Site-Specific Tile Drainage Design IF-05

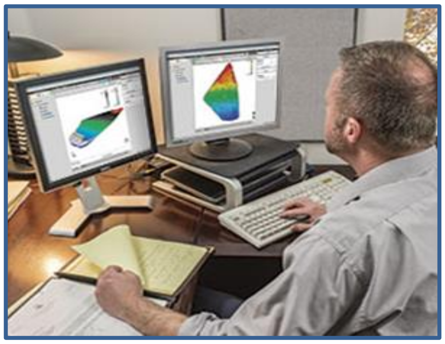

Figure 1. Knowledge of the site-specific field conditions and design experience are required for sustainable designs.

What can site-specific tile drainage design accomplish?

In addition to removing excess water from the root zone, the objectives of site-specific tile drainage design include ***Conserving Water*** and ***Improving Water Quality.*** Proper planning of a tile drainage project requires knowledge of soil and geologic conditions, and movement of groundwater, nutrients and salt. This knowledge helps to inform and guide the design of a sustainable tile drainage system. The result is a project that achieves drainage targets, improves crop productivity, limits salt and nutrient discharge and avoids impacting shallow aquifers and springs. The goal is to drain only what is necessary and not a drop more.

Overview of site-specific tile drainage design

For an introdution to tile drainage design, please refer to ***Drainage Guide for Ontario - Publication 29***.

Site-specific tile drainage design involves a sensitivity analysis of the following components to optimize both agronomic and environmental performance:

- Drainage intensity or coefficient;
- Tile depth (d) and spacing (S) (Figure 2);
- Layout of lateral and main lines;
- Topography;
- Outlet location, depth and capacity, as well as gravity vs. pumped outlet;
- Materials (e.g. solid mains, tile sock);
- Additional Beneficial Management Practices (see BMPs in this series).

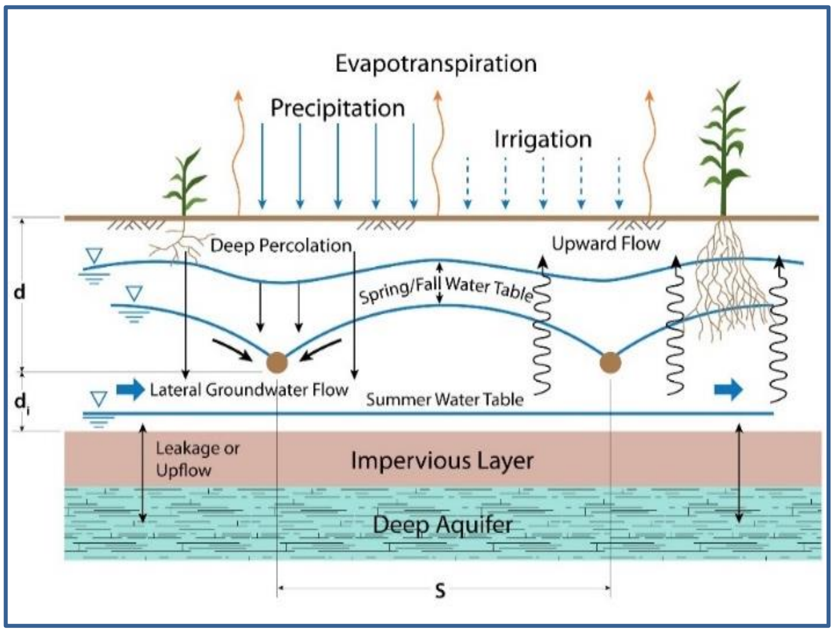

Figure 2. Environmental and geologic factors affecting tile design and performance (Source: modified from University of California, 2015).

To identify potential impacts on water conservation and water quality, the designer should consider the following site-specific factors:

- *Soil constraints* such as texture, structure, hydraulic conductivity, salinity and sodicity; including how these factors vary across the field;
- *Geologic constraints* including depth to impervious layer [d_i], lateral and/or artesian (i.e. upward) groundwater flow which can be influenced by the location and depth to the top of aquifers, aquitards (e.g. clay soils, glacial till), and bedrock (e.g. shale, limestone, sandstone) below the field;

- *Crop water balance* accounting for local climate and other conditions which impact: i) demand for water by the crops in rotation on the field, and ii) sources/supplies of water that meet crop water demand, including precipitation and capillary rise (upward flow) from the shallow groundwater table;
- *Environmentally vulnerable areas* such as aquifers, springs, creeks and wetlands.

Applicability of site-specific tile drainage in Manitoba

For fields where it is determined that tile drainage is appropriate, site-specific tile drainage design will optimize the system based on the characteristics of the site and the performance objectives. In addition to tile design practitioners, *Professional Services* (see *BMP EA-01*) in soil science, engineering and hydrogeology can contribute to the planning and design phases. These services can provide a detailed understanding of the local soil-landscape, agronomic and hydrogeologic conditions and risks, in order to fully customize the design.

Site-specific tile drainage design to conserve water

Tile depth

In semi-arid regions like Agri-Manitoba, crop water demand exceeds precipitation in most years. It is known that the shallow groundwater table in some areas can provide a significant percentage of a crop's water demand (Cordeiro, 2013; Ayers et al., 2006). This should be exploited when designing the tile drainage system by balancing drainage for the root system with maintenance of the water table for crop water uptake. Where possible, the depth of the tiles should be sufficiently shallow to maximize plant available water in the summer. With shallower tiles, a narrower spacing is necessary to achieve the same target drainage coefficient. As well, *Controlled Drainage* (BMP IF-04) could be implemented to further manage water table height, slope permitting. The additional cost of tiles or controlled drainage structures should be weighed against the benefits to the crop of increasing available water during periods of water deficit.

Figure 3 provides a Manitoba example that demonstrates how water table dynamics respond to the installation depth of the tile. It illustrates the relationship between rainfall and the level of the water table during the growing season at a site in the Red River Valley where tile was installed at a depth of 90 cm (35 in). During the spring when moisture levels and precipitation were high and plant uptake of water was low, the water table fluctuated from near the ground surface to the tile depth. In mid-July and August, when plant growth and evapotranspiration were higher and precipitation was lower, the water table fell below the tile. The drop in the water table in July and August is attributable to heavy water use by the crop that required capillary rise in addition to precipitation. For this example, if the tile were installed shallower (e.g. 70 cm (28 in) to 80 cm (31 in)) with the same spacing (e.g. reduced drainage intensity) or if *Controlled Drainage* (BMP IF-04) were employed one would conserve more of the spring precipitation for consumption by the crop in July and August.

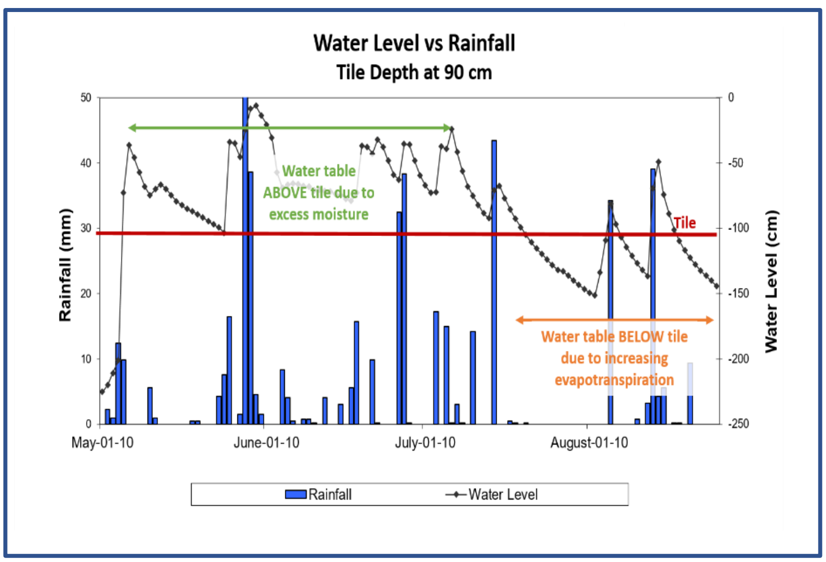

Figure 3. Water level vs. rainfall and tile depth – Red River Valley (Agriculture and Agri-Food Canada, unpublished).

Tile layout and materials selection

Vulnerable hydrological features must be identified and protected with a suitable tile drainage design. Such features include aquifers associated with shallow sand channels (e.g. former rivers), near surface bedrock (Figure 4), and buried sand and gravel layers (Figure 5). These aquifer features can include lateral and artesian groundwater flows and springs in the field to be tiled.

In Manitoba, there have been several cases in which tile drainage systems have intercepted shallow aquifers or springs. These unintentional (i.e. non-designed) connections between tile networks and underground water sources have caused problematic, lengthy or continuous flow from the tile.

In some situations, it may be appropriate to remove areas of a field from a tile design. For instance, Figure 5 shows a tile layout that avoids a near-surface glacial outwash aquifer (i.e. orange and yellow).

In certain circumstances, non-perforated tile can limit risk to groundwater quantity and quality by:

- Limiting ingress of groundwater into deeper portions of the main lines.
- Preventing leakage of tile water into unconfined aquifers being crossed by a tile main.

Detailed geologic site characterization enables the designer to account for vulnerable groundwater features in choosing the layout and materials for a specific project.

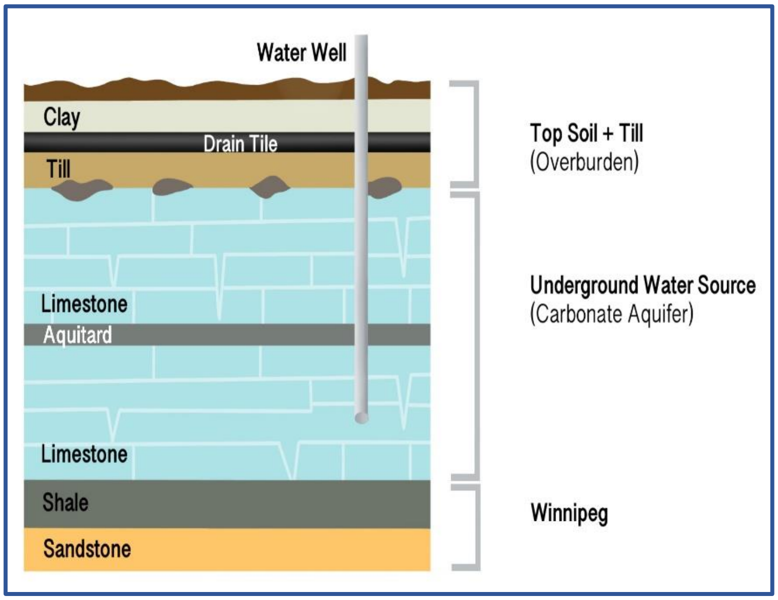

Figure 4. Typical confined bedrock (limestone) aquifer; depth and cover of the overburden dictates risk to aquifer (East Interlake Conservation District, 2011).

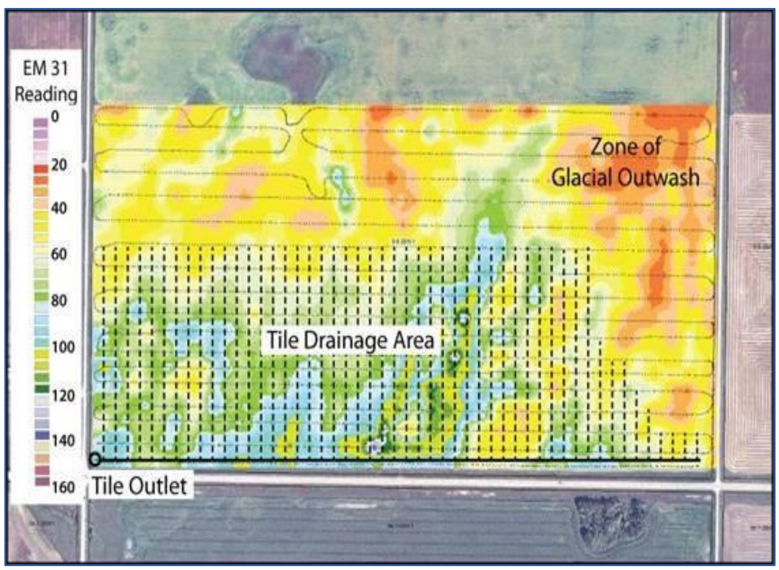

Figure 5. Tile layout (black lines) designed to avoid glacial outwash aquifer illustrated by the yellow and orange areas (EM31 map courtesy of PBS Water Engineering Ltd.; South-west Manitoba location).

EM31 refers to mapping of soil electromagnetic resistance using sensors and GPS; the resulting maps reveal changes in subsurface texture, and potential location of coarse textured soils (sands/gravels) and other geologic anomalies (e.g. shallow bedrock). EM31 maps require calibration with field test drilling.

Site-specific tile drainage design to improve water quality

Tile drainage water contains nutrients and salts. The amount or load discharged via the tiles is a function of the volume of water discharged and the concentration of the salt or nutrient in the water:

$$\boldsymbol{Load\ (weight) = volume\ of\ water\ \times concentration\ of\ nutrient\ or\ salts}$$

The volume of water discharged is dictated by the drainage coefficient and the tile depth (d). A reduction in the drainage coefficient will reduce the load of nutrient or salt discharged by the tile (Sands et al., 2008). Similarly, lower nutrient or salt concentrations in the tile water will result in reduced loads if the drainage coefficient remains the same.

Luo et al. (2010) modelled changes in annual nitrate loads resulting from a reduction in drainage coefficient by adjusting tile depth from conventional to shallow depth (i.e. from 4 to 3 feet) and varying tile spacing (Figure 6). Nitrate loads were significantly lower when the drainage volume was reduced with shallower tiles or wider spacing. In saline soils, where salinity increases with depth, shallower tiles can be expected to remove less salt (i.e. generate a smaller salt load) from the soil profile than deeper tiles (Ayers et al., 2006; Christen et al., 2001).

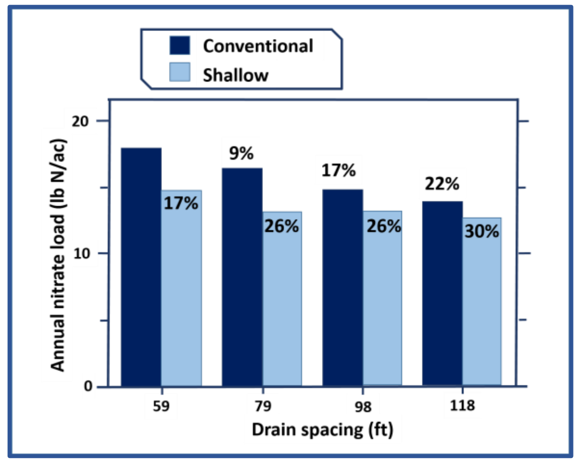

Figure 6. Modelled nitrate load versus drain spacing/depth (Christianson et al. 2016 citing Luo et al., 2010).

Heavy clay soils prone to cracking may also warrant shallower tiles. In these soils water moves through secondary soil structures (e.g. moisture cracks and biologic macropores), rather than through the soil matrix. OMAFRA (2007) recommends a shallow tile depth of approximately 60 cm (24 in) in these soils. In this case the shallow tiles may perform better in terms of moving drainage water more rapidly while also avoiding draining more water than is necessary to meet agronomic objectives. On the other hand, the direct connection of surface water to tile through the macropores can lead to higher phosphorus concentration and load. For such soils *Nutrient Management BMP IF-01* are critical for water quality, especially if manure is being applied.

Following the golden rule of drainage (that is, to drain only what is necessary and not a drop more) when designing a tile drainage system, will reduce the loads of salts and nutrients to surface water.

Outstanding questions and potential future improvements

The following activities would facilitate better assessments of candidate tile drainage sites and enhance design capability in Manitoba:

- Calculate multi-year water balances using software such as DRAINMOD-S and DRAINMOD-NII (Skaggs et al., 2012; Kandil et al., 1992; Luo et al., 2010) to establish relationships between tile layout, depth and spacing and nutrient/salt loadings. Cordeiro (2013) provides an excellent start to this exercise with calibrated DRAINMOD results for fine sandy loam soils and corn crop, in Manitoba conditions.
- Develop a means to predict salt loads in tile water based on measured soil salinity levels in candidate fields.

- Create tile depth and spacing recommendations for Manitoba soils that achieve desired drainage intensity without compromising environmental performance objectives.
- Conduct regional and aquifer-specific risk mapping to guide tile drainage projects.
- Develop training materials on professional investigation of site conditions (e.g. soils, geology, hydrology) that would guide designers and contractors on site-specific planning.

Complementary practices

Site-specific designing of tile drainage projects is complementary with other BMPs that reduce nutrient loads in tile outflow or drainage volume:

- *IF-01 – Nutrient Management and IF-02 Cover Crops;*
- *EF-01 – Bioreactors, EF-02- Saturated Buffers and WS-02 – Constructed Wetlands.*

Design aids

ASABE, 2008. ASABE Standard EP 480. Design of subsurface drains in humid areas. American Society of Agricultural and Biological Engineers. St. Joseph, MI.

Ontario Ministry of Agriculture Food and Rural Affairs, 2007. Drainage Guide for Ontario. Publication 29.

Additional BMP resources

Christianson, L.E., J. Frankenberger, C. Hay, M.J. Helmers, and G. Sands, 2016. Ten Ways to Reduce Nitrogen Loads from Drained Cropland in the Midwest. Pub. C1400, University of Illinois Extension.

Miller, T. P., J. R. Peterson, C. F. Lenhart, and Y. Nomura, 2012. The Agricultural BMP Handbook for Minnesota. Minnesota Department of Agriculture.

References

Ayers, J.E., E.W. Christen, R.W.O. Soppe, and W.S Meyer, W.S., 2006. Resource potential of shallow groundwater for crop water use; a review. Irrigation Science 24:147-160.

Christen, E.W., and J.E. Ayars, 2001. Subsurface drainage system design and management in irrigated agriculture; Best Management Practices for reducing drainage volume and salt load. Technical Report 38-01. CSIRO Land and Water; Griffith, NSW, Australia.

Cordeiro, M.R.C., 2013. Agronomic and environmental impacts of corn production under different water management strategies in the Canadian Prairies. PhD thesis, Dept. of Bio Systems Engineering, University of Manitoba.

East Interlake Conservation District, 2011. Netley-Grassmere integrated watershed management plan.

Kandil, H., C. T. Miller and R. W. Skaggs, 1992. Modeling long-term solute transport in drained unsaturated zones. Water Resources Research. Vol. 28(10):2799-2809.

Luo, W., G.R. Sands, M. Youssef, J.S. Strock, I. Song, and D. Canelon, 2010. Modelling the impact of alternative drainage practices in the northern corn belt with DRAINMOD-NII. Ag. Water Man. 97: 389-398.

Skaggs, R.W., M.A. Youssef, and G.M. Chescheir, 2012. DRAINMOD: Model use, calibration, and validation. Transactions of the ASABE. Vol. 55(4): 1509-1522.

Sands, G.R., I. Song, L.M. Busman, and B.J Hansen, 2008. The effects of subsurface drainage depth and intensity on nitrate loads in the northern cornbelt. Transactions of the ASABE. Vol. 51(3): 937-946.

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