HIGHER LINEAR LOADING RATES BASED ON WATER TABLE MOUNDING MEASURED DURING FULL-SCALE MULTI-DAY TESTING

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Abstract

In our work designing onsite sewage systems, we find many properties with limited length on contour for installing a drainfield. We often solve this problem by using a Water Table Mounding Test. This test directly measures the site's natural discharge capacity, allowing us to validate a custom hydraulic linear loading rate for that property. Over time, we noticed that these full-scale tests usually supported a linear loading rate much higher than allowed in regulatory standards. This paper reviews linear loading rate standards in British Columbia, Canada. We describe the use of water table mounding tests to support higher linear loading rates for small onsite systems. Results from water table mounding tests in BC suggest that we can use higher linear loading rates than specified in many state and provincial standards. We conclude that hillslope-scale hydraulic conductivity is often higher than expected based on small-scale soil permeability tests (or percolation tests). The test results suggest that widely accepted linear loading rate standards may be overly conservative by a factor of 1.5 to 5.

Background to contour loading rates in system design

Water table mounding

Water table mounding is the rise of the water table in response to application of water. When a dispersal system (septic field, sand mound or seepage bed) discharges effluent, the underlying water table rises. This rise in the water table provides the head to overcome resistance to water flow in soils below the water table and drives flow away from the dispersal system.

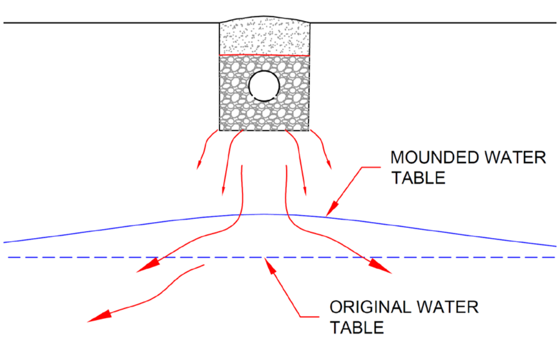

Fig. 1. Schematic cross section of dispersal trench showing water table mounding

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Vertical separation

Dispersal systems rely on unsaturated soils (above the water table) for effective soil-based treatment of effluent. This is particularly important for pathogens and complex organic compounds. The height of this column of unsaturated soil is termed "vertical separation" (VS).

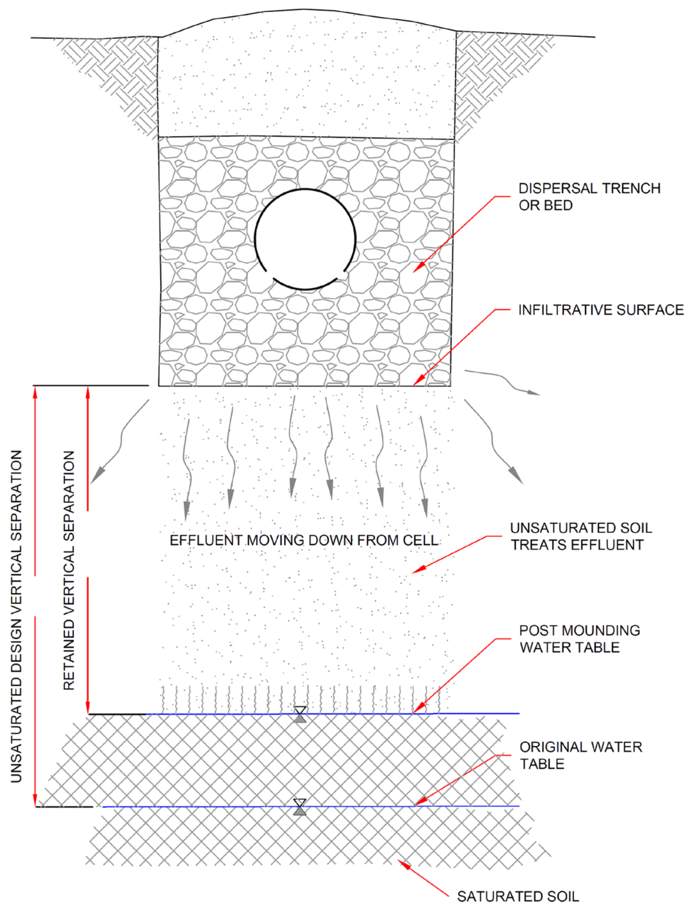


Fig. 2. Schematic cross section of dispersal system showing vertical separation

Through soil-based treatment, a properly planned and operated onsite dispersal system will result in percolate (water) at the base of the unsaturated vertical separation meeting recreational ambient water objectives and no longer being considered "effluent" or a health hazard (Ralston & Payne, 2014).

Based on reported virus attenuation rates, unsaturated flow in a sandy soil is in the order of 50 to 500 times more effective for attenuation of viruses than saturated flow (Emerick et al., 1999; Krauss & Griebler, 2011; Quanrud et al., 2003, 2003; Schijven et al., 2006; Standridge et al., 2001; Wespetal & Frekot, 2001; Winneberger, 1984).

Water table mounding reduces the vertical separation, thus reducing pathogen removal in the soil in the "retained vertical separation" (see Figure 2). In the worst case, the rising water table will meet the near saturated zone below a dispersal trench or bed, resulting in short circuiting of effluent to the water table with little treatment (see Figure 3). Eventually, high enough water table mounding will lead to surfacing of effluent.

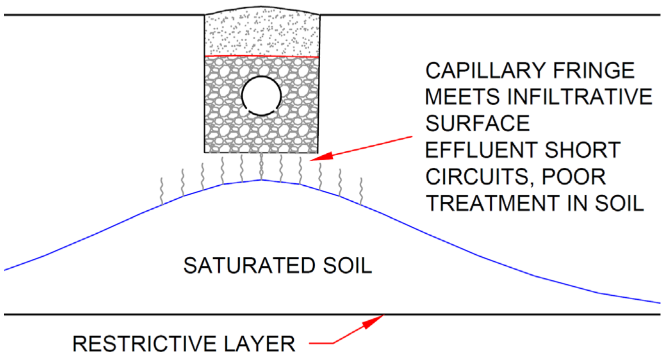


Fig. 3. Illustration of water table mounding and short circuiting

Linear Loading Rate

For any one site and effluent flow rate, the height of the water table mound is proportional to the linear loading rate (contour loading rate or hydraulic linear loading rate). Under a shorter and wider dispersal system, water table rises higher (see Figure 4). The Linear Loading Rate (LLR) is calculated in units of volume flow rate per day per unit of length; for example, litres per day per lineal metre (L/day/m) or US gallons per day per foot (usgal/day/ft).

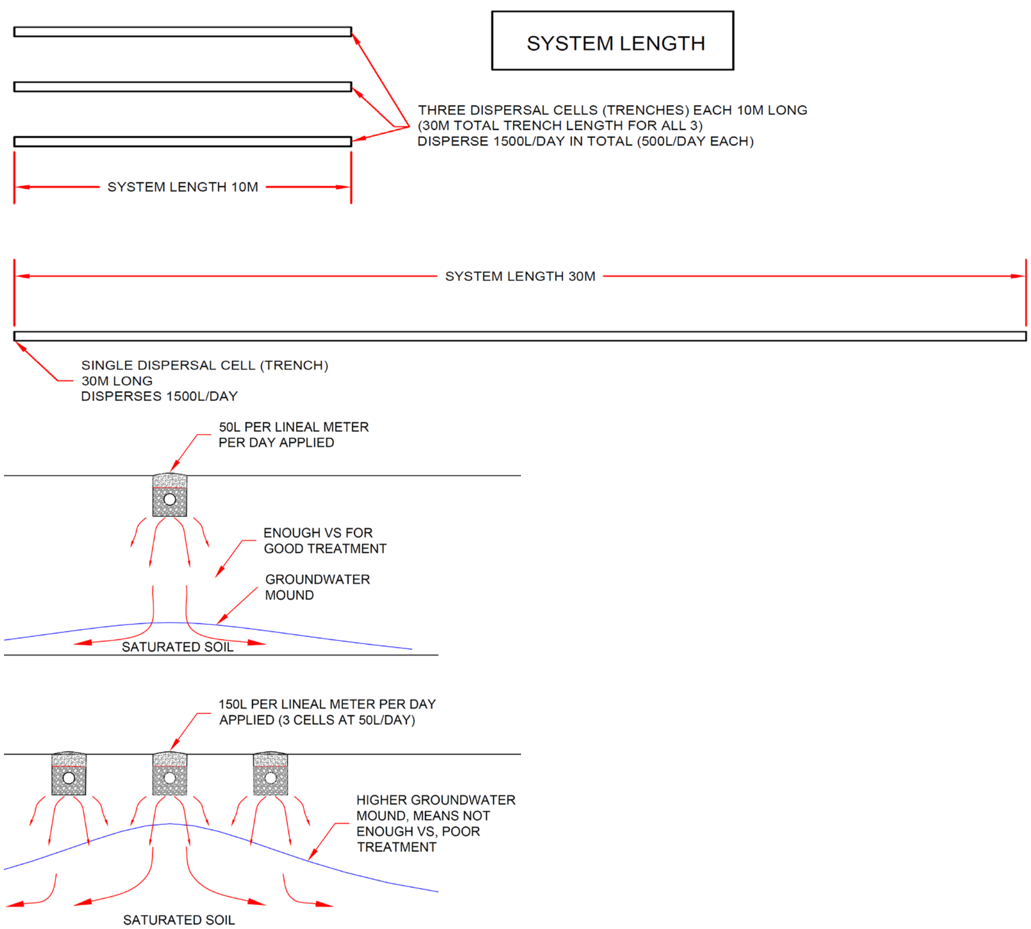


Fig. 4. Illustration of Linear Loading Rate and related water table mounding

Relationship between water table mound and Linear Loading Rate

Many onsite dispersal sites are either sloping or are situated above a water table that has a flow direction induced by a drain, for example, a house perimeter drain, a ditch, a bank with breakout or a water body. The slope of the water table affects the rise of the water table mound. When analyzing small systems, we often estimate the slope of the water table from the land slope. This simplification may lead to errors where the water table surface dips differently than the land surface. A groundwater elevation survey allows a better estimate of the water table slope.

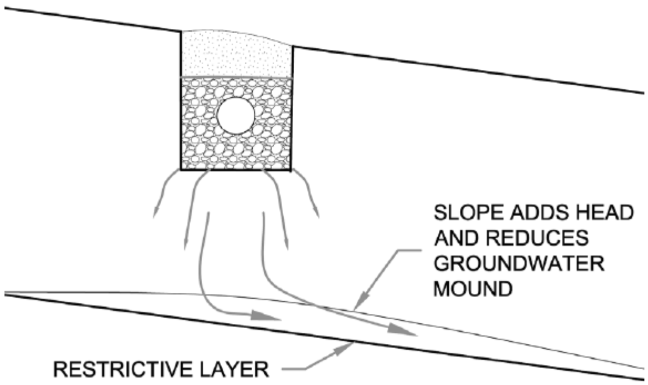


Fig. 5. Water table mounding on a slope.

For flat sites or those with a very low slope, a water table mound may be the sole driver for flow away from the dispersal system. This causes a higher water table mound than we would observe on a sloping site, see Figure 5.

Together with soil depth, the other key factor influencing the height of the water table mound is the soil or underlying material permeability (hydraulic conductivity). A lower permeability soil resists flow and causes the water table to rise higher. Seasonal variation in the background water table causes seasonal fluctuation in the mounded water table.

Linear Loading Rate standards in North America

During the 1980s and 1990s, many new regulations and standards incorporated maximum allowable LLR rather than merely recommending longer systems. For larger wastewater systems, regulations specify modeling of water table mounding, large scale testing, and ongoing monitoring. For smaller systems, regulations often use design tables based on soil characteristics.

Tyler and Converse described the importance of LLR (Converse & Tyler, 1984). This work culminated in a table of recommended safe LLR for a range of soil conditions, slopes and soil depths (Converse & Tyler, 1997; Tyler, 2001; Tyler & Kuns, 2000).

In the intervening time, many North American jurisdictions have adopted the Tyler table, and the United States Environmental Protection Agency adopted the concept of LLR in their authoritative 2002 manual (Otis et al., 2002).

Many US states have adopted the "Tyler" table, while some jurisdictions have adapted or modified that approach. In British Columbia, for example, design tables published in 2014 varied Tyler's 2001 loading rates to a slightly less conservative standard (Ralston & Payne, 2014). The state of Vermont, for another example, offers the option of a simplified prescriptive approach using Darcy's Law to calculate the height of the water table mound (Vermont DEC, 2003).

Meanwhile, for larger flow systems, designers often estimate water table mound height on a site specific basis using modeling and large-scale testing, and then calibrating models after monitoring (Poeter et al., 2005; Zlotnik et al., 2017).

The British Columbia context

The province of British Columbia (BC) Canada is larger than Texas with widely varying terrain and climate. Climate ranges from desert to temperate rainforest, with some regions experiencing annual rainfall exceeding 6 metres (20 feet).

BC has more than one million onsite sewage systems in rural and suburban areas. Challenges for sewerage system design are similar to those found elsewhere in North America, especially for older small lot subdivisions on shallow soil.

BC Regulations and Standard Practice

In BC, sewage systems with dispersal to soil and a peak day flow rate of less than 22,700 litres per day (6,000 US gallons per day) fall under the BC *Public Health Act* and Sewerage System Regulation (SSR).

BC's Regulation is a performance-based professional-reliance regulation. It requires that "Authorized Persons" design and install systems following "Standard Practice". The regulation references the BC Sewerage System Standard Practice Manual (the SPM) as a source of Standard Practice, referred to in this paper as "the BC standard". The SPM is published by the BC Ministry of Health (Ralston & Payne, 2014).

The BC Standard provides pre-validated methods to meet performance objectives and includes written rationale for standards and objectives. Engineers may depart from the BC standard by using performance-based design. This allows for custom design of sewage systems on sites that cannot meet the pre-validated standards. The provincial engineering regulatory body, Engineers and Geoscientists BC, has published a guideline for professionals that advises on how to validate departures from the SPM (McMurtrie et al., 2018).

In British Columbia, the BC standard allows for systems on a wider range of soil types and shallower soil vertical separation than many other jurisdictions (Ralston & Payne, 2014). The standards rely on the system vertical separation for pathogen attenuation, placing less emphasis on horizontal separation distances. To support this, key standards, including vertical separation, hydraulic and linear loading rates are linked. In BC, understanding of water table mounding is especially important because we allow onsite systems on sites with shallow soils.

Contour loading rate standards in British Columbia

BC's standards include maximum allowable LLR. The standards aim to maintain adequate vertical separation to support performance objectives. These standards simplify system design, without requiring designers to estimate the water table mound.

BC standards follow a "two pronged" approach for selecting a loading rate. Using soil depth and site slope categories, this works as follows:

- Select an allowable LLR based on soil characteristics (texture, structure and consistence).
- Select an allowable LLR based on measured field saturated hydraulic conductivity or percolation rate (Ryon percolation rate).
- For design, use the lower of the two LLRs above.

Refer to BC SPM Tables II-26, 27 and 28 (Ralston & Payne, 2014). BC standards use a similar process to select soil hydraulic loading rates (effluent applied per area per day). The BC standard follows the USDA soil classification system and arranges soil texture in a set of simplified groups in the design tables. The BC standard provides a table (II-4) which uses soil structure and consistence to provide a category (Favorable, Poor, Very Poor or NA) for use in other tables.

The BC standard limits the width of seepage beds and sand mound beds to 3.0 m (10 ft) to limit organic contour loading and provide for oxygen transfer.

BC standards include allowable LLR based on Tyler's 2001 table, with adjusted loading rates using Darcy's Law calculations and a cap of 400 L/day/m (32 usgal/day/ft) on LLR. The LLR standards limit the height of the resulting water table mound to no more than 50% of the original design vertical separation, based on Darcy's Law.

In BC, the allowable LLR relates to the peak day design flow rate. The standards use a peak day flow rate of two times the average day flow rate (peaking factor of 2.0), so the allowable LLRs are two times higher than they would be for average daily flow rates.

BC standards recommend site specific analysis of water table mounding for systems with a peak day flow rate over 9,100 L/day (2,400 usgal/day).

Water table mounding analysis

Methods used to estimate water table mounding range from simple to complex numerical modeling.

Darcy's Law equation

Darcy's Law is an empirical law that describes macroscopic flow in porous media where that flow is laminar. Henry Darcy developed the formula in 1856. The base equation for flow in an aquifer is (Cedergren, 1997):

$Q = K\,A\,i$

Where:

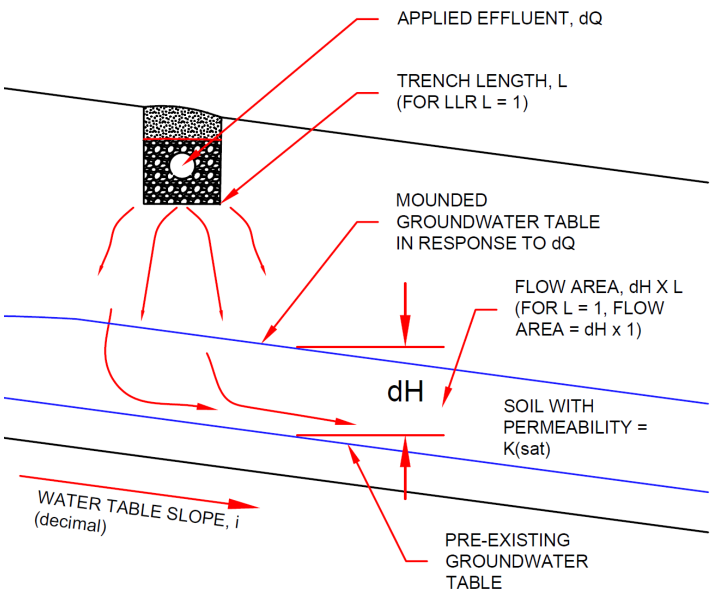
Q = Q(h) = average volumetric flow rate through the aquifer. This is the horizontal saturated flow in the case of contour loading rate and water table mounding. It represents the macroscopic flow velocity rather than microscopic flow velocity. Units are volume/time.

K = K(sat) = average saturated hydraulic conductivity. For anisotropic soils with "horizontal" flow parallel to bedding, this may be the horizontal component. However, for simple analysis, we often use the field measured average hydraulic conductivity (Reynolds & Elrick, 1985). Flow away from a dispersal system may be at an angle to bedding layers. Units length/time

i = hydraulic gradient, also expressed as dh/dl. Dimensionless.

A = cross sectional saturated flow area = L x H = contour length x height (saturated thickness). When calculating a water table mound or a LLR, we measure H vertically, discounting a slight difference from flow path height on sloping sites. Units length^2.

Figure 6 shows the mounded water table, LLR, and formulas based on Darcy's Law.



Darcy's Law, Q = K A i

For contour loading, Q = K x L x H x i, *where L x H is the saturated flow area.*

For increase in groundwater flow, due to infiltrating effluent, dQ = K x L x dH x i

Where dQ is the increase in flow rate from infiltrating effluent

dH is the height of the resulting water table mound

K and L are assumed constant for simplicity (although in reality they may vary due to lateral spread and the engagement of new soil layers)

Hydraulic gradient (i) is the same pre-existing hydraulic gradient (in reality the hydraulic gradient will increase slightly)

Rewriting, dH = dQ / (K x L x i)

Considering LLR, L = 1, LLR = dQ/L = K x dH x i

For calculation of K(sat) from experimental results, as:

K = LLR / (dH x i)

Fig. 6. Darcy's Law applied to contour loading and linear loading rate

There are a few simplifying assumptions. However, we have found that this equation works well for small sewage systems with a downslope drain or breakout point. It is also useful for calculating the effective hillslope-scale "horizontal" hydraulic conductivity from large scale tests.

Drainage equations

For low slope sites, or where the hydraulic gradient increases after applying effluent, we have found that drainage equations provide useful advice in cases with a downslope drain (fixed head boundary) (F. J. Cook et al., 2009; Ritzema, 1994; Vlotman et al., 2020).

Other calculations and modeling

Onsite system designers have used several methods for calculating or modeling of water table mounding. These include the method of Hantush, the Khan method and the Zlotnik method together with numerical modeling methods (Finnemore, 1993; Khan et al., 1976; McCray et al., 2008; Poeter et al., 2005; Zlotnik et al., 2017).

Edge and scale effects in small onsite sewerage systems

Drainage from small onsite systems is subject to edge and scale related effects. These effects often confound the assumptions used in water table mounding calculations and modeling and can result in an uneven water table surface (D. I. Cook et al., 2008).

Edge effects include:

- Nearby drains, such as perimeter drains and road ditches: These drains can help increase the hydraulic gradient as the water table rises.
- Lateral spread and down gradient flow of percolate by unsaturated flow: This increases flow rates in cases where surrounding soils are dry, or the dispersal system is relatively small or has a short contour length.
- Evapotranspiration from the dispersal and receiving areas: This includes effects enhanced by dispersal system operation, architecture, aspect ratio, contour length and biological activity (Bernhart, 1973; Nivala et al., 2022).

Permeability testing for onsite system design is small in scale using permeameters in auger holes, small ring infiltrometers or percolation tests. Studies of hillslope-scale hydraulic conductivity frequently show a higher hydraulic conductivity than smaller scale tests (Brooks et al., 2004). Scale effects may include:

- Anisotropy of hydraulic conductivity, including changes to anisotropy in response to changes in water saturation (Assouline & Or, 2006; Vlotman et al., 2020): In deeper parent material, horizontal hydraulic conductivity is often higher than vertical, especially in sedimentary deposits.
- Heterogeneity of hydraulic conductivity: For example, thin soil layers with high hydraulic conductivity can increase the measured hydraulic conductivity. This can include soil layers above a flow restrictive layer or weathered bedrock.
- "Vertical" flow, or flow in underlying vadose zone layers: This can include flow in soil or vadose zone layers initially assessed as low permeability, for example, fissures in till, cemented soil layers, or weathered or fractured bedrock.

Water table mounding test

General description

A water table mounding test (WTMT) is a large-scale test in which we apply clean water at a measured rate to soils in a dispersal area, and then measure the rise of the water table using standpipes or monitoring wells.

This test is commonly recommended for design of larger effluent dispersal systems (Poeter et al., 2005). We have found the test approach to be simple, low cost and appropriate for design of smaller systems on sites where the contour length is too short to meet LLR standards. Typically, the time required for a simple WTMT is 8 hours by a field technician plus 4 hours by an engineer.

Advantages of the WTMT include: (1) its simplicity; (2) the direct and reliable results, and (3) simple test analysis.

Form of test

We have taught this test in advanced onsite system courses in BC. We are writing a standard method for this test. It typically includes:

- A wetting period, with a higher flow rate to establish an initial response.
- A constant flow rate period.
- Continuing the flow until the water table stabilizes at a new height.

A full-scale test is one along the planned dispersal system contour length, with a flow rate equal to the planned average daily flow rate. A pilot scale test uses a shorter contour length and proportional flow rate. In some cases, the test is combined with a basin flooding test (Crites et al., 2006).

Designers may start a test with a flow rate higher than the proposed average daily flow rate, to obtain a more rapid response and to provide a safety factor. In this case, the reduced rate period may be at the average daily flow rate.

Typical methods

We use one of these methods for the test:

- A trench or bed excavated on contour to the proposed infiltration depth: We apply water to this trench at a steady rate using flooding or using a low-pressure distribution system.
- Apply water to an existing dispersal system: In this case we add water to the system pump dosing tank or distribution box, or directly to the trenches or bed.
- A shallow trench: We can excavate a trench along the contour and use drip dispersal tubing with pressure compensating emitters installed along the trench, with valves to adjust the flow rate. This can be continuous application or controlled by an irrigation timer.
- Sand bed: For very shallow soils, or for sand mounds, we can build a sand bed and add water to the bed.

A flow meter records the applied daily flow rate. This may be a data logging meter, or one read daily at time of test inspection.

Water table observation

We install standpipes (monitoring wells) consisting of slotted or perforated PVC pipe. We install to the depth of the flow-restrictive horizon or into the water table, both upslope and downslope of the trench or bed.

For longer systems, we install standpipes at the mid point of the trench and toward both ends. We may also install pipes further downslope or at a suspected breakout location such as an existing ditch bank or drain. For a site with a deep water table, we can use boreholes. Otherwise, standpipes are commonly shallower than 1.8 m (6 ft) and installed by hand or in machine dug pits.

During the test, a technician typically visits the site daily or once every few days. The technician uses a spreadsheet to record the flow rate, trench ponding depth, water table depths, and evidence of breakout, and may adjust the flow rate. See the appendix for an example of a sheet filled with real world data. Figure 7 illustrates a typical test, and Figure 8 shows an example of a test trench with water application using drip irrigation tubing.

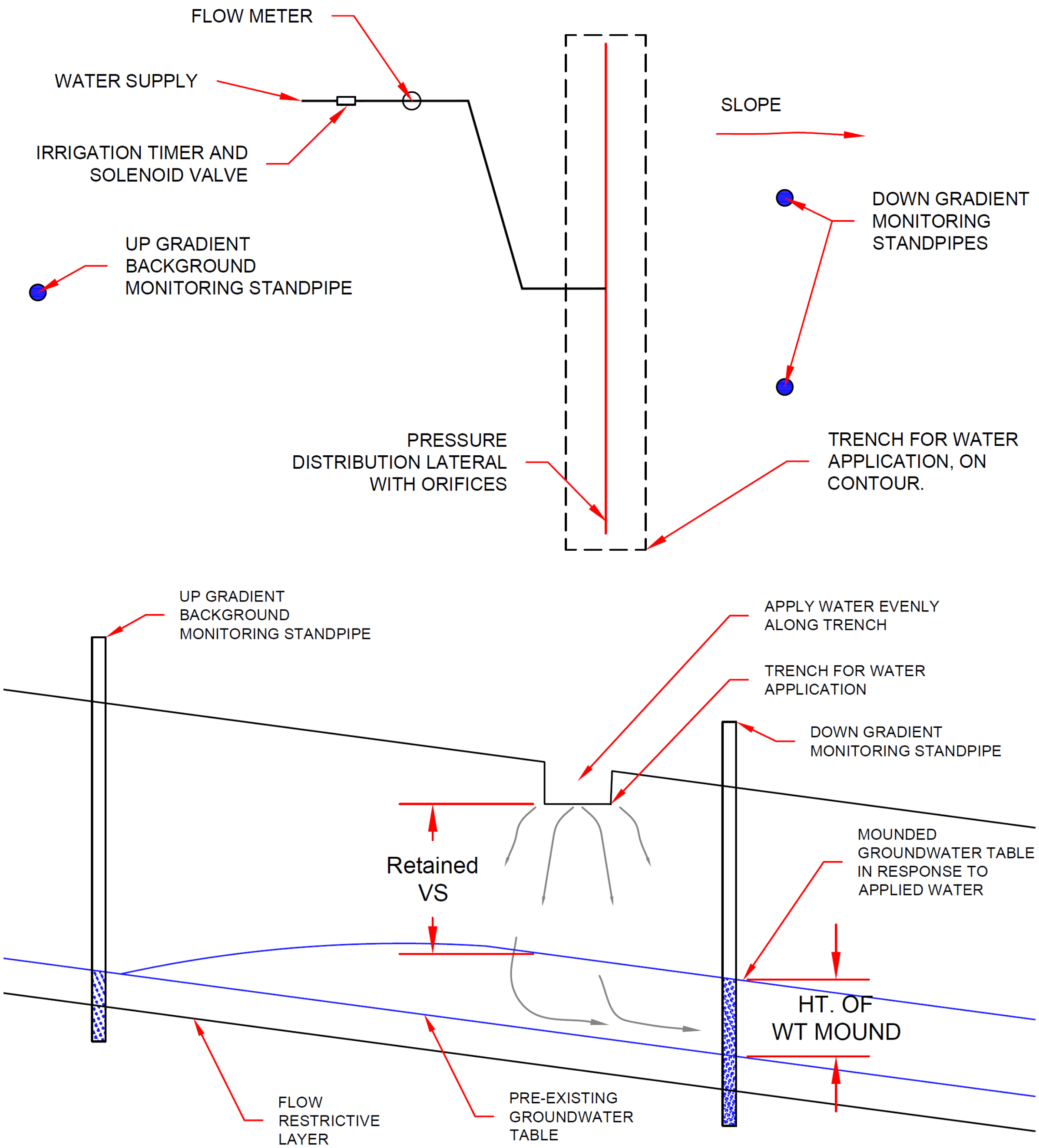


Fig. 7. Layout and schematic of a typical small system water table mounding test

Fig. 8. Test trench using drip tubing

A nearby weather station or a recording rain gauge provides rainfall input data. Ideally, we run the test during the period of the seasonal high water table. For tests during dry weather, wet season rainfall, or differences in evapotranspiration, the designer can adjust the water flow rate to compensate.

We typically run the test until the water table stabilizes at a new height. As a result, tests vary in duration, typically one to three weeks. However, sometimes, even with an extended test, the natural discharge capacity exceeds the flow rate, and we see no rise in the water table. It is important to continue the test for long enough to measure a sustainable discharge capacity which will not reach a lower limit than the applied rate due to, for example, down gradient subsurface flow restriction.

Interpreting test results

For the test, the LLR is the applied flow rate divided by the length of the test dispersal system. For this calculation, we can adjust the applied flow rate for measured rainfall and evapotranspiration (plus or minus).

For a full-scale test, the test results provide a direct reading of water table mound height for the applied flow rate at the test LLR.

For pilot scale tests, the projected water table mounding height is the same for a longer system with the same LLR. However, we are careful about extrapolating results because of varying soils and water table gradient along the untested length and changes in edge effects.

After the test, we can compare the measured water table mounding height to the mound height "predicted" using Darcy's Law and soil permeability tests. We can also compare the test LLR to the rate allowed in regulatory standards.

Following Darcy's Law, the effective hillslope scale hydraulic conductivity, K(sat), is:

K = LLR / (dH x i)

dH is the median measured rise of the water table.

Using this hillslope scale hydraulic conductivity, we can use Darcy's Law (equations above) to estimate the height of the water table mound as a function of the LLR. For a given hydraulic conductivity and hydraulic gradient, the height of the water table mound is proportional to the LLR.

Calculating hydraulic conductivity from these tests assumes horizontal flow. Significant flow to underlying layers can affect the validity of this calculation.

We rely on the WTMT because it is a large-scale or full-scale test conducted in the location of the planned dispersal system. This test allows us to estimate the retained vertical separation during operation of the sewage system, which is usually less than before operation. Using the test results, we can compare the calculated effective hillslope-scale K(sat) to field measured K(fs) and K(sat).

Results from tests in comparison to predicted mounding

In our tests, we often measured a water table mound height that is lower than that predicted by Tyler's LLR tables or by Darcy's Law calculations based on soil permeability from small scale tests.

This prompted us to collect the results of a sample of tests for a range of soil types in BC. Table 1 summarizes 43 tests performed as part of the design of small onsite systems in British Columbia over the last 20 years. These tests supported designs of shorter systems on sites with shallow soil and limited available contour length.

Table 1 sorts the test results to three sections by soil texture:

- Sands, Loamy Sands and Gravelly Sands
- Sandy Loam
- Loam, Silt Loam and Clay Loams

For each test, the contributors provided:

- Average clean water flow rate (Q) during the test
- Soil texture
- Soil structure and consistence category (reference is the BC SPM Table II-4)
- Measured or assumed K(fs) and calculated average K(sat) from small scale field testing, with K(sat) taken as 2 x K(fs) for use in Darcy's Law
- Slope of the water table or ground surface in the test location

- Contour length of the test
- Measured water table mound
- Allowable LLR from design standards (the BC SPM and the Tyler table), where available
- Notes on specific observations or constraints related to the test.

Table 1 compares the Darcy's Law predicted water table mound with the observed mound as a ratio. The table shows the LLR allowed under BC standards and the LLR from the Tyler table based on an equivalent category to BC standards. Note that the BC standard and Tyler allowable LLRs are based on peak day flows whereas the test flow rate is an average flow rate.

The table shows median values to indicate typical parameters for each group of tests. We also calculated the 10th percentile ratio of predicted to measured water table mounding height.

In BC standards, the allowable LLRs rely on Darcy's Law calculations. This 10th percentile of the predicted to measured ratio comparison therefore indicates that the Tyler table and the BC standards are quite conservative for the sites and soils tested.

The spreadsheet shown in Table 1 calculates the 10th percentile ratio (predicted water table mound to measured water table mound) as follows:

- Sands, Loamy Sands and Gravelly Sands; 2.9
- Sandy Loam; 1.7
- Loam, Silt Loam and Clay Loams; 7.1

Implications of the results

- The observed water table mound was typically much lower than predicted from Darcy's Law calculation using soil hydraulic conductivity from small scale permeability testing.
- This means the allowable LLR for these small systems on constrained sites was higher than the Tyler table and higher than the BC standard while still retaining adequate vertical separation after mounding of the water table.
- Results suggest that dispersal systems can be shorter by a factor of 1.5 to 5 times, compared with Tyler's tables or BC standards from a hydraulic perspective.
- However, it is often better to build a longer system, if feasible, to reduce contour loading of contaminants.

Table 1. Summary of water table mounding test data

By	Ave. Test Q m3/d	Sands (incl. LS and Gr S) Soil Texture	SPM Table II-4 Category	K(fs) m/day	K(sat) m/day	i	L m	WT mound, "H" (m) Predicted H(p)	Measured H(m)	Ratio Measured / Predicted	Test LLR Lpd/m	Max LLR (Tyler 2001) Lpd/m	Max. LLR (SPMv3) Lpd/m	Foot Note
MIP	1.94	Loamy Sand	F	1.1	2.2	5%	30	0.59	0.39	0.66	65	62	60	
MIP	18.43	Loamy Sand	F	6.0	12.0	2%	50	1.54	0.24	0.16	369	75	90	
MIP	5.72	Loamy Sand	F	1.8	3.5	5%	30	1.1	0.28	0.26	191	75	75	
IPR	25.90	Loamy Sand	F	1.5	3.0	15%	15	3.8	0.33	0.09	1,727	99	100	2
IPR	2.03	Loamy Fine Sand	F	1.5	3.0	25%	8.2	0.33	0.00	0.00	245	75	90	3
IPR	2.85	Fine Sand	F	1.2	2.4	4%	15	2.0	0.05	0.03	190	68	70	4
IPR	4.50	Loamy Fine Sand	F	1.4	2.8	12%	10	1.3	0.05	0.04	450	75	90	6
IPR	4.10	Gravelly Sand	F	8.0	16.0	8%	4	0.80	0.00	0.00	1,025	87	400	10
KSP	11.60	Loamy Fine Sand	F	1.2	2.4	5%	15	6.44	0.28	0.04	773	68	70	
RJM	2.30	Loamy Sand	F	1.3	2.6	8%	15	0.74	0.12	0.16	153			13
RJM	14.14	Loamy Sand	F	9.4	18.8	4%	17	1.1	0.13	0.12	831			14
RJM	4.95	Loamy Sand	P	2.8	5.6	1%	6	15	0.05	0.00	825			16
RJM	2.29	Loamy Sand	F	0.60	1.20	2%	10	10	0.10	0.01	229			
RJM	6.84	Sand	F	1.5	3.0	4%	15	3.8	0.30	0.08	456			
RJM	1.10	Loamy Sand	F	1.5	3.0	5%	10	0.73	0.01	0.01	110			15
RJM	4.50	Very gravelly Sand	F	33	66	2%	17.5	0.19	0.40	2.05	257			16
RJM	3.40	Fine Sand	F	1.1	2.3	5%	10	3.0	0.45	0.15	340			
RJM	2.40	Fine Sand	F	1.5	3.0	3%	10	2.7	0.25	0.09	240			
RJM	2.20	Fine Sand	F	1.5	3.1	5%	10	1.4	0.03	0.02	220			
MEDIAN:	**4.1**			**1.50**	**3.00**	**5%**	**15**	**1**	**0.13**	**0.08**	**257**	**75**	**90**	
										0.34				
10th percentile of Ratio of PREDICTED to MEASURED (ratio is HIGHER than this 9 out of 10 times)										**2.91**				

By	Ave. Test Q m3/d	Sandy Loam Soil Texture	SPM Table II-4 Category	K(fs) m/day	K(sat) m/day	i	L m	WT mound, "H" (m) Predicted H(p)	Measured H(m)	Ratio Measured / Predicted	Test LLR Lpd/m	Max LLR (Tyler 2001) Lpd/m	Max. LLR (SPMv3) Lpd/m	Foot Note
MIP	1.96	Sandy Loam	F	0.65	1.3	12%	14	0.90	0.44	0.49	140	62	75	
MIP	14.92	Sandy Loam	F	0.10	0.2	6%	15	83	0.34	0.00	994	51	40	
MIP	1.18	Sandy Loam	F	2.30	4.6	12%	15	0.14	0.14	0.99	78	87	90	
MIP	3.71	Sandy Loam	F	0.54	1.1	5%	20	3.5	0.04	0.01	185	62	60	
JT	4.50	Sandy Loam	F	0.59	1.2	9%	16	2.6	0.05	0.02	281	75	75	
JT	3.00	Sandy Loam	F	0.60	1.2	12%	10	2.1	0.01	0.00	300	87	90	
IPR	3.33	Sandy Loam	F	3.30	6.6	23%	9	0.24	0.10	0.41	369	62	75	5
IPR	12.60	Sandy Loam	F	0.53	1.1	15%	35	2.3	0.86	0.38	360	87	130	7
IPR	6.80	Sandy Loam	F	0.53	1.1	15%	35	1.2	0.71	0.58	194	87	130	8
KSP	6.90	Sandy Loam	F	0.73	1.5	15%	15	2.1	0.00	0.00	460	87	130	
RJM	3.20	Sandy Loam	F	0.58	1.2	2%	10	13.8	0.10	0.01	320			
RJM	2.24	Sandy Loam	F	0.81	1.6	1%	15	9.2	0.18	0.02	149			
MEDIAN:	**3.5**			**0.60**	**1.2**	**12%**	**15**	**2.2**	**0.12**	**0.02**	**291**	**81**	**83**	
10th percentile of Ratio of PREDICTED to MEASURED (ratio is HIGHER than this 9 out of 10 times)										**1.72**				

By	Ave. Test Q m3/d	Loam, Silt Loam, Clay Loam Soil Texture	SPM Table II-4 Category	K(fs) m/day	K(sat) m/day	i	L m	WT mound, "H" (m) Predicted H(p)	Measured H(m)	Ratio Measured / Predicted	Test LLR Lpd/m	Max LLR (Tyler 2001) Lpd/m	Max. LLR (SPMv3) Lpd/m	Foot Note
MIP	1.40	Clay Loam	P	0.10	0.20	2%	14.6	24	0.32	0.01	96	25	25	1
MIP	1.01	Loam	F	1.03	2.1	12%	5	0.82	0.16	0.20	202	55	60	
MIP	1.83	Loam	F	0.56	1.1	5%	22	1.5	0.21	0.14	83	45	45	
IPR	6.38	Sandy Clay Loam	F	0.30	0.60	15%	14	5.1	0.00	0.00	456	37	45	9
IPR	3.20	Silt Loam	P	0.17	0.34	5%	22	8.6	0.25	0.03	145	37	40	11
IPR	6.80	Silt Loam	P	0.17	0.34	5%	22	18	0.93	0.05	309	37	40	12
KSP	3.20	Silty Clay Loam	F	0.23	0.46	8%	40	2.2	0.13	0.06	80	37	40	
KSP	7.70	Loam	P	0.20	0.40	11%	15	12	0.55	0.05	513	47	50	
RJM	6.46	Silt Loam	F	0.40	0.80	7%	6	19	0.10	0.01	1,077			15
RJM	0.60	Silt Loam	F	0.40	0.80	2%	6	6.3	0.24	0.04	100			15
RJM	1.51	Silt Loam	F	0.32	0.63	2%	15	8.0	0.19	0.02	101			
RJM	20.80	Silt Loam	F	0.40	0.80	6%	30	14	0.30	0.02	693			15
MEDIAN:	**3.2**			**0.31**	**0.62**	**6%**	**15**	**8**	**0.23**	**0.03**	**174**	**37**	**43**	
10th percentile of Ratio of PREDICTED to MEASURED (ratio is HIGHER than this 9 out of 10 times)										**7.06**				

Red numbers are estimated.

FOOTNOTES:

1. Precipitation recorded during the test. Sand above native soil.
2. Loamy Sand and Loamy Fine Sand. Long test on deeper soils (including those which mounding was measured in) with lower measured K(fs) at 300 mm/day, 1,500 mm/day for upper soils. The test also included a long period at half this loading rate with very little response. A relief drain (downslope curtain drain) was in place, which provided a point of discharge.
3. Very channery loamy fine sand. 70% channers so K(fs) measurement is unreliable.
4. Gravelly very fine sand. On ridgeline with low slope either side, steeper slope in receiving area further from dispersal (~15%). Sand mound on top of native soils. Water applied to sand but levels monitored in native soil, soil with restrictive layer at base.
5. Only minor response seen in monitoring wells 10 cm response recorded at seepage at a downslope cutbank.
6. Little response observed and minor ponding.
7. Higher rate test in an existing drainfield. Results reported for worst case monitoring well. Ponding above the infiltrative surface and on steeper slope in receiving area. Bed at approx. 2%, receiving area on one side at approx. 25%, 15% as average slope. Permeameter testing during installation showed lower soil layers with K(fs) of 330 mm/day, upper layer 730 mm/day, average used. Maximum allowable LLR based on original K(fs) measured at 1800 mm/day.
8. Lower rate, to existing drainfield, worst case MW during recovery, steeper slope in receiving area. Note that drainage installed to support the higher LLR for design.
9. No response, no breakout reported. K(fs) not originally measured; value inserted for consistency with SPM standards. Shale below.
10. Installed trenches stacked on slope. Deeper soils (120 cm plus), K(fs) not originally measured, value inserted for consistency with SPM standards.
11. Lower rate during recovery, same site as below
12. Higher flow rate. Note that both of these adjusted for ET and rainfall as in dry season in interior.
13. Very gravelly.
14. Loamy Sand and Sand, Gravelly to Very Gravelly.
15. And 16. No permeameter tests to date. K(fs) estimated from soil characteristics.

Limitations

This paper presents observations over 30 years of designing and testing sewerage systems, rather than academic research. The test results may be limited in the following ways:

- Designers used similar methods but there was no standard test protocol.
- We ran the tests at flow rates of less than 23,000 L/day (about 6,000 usgal/day).
- Our examples do not include Clay-textured and Silt soils.
- Most or all test locations had a downslope drain. This could be a subsurface drain, drainage ditch, seepage on a slope, or a hydraulically connected water body.
- All the referenced tests were in BC.
- Some designers adjusted their results for rainfall while others did not.
- We completed tests in different regional climates.
- For some of the tests, water flowed into underlying layers, rather than primarily horizontally. This result still helps the designer to estimate water table mounding during operation but makes it difficult or impossible to calculate the effective hillslope-scale hydraulic conductivity.

Discussion

The WTMT is a helpful design aid for smaller systems on sites with a short contour length or shallow soil depth.

This test is simple and low cost and gives us more confidence than mathematical models. We can compare the use of the WTMT to the use of Darcy's Law. Both are macroscopic scale empirical approaches. Just as Darcy's Law continues to be useful as a simple relationship, we find that the water table mounding test provides useful direct information from a simple test.

In BC several engineers have used WTMT to validate LLR that are higher than BC standard values by a factor of 1.5 to 5. The aggregated test results presented here suggest that standard LLR may be overly conservative, and could be increased.

We suspect the presented test results reflect scale effects on hydraulic conductivity. That is, the results suggest that hillslope-scale hydraulic conductivity at typical system size is higher than that calculated from small scale measurements (percolation and permeameter tests). We further suspect that edge effects may contribute to natural discharge capacity for small systems.

Given the wide range of variables that can affect water table mounding, and the critical importance of vertical separation for soil-based treatment, we recommend using monitoring wells to check the depth of the water table and retained vertical separation during operation.

Next steps

We would be interested to see the results of similar tests completed elsewhere in North America, especially in Silt and Clay textured soils.

We have drafted a guideline for Water Table Mounding Tests which the Canadian Onsite Technical Resource Association (COTRA) plans to publish. This should promote consistent testing methods and improve the quality of data for further analysis.

We look forward to discussing potential adjustments to LLR standards based on the results of these tests, further test results, and long-term monitoring of operating sewage systems.

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APPENDIX: Example of filled record of WTMT

WATER TABLE MOUNDING TEST - Example with real world field notes

Client:	Page Turner		
Project:	123 Literary Road, District of Fiction	Date:	2016-02-24 [wet season]
File:	NWS-15-1	By:	JPL and MIP

Paperback Consulting Company

Test Setup:

Location of discharge: 4 metres downslope from existing septic field. Land slope is 12%.

Discharge area dimensions: Length: 14 m Width: 0.5 m Area: 7 sq.m. Depth: 0.4 m

DOSING PLAN Water source: Domestic Transport method (hose, pipe, truck): Garden hose

Flow rate (range): 14 litres per minute Hose needed: Yes Pipe needed: Yes

Dose frequency: 6/day Dose volume: 320 litres LLR: 140 Lpd/m (LLR as tested) (4)

Locations of Observation Wells: 2 down-slope wells and 1 up-slope (ambient) wells

Depth and Elevation of Observation Wells:

	Length	Stickup	Depth	Top elev	WL @ start of test		Dist from	
MW #	*cm*	*cm*	*cm BGS*	*cm*	Depth	Elev	**discharge**	**Note**
1	200	120	80	NA	> 80		2.5 m	Soil texture is sandy loam
2	210	143	67	NA	> 67		2.5 m	Structure is granular, strong grade
3	200	140	60	NA	> 60		5 m	Upslope well. Shallow bedrock.

Water level reference point: *Ground surface*

Flow Rate and Rise of Water Table in Observation Wells:

		Time	Time	Flow	Total	Average	Depth to water in wells *(cm)*				
	Time	**elapsed**	**elapsed**	**meter**	**flow**	**flow**	1	2	3	4	
Date	of day	*mins*	*days*	*litres*	*litres*	*Lpd*	MW-1	MW-2	MW-3		Remarks
2016-02-24	9:36	0	0.00	903,224	0		> 80	> 67	> 60		
2016-02-24	10:06	30	0.02	903,655	431		> 80	> 67	> 60		
2016-02-25	9:53	1,457	1.01	905,727	2,503	2,474	47	28	> 60		
2016-02-26	10:31	2,935	2.04	907,565	4,341	2,130	32	28	> 60		
2016-02-28	10:21	5,805	4.03	911,291	8,067	2,001	31	30	> 60		
2016-02-29	11:07	7,291	5.06	913,156	9,932	1,962	31	29	> 60		Note (1)
Totals (and WL rise):		**7,291**	**5.06**		**9,932**		**(49 cm)**	**(38 cm)**	**(NA)**		
Averages:						**1,962**					Note (2)

NOTES:

(1) System design flow rate (peak day) is 2,300 Lpd.

(2) Average test flow rate of 1,962 Lpd caused the water table to rise an average of 44 cm (range 38-49 cm).

(3) For the proposed Sand Mound, the remaining vertical separation (after mounding) is 30 cm (range 29-31 cm).

(4) Maximum allowable LLR following the Tyler table is 62 Lpd/m.