Hydraulic Conductivity of Pliocene and Pleistocene Sediments in the San Diego Bay Area Subsurface

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ABSTRACT

Hydraulic conductivity was measured one to 32 times at various discrete depths (20’-1605’ below surface level) in thirty-six wells in the San Diego Bay area by means of single-well slug testing. Using these data, a three-dimensional hydraulic conductivity map was created for a 140 mi² area around the San Diego Bay. The values range from 0.02 feet per day to 100 feet per day, with a mean of 13.8 feet per day. Hydraulic conductivity of the subsurface is widely suppressed by the presence of clay minerals and considerable heterogeneity exists both vertically and laterally along the coast. The data therefore agree with and expand upon existing suggestions of a complex coastal stratigraphy in the region, composed of an embayment as well as fluvial systems that include both steep arroyos and shallower river valleys with estuarine components.

Keywords: hydraulic conductivity, slug tests, permeability, shallow aquifers, ground water
PURPOSE

I measured hydraulic conductivity readings for the Pliocene and Pleistocene sediments of the shallow subsurface in the San Diego area (Fig. 1). I looked for patterns in hydraulic conductivities, through depth and across surface area. I have created a background database of identified materials and locations that are conducive to groundwater flow from which predictions can be made about other materials and locations. This study is the most extensive of its kind in San Diego to date. It serves as a pilot study that will give a strong basis for further development of a conceptual model that can provide direction to groundwater resource development in the San Diego area.

BACKGROUND

Physical Properties and Their Importance to Understanding Aquifers: Why Hydraulic Conductivity?

A subsurface unit is frequently described as either an aquifer, a group of media that are permeable to water, or an aquitard, a group of media that are very slowly permeable to water (Lohman, 1972; AGI, 1980). This study reinforces the truth that permeability is a continuous spectrum, along which there is no universally-defined break between aquifer and aquitard. Locally, an aquifer is a section of the subsurface through which more water is transmitted. This is because it has a higher permeability relative to
Figure 1. Location map. Markers represent sites of eight nested monitoring wells in the San Diego Bay area in southwestern San Diego County, California.
surrounding subsurface layers and therefore more water passes through it than through the surrounding layers during any given time period.

When we talk about permeability in terms of a potential velocity for water movement, we use the term hydraulic conductivity. Hydraulic conductivity is the ability of a medium to conduct water (Bear, 1972). It is measured in the linear distance water can travel through the medium in a set amount of time. This study will report values of hydraulic conductivity (K) in feet per day, as prescribed by the United States Geological Survey (USGS). Hydraulic conductivity, in these units of measurement, varies on a scale of 14 orders of magnitude, from $2 \times 10^{-8}$ to $2.8 \times 10^5$ feet per day (Cherry and Freeze, 1979). The lower end of the scale is mostly associated with bedrock formations, which generally exhibit much lower conductivity than the alluvial and near-shore marine deposits of the San Diego area. Therefore, one might expect to see K values of 0.0003 feet per day to $2.8 \times 10^5$ feet per day for the local Pliocene and Pleistocene sediments.

For hydrostratigraphy, a higher conductivity suggests that the layer could serve as a local aquifer. For production of groundwater, hydraulic conductivity is a desirable value to know because of its application in Darcy’s Law (Bear, 1972):

$$Q = K \times i \times A$$

Q is the rate of flow for a liquid traveling through a porous medium

K is the hydraulic conductivity of that medium

i is the local piezometric gradient, a unitless ratio

A is the cross-sectional area through which the liquid is traveling

i is found by dividing the drop in piezometer head by the distance between two piezometers in the same aquifer.
Knowing the hydraulic conductivity of the subsurface medium at a given depth is a critical step in determining the rate at which a production well could draw water from that depth.

Transmissivity is another common form in which to present physical properties of a subsurface layer (Lohman, 1972). Transmissivity is given in square-feet per day, with the second dimension of distance taken from the thickness of the aquifer layer. This paper does not emphasize values of transmissivity because the thicknesses of specific subsurface formations are thought to have significant lateral variation.

*Geologic setting and aquifer description –*

Jurassic (~150 Ma) granites and rhyolite constitute the Peninsular Range. They underlie the San Diego area and are exposed farther to the east and south. Cretaceous batholiths arose in and around the embayment between 128 and 117 Ma. Sediments filled in the embayment next to this volcanic range and among the batholiths. The earliest deposition that is preserved took place from 76-71 Ma and shows evidence of a fully marine environment. Later sediments were deposited terrestrially, including the top portion of the San Diego Formation and the more recent Linda Vista Formation. The majority of sediment deposition took place 55-36 Ma in the Paleogene, but the most hydrologically significant sediments were deposited in the Pleistocene and Pliocene. Most of these sediments are part of either the Linda Vista Formation (1-1.5 Ma) or the San Diego Formation (1.5-3 Ma).

The San Diego Formation, extending approximately 20 miles NNW-SSE, crosses the international border between Alta California and Baja California (Keller and Ward, 2000). Its sediments fill in a pull-apart structural basin, a byproduct of the Rose Canyon
fault zone and parallel faults (Fig. 2) (Kennedy and Peterson, 1975). This strike-slip regime represents the border between the Peninsular Ranges and Continental Borderlands geomorphic regions. The pull-apart basin is central in the embayment and has created San Diego Bay as it is today. Keller and Ward state that the San Diego Formation itself has experienced faulting, and resultant internal fracturing. Here, fracturing refers to splitting of the formation followed by in-fill of conglomerates, creating a hydrogeologic barrier. Topographic evidence of faulting is seen in the study area, particularly in the north around the Balboa Park and Aqua Culture well sites.

The San Diego Formation is composed of widely varying sediments of both terrestrial and marine origin (Huntley, 1994). Silt and fine sand are present in most sections and cores of the Formation. Cores of the Formation also feature a shift from marine to terrestrial deposition with younging. The Formation is most consistent in grain size distribution at its deepest, with a thick layer of marine clay and silt. The switch in depositional environment from marine to terrestrial occurs approximately halfway through the thickness of the San Diego Formation. It is the first such transition in a set of alternations in the area’s shallow sediments, proposed by Huntley et al. (1996).

In the San Diego area, the most significant groundwater occurrence and developable storage is attributed to the San Diego Formation (Dall, 1898). The USGS San Diego Hydrogeology office is exploring a subdivision of the San Diego area groundwater units through tritium analysis of water from multiple depths. The San Diego Bay and Pacific Ocean bound the aquifer on the west. The base of the Peninsular Range constitute the east and south aquifer boundaries. The north boundary of the aquifer is a
Figure 2. Border features and location of fault lines in the San Diego Formation. The San Diego Formation is mapped in yellow. Borders are the Pacific Ocean to the west, the Mission Valley to the north, and the base of the Peninsular Range on the east. The international border with Mexico truncates mapping to the south. The light blue line (long central) is the local propagation of the Rose Canyon Fault System. The dark blue lines (far right) are faults belong to the La Nacion Fault Zone. The green lines (far left) are in the Point Loma Fault Zone. The three subparallel red lines are faults at the center of the pull-apart basin. Mapping was done by San Diego State University.
fault system and Mission Valley. As shown in Fig. 2, the formation is segmented by faults and erosional systems.

The other large water reservoirs in the area are directly related to surface water systems. Above or below this aquifer in small sections are the Lower Sweetwater Basin and the Lower Tijuana River Valley Basin (California DWR, 2003). Adjacent to the north is the Mission Valley Basin. These other three basins are all centered on single river channels. They are characterized by alluvial grains of much larger size, coarse sand to gravel, and many layers are well-sorted.

TEST METHODS

*Well description –*

The USGS San Diego Hydrogeology Project installed the wells used for these slug tests to aid in the study of ground water in the San Diego, much of which is contracted by the City of San Diego and the Sweetwater Water Authority. U.S. Geological Survey Western Region Research Drilling Unit and U.S. Geological Survey San Diego Project Office personnel drilled and constructed all 35 wells using standard mud rotary techniques. Geophysical logs (electric, EM, and caliper) were run in each borehole prior to well construction. The piezometers are constructed of screw-together flush-threaded 2-inch diameter schedule 80 polyvinyl chloride (PVC) with the exception of Mile of Cars #1, Naval Base #1, and Otay Trolley #1, all of which are 3 inches in diameter. The screened interval of the piezometers is 20 feet except for El Toyon Park #1, Mile of Cars #1, Naval Base #1, and Otay Trolley #1, all of which have screened intervals of 40 feet. All screens have a slot size of 1.2 inches x 0.02 inches and are gravel-packed with #3 sand. The borehole diameter of the screened interval varies from
22.5 to 4.5 inches, depending on the site and depth of the well. Each piezometer is nested with 4 other piezometers of different depths and bentonite grout seals separate the gravel packs (Fig. 3). Well development used an air-lifting and surging technique until no drilling mud was visible in the discharge and several water quality parameters (conductance, pH, temperature) had stabilized. Table 1 provides key information about each well.

Sources of interference –

In this urban setting, interferences to static water level readings exist. For example, the close proximity of the monitoring wells to nearby production wells or proximity to the coast can affect water levels. Only wells at Naval Base gave any recognizable sign of being affected by tidal fluctuation, and even there the effect on water level in the well was not enough to disrupt testing. Water level changes during the testing periods of individual wells varied between an increase in water level of 0.3 feet and a decrease in water level of 0.1 feet. A fluctuation in static head of 0.4 feet is 2% or less of the average head in each piezometer and does not compromise my tests.

Equipment

Slug description –

All four slugs used for these tests were PVC pipes with both ends capped and I filled each with sand for weight. I connected the slugs to a cord at one end, allowing for quick and easy insertion and removal of the slugs into or from the water. I used two sizes of slugs for both 2-inch and 3-inch wells. The smaller slug used for the displacement of volume in the 2-inch diameter wells was a 1-inch PVC pipe 62.5 inches long. The
Figure 3. Example of construction of a nested well site. Five piezometers are nested together in a single vault. Each has an open interval that is protected by bentonite fill. The bentonite also separates the piezometers.
<table>
<thead>
<tr>
<th>Slug Test File Name</th>
<th>Analysis Method</th>
<th>Local Designation</th>
<th>Test Date</th>
<th>Water Level Prior to Test (ft)</th>
<th>Water Level After Test (ft)</th>
<th>Station ID number</th>
<th>Local well number</th>
<th>Altitude (ft)</th>
<th>Well Depth (ft)</th>
<th>Depth to top interval (ft)</th>
<th>Well Completion Date</th>
<th>Well Diameter (ft)</th>
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<td>50</td>
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<td>4/02/04</td>
<td>2</td>
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</tbody>
</table>

**TABLE 1: Well-identification and Construction Information of Slug Test Data Collection Sites, San Diego County, California**
displacement of this slug gave an equivalent head displacement of 1.44 feet in a 2-inch well. The larger slug used for the displacement of volume in the 2-inch diameter wells was a 1.25-inch pipe, 63.2 inches long. The displacement of this slug gave an equivalent head displacement of 2.28 ft. in a 2-inch well. The smaller slug used in the 3-inch diameter well was a 1.75-inch PVC pipe 70 inches long. The larger slug used in the 3-inch diameter well was a 2.35-inch PVC pipe 66 inches long. These two slug sizes have displacement with equivalent head displacement of 1.44 feet and 2.28 feet, respectively, in a 3-inch well.

Instrument description –

I recorded data from these tests using the In-Situ Level Troll 700 10 psi gauged pressure transducers with built-in data logging. The U.S.G.S. Hydrologic Instrumentation Facility calibrated the transducer in a calibration tube prior to use, and I always used the transducer with a vented communication cable.

Slug test procedure –

I took a reading of the water level in each well before each test began (Table 1). I then allowed sufficient time, 15-20 minutes for all wells, and measured again to be sure of a static water level. I then set the transducers at a depth ranging from 14.1 to 16.5 feet below the water level and lowered the slug to approximately 5 feet above the water. During these periods I measured water levels routinely from the surface with a graduated water level sensor. Appendix A has the hydrographs for each piezometer during the period of testing. I set the data logger to record water level every second, and the slug was dropped into the water. I then allowed sufficient time for recovery of the water to the
original static level. Recovery times ranged from 30 seconds to over 3.5 hours, with most wells recovering within 2-4 minutes. I then quickly removed the slug and again allowed sufficient time for recovery to the static level. I repeated alternating tests (slug in, slug out) 3 to 16 times per well depending on the recovery conditions. Each hydrograph displays: the measured water level, a line indicating the initial static water level, lines indicating the calculated head displacements for the addition and removal of each slug size.

The term “1.5-ft slug” describes the tests where the slug used was designed to create a 1.44-foot change in head. The term “3-ft slug” describes the tests where the slug used was designed to create a 2.28-foot change in head. At El Toyon Park wells #1, #2, and #4, I collected data with only one slug size because of complications with recording at the relatively great depth of those wells. Testing of Tijuana River Valley 1 well #4 was abandoned after only one test for time considerations, as the first test only returned to a stable level after over 3.5 hours. Time limitations also led to using only one slug size in testing of Otay Trolley #1. The two stagnant periods in the 3-ft slug testing of Tijuana River Valley 1 #2 are from issues with charging the laptop computer to which the Level Troll was attached. During these times I suspended data logging to avoid unnecessary erratic levels.

Computation procedure –

I converted the recorded water levels to hydraulic conductivity measurements using an Excel spreadsheet created by Keith Halford (Halford, 2002) of the USGS using methods developed by James Butler of the Kansas Geological Survey (Butler, 2000). The following assumptions are necessary for computation of the data: the volume of water is
injected into, or is discharged from, the well instantaneously at $t = 0$, and the well is of finite diameter and fully penetrates the aquifer. The program assumes the aquifer to be confined, homogeneous, isotropic, of uniform thickness, and the flow within the aquifer is horizontal and radially symmetric and that the entire screened interval influences the response. Thus for these calculations I assume the aquifer thickness to be equal to the length of the screened interval of the monitoring well.

The Excel spreadsheet created by Keith Halford allows for multiple tests –up to 20– to be entered and simultaneously analyzed. The type curve can be automatically or manually fit to match the observed response by adjusting the dimensionless damping coefficient (MF) and the hydraulic conductivity (K). A graph for each piezometer with a matched curve is included in Appendix B. The accuracy of the fit between the match curve and the measured response curve is best characterized by the residual standard error (RMS).

The observed initial head displacement ($H_o$) differs from the equivalent head displacement between tests within the same piezometer, especially between slug-in and slug-out tests. The discrepancy was at times over 33% and the cause of the difference is uncertain. To eliminate selective deletion and/or changing of data points the observed initial head displacement was used for processing the results.

Separate analyses were performed for the two different slug sizes for each well. For each approach the individual tests were manually examined and tests that contained errors were removed from the batch. Commons errors included: measured displacements varying greatly from the equivalent head displacement, irregular recoveries, and tests
containing anomalous readings. In general the hydraulic conductivities were greater for
the 3-foot tests than the 1.5-foot tests.

*Flow test procedure* –

Flow tests were conducted on the four deepest wells at the Aquaculture site
because they are artesian. Testing involved uncapping the wells and allowing water to
flow into a graduated container, marked with two-liter intervals. The time taken for the
water to reach each of the two-liter marks was recorded. Ten tests were deemed valid for
Wells 2 & 3, nine on Well 1, and eight on Well 4. An average of the time taken to for two
liters to flow was used to find an average $Q$ for each well in liters per minute, which was
translated to cubic feet per day.

The following variation of the Jacob-Cooper formula for flow was used to solve
for the transmissivity of the sediments at each open interval.

$$T^2 = \frac{(Q*r_w^2)}{(2\pi s_w)}$$

$T$ is the transmissivity ($L^2/t$)
$Q$ is flow out of the well ($L^3/t$)
$r_w$ is the effective radius of the piezometer ($L$)
$s_w$ is the head loss during pumping ($L$)

Because no pumping was involved, $r_w$ is the radius of the piezometer and not
related to a cone of depression. Conversion to $K$ was done by dividing $T$ by the thickness
of the open interval ($L$). The values (0.33-4.9 ft/day) are in the expected range for the
area and correlate well with the fine sands and silts found at the four deepest open
intervals.
RESULTS

Summary of data –

Hydraulic conductivities ranged from 0.02 ft per day to 100 ft per day (Table 2). This range encompasses three divisions: low conductivity (0.02-2.99 ft/day), medium conductivity (3-19.99 ft/day), and high conductivity (20-100 ft/day).

Individual well results (Appendix B) –

The SDBP data show a general decrease in hydraulic conductivity with increasing depth (Fig. 4). The largest value (15.18 ft/day) was found in the open interval from 100-120 feet below the surface. The four values in the next 1375 feet are all an order of magnitude less (2.60, 1.72, 3.70, and 3.67 ft/day). Even within this group of values, variance can be related to changes in sediment grain size distribution. The 1.72 feet per day value is from a depth of 560-580 feet, where sediments are silt-rich sands and belong to the marine Lower San Diego Formation. The values of 3.70 and 3.67 are remarkably similar, especially coming from intervals 430 feet apart, depths of 1020-1040 feet and 1470-1490 feet, respectively. However, these two values come from sediments of different grain size distribution. The grain size distribution of the higher interval is best described as gravel granules and the lower interval is sandy, clayey silt. At a depth of 1498 feet, the conductivity is another order of magnitude less (0.15 ft/day) and the sediments are clayey silts. This deepest value is from testing run on a core sample by the USGS.

The SDET (El Toyon Park) data show a shallow layer of very low conductivity over four deeper points of medium conductivity (Fig. 5). The four points of medium conductivity can be divided into two lower values in the middle of that interval
sandwiched by two higher values. The conductivity in the column’s uppermost opening is a mere 0.062 feet per day over the opening from 150-170 feet below the surface. The sediment in this interval is characterized as semi-cemented coarse sand. The next measurement in the hole showed a conductivity of 5.8 feet per day at a depth of 410-430 feet, an interval of gravelly silty sand. Below this were the two lower medium conductivities, 1.7 feet per day from 740-760 feet and 1.2 feet per day from 920-960 feet. These two values correspond with sediments characterized as marine sandy clayey silt and marine clayey silt, respectively. The bottom opening of 1260-1300 feet showed a conductivity of 3.6 feet per day in sediments divided into sandy clay above gravelly sand.

The SDMC (Mile of Cars) data show two regionally high conductivity values in the top 280 feet of subsurface, below which conductivity declines over three deeper intervals (Fig. 6). The open interval of 30-70 below the surface was found to have a conductivity of 48.5 feet per day. Sediments in this interval are characterized as gravelly sand. The second regionally high conductivity is the highest value in this study, 100 feet per day at 260-280 feet. The sediment at that depth are coarse-very coarse sands. The three deeper conductivities are still higher than the regional average. They fall from 20.5 feet per day at 700-720 ft to 18 feet per day at 1100-1120 and down to 8.7 feet per day at 1440-1480 feet. The corresponding sediments change from coarse-very coarse sand to well-sorted coarse-very coarse sand to silty sand.

The SDNB (Naval Base) data demonstrate the presence of at least four separate units of subsurface, with two alternations of lower to higher conductivity with depth (Fig. 7). Over the open interval from 20-25 feet below the surface, the conductivity was 6.3 feet per day. Sediments in that interval are characterized as silty medium-coarse sand.
The next two conductivities (80-85 feet and 180-200 feet) are an order of magnitude higher, at 24 and 38 feet per day respectively. The sediments in each of those intervals are a combination of sand and gravel. The next deepest conductivity is of the lower order of magnitude, measuring 4.6 feet per day at 660-680 feet. In that interval, the sediment is the same silty medium-coarse sand as the shallowest interval. The deepest value returns to the higher order of magnitude, a conductivity of 35 feet per day at 1460-1500 feet. Sediments in that interval are unsorted sand of widely-varying sizes.

The SDOT (Otay Trolley) data include three regionally higher conductivities bounded by a lower datum for the shallowest depth and two low conductivities for the deepest interval (Fig. 8). The conductivity for the uppermost open interval, 45-65 feet below the surface, was found to be 2.95 feet per day. Sediments in that interval are medium-very coarse sands. The group of three higher conductivities begins at 215-235 feet, where a value of 38 feet per day was measured, and is followed by measurements of 19.5 feet per day at 540-560 feet and 38 feet per day at 910-930 feet. The interval from 215-235 feet is composed of sediments that are characterized as fine-very coarse sand with gravel. Sediments in the interval from 540-560 feet are silty fine-medium sands. The deepest two values represent a drop of two orders of magnitude from the three medium-depth conductivities. Those two values are 0.55 feet per day at a depth of 1455-1495 feet and 0.92 feet per day at 1605 feet. The deepest value is from testing run on a core sample by the USGS. Sediments in the interval from 1455-1495 feet are silts and clays, while the deepest conductivity is from sediments characterized as sandy silts and clays.

The TJV1 (Tijuana 1) data show consistently lower values including the regional low conductivity (Fig. 9). The highest conductivity at the site, 7.2 feet per day, was found
in the uppermost open interval of 260-280 feet below the surface. Sediments in that interval are characterized as very fine-coarse sands, with fine sands predominant. The regional low conductivity of 0.02 feet per day was measured at 580-600 feet. That interval is composed of sandy silt, with the sands being uniformly very fine. The deepest three conductivities are consistent with each other. A conductivity of 1.0 feet per day was measured at a depth of 945-965 feet, followed by 2.6 feet per day at 1170-1190 feet and 1.61 feet per day at 1340-1360 feet. The sediments of those three intervals are also composed of similar grain sizes – silts and fine sands. The 945-965-feet interval is composed of silt with very fine sand, while the 1170-1190-feet interval is very fine-medium sand and the deepest interval is very fine-fine sand.

The only datum gathered at TJV2 (Tijuana 2) is from the interval 250-270 feet below the surface and is a conductivity of 1.4 feet per day. The sediments are characterized as clayey silt with fine sand.

The Aquaculture data are shown in Fig. 10. The shallowest interval, from 30-50 feet below the surface, has a conductivity of 11.4 feet per day and sediments are silty gravel. The iron-richness of these sediments suggests that they belong to the Linda Vista Formation, or at least a completely terrestrial depositional environment. The four other intervals have sediments skewed toward fine grain sizes. Concurrently, they yielded values of 1.7, 4.1, 4.9, and 0.3 feet per day. The depths of these intervals are 145-165, 465-485, 710-730, and 840-940 feet below the surface, respectively.

A comparison of K values between well sites is shown in Figure 11.
### TABLE 2: Results of Slug Tests from Monitoring Wells in the San Diego Basin, San Diego County, California

<table>
<thead>
<tr>
<th>WELL NAME</th>
<th>METHOD</th>
<th>AVERAGE (tests each)</th>
<th>1.5-ft Slug (tests each)</th>
<th>3.0-ft Slug (tests each)</th>
<th>Tets Date</th>
<th>Depth of Transducer</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MF (1/sec)</td>
<td>K (ft/day)</td>
<td>RMS (feet)</td>
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<td>16 0.36 2.12</td>
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<td>- - - -</td>
<td>7/28/2008</td>
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<td>12 3.62 1.4 0.13</td>
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<td>16 3.97 22 0.15</td>
<td>16 3.83 19 0.34</td>
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<tr>
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<td>KGS_High-K</td>
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<td>12 5.73 38 0.18</td>
<td>12 6.29 32 0.19</td>
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<tr>
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<td>14 0.57 5 0.08</td>
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<td>KGS_High-K</td>
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<td>12 1.00 24 0.18</td>
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<td>7 9.96 0.55 0.15</td>
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<td>15.5</td>
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<td>7/22/2008</td>
<td>15.6</td>
</tr>
<tr>
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<td>KGS_High-K</td>
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<td>15.4</td>
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<td>12 1.73 1.4 0.074</td>
<td>6 2.06 1.5 0.22</td>
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<td>15.3</td>
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</table>
Figure 4 - Hydrostratigraphy of the Balboa Park Well

0-160 ft
Sandy Gravel
Granules to medium pebbles with fine-very coarse sand
Yellowish-brown or olive

160-640 ft
Silts, clays, and very fine sand
Alternating in predominance of clay or silt on the 100-ft scale
Tan to dark grey

640-700 ft
Gravel
Granules to medium pebbles
Light grey

700-1000 ft
Silty Sand & Gravel
Very fine sand to small pebbles with silt
Light grey to green-grey

1000-1260 ft
Gravel
Granules to medium pebbles
Light grey

1260-1501 ft
Clayey silt
Silt with clay and some fine sand
Dark grey

700-1000 ft
Silty Sand & Gravel
Very fine sand to small pebbles with silt
Light grey to green-grey
Figure 5 - Hydrostratigraphy of the El Toyon Park Well

0-300 ft
Coarse sand and silt
Alternating in predominance on 20-60-ft intervals, poorly sorted
Consistently reddish-brown

300-660 ft
Sandy silt
Silt with very poorly sorted sands
Light grey to olive

660-1160 ft
Clays and silts
Very fine sediments with occasional intervals containing a few sand and pebble grains
Olive to dark greenish grey

1160-1300 ft
Silty sand and gravel
Poorly sorted medium sand to granules with nearly consistent silt presence
Greenish grey

1260-1300 ft: 3.7 ft/day

150-170 ft: 0.06 ft/day

740-760 ft: 1.7 ft/day

920-960 ft: 1.2 ft/day
Figure 6 - Hydrostratigraphy of the Mile of Cars Well

0-80 ft
Sand
Well-sorted, subrounded coarse sand
Tan and red

80-160 ft
Silts and sand
Alternating in predominance; some sorted intervals; varying sand sizes
Grey

160-900 ft
Gravel and sand
Well-sorted coarse to very coarse sand and granules, alternating in predominance

900-1090 ft
Silt and sand
Very fine sand and silt with shell fragments

1090-1220 ft
Sand
Very well-sorted coarse to very coarse sand

1220-1499 ft
Silty sand
Moderately-sorted very fine sand with silt, nearly consolidated siltstone in deepest 25 ft

1440-1480 ft: 8.7 ft/day

30-70 ft: 48.5 ft/day

260-280 ft: 100 ft/day

700-720 ft: 20.5 ft/day

1100-1120 ft: 18 ft/day
Figure 7 - Hydrostratigraphy of the Naval Base Well

0-80 ft
Silty sand
Medium to very coarse sand with silt; nearly all silt for bottom 20 ft
Light brown

80-90 ft
Sandy gravel
Granules with very coarse sand; Dark yellow

90-150 ft
Sandy clay
Clay with coarse sand; Greyish brown

150-380 ft
Gravelly sand
Medium to very coarse sand with granules
Light brown

380-460 ft
Clay; Dark greyish brown

460-690 ft
Silty sand
Medium to very coarse sand with silt
Olive brown

690-890 ft
Sandy clay
Clay with poorly sorted coarse sand
Light olive brown

890-1440 ft
Silty sand
Medium to very coarse sand with silt
Dark greenish grey

1440-1501 ft
Sand
Poorly sorted sand of widely varying sizes
Olive grey
Figure 8 - Hydrostratigraphy of the Otay Trolley Well

0-65 ft
Gravelly sand
Medium to very coarse sand with pebbles

65-180 ft
Silty sand
Poorly-sorted sands of widely varying sizes with silt

180-270 ft
Gravelly sand
Well-sorted coarse sand to pebbles, underlain by 40 ft of clayey silt

310-430 ft
Sandy Gravel
Well-sorted medium to coarse sand with pebbles

430-900 ft
Clayey silt with sand window
Marine silty clay with shell fragments; window of silty sand 520-560 ft

900-930 ft
Silty sand
Very fine to fine sand with silt

930-1600 ft
Clay and silt
Marine clays and silts, siltier with depth
Figure 9 - Hydrostratigraphy of the Tijuana #1 Well

0-100 ft
Silty sand
Poorly-sorted sand of all sizes with silt, some gravel at bottom of interval
Light olive grey

100-300 ft
Sand
Moderately- to well-sorted sand, fining with depth and adding silts
Yellow to olive

300-1030 ft
Sandy silt
Well-sorted silt and very fine sands, some clay
Greenish grey

1030-1390 ft
Sand
Well-sorted very fine to medium sand
Greyish green

1390-1420 ft
Silty sand
Very fine to coarse (skewed to fine) sand with silt and some clay
Light grey
Figure 10 - Hydrostratigraphy of the Aquaculture Well

0-90 ft
Sand
Well sorted with occasional silt
Brown to dark grey

30-50 ft: 11.4 ft/day
145-165 ft: 1.7 ft/day

465-485 ft: 4.1 ft/day

710-730 ft: 4.9 ft/day

840-860 ft, 880-900 ft, 920-940 ft: 0.3 ft/day

0-90 ft
Sand
Well sorted with occasional silt
Brown to dark grey

90-730 ft
Very fine sand and silt
Very well sorted subrounded sands and silt
Tan to dark grey

730-840 ft
Clay, silt, & sand
Poorly sorted fine sand, silt, and clay
Olive to dark grey

840-945 ft
Silty sand
Moderately sorted fine sand and silt
Greenish grey & dark grey

945-947.5 ft
Bedrock
Volcanic hard rock
Mean K at each well site. Calculated mean hydraulic conductivity for all open intervals at each well site, in feet per day.

High K at each well site. Values are the highest hydraulic conductivity among all open intervals at each well site, in feet per day.

Range of K at each well site. The values represent the difference between the highest and lowest hydraulic conductivity among open intervals at each well site, in feet per day.
DISCUSSION

The range of $K$ values found in this study is moderate within the range of possible
$K$ values for subsurface materials. The fact that over two-thirds (68\%) of the data points
are between 0.1 feet per day to 20 feet per day is indicative of the poor sorting and
generally fine-grained nature (Darcy, H. 1856; Bear, J. 1972; AGI 1980) of sediments in
the San Diego subsurface. Despite the lack of thick, well-defined layers in the subsurface,
some patterns exist between hydraulic conductivity and setting, both stratigraphic and
geographic.

The Pliocene and Pleistocene sediments in the area of testing constitute around 40
cubic miles (~213 million cubic feet) of subsurface material. This study was able to look
at 38 windows in the subsurface, none more than 60 feet thick and most twenty feet thick.
The windows represent a wide variety of elevations and depth from the surface. They
also are spaced well across the land surface. The wells are constructed well enough that
each $K$ value is certainly relatable to that specific depth in the subsurface. Resolution of
this study is therefore better on the site-specific scale than on the regional scale.

Conductivity variation with respect to surface water proximity –

Since sediments in the area have been deposited recently, it makes sense that
surface water distribution and drainage basins would have been similar at the time of
deposition as they are now. If the modern systems are the same as those during Pliocene
and Pleistocene deposition, it is prudent to look at current river valleys as being the area
with the most potential for conductive strata. Only during prolonged regimes of higher
sea level – high enough to advance up the river valleys – would these areas not have had
moving water winnowing out the finer sediments as deposition proceeded. Therefore, I
would expect to find intervals in these settings of sediments with coarser grains and good sorting.

Significant proximity to contemporary surface water was defined as within 500 feet for the purpose of this investigation. With this definition the sites designated as proximal to surface water were Aquaculture (SDAQ), Mile of Cars (SDMC), Naval Base (SDNB), and Otay Trolley (SDOT). The sites designated as distal to surface water were Balboa Park (SDBP), El Toyon Park (SDET), and the Tijuana Valley sites (TJV1 & TJV2). This division creates a group of 17 surface-water-proximal hydraulic conductivity values and a group of 17 surface-water-distal values. The mean hydraulic conductivity for the proximal sites was 20.3 feet per day for a range of 0.3 feet per day to 100 feet per day. This is considerably higher than the mean hydraulic conductivity of distal sites, which was 3.1 feet per day with a range from 0.02 feet per day to 15.2 feet per day. The two means are statistically significant with over 99% confidence.

If the more permeable materials that could be called aquifers indeed follow valleys, the developable groundwater resources in the area are very restricted. This would be especially true if, as it seems, only relatively steep valleys such as that of the Sweetwater River are conductive enough for groundwater development. The San Diego Formation aquifer would then sit in these narrow, dendritic valleys that propagate only a few miles in from the shore and are confined latitudinally by Mission Valley and the Tijuana River Valley.

*Huntley’s marine-land-marine-land succession* –

Huntley (1994) proposes a series of alternations in depositional environment across much of the study area during the Pliocene and Pleistocene epochs. The succession
begins with high sea level such that the depositional environment is marine. It is followed
by a time with lower sea level that created a terrestrial depositional environment.
Following this first terrestrial interval is a second marine interval followed by a second
terrestrial interval.

The sediment cores and the results from hydraulic conductivity tests reinforce the
idea of multiple changes in sea level during the recent sediment deposition in the San
Diego area. A general pattern from oldest to youngest sediment began with marine
sediments around 1500 feet of depth with a switch to terrestrial followed by another
marine stage followed by a final switch to terrestrial.

Table 3 shows the succession for each well site, based on interpretation of
sediment cuttings saved during drilling. Sediments were classified using four categories
for depositional environment. The categories of marine and terrestrial are on opposite
ends of a spectrum. Sediments interpreted as marine are grey, green, or black in color,
frequently contain shell fragments, and generally are of finer grain size (silts and clays).
Sediments interpreted as terrestrial are lighter in color, frequently stained red with
oxidized hematite, and tend to be of larger grain size (sands and gravels). Two other
categories are interpreted as intermediate on the spectrum. Fine, white, nearly
homogeneous sand is interpreted as beach swash. It is similar in appearance to sand
found on the current foreshore of the San Diego coast. The fourth category is for the
environment which generates silt-covered gravel, or silt with gravel interspersed. It
cannot be determined from cuttings whether the gravel is in laminations which are
horizontally- but not vertically-continuous or whether the gravel was distributed
consistently during deposition of the silt. Either way, the proximity of two genetically
Table 3. K Values with Huntley’s Depositional Succession

<table>
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<tr>
<th>Well Site</th>
<th>Number</th>
<th>Well Screens (depth in ft)</th>
<th>Conductivity (ft/day)</th>
<th>Huntley Units</th>
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<td>840-860, 880-900, 920-940</td>
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<td>LM UT = Upper Terrestrial</td>
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<td>2</td>
<td>710-730</td>
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<td>SG UM = Upper Marine</td>
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<td>465-485</td>
<td>4.1</td>
<td>SG LT = Lower Terrestrial</td>
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<td>1.74</td>
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<td>80-85</td>
<td>24</td>
<td>UT</td>
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<td>20-25</td>
<td>6.3</td>
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<td>M</td>
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<td>0.55</td>
<td>M</td>
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<tr>
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<td>910-930</td>
<td>38</td>
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<tr>
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<td>540-560</td>
<td>19.5</td>
<td>M</td>
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<td>945-965</td>
<td>1</td>
<td>UM</td>
<td></td>
</tr>
<tr>
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<td>580-600</td>
<td>0.02</td>
<td>UM</td>
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<tr>
<td>5</td>
<td>260-280</td>
<td>7.2</td>
<td>UT</td>
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</tr>
</tbody>
</table>
different sediments in the same interval represents a boundary or other relationship between marginal marine and terrigenous deposits.

Conductivity with respect to depth from land surface –

Hydraulic conductivity is compared against depth for seven well sites in Fig. 12. Each well site graphs as a connected series of points that represent the measured hydraulic conductivities at the five or six depths with open intervals. This graph allows for exploration of correlation between the two variables, K and depth, that may be consistent across the San Diego Bay region. A single trend is not identifiable across the various series. The Balboa Park series and Tijuana Valley 1 series have decreases in K from their uppermost screened interval to the lower screened intervals. The Mile of Cars series has a difference of two orders of magnitude between the K value of the second-shallowest screened interval to the lowest screened intervals.

The inverse relationship between depth and K seen in the graph cannot be solely correlated to sediment compaction because of the tendency of the lower sediments to be marginal marine and therefore finer grained. Outside of this tendency, there is no inherent connection between increasing depth and decreasing K. However, the Otay Trolley, Naval Base, and El Toyon Park series have K values that show no recognizable decrease or increase related to increasing depth. The Otay Trolley series shows twin peaks of 38 feet per day readings recorded at 225 and 920 feet below the surface. These values are on either side of a 19.5 feet per day reading at 550 feet below the surface. The three values together represent a region of high conductivity in the middle of the borehole interval.
The graph shows some correlation between increasing depth below the surface and decreasing hydraulic conductivity. There are a few obvious outliers and the relationship suggested by the trend line is not followed uniformly by the data.
Conductivity with respect to mean sea level (altitude of sediments) –

More information can be taken from the graph of conductivity against altitude (Fig. 13). Altitude was found by subtracting the depth to the middle of each open interval from the height above mean sea level of the well site surface. The values are plotted logarithmically on the graph and gradually increase in hydraulic conductivity with increasing altitude. However, a moving average would jump considerably both up and down because of order of magnitude differences between conductivity in any interval of more than four altitudes. The gradual increase in conductivity is broken sharply by the lowest two K values in the study, 0.02 feet per day at -555 feet and 0.06 feet per day at -51 feet. For only three of the seven well sites was the highest K value at the highest open interval and for only three was the K value for the highest open interval over 7.2 feet per day.

CONCLUSION

The sediments of the San Diego Bay area subsurface are laterally heterogeneous and, in general, poorly sorted. The first reason for lateral heterogeneity is natural variation in energy environments along the coast during deposition. This variety included complexities of a lagoonal bay, estuaries, and ephemeral fluvial processes. Syndepositional tectonics created yet more natural variation in environments. The Rose Canyon and National fault systems offset strata in the area and both were active during deposition of the Pleistocene and Pliocene. Lack of sorting can be attributed to the energy environments that likely dominated during this time, namely the lagoonal and estuarine settings. The dampened K values for alluvial and shore zone deposits reflect the poor sorting in these paleoenvironments.
The trend line of the graph shows a mild increase in K with increasing altitude. However, there is variation of orders of magnitude in every section of the graph.
The most important result of this study is to have the first extensive testing of subsurface conductivities in the San Diego area. With the diversity of depths tested, 0.02 feet per day to 100 feet per day is a reasonable approximation of the actual range in local conductivity. This study separated the range into three divisions: low conductivity (0.02-2.99 ft/day), medium conductivity (3-19.99 ft/day), and high conductivity (20-100 ft/day). The lowest range is typical of sediments that are rich in silt in their grain size distribution. The medium range is typical of sediments dominated by fine and medium sands. The upper range likely represents an increased sorting of the sediments as much as it represents larger sand grains.

**Direction for future testing** –

After this set of testing was completed, another well was completed in the Otay Valley, almost two miles upstream of the Otay Trolley site. This new site, called Otay River, is in line with the current strategy of placing monitoring wells parallel to the coast on two transects. One transect is near the shore of the San Diego Bay and the other is a couple miles farther inland.

The Otay River site also follows precedent by being in a fluvial valley. My study suggests this is the most important factor in finding a section of the subsurface that conducts water well. The Pliocene embayment’s organically-rich environment and the abundance of clay-sized grains provided a consistent supply of finer grains to the contemporary formations. If these finer grains were not scoured from the sediments before burying, they will retard hydraulic conductivities in the subsurface. With the higher conductivities at sites such as Otay Trolley and Mile of Cars, it seems that the rivers were able to winnow out finer sediments in their downstream reaches. More
monitoring wells need to be placed both in and out of river channels to confirm or
disprove this association.

More work is also needed to identify the extent and thickness variations of
stratigraphic units in the San Diego area. Conductivity data for sediment types are
somewhat useless if they can only be attributed to points and not volumes. Drilling of
more monitoring wells will help in this process, providing that driller’s logs are taken
carefully and uniformly. Wells and logs in the north section of the city would be
particularly helpful in determining continuity of formation thickness. Moving forward
with plans to pump or store and recover from local formations before obtaining more
information would be unwise.

REFERENCES CITED

Diego Formation, southwestern San Diego County. Report of Investigation., San Diego
Resources: 145-54.
Huntley, D. (1994). Groundwater Studies of the San Diego Formation. San Diego, California,
Boyle Engineering Corporation and Sweetwater Authority: 25.

ACKNOWLEDGEMENTS

Thank you to the United States Geological Survey for funding this work and to Wesley
Danskin for allowing me to take on this project and encouraging me along the way.
Thank you to Rhett Everett for teaching me how to do slug testing. Thank you to Keith Halford for providing Excel programs and otherwise being a great resource. Thank you to Mary Savina and Clint Cowan for advising me on the synthesis of my ideas and the writing of this paper. Thanks for the help from all the others at San Diego Hydrogeology, including Michael O’Hare, Gregory Mendez, Perry Spector, Matthew Cha, Joshua Agozino, Eric Reichard, Robert Anders, Damon Jordan, Joseph Nawikas, and Zhen Li. Thanks for help and encouragement also goes to: Gail Anderson and Daniel Elsass, Sarah Crump, Elizabeth Pedreiro, Nelson, Pine Tree Lumber Co., Frank Toyota of National City, Mark Carnley and the great guys at the Hydrologic Instrumentation Facility, In-Situ, Inc. and the Level Troll 700.
Appendix A - Hydrographs from Slug Testing
Balboa Park Well #4

Time (HH:MM:SS)

Water Level (feet above transducer)

WaterLevel
Static Water Level
Static - Equivalent Head for small slug
Static - Equivalent Head for large slug
Static + Equivalent Head for small slug
Static + Equivalent Head for large slug
SDNB Well #2

Time (HH:MM:SS)

Water Level (feet above transducer)

- WaterLevel
- Static Water Level
- Static - Equivalent Head for small slug
- Static + Equivalent Head for small slug
- Static - Equivalent Head for large slug
- Static + Equivalent Head for large slug
SDNB Well #3

Water Level (feet above transducer)

Time (HH:MM:SS)

- WaterLevel
- Static Water Level
- Static - Equivalent Head for small slug
- Static + Equivalent Head for small slug
- Static - Equivalent Head for large slug
- Static + Equivalent Head for large slug
Tia Juana Valley Well #1

Time (HH:MM:SS)

Water Level (feet above transducer)

- WaterLevel
- Static - Equivalent Head for small slug
- Static - Equivalent Head for large slug

Static Water Level

Static + Equivalent Head for small slug

Static + Equivalent Head for large slug
Appendix B - Matched Curves for Calculating K
WELL ID: {NAME HERE}

Local ID: {ID HERE}

Date: 4/27/2008
Time: 0:00

Aquifer Thickness = 68 Feet

\( y_0-\text{DISPLACEMENT} = 1.89 \text{ Feet} \)
\( y_0-\text{SLUG} = 1.47 \text{ Feet} \)
\( L_{\text{ESTIMATED}} = 18 \text{ Feet} \)
\( L_{\text{THEORETICAL}} = 1500 \text{ Feet} \)

MF = 0.753 1/sec

\( K = 3.3 \text{ Feet/Day} \)

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Local ID: {ID HERE}

INPUT

Date: 4/27/2008
Time: 0:00

Construction:
- Casing dia. \((d_c)\) = 1.939 Inch
- Annulus dia. \((d_w)\) = 1.939 Inch

Depths to:
- Water level \((DTW)\) = 24 Feet
- Top of Screen = 1470.0 Feet
- Base of Screen = 1490.0 Feet
- Top of Aquifer = 1433 Feet
- Base of Aquifer = 1501 Feet

Annular Fill:
- Across screen -- Medium Sand
- Above screen -- Bentonite

Aquifer Material:
- Fine Sand

COMPUTED

- Aquifer Thickness = 68 Feet
- \(y_0-DISPLACEMENT\) = 2.82 Feet
- \(y_0-SLUG\) = 3.00 Feet
- \(L_{ESTIMATED}\) = 200 Feet
- \(L_{THEORETICAL}\) = 1500 Feet
- \(MF\) = 2.5 1/sec
- \(K\) = 3.8 Feet/Day

#VALUE!

REMARKS:
- Butler, Garnett, and Healey, 2003, Ground Water 41(5)

**WELL ID: {NAME HERE}**

**Local ID: {ID HERE}**

<table>
<thead>
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<tr>
<td>Casing dia. ($d_c$)</td>
<td>1.939 Inch</td>
<td></td>
</tr>
<tr>
<td>Annulus dia. ($d_w$)</td>
<td>1.939 Inch</td>
<td></td>
</tr>
<tr>
<td>Depths to:</td>
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</tr>
<tr>
<td>water level (DTW)</td>
<td>17.6 Feet</td>
<td></td>
</tr>
<tr>
<td>Top of Screen</td>
<td>1020.0 Feet</td>
<td></td>
</tr>
<tr>
<td>Base of Screen</td>
<td>1040.0 Feet</td>
<td></td>
</tr>
<tr>
<td>Top of Aquifer</td>
<td>998 Feet</td>
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</tr>
<tr>
<td>Base of Aquifer</td>
<td>1060 Feet</td>
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<td></td>
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<tr>
<td>above screen -- Bentonite</td>
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</tr>
<tr>
<td>Aquifer Material -- Fine Sand</td>
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<table>
<thead>
<tr>
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<tr>
<td>Aquifer Thickness</td>
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<tr>
<td>$y_0$-DISPLACEMENT $=$</td>
<td>2.49 Feet</td>
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</tr>
<tr>
<td>$y_0$-SLUG $=$</td>
<td>3.00 Feet</td>
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<tr>
<td>$L_{ESTIMATED}$ $=$</td>
<td>15 Feet</td>
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</tr>
<tr>
<td>$L_{THEORETICAL}$ $=$</td>
<td>1000 Feet</td>
<td></td>
</tr>
<tr>
<td>$K$ $=$</td>
<td>0.689 1/sec</td>
<td></td>
</tr>
<tr>
<td>$= 3.8$ Feet/Day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMS $=$</td>
<td>0.16 Feet</td>
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</tbody>
</table>

**REMARKS:** Butler, Garnett, and Healey, 2003, Ground Water 41(5)

**EXAMPLE from Butler, J.J., Jr., and E.J. Garnett, 2000, Simple procedures for analysis of slug tests in formations of high hydraulic conductivity using spreadsheet and scientific graphics software, Kansas Geological Survey Open-File Rept. 2000-40, Lawrence, Ks.**
INPUT

Construction:
- Casing dia. \( (d_c) \): 1.939 Inch
- Annulus dia. \( (d_w) \): 1.939 Inch

Depths to:
- Water level (DTW): 17.6 Feet
- Top of Screen: 1020.0 Feet
- Base of Screen: 1040.0 Feet
- Top of Aquifer: 998 Feet
- Base of Aquifer: 1060 Feet

Annular Fill:
- Across screen: Coarse Sand
- Above screen: Bentonite

Aquifer Material:
- Stream Terrace Deposits

Computed:
- Aquifer Thickness: 62 Feet
- \( y_0 - \text{DISPLACEMENT} = \): 1.39 Feet
- \( y_0 - \text{SLUG} = \): 1.54 Feet
- \( L_{\text{ESTIMATED}} = \): 13 Feet
- \( L_{\text{THEORETICAL}} = \): 1000 Feet
- \( MF = \): 0.629 1/sec
- \( K = \): 3.6 Feet/Day

RMS = 0.062 Feet

REMARKS:
Butler, Garnett, and Healey, 2003, Ground Water 41(5)

OUTPUT Chart 41

The chart illustrates the normalized displacement measured over time compared to the simulated data. The data points are shown as circles, with a red line representing the simulated data. The x-axis represents elapsed time in seconds, ranging from 00:00 to 03:36, while the y-axis represents normalized displacement, ranging from 1 to 0. The chart shows a general trend of decreasing normalized displacement over time, with slight variations between the measured and simulated data points.
**WELL ID: {NAME HERE}**

**Construction:**
- Casing dia. \((d_c)\) 1.939 Inch
- Annulus dia. \((d_w)\) 1.939 Inch

**Depths to:**
- water level (DTW) 81.6 Feet
- Top of Screen 560.0 Feet
- Base of Screen 580.0 Feet
- Top of Aquifer 550 Feet
- Base of Aquifer 590 Feet

**Annular Fill:**
- across screen -- Coarse Sand
- above screen -- Bentonite

**Aquifer Material:** Medium-Grained Sand

**INPUT Date:** 4/27/2008  
**Time:** 0:00

**COMPUTED**

<table>
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<td>(y_0)-DISPLACEMENT</td>
<td>2.90 Feet</td>
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<tr>
<td>(y_0)-SLUG</td>
<td>1.54 Feet</td>
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<tr>
<td>(L_{\text{ESTIMATED}})</td>
<td>11 Feet</td>
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<td>(L_{\text{THEORETICAL}})</td>
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<tr>
<td>MF</td>
<td>0.573 1/sec</td>
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<tr>
<td>(K)</td>
<td>1.5 Feet/Day</td>
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</table>

**RMS = 0.36 Feet**

**REMARKS:**

OUTPUT Chart 41

The chart shows the normalized displacement over elapsed time, with measured data represented by black circles and simulated data by red line. The y-axis represents normalized displacement ranging from -0.2 to 1.0, and the x-axis represents elapsed time in seconds ranging from 00:00 to 02:18.
### WELL ID: {NAME HERE}

**Local ID:** {ID HERE}

**Date:** 4/27/2008  
**Time:** 0:48

### COMPUTED

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<td>L_ESTIMATED</td>
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<td>L_THEORETICAL</td>
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<tr>
<td>MF</td>
<td>1.2 1/sec</td>
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<tr>
<td>K</td>
<td>2.6 Feet/Day</td>
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### INPUT

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<td>Annulus dia. (d_w)</td>
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<tr>
<td>Base of Aquifer</td>
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<tr>
<td>above screen</td>
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**Input is consistent.**

**REMARKS:** Butler, Garnett, and Healey, 2003, Ground Water 41(5)

INPUT

Construction:
- Casing dia. \( (d_c) \) 1.939 Inch
- Annulus dia. \( (d_w) \) 1.939 Inch

Depths to:
- Water level (DTW) 76 Feet
- Top of Screen 100.0 Feet
- Base of Screen 120.0 Feet
- Top of Aquifer 90 Feet
- Base of Aquifer 130 Feet

Annular Fill:
- Across screen -- Coarse Sand
- Above screen -- Bentonite

Aquifer Material -- Fine Sand

COMPUTED

Aquifer Thickness 40 Feet
\( y_0 \)-DISPLACEMENT = 1.77 Feet
\( y_0 \)-SLUG = 1.54 Feet
\( L_{\text{ESTIMATED}} \) = 240 Feet
\( L_{\text{THEORETICAL}} \) = 34 Feet

\( MF = 2.74 \) \( 1/\text{sec} \)
\( K = 13 \) Feet/Day

RMS = 0.35 Feet

REMARKS:

Butler, Garnett, and Healey, 2003, Ground Water 41(5)

Chart 41

OUTPUT Chart 41

NORMALIZED DISPLACEMENT

MEASURED

SIMULATED

ELAPSED TIME, IN SECONDS
WELL ID: {NAME HERE}

Local ID: {ID HERE}

Date: 4/27/2008
Time: 0:00

INPUT

Casing dia. (d_c) 1.939 Inch
Annulus dia. (d_w) 1.939 Inch

Depth to:
- water level (DTW) 131 Feet
- Top of Screen 920.0 Feet
- Base of Screen 960.0 Feet
- Top of Aquifer 910 Feet
- Base of Aquifer 975 Feet

Annular Fill:
- across screen -- Coarse Sand
- above screen -- Bentonite

Aquifer Material -- Surficial Aquifer, central

COMPUTED

Aquifer Thickness 65 Feet

\(y_0\text{-DISPLACEMENT} = 2.96\) Feet
\(y_0\text{-SLUG} = 1.54\) Feet
\(L_{\text{ESTIMATED}} = 96\) Feet
\(L_{\text{THEORETICAL}} = 810\) Feet

\(M_F = 1.72\) 1/sec
\(K = 1.2\) Feet/Day

RMS = 0.2 Feet

KGS_High-K

REMARKS:

Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Local ID: {ID HERE}

Date: 4/27/2008
Time: 0:00

INPUT

Construction:
- Casing dia. (d_c) 1.939 Inch
- Annulus dia. (d_w) 1.939 Inch

Depths to:
- water level (DTW) 106.3 Feet
- Top of Screen 1260.0 Feet
- Base of Screen 1300.0 Feet
- Top of Aquifer 1250 Feet
- Base of Aquifer 1310 Feet

Annular Fill:
- across screen -- Coarse Sand
- above screen -- Bentonite
- Aquifer Material -- Fine Sand

COMPUTED

Aquifer Thickness 60 Feet
- y_0-DISPLACEMENT = 2.34 Feet
- y_0-SLUG = 1.54 Feet
- L_ESTIMATED = 37 Feet
- L_THEORETICAL = 1200 Feet

MF = 1.07 1/sec
K = 3.6 Feet/Day

RMS = 0.12 Feet

KGS_High-K

REMARKS:
Butler, Garnett, and Healey, 2003, Ground Water 41(5)

**WELL ID: {NAME HERE}**

**Local ID: {ID HERE}**

**INPUT**

- **Construction:**
  - Casing dia. \((d_c)\) 1.939 Inch
  - Annulus dia. \((d_w)\) 1.939 Inch

- **Depths to:**
  - water level (DTW) 123.8 Feet
  - Top of Screen 410.0 Feet
  - Base of Screen 430.0 Feet
  - Top of Aquifer 400 Feet
  - Base of Aquifer 440 Feet

- **Annular Fill:**
  - across screen -- Coarse Sand
  - above screen -- Bentonite

- **Aquifer Material:**
  - Fine Sand

**COMPUTED**

- **Aquifer Thickness** 40 Feet
- **\(y_0\)-DISPLACEMENT** = 2.05 Feet
- **\(y_0\)-SLUG** = 1.54 Feet
- **\(L_{\text{ESTIMATED}}\)** = 4.1 Feet
- **\(L_{\text{THEORETICAL}}\)** = 300 Feet
- **MF** = 0.359 1/sec
- **\(K\)** = 5.8 Feet/Day
- **RMS** = 0.18 Feet

**REMARKS:**

Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Local ID: {ID HERE}
Date: 4/27/2008
Time: 0:00

INPUT

Construction:
- Casing dia. (d_c) 1.939 Inch
- Annulus dia. (d_w) 1.939 Inch

 Depths to:
- water level (DTW) 94.45 Feet
- Top of Screen 150.0 Feet
- Base of Screen 170.0 Feet
- Top of Aquifer 140 Feet
- Base of Aquifer 180 Feet

Annular Fill:
- across screen -- Coarse Sand
- above screen -- Bentonite

Aquifer Material:
- Silt, Loess

COMPUTED

Aquifer Thickness 40 Feet

\[ y_0 - \text{DISPLACEMENT} = 1.45 \text{ Feet} \]
\[ y_0 - \text{SLUG} = 1.54 \text{ Feet} \]
\[ L_{\text{ESTIMATED}} = 4600 \text{ Feet} \]
\[ L_{\text{THEORETICAL}} = 66 \text{ Feet} \]

\[ MF = 12 \text{ 1/sec} \]
\[ K = 0.055 \text{ Feet/Day} \]

RMS = 0.037 Feet

KGS_High-K

REMARKS:
Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Local ID: {ID HERE}

Date: 4/27/2008
Time: 0:00

INPUT Date: 4/27/2008
Time: 0:00

Construction: Time: 0:00
Casing dia. (d_c) 1.939 Inch
Annulus dia. (d_w) 1.939 Inch

Depths to:
- water level (DTW) 94.45 Feet
- Top of Screen 150.0 Feet
- Base of Screen 170.0 Feet
- Top of Aquifer 140 Feet
- Base of Aquifer 180 Feet

Annular Fill:
- across screen -- Coarse Sand
- above screen -- Bentonite

Aquifer Material -- Silt, Loess

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)

**WELL ID: {NAME HERE}**

**INPUT**
- Casing dia. ($d_c$) 2.939 Inch
- Annulus dia. ($d_w$) 2.939 Inch

**Depths to:**
- water level (DTW) 58 Feet
- Top of Screen 1440.0 Feet
- Base of Screen 1480.0 Feet
- Top of Aquifer 1440 Feet
- Base of Aquifer 1480 Feet

**Annular Fill:**
- across screen -- Coarse Sand
- above screen -- Bentonite

**Aquifer Material:**
- Fine Sand

**Computed**
- Aquifer Thickness 40 Feet
- $y_0$-DISPLACEMENT = 1.98 Feet
- $y_0$-SLUG = 0.67 Feet
- $L_{ESTIMATED}$ = 730 Feet
- $L_{THEORETICAL}$ = 1400 Feet
- MF = 4.77 1/sec
- $K = 8.7$ Feet/Day
- RMS = 0.09 Feet

**Remarks:**
- Butler, Garnett, and Healey, 2003, Ground Water 41(5)
**WELL ID: {NAME HERE}**

**Local ID: {ID HERE}**

**INPUT**

<table>
<thead>
<tr>
<th>Construction:</th>
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</thead>
<tbody>
<tr>
<td>Casing dia. (d_c)</td>
</tr>
<tr>
<td>Annulus dia. (d_w)</td>
</tr>
</tbody>
</table>

** Depths to:**

| water level (DTW) | 50.9 Feet |
| Top of Screen | 1100.0 Feet |
| Base of Screen | 1120.0 Feet |
| Top of Aquifer | 1090 Feet |
| Base of Aquifer | 1130 Feet |

**Annular Fill:**

- across screen -- Coarse Sand
- above screen -- Bentonite

| Aquifer Material -- Fine Sand |

**COMPUTED**

- Aquifer Thickness = 40 Feet
- y_0-DISPLACEMENT = 1.63 Feet
- y_0-SLUG = 1.54 Feet
- L_ESTIMATED = 1100 Feet
- L_THEORETICAL = 1100 Feet

- MF = 5.73 1/sec
- K = 18 Feet/Day

**RMS = 0.11 Feet**


**REMARKS:**

Butler, Garnett, and Healey, 2003, Ground Water 41(5)
**WELL ID: {NAME HERE}**

**INPUT**

**Construction:**
- Casing dia. \( (d_c) \) 1.939 Inch
- Annulus dia. \( (d_w) \) 1.939 Inch

** Depths to:**
- water level \( (DTW) \) 50.9 Feet
- Top of Screen 1100.0 Feet
- Base of Screen 1120.0 Feet
- Top of Aquifer 1090 Feet
- Base of Aquifer 1130 Feet

**Annular Fill:**
- across screen -- Coarse Sand
- above screen -- Bentonite

**Aquifer Material:**
- Fine Sand

**COMPUTED**

- Aquifer Thickness 40 Feet
- \( y_0 - \text{DISPLACEMENT} \) = 2.88 Feet
- \( y_0 - \text{SLUG} \) = 1.54 Feet
- \( L_{\text{ESTIMATED}} \) = 1100 Feet
- \( L_{\text{THEORETICAL}} \) = 1100 Feet
- \( MF = 5.73 \, 1/\text{sec} \)
- \( K = 18 \, \text{Feet/Day} \)

**RMS = 0.25 Feet**

**REMARKS:**


### WELL ID: {NAME HERE}

**Local ID: {ID HERE}**

**INPUT**

- **Casing dia. (d_c)**: 1.939 Inch
- **Annulus dia. (d_w)**: 1.939 Inch

**Depths to:**

- **water level (DTW)**: 43.5 Feet
- **Top of Screen**: 700.0 Feet
- **Base of Screen**: 720.0 Feet
- **Top of Aquifer**: 690 Feet
- **Base of Aquifer**: 730 Feet

**Annular Fill:**

- across screen -- Coarse Sand
- above screen -- Bentonite

**Aquifer Material:** Medium Sand

---

### COMPUTED

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquifer Thickness</td>
<td>40 Feet</td>
</tr>
<tr>
<td>y_0-DISPLACEMENT</td>
<td>1.55 Feet</td>
</tr>
<tr>
<td>y_0-SLUG</td>
<td>1.54 Feet</td>
</tr>
<tr>
<td>L_ESTIMATED</td>
<td>510 Feet</td>
</tr>
<tr>
<td>L_THEORETICAL</td>
<td>670 Feet</td>
</tr>
<tr>
<td>MF</td>
<td>3.97 1/sec</td>
</tr>
<tr>
<td>K</td>
<td>22 Feet/Day</td>
</tr>
</tbody>
</table>

**RMS = 0.15 Feet**

**KGS_High-K**

---

**REMARKS:**


**WELL ID: {NAME HERE}**

**Local ID: {ID HERE}**

**INPUT**

**Construction:**
- Casing dia. ($d_c$) 1.9 Inch
- Annulus dia. ($d_w$) 1.9 Inch

**Depths to:**
- Water level (DTW) 43.5 Feet
- Top of Screen 700.0 Feet
- Base of Screen 720.0 Feet
- Top of Aquifer 690 Feet
- Base of Aquifer 730 Feet

**Annular Fill:**
- Across screen -- Coarse Sand
- Above screen -- Bentonite

**Aquifer Material:**
- Fine Sand

**COMPUTED**

- Aquifer Thickness 40 Feet
- $y_0$-Displacement = 2.97 Feet
- $y_0$-Slug = 1.60 Feet
- $L_{\text{Estimated}}$ = 470 Feet
- $L_{\text{Theoretical}}$ = 670 Feet
- MF = 3.83 1/sec
- $K$ = 19 Feet/Day

**RMS = 0.34 Feet**

**REMARKS:**
Butler, Garnett, and Healey, 2003, Ground Water 41(5)

**EXAMPLE from Butler, J.J., Jr., and E.J. Garnett, 2000, Simple procedures for analysis of slug tests in formations of high hydraulic conductivity using spreadsheet and scientific graphics software, Kansas Geological Survey Open-File Rept. 2000-40, Lawrence, Ks.**
WELL ID: {NAME HERE}

Local ID: {ID HERE}
Date: 4/27/2008
Time: 0:46

INPUT

Construction:
- Casing dia. \( (d_c) \) 1.939 Inch
- Annulus dia. \( (d_w) \) 1.939 Inch

 Depths to:
- Water level \( (DTW) \) 21.9 Feet
- Top of Screen 260.0 Feet
- Base of Screen 280.0 Feet
- Top of Aquifer 250 Feet
- Base of Aquifer 290 Feet

Annular Fill:
- Across screen -- Coarse Sand
- Above screen -- Bentonite

Aquifer Material -- Coarse Sand

COMPUTED

- Aquifer Thickness 40 Feet
- \( y_0\text{-DISPLACEMENT} = 2.27 \) Feet
- \( y_0\text{-SLUG} = 1.54 \) Feet
- \( L_{\text{ESTIMATED}} = 240 \) Feet
- \( L_{\text{THEORETICAL}} = 250 \) Feet
- \( MF = 2.74 \) 1/sec
- \( K = 100 \) Feet/Day

REMARKS:

Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

INPUT

Construction:
- Casing dia. \(d_c\) = 1.9 Inch
- Annulus dia. \(d_w\) = 1.9 Inch

Depths to:
- water level (DTW) = 19.1 Feet
- Top of Screen = 30.0 Feet
- Base of Screen = 70.0 Feet
- Top of Aquifer = 30 Feet
- Base of Aquifer = 70 Feet

Annular Fill:
- across screen -- Coarse Sand
- above screen -- Bentonite

Aquifer Material -- Medium Sand

COMPUTED

Aquifer Thickness = 40 Feet
- \(y_0\)-DISPLACEMENT = 0.81 Feet
- \(y_0\)-SLUG = 1.60 Feet
- \(L_{\text{ESTIMATED}}\) = 22 Feet
- \(L_{\text{THERORETICAL}}\) = 31 Feet

- \(MF\) = 0.829 1/sec
- \(K\) = 42 Feet/Day

RMS = 0.093 Feet

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)

**WELL ID: {NAME HERE}**

**Local ID: {ID HERE}**

**DATE:** 4/27/2008  
**Time:** 0:00

**INPUT**

- **Casing dia. \((d_c)\):** 2.939 Inch  
- **Annulus dia. \((d_w)\):** 2.939 Inch

**Depths to:**

- **water level (DTW):** 35.4 Feet  
- **Top of Screen:** 1460.0 Feet  
- **Base of Screen:** 1500.0 Feet  
- **Top of Aquifer:** 1450 Feet  
- **Base of Aquifer:** 1510 Feet

**Annular Fill:**

- across screen -- Coarse Sand  
- above screen -- Bentonite

**Aquifer Material:** Medium Sand  

- **MF =** 5.73 1/sec  
- **K =** 38 Feet/Day

**COMPUTED**

- **Aquifer Thickness:** 60 Feet  
- **\(y_0\)-DISPLACEMENT =** 1.78 Feet  
- **\(y_0\)-SLUG =** 0.67 Feet  
- **\(L_{\text{ESTIMATED}} =** 1100 Feet  
- **\(L_{\text{THEORETICAL}} =** 1400 Feet

**RMS =** 0.18 Feet

**REMARKS:**


**EXAMPLE from Butler, J.J., Jr., and E.J. Garnett, 2000, Simple procedures for analysis of slug tests in formations of high hydraulic conductivity using spreadsheet and scientific graphics software, Kansas Geological Survey Open-File Rept. 2000-40, Lawrence, Ks.**
**WELL ID: {NAME HERE}**

**Local ID: {ID HERE}**

**INPUT**

**Date:** 4/27/2008  
**Time:** 0:33

**Construction:**
- Casing dia. \( d_c \): 2.939 Inch
- Annulus dia. \( d_w \): 2.939 Inch

**Depths to:**
- Water level (DTW): 35.4 Feet  
- Top of Screen: 1460.0 Feet  
- Base of Screen: 1500.0 Feet  
- Top of Aquifer: 1450 Feet  
- Base of Aquifer: 1510 Feet

**Annular Fill:**
- Across screen -- Coarse Sand  
- Above screen -- Bentonite

**Aquifer Material:**
- Medium Sand

---

**COMPUTED**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquifer Thickness</td>
<td>60 Feet</td>
</tr>
<tr>
<td>( y_0 )-DISPLACEMENT</td>
<td>3.57 Feet</td>
</tr>
<tr>
<td>( y_0 )-SLUG</td>
<td>0.67 Feet</td>
</tr>
<tr>
<td>( L_{\text{ESTIMATED}} )</td>
<td>1300 Feet</td>
</tr>
<tr>
<td>( L_{\text{THEORETICAL}} )</td>
<td>1400 Feet</td>
</tr>
<tr>
<td>MF</td>
<td>6.29 1/sec</td>
</tr>
<tr>
<td>K</td>
<td>32 Feet/Day</td>
</tr>
</tbody>
</table>

**RMS = 0.19 Feet**

**KGS_High-K**

---

**REMARKS:**


WELL ID: {NAME HERE}

INPUT

Casing dia. (dc) 1.939 Inch
Annulus dia. (dw) 1.939 Inch

Depths to:
- water level (DTW) 23.5 Feet
- Top of Screen 660.0 Feet
- Base of Screen 680.0 Feet
- Top of Aquifer 650 Feet
- Base of Aquifer 690 Feet

Annular Fill:
- across screen -- Coarse Sand
- above screen -- Bentonite
- Aquifer Material -- Fine Sand

Local ID: {ID HERE}
Date: 4/27/2008
Time: 0:36

COMPUTED

Aquifer Thickness 40 Feet
- y0-DISPLACEMENT = 2.01 Feet
- y0-SLUG = 1.54 Feet
- LESTIMATED = 1300 Feet
- LTHEORETICAL = 650 Feet

MF = 6.29 1/sec
K = 4.2 Feet/Day

RMS = 0.22 Feet

REMARKS:

- Butler, Garnett, and Healey, 2003, Ground Water 41(5)
WELL ID: {NAME HERE}

Local ID: {ID HERE}

Date: 4/27/2008
Time: 0:00

Aquifer Thickness 40 Feet

\[ y_0 - \text{DISPLACEMENT} = 1.35 \text{ Feet} \]
\[ y_0 - \text{SLUG} = 1.54 \text{ Feet} \]
\[ L_{\text{ESTIMATED}} = 97 \text{ Feet} \]
\[ L_{\text{THEORETICAL}} = 180 \text{ Feet} \]

\[ MF = 1.73 \text{ 1/sec} \]
\[ K = 26 \text{ Feet/Day} \]

RMS = 0.16 Feet

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Local ID: {ID HERE}

INPUT

Date: 4/27/2008
Time: 0:00

Casing dia. (d_c) 1.9 Inch
Annulus dia. (d_w) 1.9 Inch

Depths to:

- water level (DTW) 8.3 Feet
- Top of Screen 20.0 Feet
- Base of Screen 25.0 Feet
- Top of Aquifer 15 Feet
- Base of Aquifer 30 Feet

Annular Fill:
- across screen -- Coarse Sand
- above screen -- Bentonite

Aquifer Material -- Fine Sand

COMPUTED

Aquifer Thickness 15 Feet

- y0-DISPLACEMENT = 2.17 Feet
- y0-SLUG = 1.60 Feet
- LESTIMATED = 46 Feet
- LTHEORETICAL = 14 Feet

MF = 1.2 1/sec
K = 6 Feet/Day

RMS = 0.28 Feet

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)
WELL ID: {NAME HERE}  Local ID: {ID HERE}

**INPUT**

Construction:
- Casing dia. \((d_c)\) 2.939 Inch
- Annulus dia. \((d_w)\) 2.939 Inch

Depths to:
- water level (DTW) 32.7 Feet
- Top of Screen 1455.0 Feet
- Base of Screen 1495.0 Feet
- Top of Aquifer 1425 Feet
- Base of Aquifer 1600 Feet

Annular Fill:
- across screen -- Coarse Sand
- above screen -- Bentonite

Aquifer Material:
- Surficial Aquifer, centr

**COMPUTED**

- Aquifer Thickness 180 Feet
- \(y_0\)-DISPLACEMENT = 2.07 Feet
- \(y_0\)-SLUG = 0.67 Feet
- \(L_{ESTIMATED}\) = 3200 Feet
- \(L_{THEORETICAL}\) = 1400 Feet
- MF = 9.96 1/sec
- \(K\) = 0.55 Feet/Day

**REMARKS:**

Butler, Garnett, and Healey, 2003, Ground Water 41(5)


---

![Graph](image_url)
WELL ID: {NAME HERE}

Local ID: {ID HERE}

Date: 4/27/2008
Time: 0:00

INPUT

Construction:
- Casing dia. (d_c) 1.939 Inch
- Annulus dia. (d_w) 1.939 Inch

Depths to:
- water level (DTW) 42.8 Feet
- Top of Screen 910.0 Feet
- Base of Screen 930.0 Feet
- Top of Aquifer 890 Feet
- Base of Aquifer 945 Feet

Annular Fill:
- across screen -- Coarse Sand
- above screen -- Bentonite

Aquifer Material -- Medium Sand

COMPUTED

Aquifer Thickness = 55 Feet

y_0 - DISPLACEMENT = 1.80 Feet

y_0 - SLUG = 1.54 Feet

L_ESTIMATED = 510 Feet

L_THEORETICAL = 880 Feet

MF = 3.97 1/sec

K = 35 Feet/Day

RMS = 0.34 Feet

KGS_High-K

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Local ID: {ID HERE}

INPUT

Date: 4/27/2008
Time: 0:00

Construction:

Casing dia. (d_c) 1.939 Inch
Annulus dia. (d_w) 1.939 Inch

Depth to:
water level (DTW) 42.8 Feet
Top of Screen 910.0 Feet
Base of Screen 930.0 Feet
Top of Aquifer 890 Feet
Base of Aquifer 945 Feet

Annular Fill:
across screen -- Coarse Sand
above screen -- Bentonite

Aquifer Material -- Medium Sand

COMPUTED

Aquifer Thickness 55 Feet

y_0-DISPLACEMENT = 3.00 Feet
y_0-SLUG = 3.00 Feet
L_ESTIMATED = 350 Feet
L_THEORETICAL = 880 Feet

MF = 3.3 1/sec
K = 38 Feet/Day

RMS = 1.1 Feet

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Local ID: {ID HERE}

Date: 4/27/2008
Time: 0:00

COMPUTED

Aquifer Thickness 90 Feet

\[ y_0 - \text{DISPLACEMENT} = 1.50 \text{ Feet} \]
\[ y_0 - \text{SLUG} = 1.54 \text{ Feet} \]
\[ L_{\text{ESTIMATED}} = 370 \text{ Feet} \]
\[ L_{\text{THERORETICAL}} = 530 \text{ Feet} \]

\[ \text{MF} = 3.4 \text{ 1/sec} \]
\[ K = 19 \text{ Feet/Day} \]

Aquifer Material -- Fine Sand

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Local ID: {ID HERE}

Date: 4/27/2008
Time: 0:00

Aquifer Thickness 90 Feet

\[ Y_0-DISPLACEMENT = 3.00 \text{ Feet} \]

\[ Y_0-SLUG = 3.00 \text{ Feet} \]

\[ L_{ESTIMATED} = 290 \text{ Feet} \]

\[ L_{THEORETICAL} = 530 \text{ Feet} \]

\[ MF = 3.01 \text{ 1/sec} \]

\[ K = 20 \text{ Feet/Day} \]

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)

**WELL ID: {NAME HERE}**

**INPUT**

<table>
<thead>
<tr>
<th>Construction:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Casing dia. (d_c)</td>
<td>1.939 Inch</td>
</tr>
<tr>
<td>Annulus dia. (d_w)</td>
<td>1.939 Inch</td>
</tr>
</tbody>
</table>

**Depths to:**

- Water level (DTW) 43.8 Feet
- Top of Screen 1340.0 Feet
- Base of Screen 1360.0 Feet
- Top of Aquifer 1330 Feet
- Base of Aquifer 1370 Feet

**Annular Fill:**

- Across screen -- Coarse Sand
- Above screen -- Bentonite

**Aquifer Material:**

- Surficial Aquifer, central

---

**COMPUTED**

<table>
<thead>
<tr>
<th>Aquifer Thickness</th>
<th>40 Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_0$-Displacement</td>
<td>3.22 Feet</td>
</tr>
<tr>
<td>$y_0$-Slug</td>
<td>1.54 Feet</td>
</tr>
<tr>
<td>$L_{estimated}$</td>
<td>170 Feet</td>
</tr>
<tr>
<td>$L_{theoretical}$</td>
<td>1300 Feet</td>
</tr>
<tr>
<td>$MF$</td>
<td>2.28 1/sec</td>
</tr>
<tr>
<td>$K$</td>
<td>1.5 Feet/Day</td>
</tr>
</tbody>
</table>

**RMS = 0.31 Feet**

**REMARKS:**

- Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Construction:
- Casing dia. \((d_c)\) 1.939 Inch
- Annulus dia. \((d_w)\) 1.939 Inch

 Depths to:
- Water level (DTW) 44 Feet
- Top of Screen 1170.0 Feet
- Base of Screen 1190.0 Feet
- Top of Aquifer 1160 Feet
- Base of Aquifer 1200 Feet

Annular Fill:
- Across screen -- Coarse Sand
- Above screen -- Bentonite

Aquifer Material -- Surficial Aquifer, central

INPUT Date: 4/27/2008
Time: 0:00

COMPUTED

- Aquifer Thickness 40 Feet
- \(y_0\text{-DISPLACEMENT} = 3.00\) Feet
- \(y_0\text{-SLUG} = 1.54\) Feet
- \(L_{\text{ESTIMATED}} = 46\) Feet
- \(L_{\text{THEORETICAL}} = 1100\) Feet
- \(MF = 1.2\) 1/sec
- \(K = 2.4\) Feet/Day

REMARKS: Butler, Garnett, and Healey, 2003, Ground Water 41(5)

**WELL ID: \{NAME HERE\}**

**Local ID: \{ID HERE\}**

**INPUT**

- Casing dia. \((d_c)\) 1.939 Inch
- Annulus dia. \((d_w)\) 1.939 Inch

**Depths to:**
- Water level (DTW) 44 Feet
- Top of Screen 1170.0 Feet
- Base of Screen 1190.0 Feet
- Top of Aquifer 1160 Feet
- Base of Aquifer 1200 Feet

**Annular Fill:**
- Across screen -- Coarse Sand
- Above screen -- Bentonite

**Aquifer Material:**
- Surficial Aquifer, central

**COMPUTED**

- Aquifer Thickness 40 Feet
- \(y_0\)-Displacement \(=\) 3.00 Feet
- \(y_0\)-Slug \(=\) 1.54 Feet
- \(L_{\text{ESTIMATED}}\) \(=\) 46 Feet
- \(L_{\text{THEORETICAL}}\) \(=\) 1100 Feet
- MF = 1.2 1/sec
- \(K =\) 2.6 Feet/Day

**REMARKS:**


INPUT

Construction:

- Casing dia. (d_c) 1.939 Inch
- Annulus dia. (d_w) 1.939 Inch

Depths to:

- water level (DTW) 19.4 Feet
- Top of Screen 580.0 Feet
- Base of Screen 600.0 Feet
- Top of Aquifer 570 Feet
- Base of Aquifer 625 Feet

Annular Fill:

- across screen -- Coarse Sand
- above screen -- Bentonite

Aquifer Material -- Silt, Loess

COMPUTED

Aquifer Thickness 55 Feet

\( y_0 - \text{DISPLACEMENT} = 1.53 \text{ Feet} \)

\( y_0 - \text{SLUG} = 1.54 \text{ Feet} \)

\( L_{\text{ESTIMATED}} = 9700 \text{ Feet} \)

\( L_{\text{THEORETICAL}} = 570 \text{ Feet} \)

\( MF = 17.3 \text{ 1/sec} \)

\( K = 0.022 \text{ Feet/Day} \)

RMS = 0.059 Feet

KGS_High-K

REMARKS:

Butler, Garnett, and Healey, 2003, Ground Water 41(5)

WELL ID: {NAME HERE}

Local ID: {ID HERE}

INPUT

Date: 4/27/2008
Time: 0:39

Construction:

- Casing dia. \((d_c)\) 1.939 Inch
- Annulus dia. \((d_w)\) 1.939 Inch

Depths to:

- water level (DTW) 19.2 Feet
- Top of Screen 260.0 Feet
- Base of Screen 280.0 Feet
- Top of Aquifer 250 Feet
- Base of Aquifer 295 Feet

Annular Fill:

- across screen -- Coarse Sand
- above screen -- Bentonite

Aquifer Material -- Fine Sand

COMPUTED

- Aquifer Thickness 45 Feet
- \(y_0\)-DISPLACEMENT = 1.55 Feet
- \(y_0\)-SLUG = 1.54 Feet
- \(L_{ESTIMATED}\) = 350 Feet
- \(L_{THEORETICAL}\) = 250 Feet

- MF = 3.31 1/sec
- \(K\) = 7.9 Feet/Day

RMS = 0.16 Feet

REMARKS:

Input is consistent.

**WELL ID: {NAME HERE}**

**Local ID: {ID HERE}**

**Date:** 4/27/2008  
**Time:** 0:00

**INPUT**

- **Construction:**
  - Casing dia. \( (d_c) \): 1.939 Inch
  - Annulus dia. \( (d_w) \): 1.939 Inch

**Depths to:**

- **water level (DTW):** 9.3 Feet
- **Top of Screen:** 250.0 Feet
- **Base of Screen:** 270.0 Feet
- **Top of Aquifer:** 240 Feet
- **Base of Aquifer:** 280 Feet

**Annular Fill:**

- across screen -- Coarse Sand
- above screen -- Bentonite

**Aquifer Material:**

- Surficial Aquifer, central

**COMPUTED**

- **Aquifer Thickness:** 40 Feet
- **\( y_0-\text{DISPLACEMENT} \):** 1.61 Feet
- **\( y_0-\text{SLUG} \):** 1.54 Feet
- **\( L_{\text{ESTIMATED}} \):** 46 Feet
- **\( L_{\text{THEORETICAL}} \):** 250 Feet

- **MF =** 1.2 1/sec
- **\( K = \) 1.4 Feet/Day**

**RMS = 0.098 Feet**


**REMARKS:**

Butler, Garnett, and Healey, 2003, Ground Water 41(5)
WELL ID: {NAME HERE}

**INPUT**

<table>
<thead>
<tr>
<th>Construction:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Casing dia. (d_c)</td>
<td>1.9 Inch</td>
</tr>
<tr>
<td>Annulus dia. (d_w)</td>
<td>1.9 Inch</td>
</tr>
</tbody>
</table>

**Depths to:**

| Water level (DTW) | 9.3 Feet |
| Top of Screen    | 250.0 Feet |
| Base of Screen   | 270.0 Feet |
| Top of Aquifer   | 240 Feet |
| Base of Aquifer  | 280 Feet |

**Annular Fill:**

- across screen -- Coarse Sand
- above screen -- Bentonite

**Aquifer Material:** Surficial Aquifer, central input is consistent.

**COMPUTED**

- Aquifer Thickness: 40 Feet
- \(y_0\)-DISPLACEMENT = 2.94 Feet
- \(y_0\)-SLUG = 1.60 Feet
- \(L_{\text{ESTIMATED}}\) = 140 Feet
- \(L_{\text{THEORETICAL}}\) = 250 Feet
- MF = 2.08 1/sec
- K = 1.5 Feet/Day

**RMS = 0.22 Feet**

**REMARKS:** Butler, Garnett, and Healey, 2003, Ground Water 41(5)

**EXAMPLE from Butler, J.J., Jr., and E.J. Garnett, 2000, Simple procedures for analysis of slug tests in formations of high hydraulic conductivity using spreadsheet and scientific graphics software, Kansas Geological Survey Open-File Rept. 2000-40, Lawrence, Ks.**