3 shows this trend at the Oneida site for 24-hours of data obtained from MW6 on September 5,

1999. No rainfall occurred on this date. The total amplitude of the fluctuation is approximately 0.05 feet. Barometric pressure changes also result in a diurnal fluctuation of the water table. It results in a decline of the water table during nighttime hours and a rise during the daytime. Figure 3.4 is data taken from the Oneida site for a 24-hour period on October 15, 1999. No rainfall occurred on this date. Mid-October is a time of year when the trees are practically dormant. The blip in the data shown in Figure 3.4 that occurs between 10:00 a.m. and 6:00 p.m. is due to a fall and subsequent rise in the barometric pressure. Temperature changes can only directly affect the water table if it is a few centimeters below the surface (not the case at Oneida). Seasonal changes in the temperature can result in long term rising and lowering of the water table. This would not affect use of the White Equation, but it is doubtful that seasonal variations in temperature are extreme enough in Tennessee to result in a significant effect anyway. The original experiments on temperature effects on the groundwater table were done in Minnesota where winters are extremely harsh (Meyer 1960). Recharge events prohibit the use of the White Equation and inflow/outflow of the aquifer is accounted for in the equation itself.

Revisiting White's Equation:

$$q = y(24r \pm s) \tag{3.3}$$

where:

q = depth of groundwater withdrawn (ft/day)
y = specific yield of the soil
r = hourly rate of change of the water table from midnight to 4 a.m. (ft/hour)
s = net fall or rise of the water table during the 24-hour period (ft/day)
= (positive when a net fall and negative when a net rise)

The final case where White's Equation is used at Oneida is when r is negative and $|24r|>|s|$. At first glance, this does not make any sense. If the trees are not using water then $|24r|=|s|$. Taken literally, $|24r|>|s|$ means that the trees are injecting water into the aquifer. To understand this case one must understand the assumptions made in using this equation. It is assumed the slope from midnight to 4 a.m. represents the *constant* recharge rate for the entire 24 hours. The slope represents not only the recharge of surrounding water that replaces what is used by the trees during the day, but also the natural decline of the water table in the absence of precipitation. Both of these rates are nonlinear. The constant recharge assumption results in two potential errors.

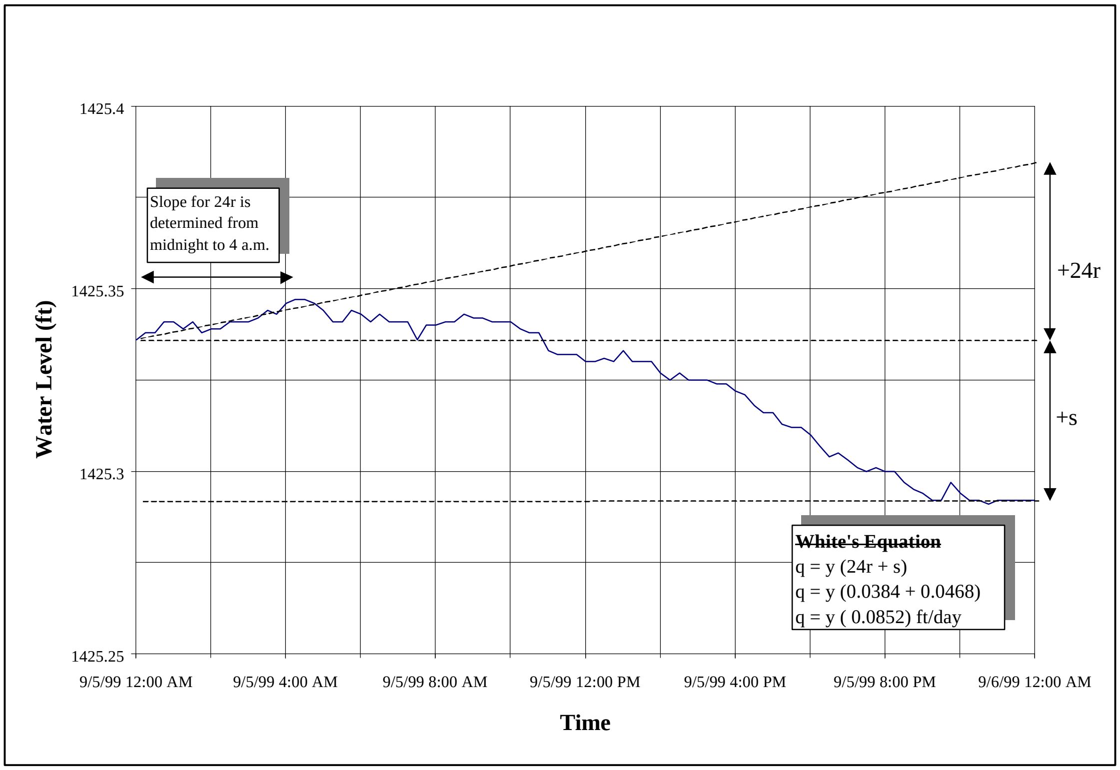


Figure 3.3 – Example of White's Equation on September 5, 1999, at the Oneida site showing the typical application of White's Equation as seen in the literature (positive r and positive s)

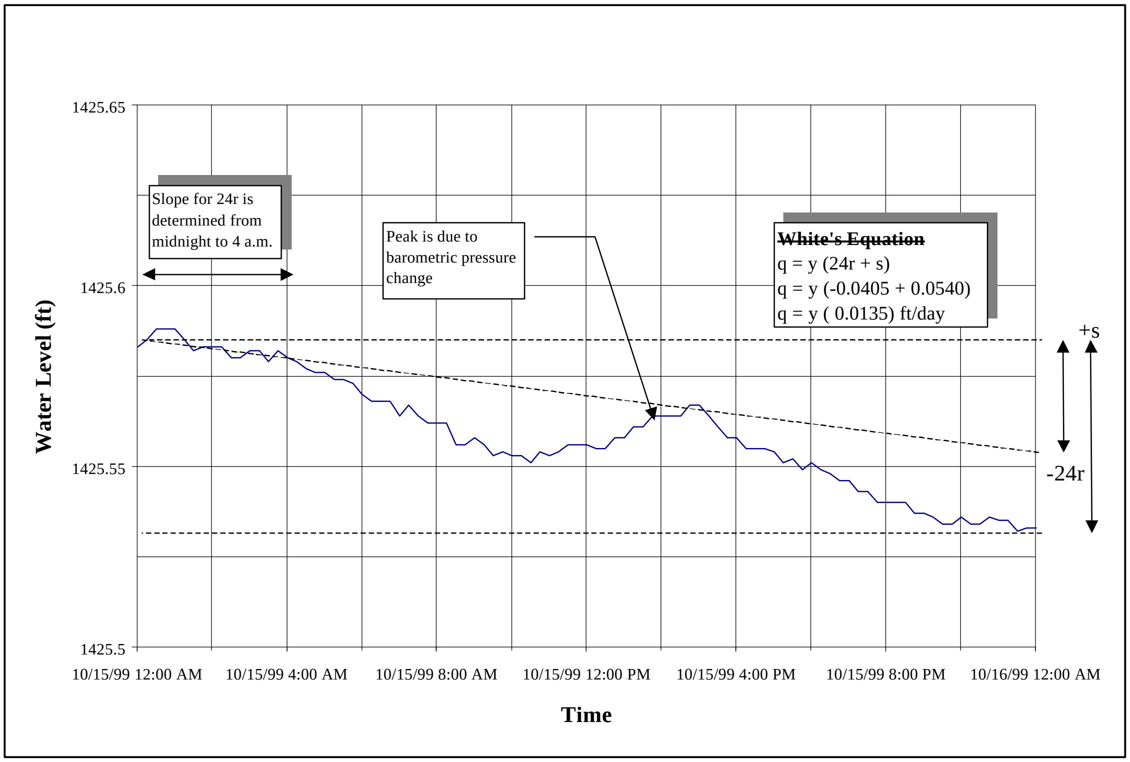


Figure 3.4 – Example of White's Equation on October 15, 1999, at the Oneida site showing the application of White's Equation when r is negative and s is positive and |24r|<|s|

Troxell (1936) explains that during the night, surrounding water begins to fill the "hole" created by tree consumption of water during the day. As this happens, the head difference between the water level in the middle of the stand of trees and the water level outside the trees lessens, resulting in a decreased recharge rate over time. This error would change the constant r curve as shown in Figure 3.5.

The second error is explained by understanding the groundwater recession curve. The groundwater recession curve is nonlinear. The water table declines from a relatively high water level to a relatively low level at a decreased rate. This should cause the r curve to bend slightly upward as the rate of water leaving the aquifer declines increasing the percentage of recharge from surrounding water as shown in Figure 3.6.

It appears that the two errors cancel each other out and the constant recharge assumption remains a good one. Unfortunately, there is not a way to determine the magnitude of the error Troxell mentions given available data. Water level versus time data does not exist outside the stand of trees and transpiration rates can vary due to daylight, humidity, temperature, etc. Figure 3.6 shows data taken at the Oneida site on November 6, 1999. The difference between 24r and s is approximately 0.02 feet which can be significant since tree fluctuations observed result in an amplitude of 0.05 feet. This fact results in the anomaly of $|24r|>|s$. When the sum of (24r + s) is consistently negative, the trees are either dormant or active to such small degree that they are unable to overcome the magnitude of the error.

After the sum of (24r + s) is known, the quantity is multiplied by the specific yield (y) to determine the rate of consumption by the trees. Instead of using the true specific yield, Meyboom (1967) recommends using the *readily available* specific yield. Meyboom determined that this value is 50% of the true specific yield determined for the aquifer.

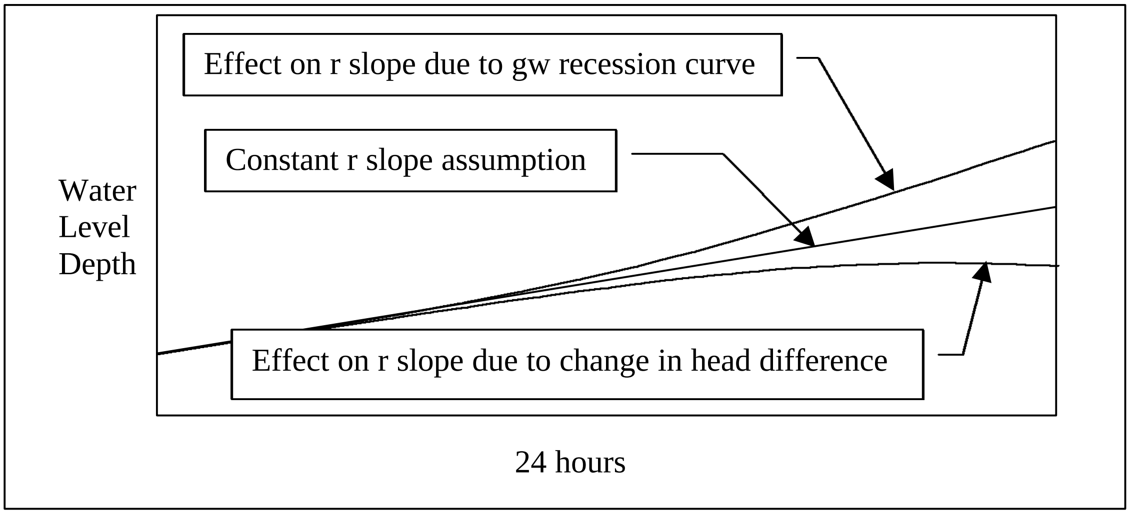


Figure 3.5 –Plot showing effects of constant recharge assumption made in using White's Equation: 1) constant rate does not reflect nonlinear gw recession curve 2) recharge rate from the surrounding aquifer decreases over time as the head difference is reduced

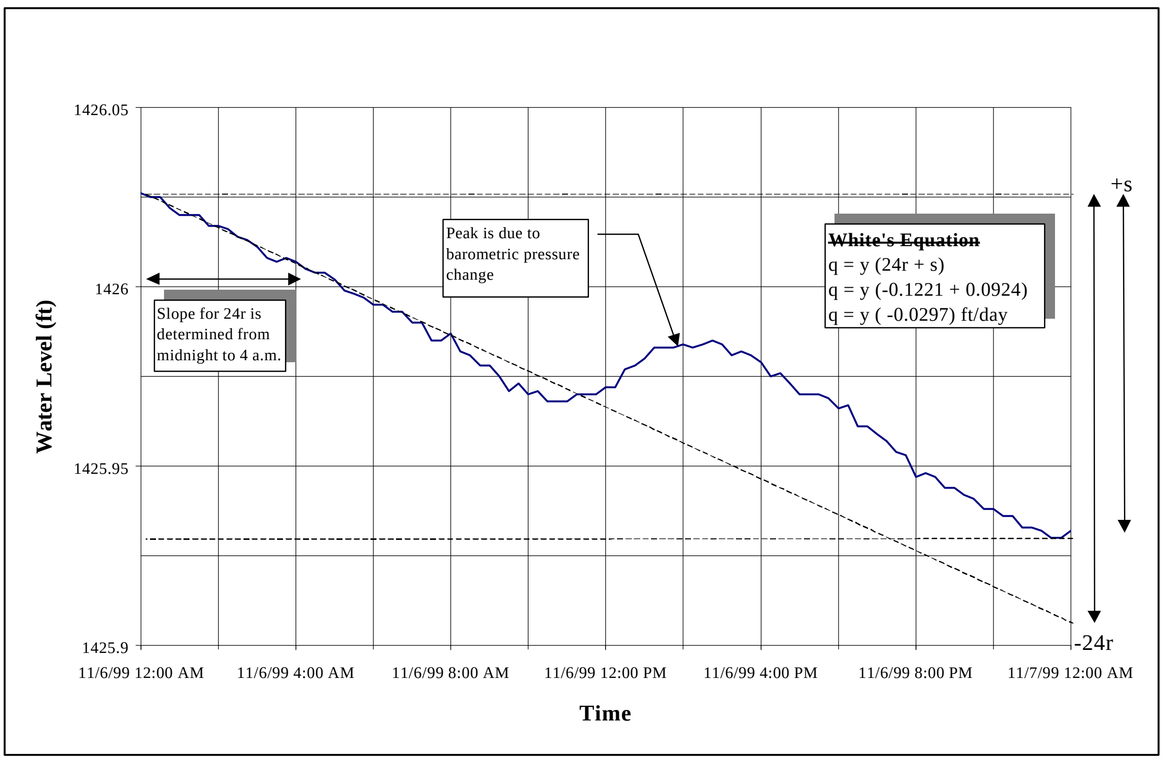


Figure 3.6 - Example of White's Equation on November 6, 1999, showing the error that results due to the nonlinear groundwater recession curve when r is negative and |24r| > |s|

3.4 Discussion of Groundwater Recession Method

Another method of determining poplar tree consumption by observation of the groundwater table is to compare summer and winter groundwater recession curves. In the summer, the decline of the water table after a rain event is due to natural outflow of the aquifer, tree consumption, and interception trench consumption. In the winter months, groundwater recession is due to natural outflow of the aquifer and interception trench consumption. Because the water table is 4 to 8 feet below the surface, it is unavailable to grasses, and evaporation from the water table is negligible (See literature review.). At a given water level, it is assumed natural outflow of the aquifer and interception trench consumption will be equal in winter and summer months. Because the trees are dormant in the winter (do not consume water), the difference between the groundwater recession slope in the summer and in the winter should be due only to water consumption of the trees at a given elevation. The slopes are only compared in the absence of rainfall events because the amount of infiltration due to rainfall events is highly variable and difficult to quantify.

Slopes are determined by finding the slope of the best-fit line through the 12-hours preceding and 12-hours following the time at which the target water level occurs. This averaging approach is done to eliminate any variability in data caused by instruments or hourly changes in slope caused by barometric pressure changes or tree use. After finding the absolute value of the difference in slopes (ft/d), the value is multiplied by the specific yield of the aquifer (0.1) to obtain water consumption by the poplar trees. Figure 3.7 shows data from MW6 taken from 8/29/99 – 9/3/99 and 11/9/99 –11/14/99 that begin at approximately the same elevation. Both of these series of dates begin soon after significant recharge events (>0.75 inches).

Some difficulties are encountered when applying this procedure. Water levels tend to be significantly higher during the winter months than during the summer months. This reduces the likelihood that summer and winter recession curves will be at the same elevation and could be used for comparison. Rain can also cause problems. Ideally, a large rain event would be followed by several weeks of no rain to develop uninterrupted recession curves. Frequent rainfall often disrupts the data for slope comparison purposes. No rainfall occurred during the series of dates chosen in Figure 3.7.

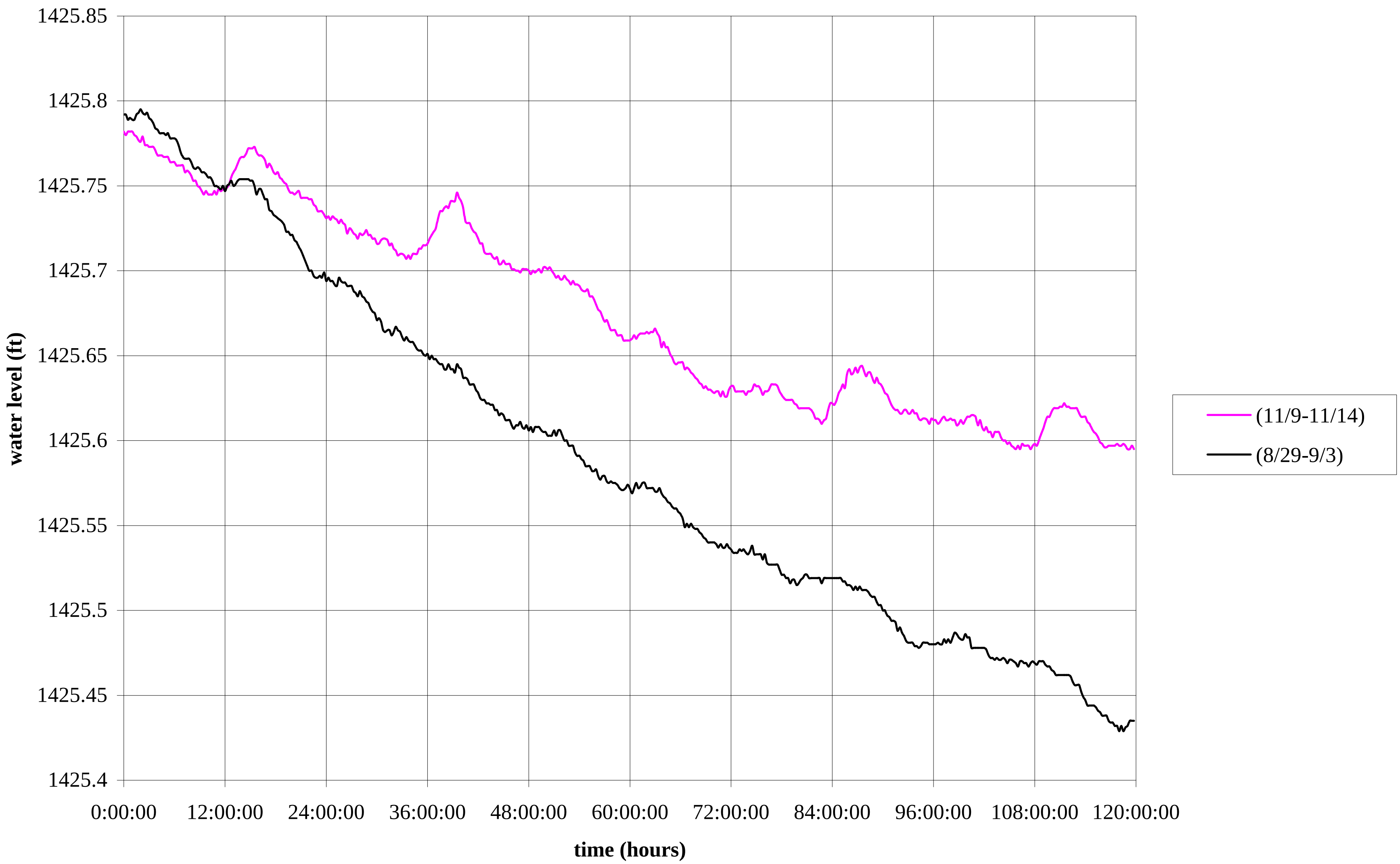


Figure 3.7 - Comparison of MW6 Water Level Data at the Oneida site in August and November (1999) showing the faster rate of decline when the poplar trees are active in August than when they are dormant in November