# THE MYTH OF MEASURING GROUND WATER

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## ABSTRACT

The objective of this paper is to analyze the common practice of making weekly ground water elevation measurements in Infiltration and Inflow (I/I) studies and to determine if this method of looking at ground water has sufficient temporal and spatial resolution to be useful as an I/I diagnostic tool. A comparison is made between ground water elevations in a sewer trench and in nearby native soil. A comparison is also made between well drained and poorly drained native soils. The impact of both ground water and trench water elevation on infiltration rates is also analyzed. It is concluded that the elevation of ground water, and especially trench water, is more dramatic than is often believed and that the common practice of measuring ground water elevation on a weekly basis lacks sufficient temporal resolution for short term I/I studies. Failure to understand ground water and trench water behavior during an I/I study may lead the engineer to faulty conclusions about sources of clear water entering the sewer. The authors attempt to characterize the behavior of the trench water and the native soil during short term I/I studies in the Bridgeport and Lick Creek Basins in Indianapolis.

**Keywords:** diurnal, ground water, I/I, SSES, trench water

## INTRODUCTION

Since the early 1970's Infiltration and Inflow (I/I) studies in the United States have incorporated ground water measurement as a key diagnostic tool (ASCE & WEF). By conducting internal televising and flow monitoring when "ground water is high", it is believed that I/I sources will be detected. It is also believed that if smoke testing is done when ground water is low, inflow defects are more likely to become visible. Many regulatory agencies have provided guidance for I/I studies calling for ground water monitoring, but little guidance is given to the number and location of wells or the frequency of readings. Monitoring wells are often recommended for installation at the base of the study basin near a flow monitoring station. Depth observations are made weekly, usually during visits to collect flow monitoring data (ASCE) and often continue on a bi-weekly or monthly basis until Sewer System Evaluation Survey (SSES) work is completed.

Ground water hydrology is quite variable throughout the country and even within a community. It is not uncommon for static ground water elevations to be several feet different within a study basin. There are also temporal fluctuations in ground water elevations due to tidal, barometric and temperature variations (ASCE). However, in practice most I/I programs seem to be based upon the belief that ground water behaves as a lake and that "ground water elevation" moves up and down uniformly over a geographic area in response to seasonal hydrologic changes. This belief results in the conclusion that ground water is either below the sewer (Figure 1) or above the sewer (Figure 2).

This model may be valid for "loose" soils with high permeability; however in "tighter" impermeable clay soils, groundwater behaves much differently. In many of the clay soils, particularly in the Midwest,

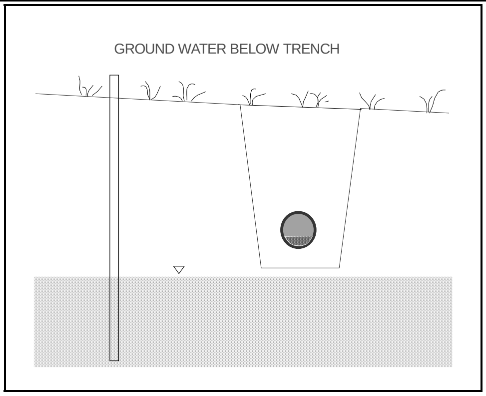


**Figure 1 Ground Water Below the Sewer.**

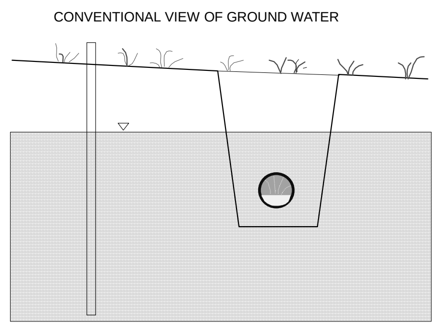


**Figure 2 Ground Water Above the Sewer.**

the annual ground water in native soil varies between 1 and 2 meters (3 and 7 feet). In theory, the ground water would never be below the elevation of most sanitary sewers. Ground water surface elevations frequently are contoured as shown in Figure 3 and do not necessarily follow sewer profiles.

If a sewer constructed in native clay soil incorporated granular bedding and backfill, a "French Drain" effect is created. In this situation the sewer trench will continuously lower the groundwater of the adjacent native soil and a cone of depression or drawdown zone will be created as shown in Figure 4. The situation in Figure 4 could easily lead an analyst to conclude that the pipe is relatively free from defects since the ground water is above the pipe and the dry weather infiltration is low. In truth, the pipe could be leaky as a sieve and the rate of infiltration is controlled by the rate at which ground water migrates from the clay soil into the trench, not the number and severity of pipe defects.

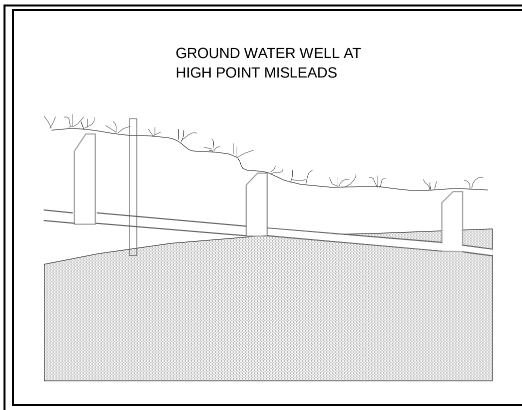


**Figure 4 Groundwater Contours Differ from Surface and Sewer Profile.**

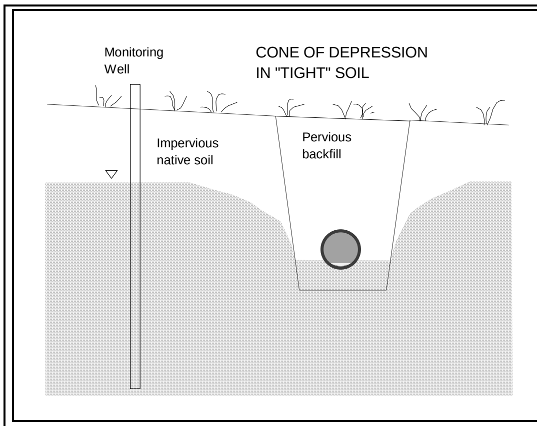


**Figure 3 Zone of Depression in "Tight" Soil.**

To avoid being misled by groundwater elevations in native soil, some regulatory agencies and engineers attempt to measure trench water elevation. Trench water elevation is then correlated with infiltration rates to isolate areas of high infiltration and judge the suitability of internal televising or smoke testing. The most popular method of measuring trench water elevation is through the use of sight tubes installed in manholes as shown in Figure 5. These sight tubes are often installed in the manhole used for flow monitoring and the elevation is read weekly during collection of flow monitoring data. The theory is that seeing water above the pipe indicates that infiltration defects should be evident and water below the pipe indicates that smoke testing will work best.

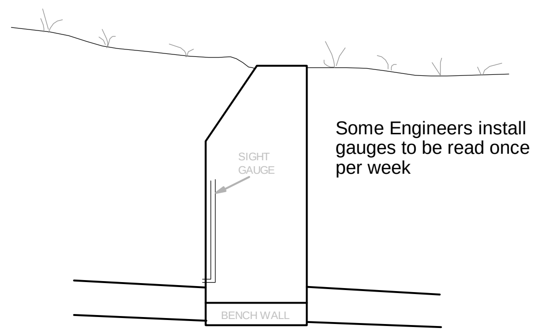


**Figure 5 Sight Gauges Measure Trench Water Elevation.**

However, the use of granular backfill material in clay soils and rock may create a “French Drain” which acts a conduit for rapid runoff during rain events (ASCE). The rapid response (sometimes just hours in duration) of trench water elevation to a rain event would be undetected in a program of weekly elevation readings. An engineer having only flow monitor data and ground water data from a distant well, will almost always conclude that a rapid flow response in a mini-basin is the result of traditional inflow defects. The engineer may then elect to employ smoke testing as the only tool to locate defects in this mini-basin. However, the clear water may be from rapid infiltration and the rehabilitation of the mini-basin may be unsuccessful. Distinguishing between inflow and rapid infiltration is one of the most difficult tasks facing collection systems engineers.

**METHODOLOGY**

The Bridgeport I/I study was performed in 1993 on a basin of approximately 120,000 meters (350,000 L.F.). The basin was divided into 41 mini-basins with an average size of 2,900 meters (8,500 L.F.). A mini-basin with clay soils (BR14) and one with well drained soils (BR9) were selected for ground water monitoring.

In addition to the presence of ground water and the amount of rain, soil type is probably the next most significant factor in the quantity and duration of trench water response to a rain event. Soils within a majority of the Bridgeport project area, including mini-basin BR14, consist of Crosby and Brookston which are considered poorly drained soils. Both soil types are considered to be hydric soils by the U.S. Soil Conservation Service. Hydric soils are defined as poorly drained soils, water is removed so slowly that the soil is saturated periodically during the growing season or remains wet for long periods of time. Free water is common at or near the surface for extended periods of time. Poor drainage results from a high water table, a slow pervious layer within the soil profile, seepage, nearly continuous rainfall, or a combination of these. In area with sufficient grade, these low permeability soils tend to cause rainfall to run off rapidly into nearby ditches and creeks.

Areas of poorly drained soils are separated by areas of well-drained soils such as Miami, Genessee and Sloan soils. Mini-basin BR9 was located in an area of Genessee-Sloan soils. Well drained soils are typically found adjacent to creeks and streams in the Bridgeport sewer system. In well-drained soils, water is removed readily, but not rapidly. Water is available to plants throughout most of the growing season.

To determine the effect of ground water, soil type, and trench backfill and after checking for underground utilities, six 5 cm. ground water monitoring wells with 3 meters of screen were installed. The well locations were selected based upon soil types and position relative to the sewer trench. Each well was approximately 4.6 meters deep. Groundwater elevations in the wells were monitored by installing a pressure/depth sensor at the bottom of each well. Pressure sensors were connected to flow meters at the surface and depth readings were collected every 15 minutes. Three ground water monitoring wells were installed in each mini-basin. One was installed as close as possible to the sewer line and the other two were installed in native soil. One of the two native soil gauges was installed near the trench monitor, the other some distance away. Table 1 lists the wells and soil characteristics. The gauge in well number two was located in a ditch and flooding of the air vent rendered most of its data useless.

| Well No. | Mini-Basin | Soil Type | Soil Description & Drainage | Well Location |
|---|---|---|---|---|
| GW-1 | BR14 | Crosby | Clay & Sand Fill to 4 m. Well 4 m. deep. Poorly Drained | Trench |
| GW-2 | BR14 | Crosby | Silty Clay to 4 m. wet sand & gravel to 4.6 m. Well 4.6 m. deep. Poorly Drained | Native (flooded by ditch) |
| GW-3 | BR14 | Crosby | Silty Clay to 4.6 m. Well 4.6 m. deep. Poorly Drained | Native |
| GW-4 | BR9 | Genessee-Sloan | Silty Clay to 4.6 m. Well 4.6 m. deep. Well Drained | Native |
| GW-5 | BR9 | Genessee-Sloan | Moist Silty Clay (fill) to 4.6 m. well 4.6 m. deep. Well Drained | Trench |
| GW-6 | BR9 | Genessee-Sloan | Sandy Clay (possible fill) to 2.1 m. Silty Clay with Sand & Gravel to 3.7 m. Silty Clay w/ Sand seams & Gravel to bottom at 4.6 m. Well Drained | Native |
| LCGW7 | LC28 | Crosby-Miami | Clay-Silt-gravel to 2.1 m., silt-sand-gravel to 4.6 m. | Native |

**Table 1: Ground water well locations**

The Lick Creek I/I study started in early 1996 and was underway at this writing. The results presented here are preliminary and the same analysis between ground water and flow has not been conducted. Data are shown here primarily because of the pronounced observed diurnal effect . At Only one well, GW-7, was equipped with a pressure sensor, similar to those used for the Bridgeport I/I study, and recorded 15-minute data.

**RESULTS**

The rate of infiltration is considered to be a function of ground water elevation, and for both mini-basin BR9 and mini-basin BR14, hourly average ground water elevations are plotted with rain fall and the daily minimum hourly flow. Data from flow monitor BR-14 and ground water gauges GW-1 and GW-3 and rain fall data are shown in Figure 6.

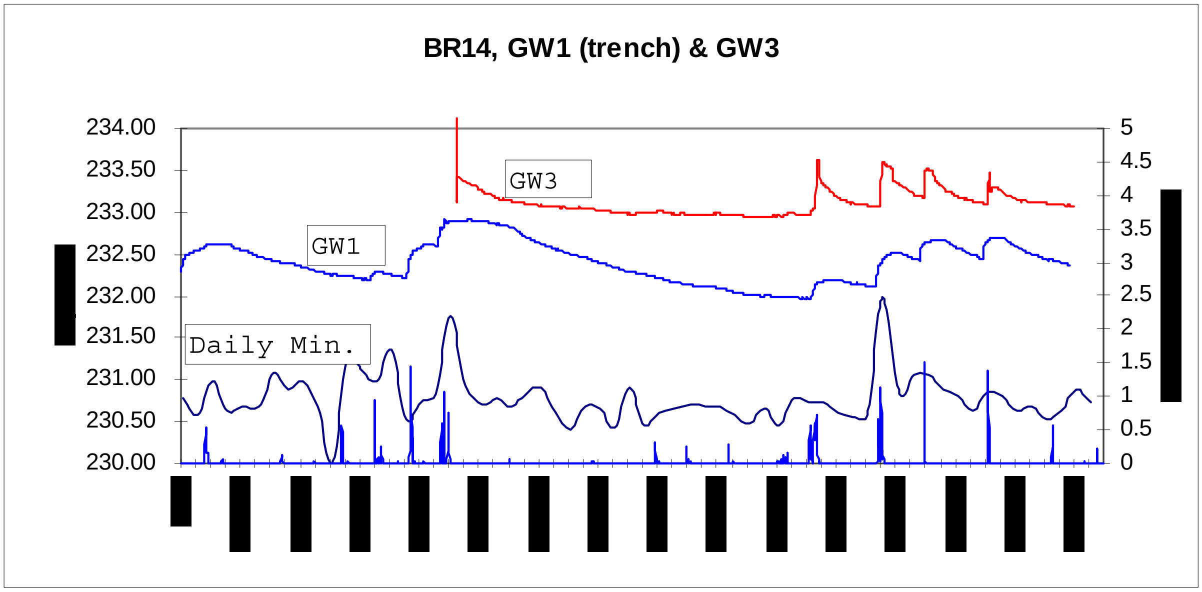


**Figure 6**

The data in Figure 6 illustrate the response of the ground water elevations to rain events. The response to rain in native soil (GW-3: upper curve) is more pronounced and of a shorter duration than the response in the trench. The native soil ground water tends to return to the pre-rain elevation whereas the ground water elevation in the trench tends to increase over time as water in the soils slowly drains into and accumulates in the more permeable trench soils. The minimum flow in the sewer (lower curve) and the trench water elevation (GW-1) tend to follow the same general increase with rain fall.

Data from flow monitor BR9 and ground water gauges GW-4, 5, and 6 are presented in Figure 7.

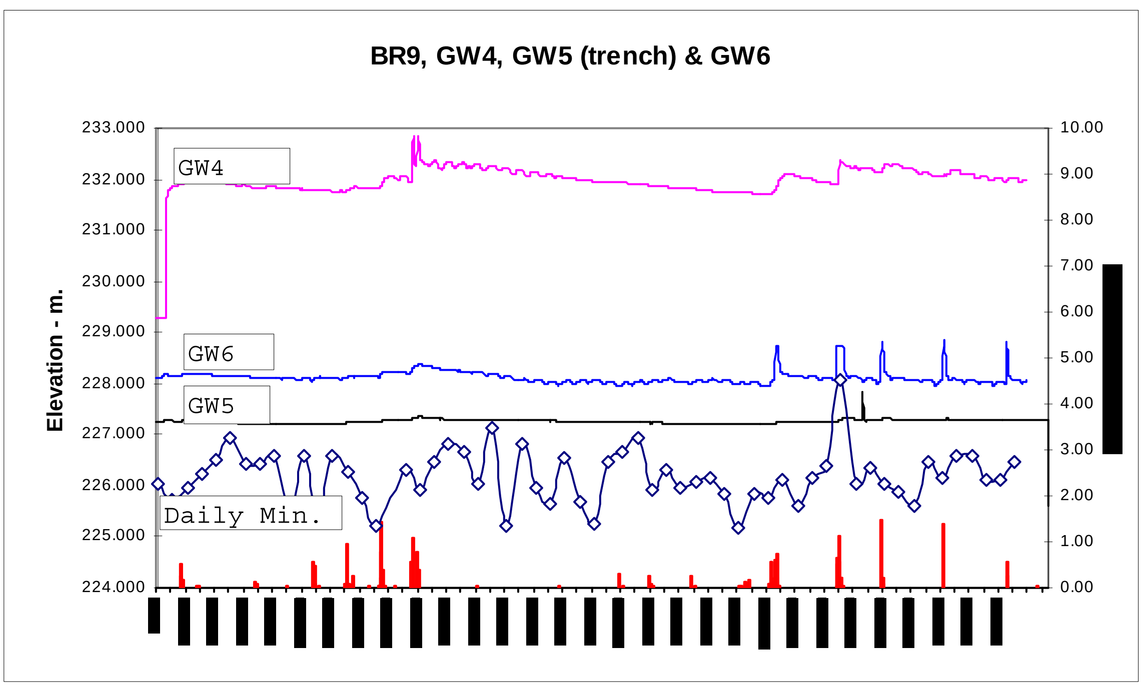


**Figure 7**

Based upon the soils map, it was anticipated the three groundwater gauges in Figure 7 would all be in the same type of soil. As it turned out, the soil boring report showed that GW-4 was constructed in clay soils, while GW-6 was constructed in sandy clay native soil and GW-5 was constructed in fill (sewer trench) which has more silty clay and is less permeable than the surrounding native soils. GW6 is located near a creek and the well's quick response may be associated with creek levels.

Because of a better uniformity of soil type in mini-basin BR14, a statistical comparison was made of minimum daily flow and total daily volume with both the trench and native ground water elevations. Figures 8 and 9 compare minimum flow with trench and native ground water elevations. Figures 10 and 11 compare total daily volume with trench and native ground water elevations. In general there is poor correlation between the parameters, but there appears that minimum flows correlate better with native ground water elevations, while total volume correlates better with trench ground water elevation.

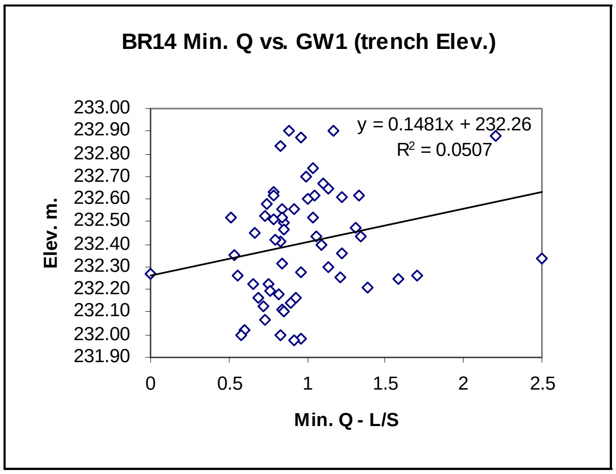


Figure 8

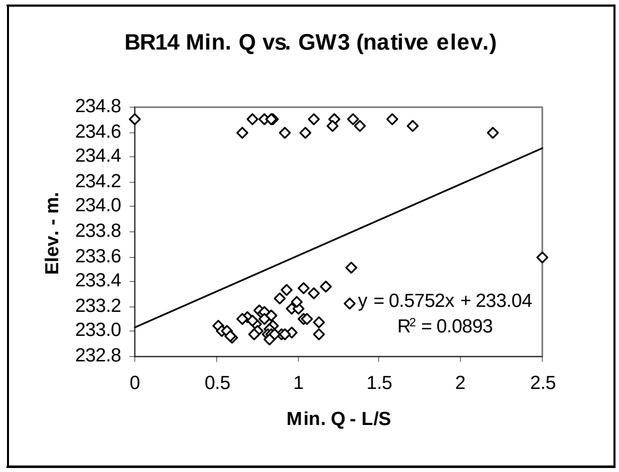


Figure 9

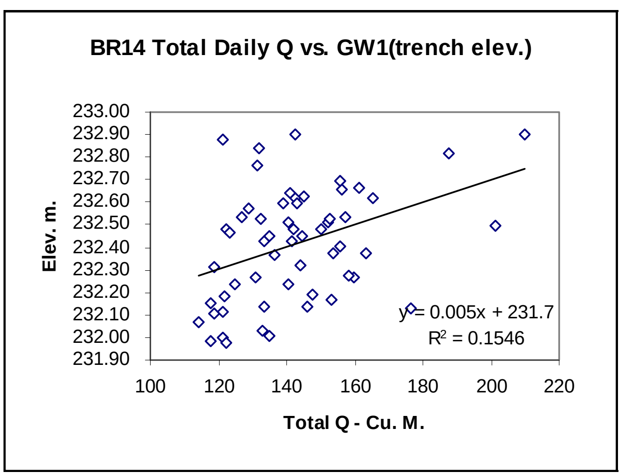


Figure 10

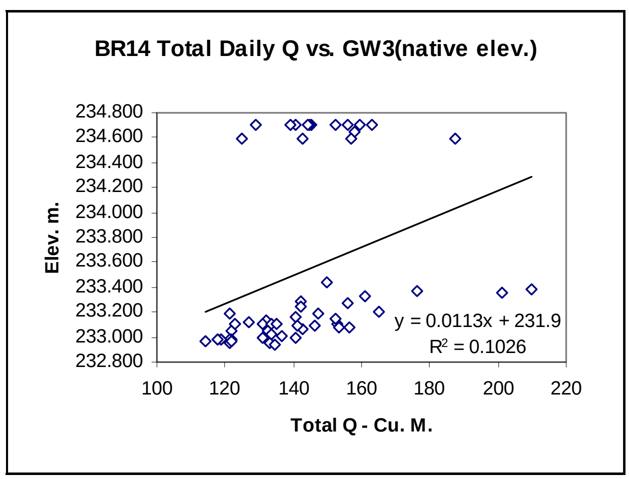


Figure 11

A diurnal pattern was observed in data from both the Bridgeport project in 1993 and the Lick Creek project in 1996. Figures 12 and 13 are the most vivid examples and are the same data shown in pervious Figures, but at a greater resolution to show this phenomenon. At this writing there has not been a clear explanation of the phenomenon. Testing is underway to determine if temperature of the data logger affects the reading of the pressure sensor. Possible causes are:

1. Tidal response similar to open bodies of water, however there is not a time shift associated with tides.

2. Hydraulic communication with the sewer, but not likely since the elevations are typically above the sewer and the effect is more pronounced in the native soils.

3. Temperature changes in the data logger on the surface due to sun shine or air temperature. This is a possibility, but the temperature and cloud cover in May of 96 were highly variable while the diurnal pattern was quite regular (Figure 13). The occurrence of rain dampened the pattern.

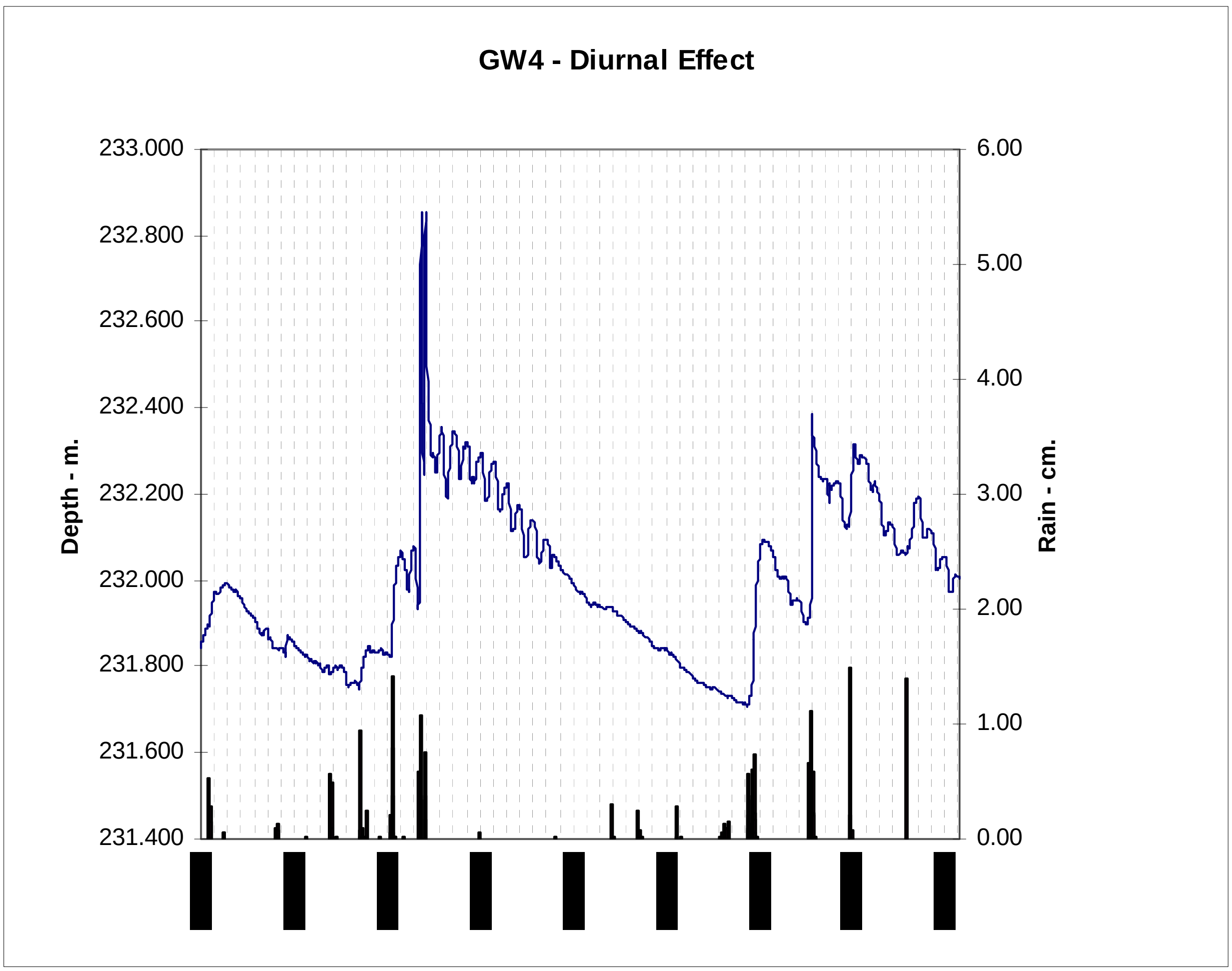


**Figure 12 Diurnal pattern in depth data.**

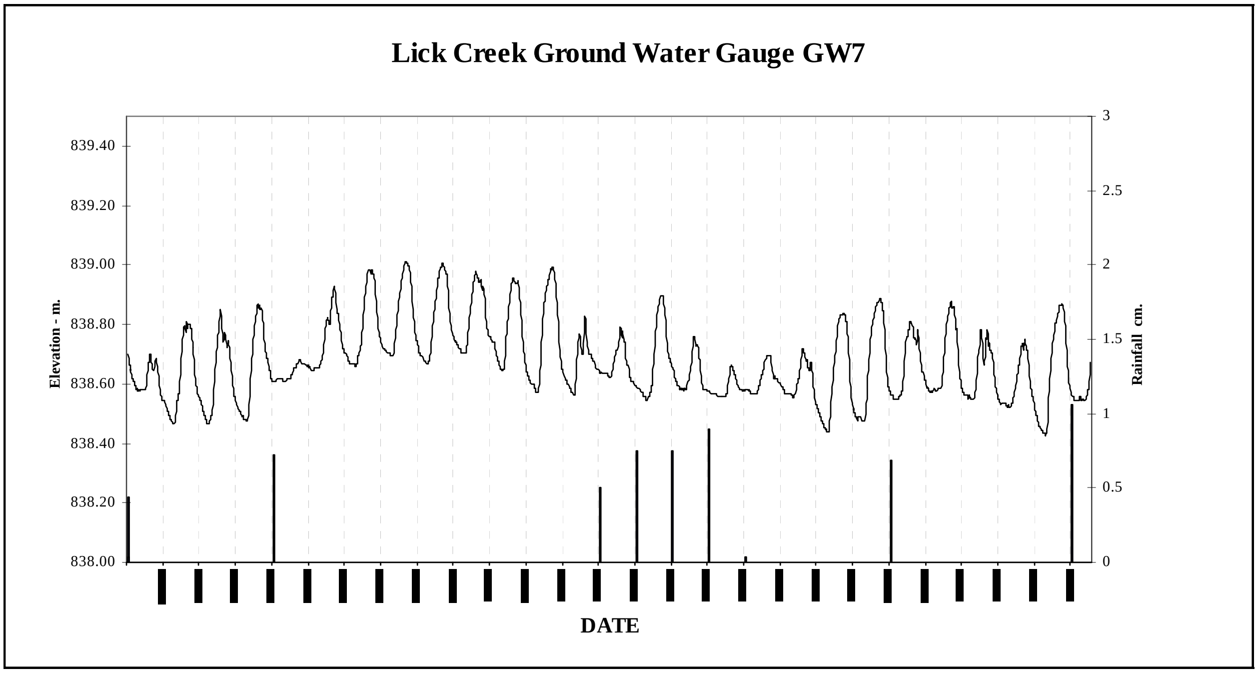


**Figure 13 Rainfall Dampens Diurnal Effect**

## CONCLUSIONS

1. Wet weather response of ground water and trench water elevations can be dramatic and very short in duration (on the order of hours). The swiftness of the wet weather response of trench elevation will make it invisible among weekly readings of depth. Weekly ground water readings will likely leave the engineer clueless to the dynamics of trench water levels and may allow rapid infiltration defects to be incorrectly eliminated as a source of I/I

2. Soils in BR14 exhibited a “French drain” effect and the trench elevation made rapid and accumulative changes in response to rain. The sewers were new and exhibited little infiltration. Inaccuracies in measuring very low flows may have contributed to the low correlation between trench elevation and minimum flow.

3. The trench water in the better drained soil (GW5) was more stable and less responsive than the native soil. Boring logs show that the native soil was stratified with sand and gravel seams at the bottom, whereas the trench was a blended mix of clay and gravel. The trench is likely more impermeable than the native soil.

4. In soils likely to create a “French drain” effect, I/I programs should include trench wells with spatial resolution sufficient to capture terrain features. Data collection should be on the order of hours or daily to capture rapid responses.

## REFERENCES

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Sewer System Infrastructure Analysis and Rehabilitation Handbook, U.S. Environmental Protection Agency, 1991.