Czech University of Life Sciences Prague

Faculty of Environmental Sciences

Department of Land Use and Improvement

DESIGN OF INTEGRATED DRAINAGE SYSTEM AND IRRIGATION FOR AGRICULTURAL LAND IN GBELY MEADOWS - SOUTH MORAVIA, CZECH REPUBLIC

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Declaration

I hereby declare that this thesis entitle "*Design of Integrated Drainage System and Irrigation for Agricultural Land in Gbely Meadows – South Moravia, Czech Republic*" written and submitted by me, in partial fulfilment of University regulation for the award of Degree **Master of Engineering** (**Ing.**) in **Environmental Sciences.** I further declare that this thesis has not been submitted to any other University for any degree or equivalent course.

Prague, 18^{th} of April 2016 Dine Naraisa

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

Dine Naraisa

Land and Water Management

Thesis title

Design of Integrated Drainage System and Irrigation for Agricultural Land in Gbely Meadows – South Moravia, Czech Republic

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Objectives of thesis

a) Review the literature on existing rational analysis of drainage system, and select one model using simple mathematical equation with a very close result with complicated developments

b) Analyse the summary of the hydrological data, focusing on average precipitation corresponding with the recharge and drain spacing

c) Design a drain spacing by using data from previous study, located in South Moravia, Czech Republic, nearby the border with Slovakia along the Moravian River

d) Calculate and analyse the possibility of integrated irrigation system, along with suggestion corresponding with drain spacing

e) Suggest few recommendations for more further research or project in future and also which drain design is good for the local farmer

Methodology

1.) Data collected from previous study for slope, drainage area and soil hydraulic conductivity

2.) Theory (using) select suitable hydraulic method to determine drain spacing (L)

3.) Use Hooghhoudt's equation to calculate drain spacing (L) for different values of recharge (R)

4.) Calculate inflow water from hydropower station nearby area for irrigation, description of irrigation processes

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5.)

Discussion, recommendations, conclusions

The proposed extent of the thesis

30 – 50

Keywords

water regome, drainage system, drain spacing , Hooghoudt's Equation, irrigation process

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Recommended information sources

Hillel, D. (2004). Introduction to Environmental Soil Physics. Elsevier Science (USA) (Vol. XXXIII). USA. http://doi.org/10.1007/s13398-014-0173-7.2

Luthin, J. N. (1966). Drainage Engineering. United States: John Wiley & Sons, Inc.

Pickels, G. W. (1941). Drainage and Flood – Control Engineering (2nd Editio). United States: McGraw-Hill Book Company, Inc.

Ritzema, H. (2006). Drainage Principles and Applications (third Edit). Wageningen, Alterra: ILRI Publication.

Štibinger, J., et al. (2015). Biotechnická opatření pro úpravu vodního režimu ve vybraných lokalitách modelového území Pomoravské nivy. FOREST-AGRO, Spol. S R.o., Hrušky, 1–44.

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Table of Contents

Abstract

This study presents a range of drain spacing for the drainage system design in Gbely Meadows located nearby the border of Czech Republic in South Moravia, using selected hydraulic method. The method based on suitable theory to determine drain spacing (L). The boundary condition in selected area was collected from previous study of Štibinger et al. (2015), which was conducted in the same location and area with pond created as an outlet. Hooghoudt's Equation is one of the most common and widely used method for homogenous soil, and will be suitable for this study. Situated in the line of Morava River, Gbely Meadows were suffering enough from waterlogging. Subsurface drainage combined with ditches will be one of the solution to help the local farmers, fight against waterlogging and failed crop. Due to temperature increase, which could lead to dry period together with limited amount of water and low precipitation. An integrated drainage system and irrigation was designed. To cover high rate of evapotranspiration, the area requires input water flow to keep water table at some point below the surface soil. According to the previous study of Štibinger et al. (2015), a brook located nearby selected area which has outflow water 3 m^3/s. After calculation using irrigation formula, it is sufficient enough to irrigate the selected area and develop an irrigation network integrated with drainage system. A recommendation could be provided in the end of the study to introduce the farmers an effective integrated system, to help reduce the waterlogging.

Keywords: water regime, drainage system, drain spacing, Hooghoudt's Equation, irrigation processes

Abstrakt

Tato studie poskytuje pohled na rozsah rozestavení drenážního systému za použití zvolených hydraulických metod na Gbelských loukách, které se nacházejí v blízkosti hranice České republiky na jižní Moravě. Metoda je založena na vhodné teorii určení rozestavení drenáže (L). Okrajová podmínka ve vybrané lokalitě byla získána ze studie Štibinger et al. (2015), která byla prováděna ve stejné lokalitě s retenční nádrží. Hooghoudtova rovnice je jednou z nejběžnějších a široce používanou metodou pro homogenní půdy a bude rovněž vhodná pro tuto studii. Gbelské louky nacházející se v povodí řeky Moravy trpí podmáčením. Podpovrchová drenáž kombinovaná s příkopy bude jedním z řešení jak pomoci místním zemědělcům bojovat proti podmáčení a neúrodě. To vše se děje v důsledku zvýšení teploty, které by mohlo vést k období sucha, společně s omezeným množstvím vody a malým množstvím srážek. Z těchto důvodů byl navržen integrovaný drenážní a zavlažovací systém. Oblast vyžaduje vstupní průtok vody pro udržení hladiny podzemní vody v určitém bodě pod povrchem půdy k pokrytí vysoké míry evapotranspirace. Podle předchozí studie Štibinger et al. (2015), potok nacházející se v blízkosti vybrané oblasti disponuje průtokem 3 m^3/s vody. Při výpočtu za použití zavlažovací rovnice je velmi vhodné vybranou oblast zavlažovat a dále rozvíjet zavlažovací síť integrovanou s drenážním systémem. Na závěr studie bude provedeno doporučení. Toto doporučení představí zemědělcům účinný integrovaný systém pro předcházení podmáčení.

Klíčová slova: vodní režim, drenážní systém, rozestavení drenáže, Hooghoudtova rovnice, zavlažovací procesy

1. Introduction

Agriculture is one of important sector as it is the biggest source where food is produced from healthy growth plants. Flooding irrigated area can caused a huge trouble regarding to the crop yields, and it is been an issue for century. Drainage system has big impact in protecting the environment especially if it is related with the flood control. Excess water on the surface soil or under the surface is mostly solved by drainage system.

One of the important purpose of this system is to keep the water management in balance either on surface soil or under it, which is usually called subsurface drainage system. The implementation of this system has brought up a lot of interest for the researcher and engineers. It has proven a lot of benefits not only in regard to the water management but also in soil protection by reducing Nitrogen losses, improve the crop production (sustainable crop growth), and reduce the flood risk also surfaces runoff.

Drainage system is one of the great invention which is now still in development to become more efficient and effective in regards to protect the environment. Maierhofer, one of drainage expert said “Who has seen the salinized lands in the plains of the mighty Indus, so great in extent that 40 million people would not go to bed hungry each night if the potentially high productive lands, now barren and white with salt, were adequately drained?” (Luthin, 1966).

In another hand, bad implementation of drainage system can bring losses not only in economic sector (loss of crop production) but also affect the soil and the plants (i.e. soil loss some important nutrients). The reason for this is waterlogging. It has an effect on holding the nutrient from the soil by decelerate of decomposition in organic matter and tends to remain nitrogen locked up on the soil residue, limiting the growth factor of the plants (Luthin, 1966). Hence, the good drainage systems with good maintenance is important to bring all the purposes proven, such as fertility of the soil which is one of the important and value of environmental protection in long term period.

Most of the times this issue has been a hot topic among the farmers and engineers, to fight the flood and build a sustainable yields with ecological way. One of the idea to solve this issue is a well design drain spacing on drainage system which is easy to understand and implement in future, with considering the value of efficiency and effectiveness. By assuming the soil is nearly steady – state with homogenous soil, as it is necessary to define the equation or method to design drain spacing as simple as it could be. The explanation about the decision will be follow up in the next chapter. The drainage system which I would like to consider in here is more like a parallel drain system based on the characteristic of the area and based on previous study.

The previous study of Štibinger et al. (2015) conducted in Gbely Meadows designing a drainage system with pond as an outlet. This study using all boundary condition from them, to design a drain spacing and calculate together with possibility of irrigation during the dry period with water flowing from Hydropower System in Hodonín. In this study, a recommendation to local farmers will be conclude in the end and help them to give an option of good drainage system based on the local situation, in Gbely Meadows, South Moravia.

2. Objectives

The aim for this study was to solve the water logging problem or floods in agriculture area by implementing open ditch system combine with tile drainage. Based on that idea, are developed objectives in the following:

a) Review the literature on existing rational analysis of drainage system, and select one model using simple mathematical equation with a very close result with complicated developments.

b) Analyse the summary of the hydrological data, focusing on average precipitation corresponding with the recharge and drain spacing.

c) Design a drain spacing by using data of drainage system from previous study, located in South Moravia, Czech Republic, nearby the border with Slovakia along the Moravian River.

d) Calculate and analyse the possibility of integrated irrigation system, along with suggestion corresponding with drain spacing.

e) Suggest few recommendation for further research or project in future and also which drain design is good for the local farmer.

3. Literature Review

Excess water has been an issue for over more than centuries. Drainage system as one of the solution has been invented, improved and also implemented almost everywhere all over the world. One of the example of drainage system in United Kingdom, has the largest area of wetland which has been made productively by drainage in the strips of land along east coast called Fens (Pickels, 1941). Pickles (1941) also mentioned that this area has been periodically overflowed by tides of the North Sea and nowadays it has a reclamation into prosperity of agriculture area. It has protected by the dykes, affected by numerous ditches leading into it and while water is rising, the next is to get water discharge by pumps (Pickels, 1941).

One of the purpose of drainage system is to fight against the water logging or to help reduce the surface excess water. This can happen if the optimal balance between water and air is disturbed, as the ideal ratio of water to air in the soil is between 60 – 80 % of pores filled with water and 20 – 40 % pores filled with air (Kubeček, 2013). Drainage system in agricultural land is clearly able to cause a reduction in surface and near – surface runoff, this happened due to a lowering the water table and increase the available storage capacity of the soil (Wheater & Evans, 2009).

Drainage system calculated by 2 different types of equations to define the scheme, steady state and unsteady state. First case if the discharge will be equal with the recharge to the groundwater which is constant with stable water table, this is called steady state equation. The opposite way is called unsteady state, where the reality happened with recharge of the groundwater will be depend on time and flow. The unsteady state equation is usually solved by some method such as De Zeeuw – Helinga Equation, Dupuit – Forchheimer assumption, The Glover – Dumm Equation, etc (H. P. Ritzema, 2006). By installing drainage system in saturated soils, also decreasing the level of subsurface water table and enable the creation of groundwater reservoirs without gravity water (Stibinger, 2015).

This study will be focused on water under the surface soil by using open ditches combine with subsurface drainage system or tile drainage, with dykes along the river side. Realizing the subsurface drainage system, there are 3 types of control systems which can be applied best based on their each special conditions such as hydraulic conductivity, drainage pipe or flow condition in the pipe mention below (H. P. Ritzema, 2006):

1. Tube – well Drainage
2. Open Drainage
3. Subsurface Drainage (pipe drain or mole drain)

3.1. Subsurface drainage system

Subsurface drainage system is important for certain soil types, it allows for the land to be more productive and produce better crop growth due to excess moisture condition (Riley, 2006). Subsurface drainage system located under the surface soil and has ability to control water table on the field. Implementation of drainage system can cause rise of water table until the flow into the drains is just equal to the amount of rain or irrigation water infiltrating through the soil surface.

One of recent study in United States said that tile drainage has dramatic influence to the development of agriculture, by facilitating crop growth in usually unsuitable areas. It also significantly and permanently influence the hydrology of heavily drained regions, such as the Midwest by substantially reducing surface runoff, shortening periods of surface poundage and lowering water table height (Cooke, Badiger, & García, 2001).

Recent study presented that tile drainage is able to estimate the nitrate load and simulate the effect after drainage implemented in regard to the water management by using some hydrological modelling. DRAINMOD is one of the hydrological models which require tile spacing as an input to estimate drain flow from a field or watershed (Naz, Ale, & Bowling, 2009). There are some countries in Europe such as Netherland, Lithuania or Denmark, where the ratio of drained area of total area for each country is 0.72; 0.4; and 0.37 respectively, this numbers showed us how importance of drainage policy for our living (Stibinger, 2013). Although it is important to make sure the input has to be correct to reduce the errors in the end, most of input parameters of DRAINMOD are measured directly in the field with high accuracy (Singh, Helmers, & Qi, 2006).

Sheler (2013) explained there are four types of subsurface drainage system which works based on certain characteristic, also depend on the landscape of the area (Fig. 1). This study will focus on open ditches combine with tile drainage based on the situation of the selected area. It is perfectly match with most of the points from below situation explained by Ritzema (2006), it will be explained more detail in the next chapter corresponding the total average precipitation in the South Moravia, Czech Republic. Ritzema (2006) conclude a particular situation that could be appropriate to apply combined systems of open ditches and subsurface drainage, such as:

i. Low permeability of the soil profile located under root – zone with good permeability at drain depth, it helps to lower the water table while heavy rainfall occurs.
ii. Area with deep frost penetration and snow cover during winter, when the snow melting and some soil layer is at some depth still frozen.
iii. Irrigated land in arid and semi – arid regions, subsurface drainage needed to evacuate the excess water from the rice field.
iv. A high – intensity of rainfall area which causes waterlogging on the surface soil even the drainage system is present, this will take a very narrow drain spacing and will be more efficient by surface drainage.

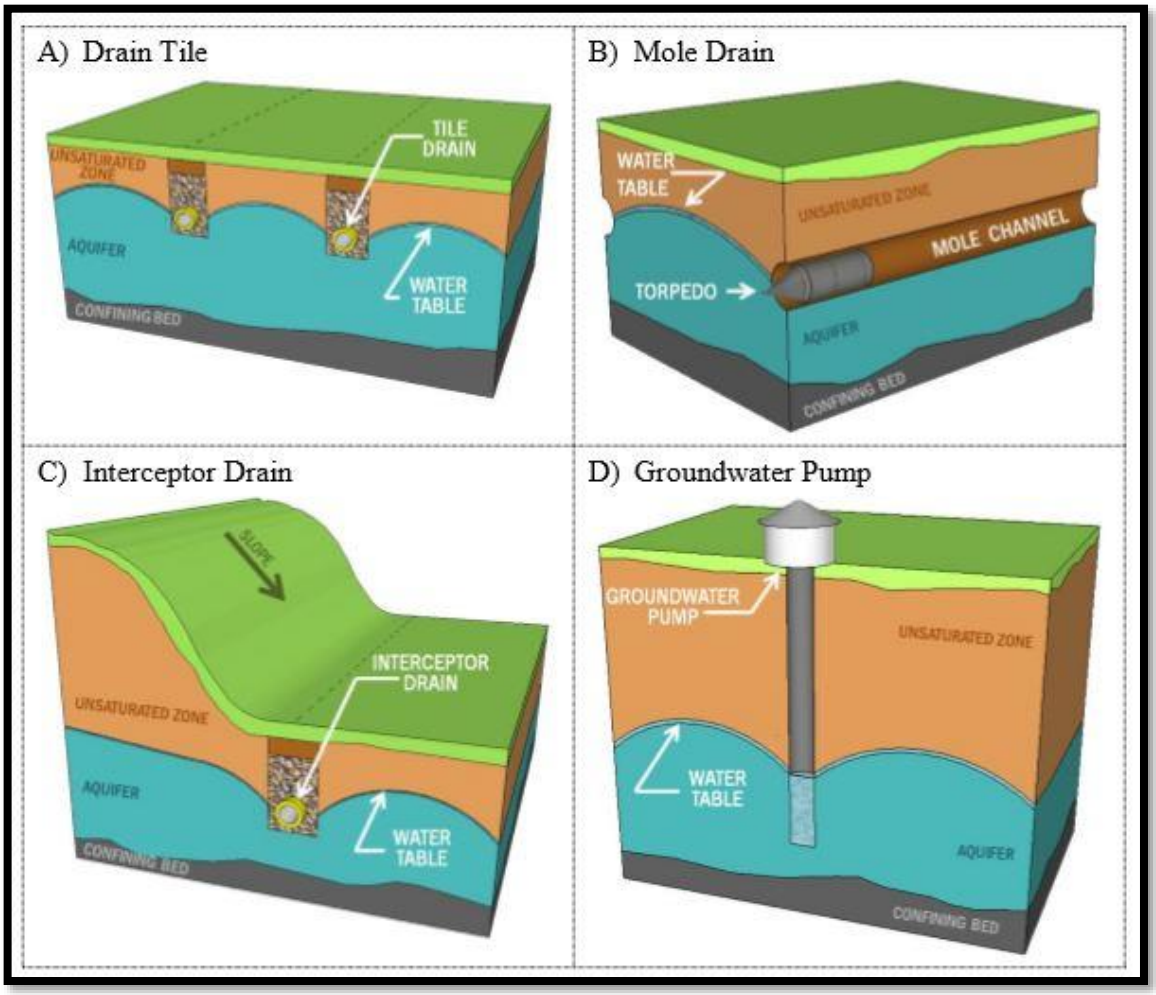
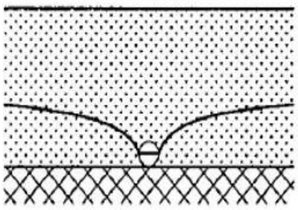
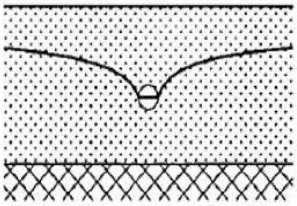
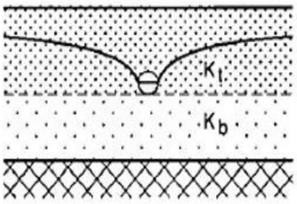
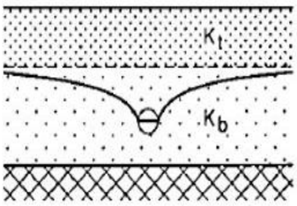
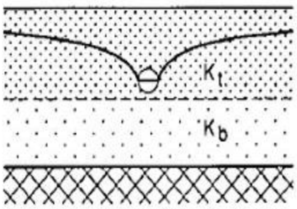


Figure 1. Four types of subsurface drainage system (Sheler, 2013)

Subsurface drainage or mostly called tile drainage has been implemented and developed for long time in many countries, as it is the most efficient yet effective compare to the others. There are some factors to be consider to determine which method can be used based on the situation of the selected area. Mostly to simplify the calculation to make it appropriate and applicable, we will assume that the soil will be nearly steady – state condition.

Table 1. Scheme for drainage solution on each condition (Sheler, 2013)

SCHEMATIZATION	SOIL PROFILE	POSITION OF DRAIN	THEORY	EQUATION
	homogeneous	on top of impervious layer	Hooghoudt/ Donnan	$q = \frac{4K(H^2 - D^2)}{L^2}$
	homogeneous	above impervious layer	Hooghoudt with equi- valent depth	$q = \frac{8Kdh + 4Kh^2}{L^2}$
	two layers	at interface of the two soil layers	Hooghoudt	$q = \frac{8K_b dh + 4K_t h^2}{L^2}$
	two layers ($K_t < K_b$)	in bottom layer	Ernst	$h = q\left(\frac{D_v}{K_t} + \frac{L^2}{8K_b D_b} + \frac{L}{\pi K_b} \ln \frac{D_r}{u}\right)$
	two layers ($K_t < K_b$)	in top layer	Ernst	$h = q\left(\frac{D_v}{K_t} + \frac{L^2}{8(K_b D_b + K_t D_t)} + \frac{L}{\pi K_t} \ln \frac{aD_r}{u}\right)$

The table 1 above represents summary of the 5 schemes of each drainage situation based on groundwater level position, drainage level and water supplies (Sheler, 2013). This thesis will be focused on homogenous soil using Hooghoudt's Equation as a method to calculate drain spacing. Hooghoudt's Equation has been widely used in the humid regions where waterlogging and traffic – ability are the main concern, and irrigated arid lands where drainage is needed primarily for salinity control (Skaggs, Youssef, & Chescheir, 2006).

Assuming there will be two impervious layer on the soil, there are 2 types of tile system: parallel and single drain. Both types of tiles system has different hydraulic conductivity, single tile draws water from a semi – infinite distance on each side and parallels system is constraining the region which got influenced by each of tiles by the neighbouring tiles (Cooke, Badiger, and García, 2001).

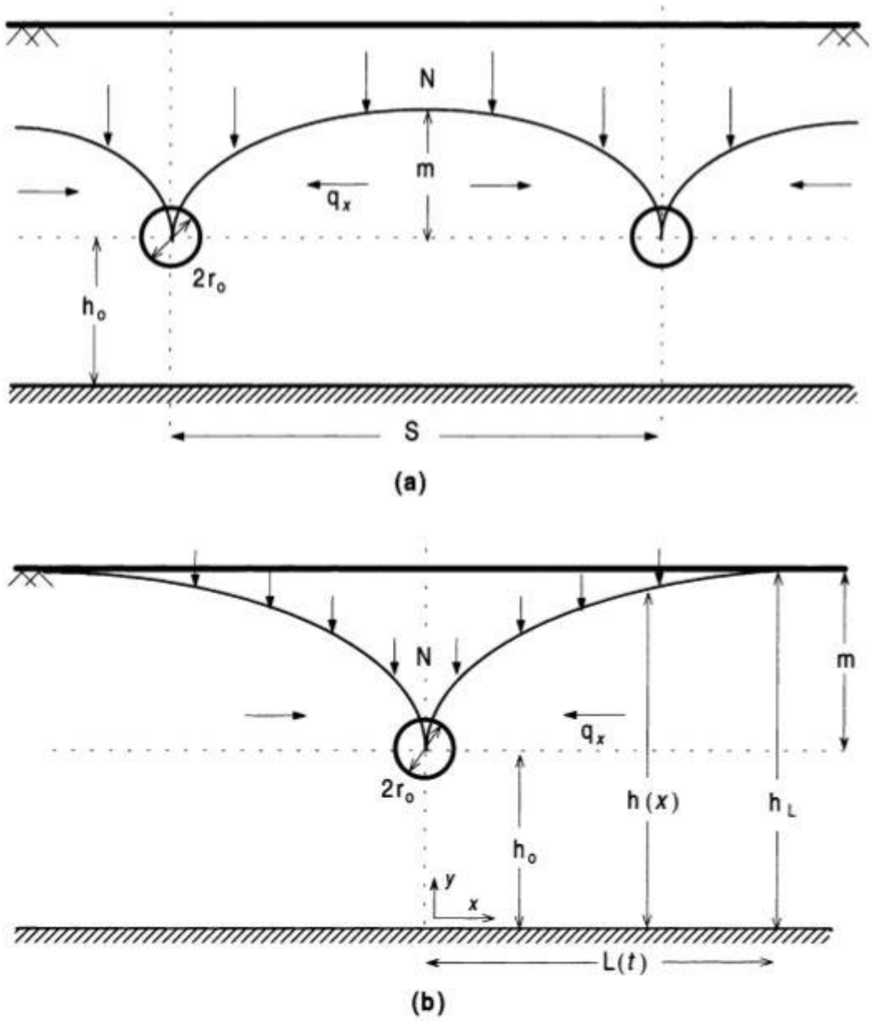


Figure 2. Tile drainage system (a) parallel system and (b) single tile (Cooke et al., 2001)

Groundwater level position is an indicator to identify at which state drainage system should be implement, beside the soil type and rainfall intensity. In any case the groundwater level position will rise, drainage intensity will decreases together with large part of subsoil will be submerged (Wesström, Messing, Linner, & Lindström, 2001). This would also affect the retention time of water increase in soil, causing high potential for water to evapotranspiration and for interim storage of soluble nutrients (Wesstro and Messing, 2007).

3.2. Water table

Water table formed by the water in the saturated soil, the height could be determined by digging a hole and noting the point where water will rise in it (Pickels, 1941). From *Luthin* (1966) defined the following factors to determine the water table position:

i. The rainfall rate or the rate at which irrigation water is applied
ii. The soil hydraulic conductivity
iii. The depth and spacing of the drains
iv. The depth to an impermeable layer

The upper limit of waterlogging on the soil called water table is usually determined by creating a hole or well and marked the height of water, which could possibly reach the maximum condition. On some point the water table could almost reach the surface, this condition describes, that the area has no drainage system. This is the example, how strong is the relation between soil and drainage system. This cases are a proof that control drainage could save environment not only the water but also the soil.

The prediction of water table has been investigated by the use of Boussinesq's equation to look at the convergence near the drain. In one recent study they predict the drain flow rates in transient condition during recharge, focused on steady state relationship between water table at drain spacing and drain flow rate assumed valid regardless to the possible effect of time dependent recharge (Bouarfa & Zimmer, 2000). In this study are also mentioned some of hydrological models for example DRAINMOD, which predicts drain flow rates by using the Hooghoudt's Equation. It needs to be underline that this relationship is only used to study the functioning of shallow drainage system in the transient condition.

For some cases, in an undrained area, water table is usually placed nearby the surface soil. This condition will cause bad effect to the crops, and in the end it's huge loss in either economy or in environment. Especially during high period of rain or after winter when the snow is melting, huge rate of recharge will occur and high water table will be expected. At this case, it will also depend on the soil permeability for water, which moves vertically through the soil layer. In case it has low value of permeability, there is big possibility that waterlogging will happen, or floods if the rain keep continue occur.

Water table will get lower by evapotranspiration process. In drained area, water table is under control even though heavy rain occurs. In the area with higher precipitation, the drain spacing will be more narrow compare to area with lower rate of precipitation.

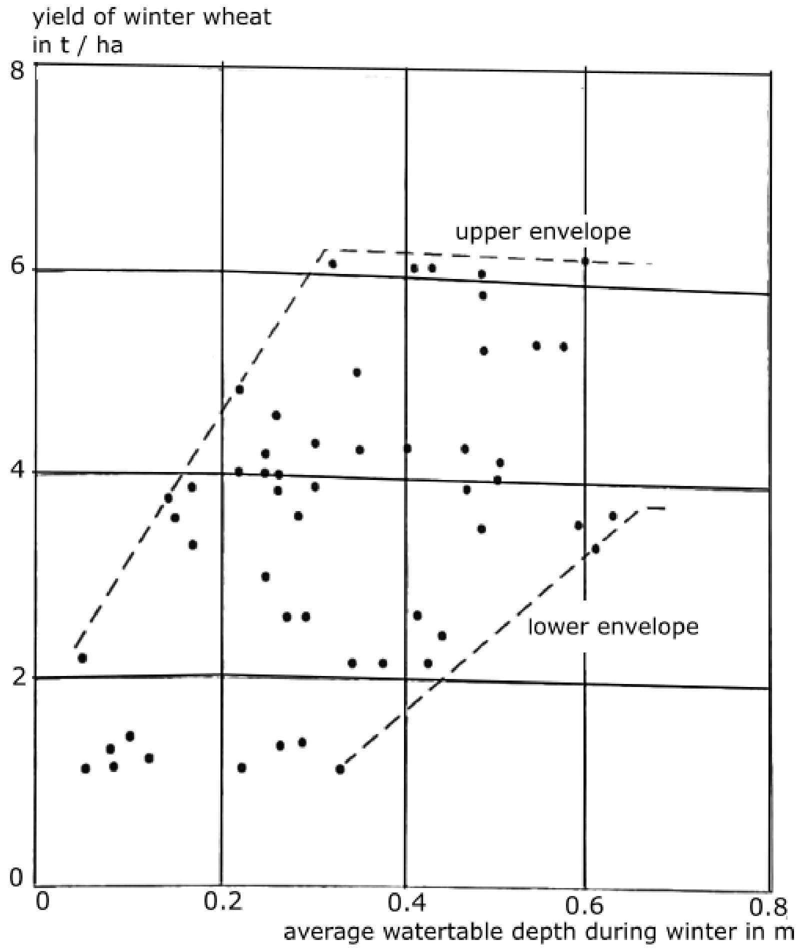


Figure 3. A plot of the yield between winter wheat with average depth of water table (H. P. Ritzema, 2006)

Figure 3 above represents a plot of the yield of winter wheat in relation with the depth of water table, the data were collected in winter period with heavy clay soil occur. The plot (fig. 3) was a result of one study, observed in England for 5 years duration. The study went in winter, because summer in England is less problem since the evapotranspiration is much higher and water tables are very low or deep (>1m) (H. P. Ritzema, 2006). From the scattered plot Figure 3, Ritzema (2006) conclude that if drainage could maintain water table in winter with calculated average depth, it is considerable that yield benefit would result, which that depth would be good enough as a criterion of agricultural drainage are based on that area from which the data were collected.

Furthermore, water table is not the only one responsible condition in the relationship with crop yield. Based on the scatter plot from Figure 3, it is logical, that there many other factors that can affect the crop growth (H. P. Ritzema, 2006).

3.3. Hydraulic conductivity

Hydraulic conductivity is usually represented by coefficient K (M.T-1), where measure the discharge per unit area at unit hydraulic gradient dependent on the porosity and on the size or shape of the material grains. K also depends on the grain size distribution and temperature of the water (H. P. Ritzema, 2006). Hydraulic conductivity is affected by the structure as well as by the texture, being greater if the soil is highly porous, fractured, or aggregated compare if it is tightly compacted and dense (Hillel, 2004). Hydraulic conductivity also depends not only on total porosity but primarily on the sizes of the conducting pores (Hillel, 2004). Hydraulic conductivity is one of the important factor to determine the flow of the groundwater to design the control drainage system, especially it will be related to the water table which will depend on the type of soil and flow of water.

Hydraulic conductivity or K ($M.T^{-1}$) could characterize the hydraulic properties of soils, earth, and also other porous materials and media. It is possible from point of view of the water flow velocity in their porous until fully saturated flow conditions. Soil conductivity is defined as a constant of proportionality in Darcy's Law. It means that the hydraulic conductivity could be determined as groundwater velocity, only when the hydraulic gradient equals unity (=1) (H. P. Ritzema, 2006).

Hooghoudt's Equation describes the flow below the drain level, and it is used if the drain level interface is between the 2 soil layers, which soil layer consists of 2 different hydraulic conductivity. If the drains are situated either above or below the interface of 2 layers, the hydraulic conductivities cannot be differentiated in the same way and usually it needs to apply Ernst Equation. Hooghoudt's Equation is one of the way to simulate the Tile Drainage system focusing on vertical column of soil located in the middle between drains, it is working same by Ernst Equation (Sheler, 2013).

Table 2. Hydraulic conductivity (K) value range by soil texture (Ritzema, 2006)

Texture	Hydraulic Conductivity – K ($m.s^{-1}$)
Gravel	$10^{3} – 10^{-3}$
Medium sand	$10^{-3} – 10^{-4}$
Sandy loam, fine sand	10^{-4}
Loam, clay loam, clay (well structured)	$10^{-5} – 10^{-6}$
Very fine sandy loam	About 10^{-6}
Clay loam, clay (poorly structured)	$10^{-7} – 10^{-8}$
Dense clay (no cracks, pores)	$10^{-8} – 10^{-10}$
Loamy soils	10^{-5} ($10^{-4} – 10^{-6}$)

To design drainage system some important information, beside the water table, landscape, soil types, which will lead to hydraulic conductivity. There are few options to determine hydraulic conductivity (K), it will be all dependent on the soil type. Basically the determination of K could be as *in situ* or *ex situ*. Laboratory measurement or so called *ex situ* is not the most used way which researcher take to compare to the *in situ* which is on the spot. For laboratory measurement, the collection of the sample must ensure few points below (Ilek & Kucza, 2014):

(1) Preservation of continuity of the sample with surrounding soil
(2) Preservation of natural residual system of soil, such as root system and soil channels within the boundary of the sample
(3) Preservation of natural porosity
(4) Preservation of main, vertical direction of infiltration of water flowing through the sample during testing
(5) Measurement errors of K will be eliminated due to leakage the boundary

Heavy clay soils with low hydraulic conductivity often have a top layer with surprisingly high hydraulic conductivity because of the activity of plant roots or the presence of a tiled layer. In such cases, rainfall will build up a perched water table on the layer just below the top layer. Under these condition, a subsurface drainage system can be effective because of the interflow in the permeable top layer, but it will only work as long as the backfilled trench remains more permeable than the original soil (H. P. Ritzema, 2006).

3.4. Soil Type

Based on some discussion, it is very clear that the relation between soil structure and methods of drainage system is important and working simultaneously. Water – flow velocity influenced mostly by the slope of the topography or the landscape as well as hydraulic gradient in regard to induce water flow similarly for infiltration, soil type properties such as roughness and permeability are also important (Lacroix, Wang, & Blavoux, 1996). To design the drainage system it will strongly depend on the condition of agricultural, especially on the soil structure (Pickels, 1941). Researcher have made laboratory experiments of water movement through various types of soil, for soil in wet areas with more or less saturate condition due to the impervious surface soil, water can pass through it very slowly with result the saturation layer is always close to the surface (Pickels, 1941).

The definition of soil is very wide. Based on this study, soil is considered as a result of weathering process during long period of time from rocks for example. Soil definition for pedologist or scientist is a result of weathered and fragmented outer layer of earth’s terrestrial surface, formed by disintegration, decomposition, and re – composition of mineral material which comes from rocks and done by physical, chemical and biological processes (Hillel, 2004). Soil is not just a solid material which we can see and feel, it is also consist of gaseous phase called soil air and liquid phase called soil moisture (Luthin, 1966).

Figure 4 represented the soil layer contrasts structure that is not typical but simple prediction of the soil profile, where horizon A represents aggregated crumb like structure, horizon B with columnar structure, C horizon incompletely weathered rock fragments. Among pedologist, soil profile is distinguished more complex by their formation and recognizable properties which are pictured in the figure 5 (Sheler, 2013). Defining soil profile is essential part of soil investigation. After the soil profile has been defined, a laboratory analysis shall take place after, usually by taking the undisturbed soil sample then get analysed for chemical, physical, and mineralogical (H. P. Ritzema, 2006). The aim for the laboratory analysis is to determine the soil classification, which will be useful to design a proper drainage system.

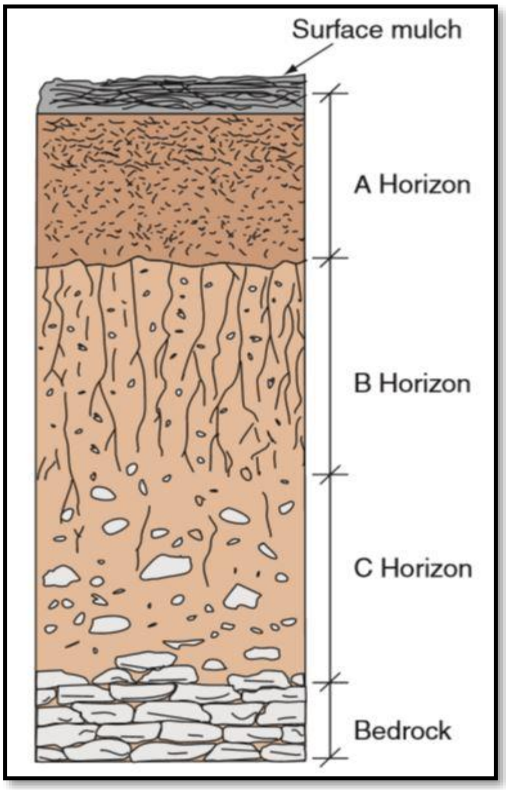


Figure 4. Prediction of soil profile (Sheler, 2013)

Mentioned in previous paragraph the texture of soil consists not only solid material, but also liquid and gaseous phases. First of all I would like to describe solid part which is distinguished into 3 type: sand, silt and clay. One of most common way or conventional method to determine the soil texture by particle size classification is using Textural Triangle (fig. 6).

Soil texture plays important role on designing a drainage system, the reason is to determine the soil permeability. Permeability is important characteristic of soil with huge values of specific information, it is fact that clay, silt and some silt loams cannot be drained perfectly. In many soils with clay as a subsoil has developed near the surface, because the high water table caused by impervious sub-layer by an accumulation of colloids. In fact all permeability characteristics, soil texture has a controlling influence on the effective strength properties of the soils and on their responses under stress and hence on stability conditions (Luthin, 1966).

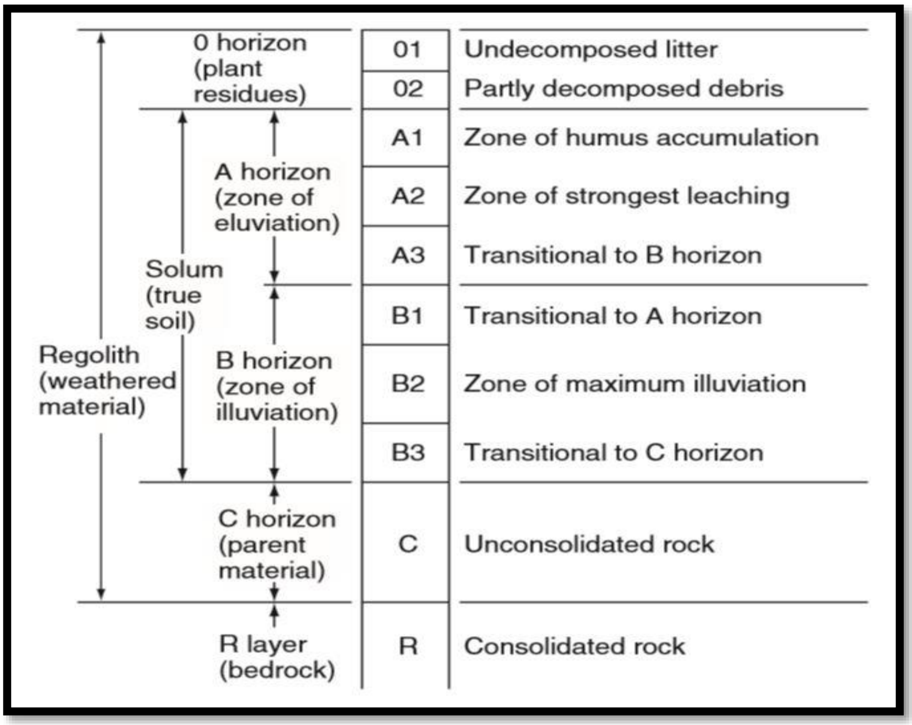


Figure 5. Terminology of soil profile (Hillel, 2004)

Table 3 below showed us the International Society of Soil Science (ISSS), it proposed the size limitation to determine the soil texture, which is most used by scientists.

Table 3. Soil classification scheme based on ISSS (Luthin, 1966)

Separate	Diameter Limits (mm)
Coarse sand	2.00 – 0.2
Fine sand	0.2 – 0.02
Silt	0.02 – 0.002
Clay	< 0.002

Drainage system placed in soil with high concentration of organic matter could bring short and long term effect. For example by lowering the water table in peatlands, could increase the amount of available storage capacity in short term and also organic matter decomposition rates, resulting in a subsequent decrease in available storage, as the organic matter content decreases and hence potentially an increase in flood peaks in long term as well as long term soil damage (Wheater & Evans, 2009). Under natural condition, peatland formed by the accumulation of vegetation, which is deposited on the waterlogged soils faster than it can decay (H. Ritzema & Wösten, 2002).

Common case in agricultural land or any other types of land which will need drainage system, had trouble with low permeability soil which is mostly the soil type is clay. Below are the explanation of each soil types relating to the size of the particles.

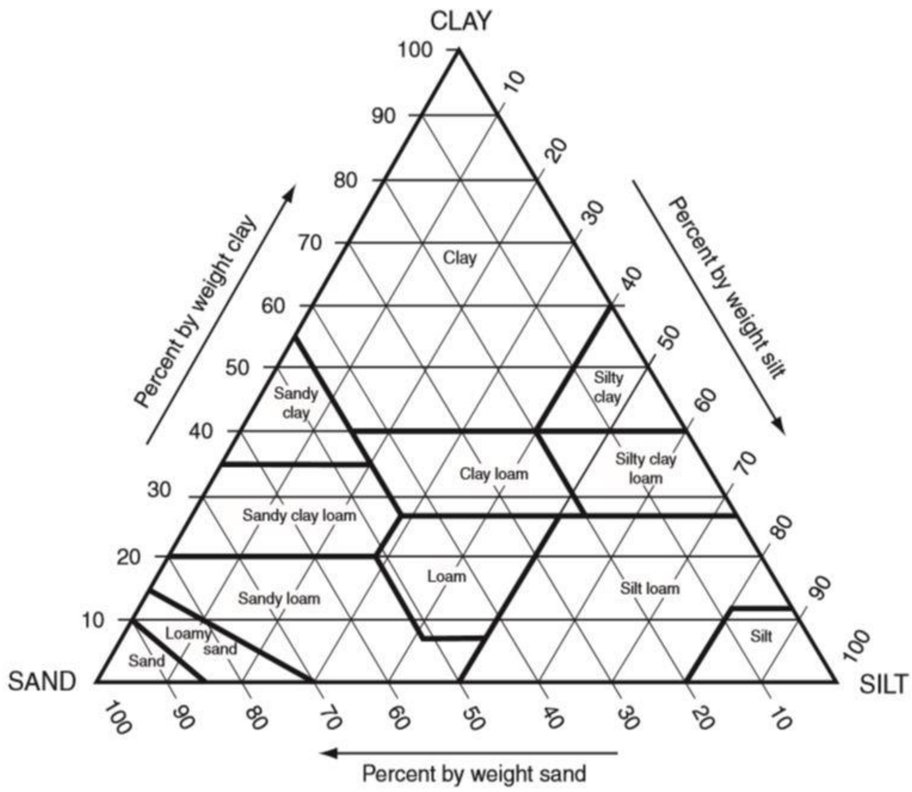


Figure 6. Textural Triangle (Hillel, 2004)

3.4.1. Sand

Sand is the most common particle we see when we are going to the beach or easily pictured by the desert. Sand has higher hydraulic conductivity compare to clay, this is the reason which also explain by Hillel (2004) that sand has more rapid infiltration but it does not sustain the evaporation process (during the surface zone become desiccated) compare to clay soil. This soil particle physically recognizable based on ISSS classification it has diameter 2 – 0.2 mm for course sand, and 0.2 – 0.02 mm for fine sand. Sand has the biggest particle size compare silt and clay.

Most common cases, sand consist of quartz either fragments of feldspar, mica and another heavy metal such as zircon, tourmaline, and hornblende although these are rarely found (Hillel, 2004).

3.4.2. Silt

Silt particle has smaller diameter compare to sand based on ISSS it is between 0.02 – 0.002 mm. Generally silt is non – reactive soil material, as it has unique characteristic which does not swell when it is exposed to water. This is the reason why silt has instability for open ditch, especially to maintain it (Luthin, 1966).

3.4.3. Clay

Clay soil are often considered as an impervious layer to water, impermeable soil combined with high intensity of rainfall which is resulting on excess surface water. This condition caused big problem in many cases but especially on agricultural land which leads to waterlogging or flood. The hydraulic conductivity for unstructured heavy clay is too low for common drainage system, even though closely spaced the tile pipe drainage is costly compare to mole drainage, yet it is still more efficient and beneficial with less maintenance (Kumar & Koga, 1995).

Clay has unique characteristic compare to another soil particles. Based on ISSS clay has diameter less than 0.002 mm, and influences the behaviour of the soil. It affected the permeability of soil related with the water table. Clays are complex aluminosilicates and it contains two elements such as aluminium and silicon combined into crystalline structure, categorized into kaolin group. This mineral components of clay fraction consist of crystalline hydrous aluminosilicates, which have layered structure composed of sheet of silicon oxide and sheet of aluminium hydroxide. Combination of silicone sheet and aluminium hydroxide could result in a different layer structure, in reality there are many different clay types that deviate from the ideal combinations of both silicone oxide and aluminium hydroxide sheets (H. P. Ritzema, 2006).

3.5. Hydrological Parameter

3.5.1. Precipitation

One of the factor which causes excess water on the surface soil is high precipitation combined with low permeability of soil. In conclusion precipitation and evaporation are two related processes in the water cycle. It is also mentioned in Pickels (1941), the source of precipitation is the water which is evaporated from oceans, lakes, rivers, and other water surfaces, and from the soil which is given off through the leaves of plants in the process of transpiration. Previously it is mentioned, that precipitation and evaporation are related to each other in one cycle and affected also by the temperature, and caused water evaporate to the atmosphere.

Continually diffused in the air and resulting the air temperature getting lower, as the air becomes cooler until relative humidity is 100% then it is saturated with water vapour. Furthermore the temperature keep decreasing related to the low atmospheric pressure, it will cause condensation of the water vapour formed in the clouds. When condensation is sufficient extent, clouds particles will coalesce and will create rain (Pickels, 1941). Another case is, if the temperature in the clouds is below freezing, this will cause snow instead of rain (Luthin, 1966).

Indeed there are many theories around related about how precipitation occurs, but most of the theories is highlighted, that it is significantly caused by the cooling water vapour condensed into cloud and fall as a rain/snow. Precipitation classified into three methods based on the movement of air mass in the atmosphere, such as cyclonic, convective, and orographic is described below.

3.5.1.1. Cyclonic

Cyclonic precipitation or some call it Frontal precipitation is caused by overlapping between cold air mass and warm moist air mass. Another case which caused by movement of an air mass due to pressure differences in an area with low pressure happened inside, the air will flow horizontally from surrounding causing the air to lift and precipitation resulting by this condition called non – frontal precipitation (Luthin, 1966).

3.5.1.2. Convective

Convective precipitation caused by heat in the surface with low pressure pushes the movement of air to vertical. Because of the warm temperature in the surface, it heats the air and cause the movement of the air molecule further and rise into atmosphere continue with condensation into cloud and precipitation.

3.5.1.3. Orographic

Orographic precipitation mostly happens in mountain area, it is caused by rises air mass over mountain barrier also by other changes in topography area. Orographic barriers tend to increase cyclonic also orographic precipitation because of the increased lifting is involved (Luthin, 1966). In order to pass the mountains, the air moves horizontally and is forced to rise and caused the moisture in the air to be precipitate on windward slope (Pickels, 1941).

The measurement of rainfall is necessary to collect data and estimate the flood risk in future. Each country most of the times provides the hydrological data including precipitation for each region. But it is still possible to estimate the precipitation from streamflow fluctuations which able to reconstructing the past precipitation, in case no precipitation records available only streamflow records are available (Kirchner, 2009). Kirchner (2009) also explained how he explores this possibility by using record of streamflow from

1974 – 2000 to reconstruct precipitation in two catchments by using an equation (2) which the analysis begins from basic conservation – of-mass equation (1) after all mathematical process to make simplicity of the system.

$$\frac{dS}{dt} = P - E - Q \qquad (1)$$

$$P_t \approx \max\left(0, \frac{\frac{Q_{t+l+1} - Q_{t+l-1}}{2}}{\frac{[g(Q_{t+l+1}) + g(Q_{t+l-1})]}{2}} + \frac{Q_{t+l+1} + Q_{t+l-1}}{2}\right) \qquad (2)$$

Where *S* is the volume of the water stored in catchment, *P* is precipitation, *E* is evapotranspiration, and *Q* is discharge, where P, E, Q, and S is a function of time, also *l* is explained as travel time lag for changes in discharge to reach the weir.

As is previously mentioned how important it is to collect the rainfall data base, the aimed to store the data continuously will help us to indicate the intensity of the rainfall. It will be low or high, along the rainfall duration. The result from the modelling will be one of the important aspect to design a proper drainage system, related to the capacity of the drain with the estimation of runoff. Luthin (1996) also mentioned the intensity of the rainfall is the rate at which it falls per one time.

There is possibility to calculate rainfall intensity such as Rational Method. According to Boucher (2010), the Duration – Frequency – Depth (DFD) curves could be one of the way to determine rainfall intensity for rational method. Few steps are necessary to be follow to get a valid result of rainfall intensity value (Boucher, 2010), such as:

i. Determine the mean seasonal precipitation from the local area.
ii. Choose the design storm frequency and use the appropriate DFD drawing.
iii. Choose a proper time of concentration (T in minutes).
iv. Choose a curve that corresponds to the mean seasonal precipitation for the selected area.
v. Find the corresponding depth of precipitation on the vertical axis.

vi. Calculate the rainfall intensity with this following formula in inches/hour.

$$Rainfall\ intensity\ (in/hr) = P / T\ (min) * 60\ (min) \quad (3)$$

In this study, we will just use the formula to calculate the rainfall intensity without drawing the curve.

3.5.2. Evapotranspiration

Evapotranspiration is a combination between evaporation of water from the surface soil with transpiration from the plant (Tancreto, 2015). Evapotranspiration (Et) occurs because of temperature raising also affected aeration, along with the types and rates of chemical reaction that takes place in the soil (Hillel, 2004). As mentioned previously, evapotranspiration involved in the precipitation cycle. Actual evapotranspiration can be measured with the soil water balance approach or with micro – meteorological methods (H. P. Ritzema, 2006). Recently some hydrological model are developed well to provide tools to measure such a parameters.

DRAINMOD is one hydrological model which is developed to be able to simulate a soil regime of drainage landscape and also predict surface runoff, infiltration, evapotranspiration, subsurface drainage, and seepage, from the soil mostly using a water balance for vertical soil column (Sheler, 2013). DRAINMOD will calculate the evapotranspiration by using temperature based on Thornthwaite method (Wang, Mosley, Frankenberger, & Kladivko, 2006). Wang *et al* (2006) also mentioned how Thornthwaite method calculate the ET by using the daily maximum and minimum temperature from the experimental drainage field or any nearby weather station, based on latitude and average heat index computed with long – term monthly average temperature in the study area. The evapotranspiration rate will be higher in warm climate area, and hence, the hazard salinity likely to be greater than in cool climate area (Hillel, 2004).

The excess surface water which is not evaporated some will goes to enter the soil layer by infiltration as we will discuss below. The rest of surface water could be as surface runoff

3.5.3. Infiltration

Infiltration is a process when the surface water either from irrigation or precipitation penetrates the soil basically on vertical or downward movement through the soil layer. Hillel (2004) explained that surface water will be partitioned into few conditions later on, some will be returned to the atmosphere directly by evaporation either transpiration from the plant after absorption, the rest of the excess water will be kept as a groundwater. The amount of the water which is being kept as a groundwater or being captured by the plants and then absorbed is called infiltration rate, which is defined by Hillel (2004) that is the infiltration rate as volume flux of water flowing through the profile per unit of soil surface area.

Infiltration divides rainfall into runoff and soil water, while soil water percolates into deep soil or groundwater and becomes unavailable for a plants (Huang, Lee Barbour, Elshorbagy, Zettl, & Cheng Si, 2011). Huang *et al* (2011) also mentioned some studies describing infiltration and drainage used to study the mechanisms of water flow and solute transport in layered soils, others study are more focused on developing numerical algorithms to estimate the inter layer hydraulic conductivity between two neighbouring nodes positioned in different soil layers for improving simulation accuracy.

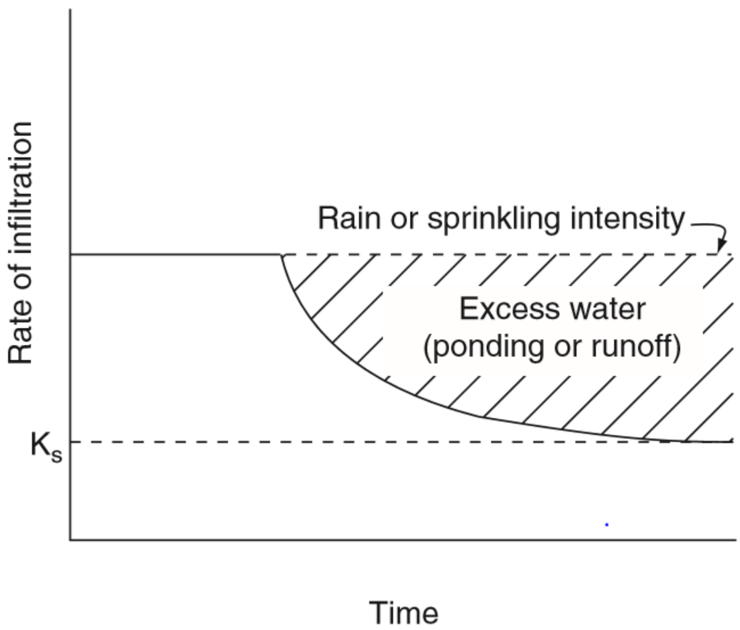


Figure 7. Time dependency of infiltration rate (Hillel, 2004)

Figure 7 shows us the infiltration rate depending on time under rainfall. In some cases, Hillel (2004) explained that in downward flow into vertical column under continuous ponding, the infiltration rate intend to be steady, gravity – induced rate that approximates the soil saturated hydraulic conductivity if the soil profile is homogenous and structurally stable.

3.6. Drain Spacing

Drainage system under the surface soil designed with drains located in a space equally distanced with each pipe. Luthin (1966) mentions about the flow rate based on Kirkham's solution for ponded water, which indicated that the flow rate is independent of the spacing. Indeed the water inflow is not independent of the drain depth, in condition with impervious layer lie down (Luthin, 1966).

The drain spacing calculated based on the boundary area to show considerable variations due to variation in soil hydraulic conductivity (H. P. Ritzema, 2006). Drain spacing represented with L, and in this study will be calculated by using Hooghoudt's Equation. Hooghoudt invented a simpler formula which is widely used nowadays, assuming the flow will be radial up to a distance of $D/\sqrt{2}$ from the drains where D is the thickness of soil layer below the tile drains, and then converted to the radial flow zones and the central Dupuit – Forchheimer (D – F) horizontal flow zone into a single equivalent zone (Mishra & Singh, 2007). The bigger picture of the scheme is represented in figure 8 below.

Drain spacing and drain depth is dependently affecting each other. Both parameters in drainage system design are helping the arrangement of water table in one preferable position, the reason was to improve the crop yield and keep the water below the root zone. To design drain spacing it will be also dependent on the recharge water or input water, which mostly come from precipitation or from snow melting. The more high the recharge the more narrow drain spacing should be designed. This is to keep the water balance stable in the preferable position.

One of the study mentioned, that prediction of tile drain spacing could be used to estimate the nitrate load and simulating the effect of drainage water management at watershed – scale, by using a hydrological modelling (Naz et al., 2009).

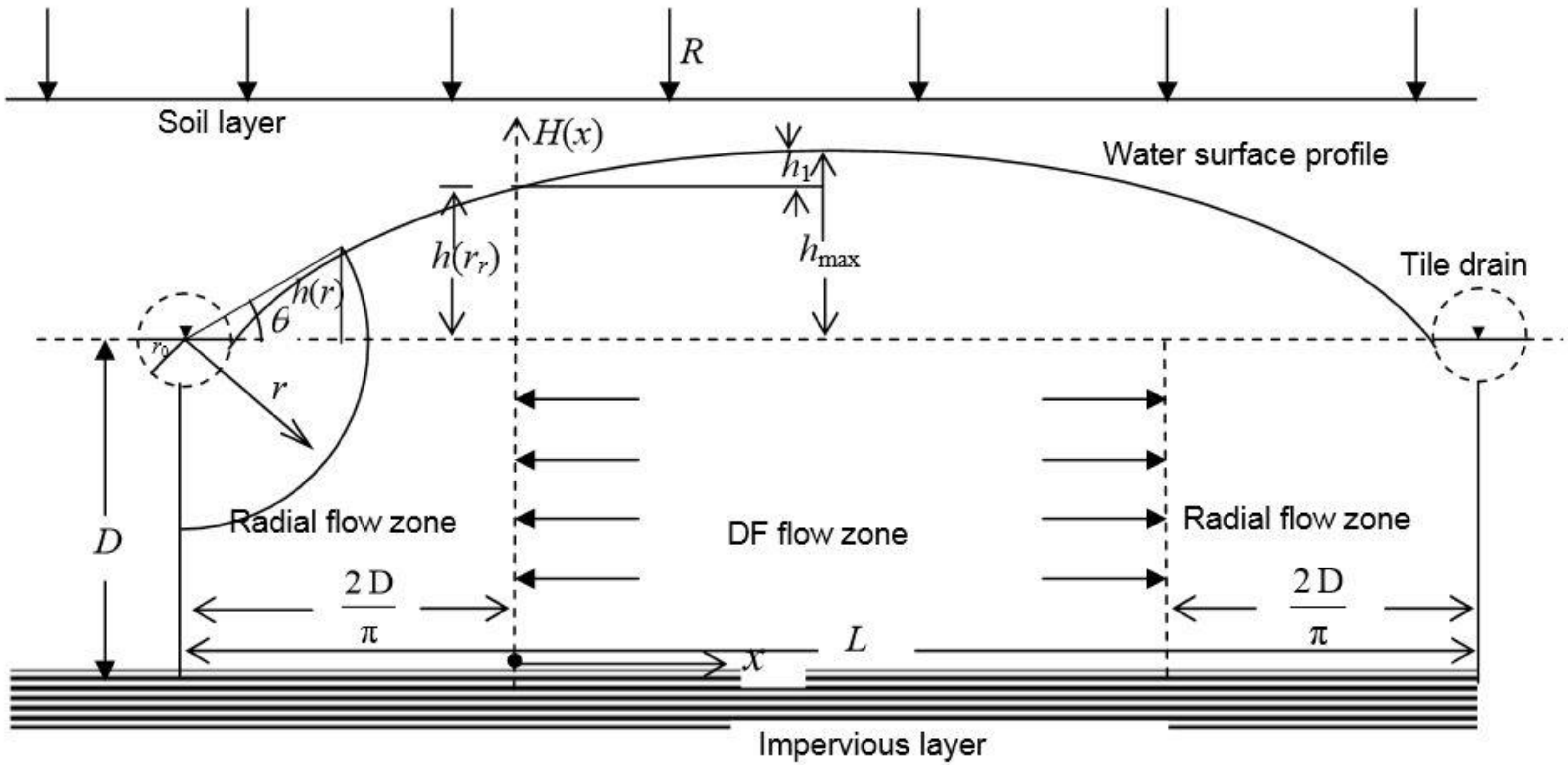


Figure 8. Scheme of steady – state flow showing Dupuit – Forchheimer and radial flow zones (Mishra & Singh, 2007)

4. Methodology

4.1. Study Area

The hydrological data collected in south part of Czech Republic, in meadows area named Gbely Meadows. The chosen area is located between Hodonin and Lanzhot in the border between Czech Republic and Slovakia. Figure below showed the location of the meadows nearby Morava River.

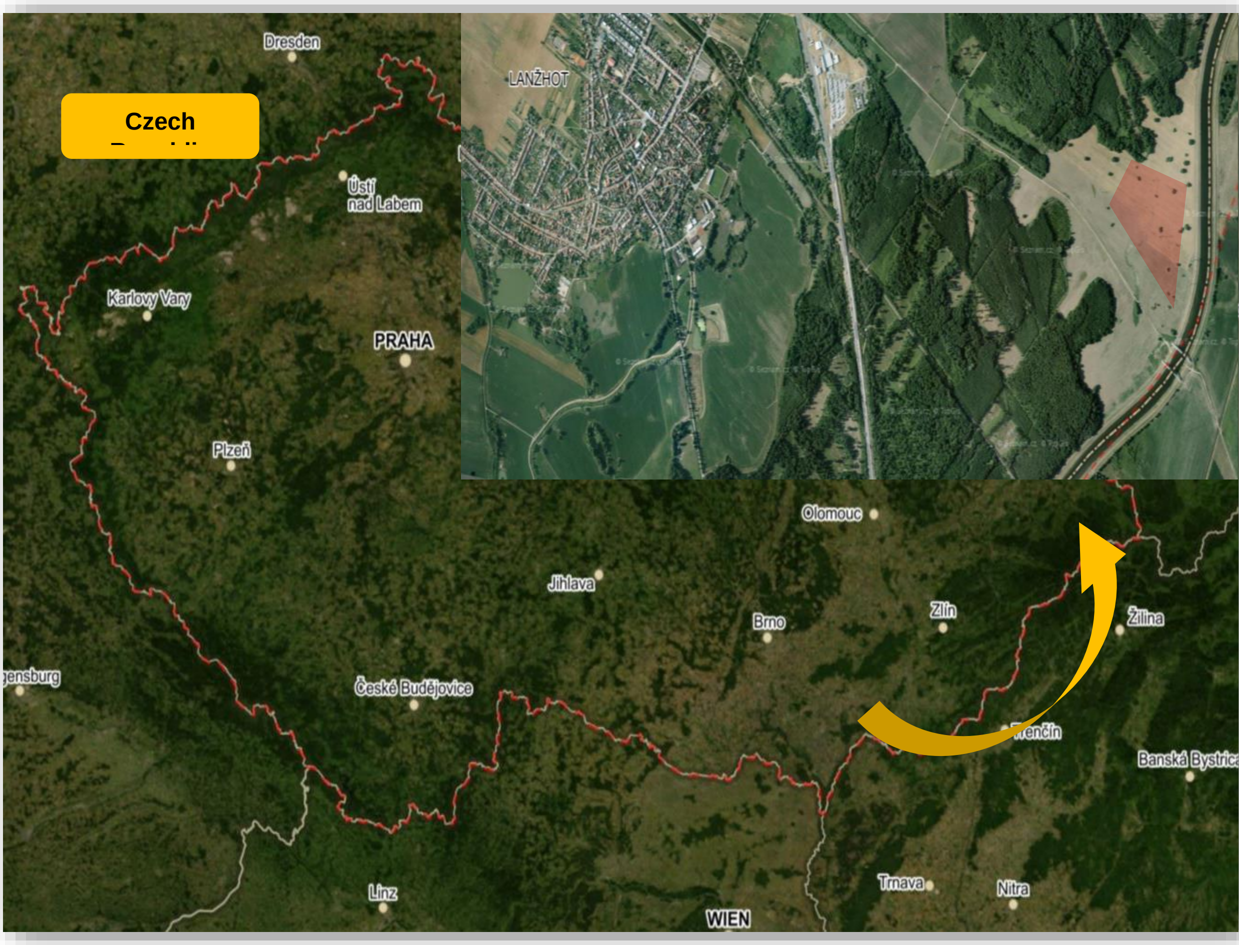


Figure 9. Selected study area in South Moravia, Czech Republic (red box), Gbely Meadows (photo taken from www.mapy.cz)

Primary data such as soil hydraulic conductivity and other parameters for drainage design were collected from previous study of “Biotechnická opatření pro úpravu vodního režimu ve vybraných lokalitách modelového území Pomoravské nivy” under group of Stibinger *et al.* (2015).

Secondary data from this area will be hydrology parameter, precipitation and temperature were collected from Czech Hydrometeorological Institute (CHMI). The calculation will continue using Hooghoudt's Equation and we will discuss more detail in further chapter. The selected area marked in red box on figure 8 is showing the location, where the drainage system will be implemented, and it was before the location of old constructed drainage.

Figure 10. Water logging in Gbely Meadows (photo taken by J. Štibinger)

Figure 10 represents the condition in the selected area, photo taken in spring period approximately in the end of March or beginning of April 2013. Spring period is perfect timing to see how soil can handle free water from the snow melting in the local area, either runoff from higher landscape which goes to Moravian River.

This areas were used for grass field by local farmers. As we can see in figure 10 and figure 11, there is high probability of floods will occur in case of heavy rain period coming.

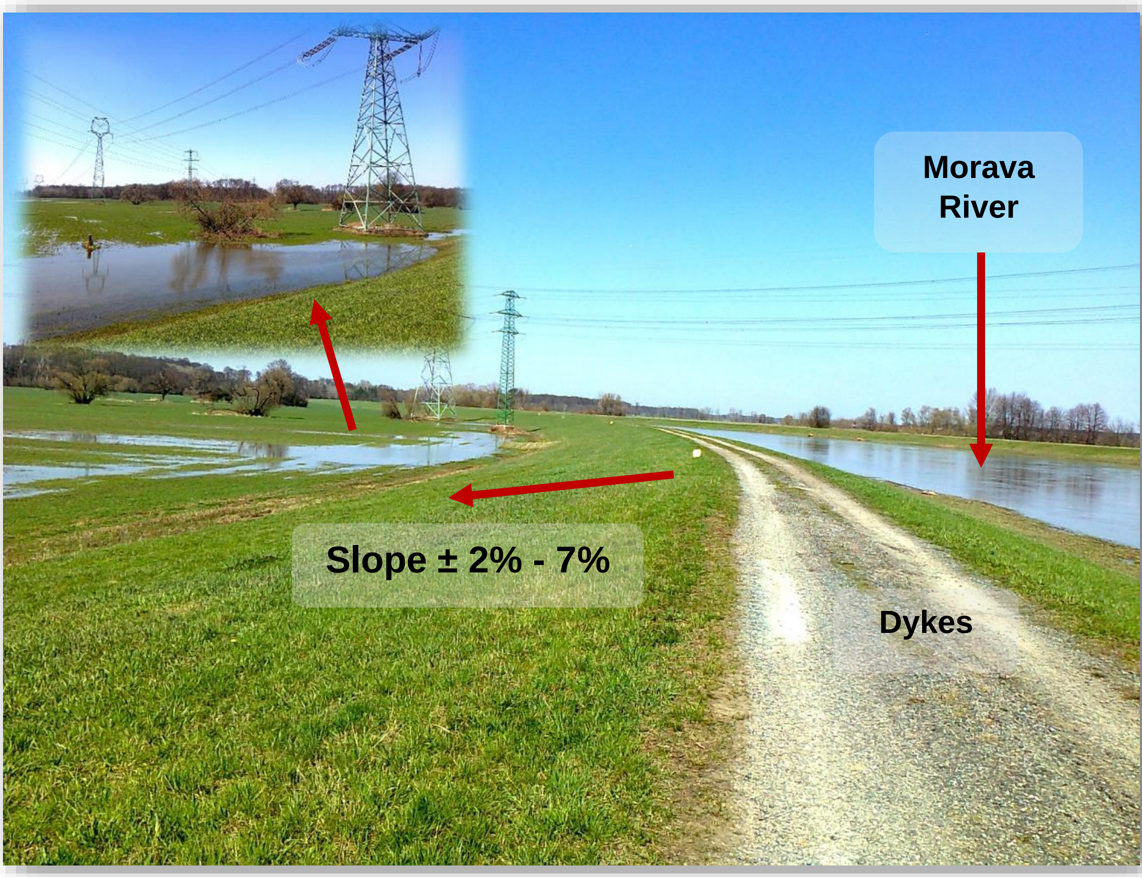


Figure 11. Real condition of landscape in Gbely Meadows (photo taken J. Štibinger)

From previous study, Štibinger *et al* (2015) tried to design a drainage system in this location with cross section showed in figure 12. They also tried to design 3 different models for this drainage system (Figure 12), in the end all models will have same outlet. All water will goes to a pond which they designed also (fig.13). Below are the picture of small pond as catchement water from drainage system.

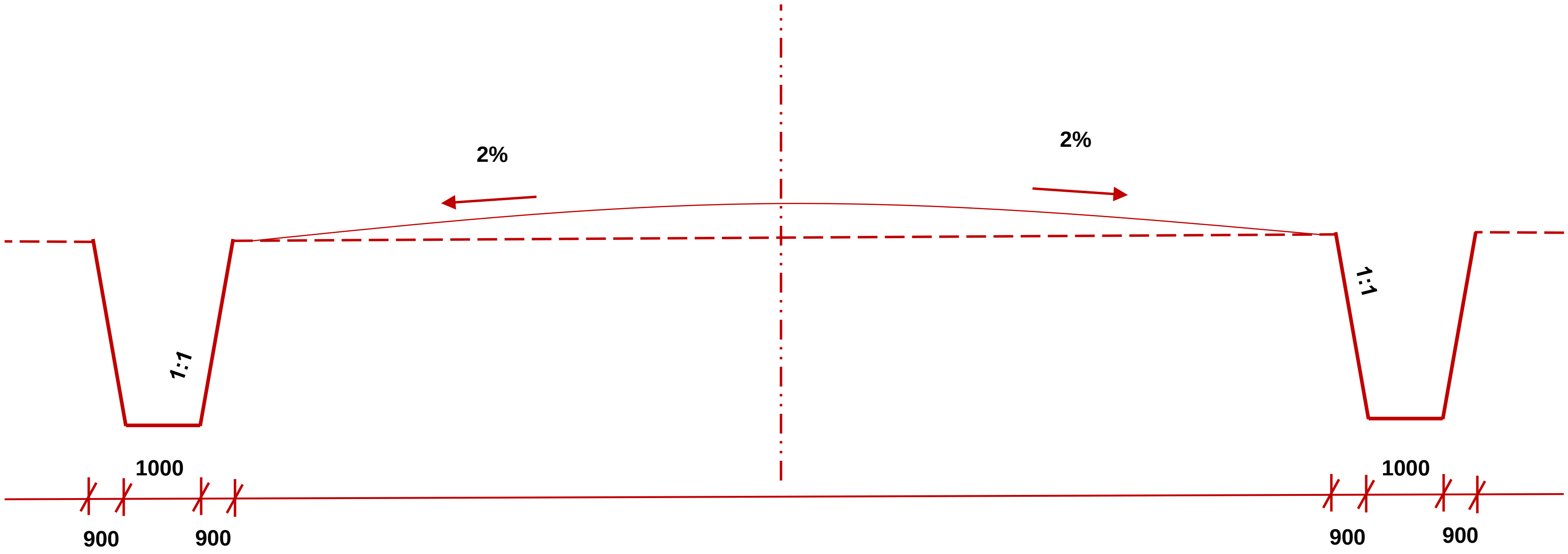


Figure 12. Cross section of drainage design in Gbely Meadows, South Moravia – Czech Republic (Štibinger et al, 2015)

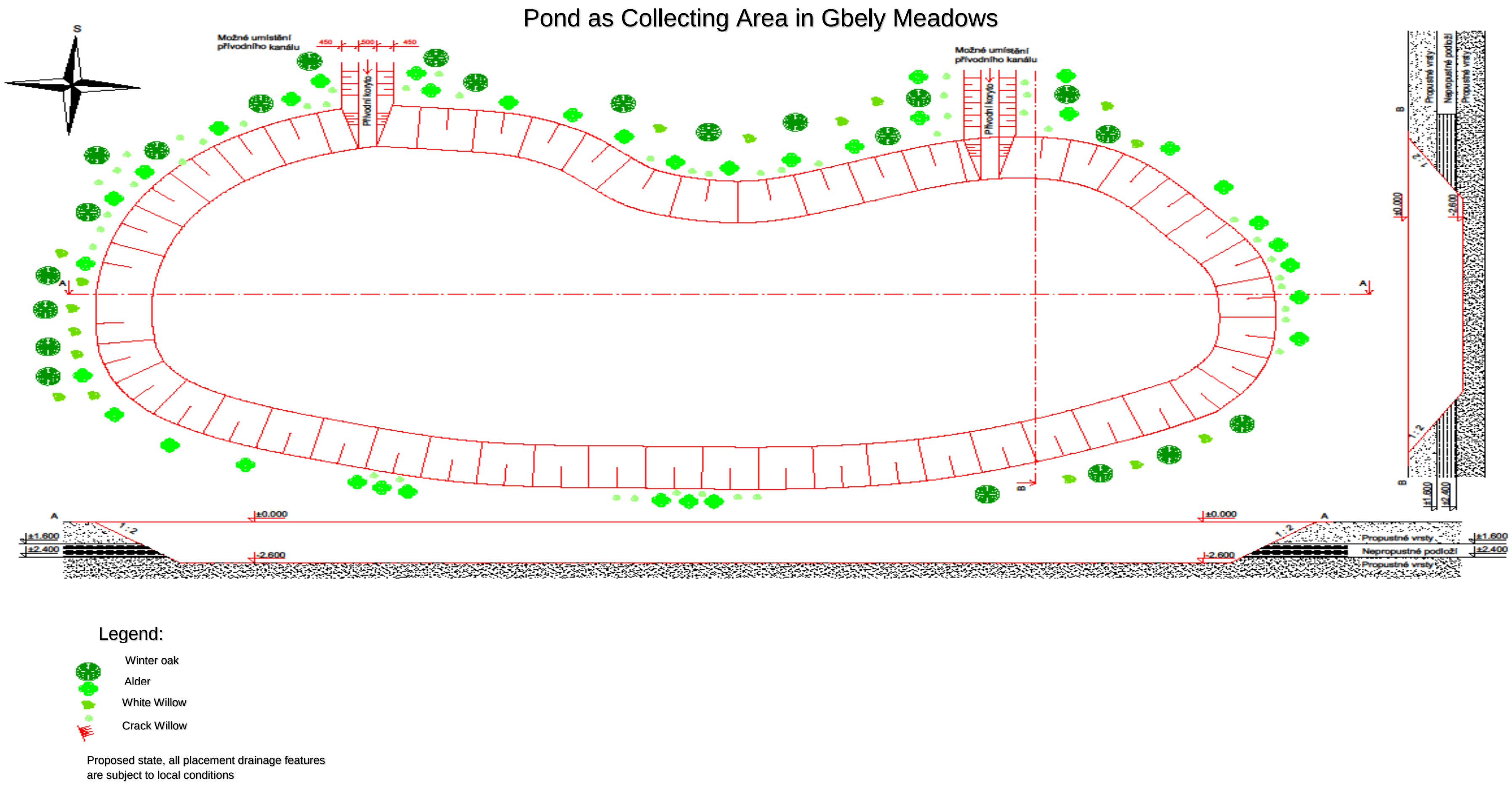


Figure 13. Draft drainage of situated Gbely meadows - situation (infiltration retention basin) (Štibinger et al., 2015)

Legend

Pond

Catchment & outlet

Drainage System Design in Three Situation

1:10 000

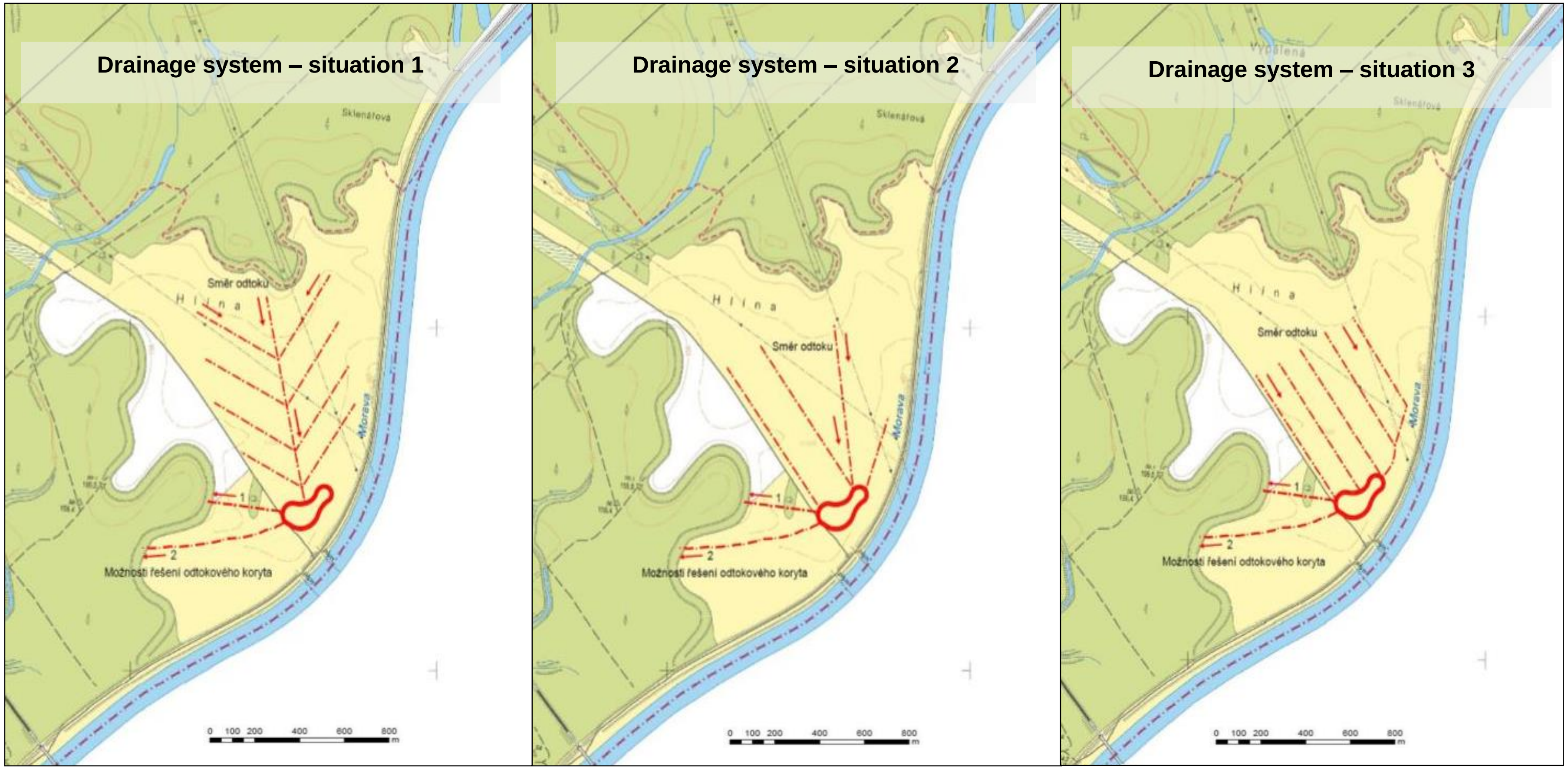


Figure 14. Three different models of drainage system design in Gbely Meadows, South Moravia – Czech Republic (Štibinger et al, 2015)

4.2. Hydrological Data

Climate has a lot of impacts to the environment as it is one of the factor which creates the diversity of vegetation, soils, topography and it is related to the water sources. One of example of climate factor is rainfall, which causes the excess water on the surface land. The hydrological data collected in this area are very basic data that are related to the design of drain spacing, such as temperature, precipitation and soil hydraulic conductivity.

DRAINMOD could be one of the way to calculate all hydrological parameters by using hydrological model, in fact it is simpler than using Penman – Monteith method used in Soil – Water – Atmosphere – Plant (SWAP), the Thornthwaite method used in DRAINMOD depends only on the mean air temperature. Unlike the Penman – Monteith method which are using more than one climatology factor to determine the potential evapotranspiration, such as: mean air temperature, relative humidity, wind speed, net radiation, saturated and actual vapour pressure (Sheler, 2013).

Data collected from Czech Hydrometeorological Institute from past 10 years 2006 – 2015 both precipitation and air temperature in table 4 and table 5. There is no weather station nearby the selected area, either in Lanžhot or Hodonín. The possibility is using data history of South Moravia. The meteorological institute provides us with monthly precipitation since 1961 – 2015, within 2016 will be serve the next year. The same thing for air temperature was served monthly with long term history from 1961 – 2015.

Table 4. Territorial precipitation (mm) from 2006 – 2015 in South Moravia, Czech Republic (database on Czech Hydrometeorological Institute)

Year / ***Month***	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
January	38	44	20	25	64	23	39	34	23	34
February	34	32	12	60	26	4	15	58	15	12
March	64	67	41	82	15	44	5	51	12	36
April	73	2	35	6	61	35	26	19	27	16
May	75	50	57	60	140	55	33	102	78	41
June	75	77	55	114	94	60	99	121	29	32
July	32	57	74	119	111	88	82	9	89	35
August	146	51	52	42	107	45	52	72	113	92
September	12	109	52	22	70	35	38	67	136	31
October	17	37	24	36	14	30	56	36	39	49
November	24	47	31	57	44	1	19	24	30	36
December	16	22	30	54	34	21	37	11	31	16

Table 5. Territorial air temperature (°C) from 2006 – 2015 in South Moravia (database on Czech Hydrometeorological Institute)

Year / ***Month***	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
January	-6.1	3.5	1.5	-3.4	-4.2	-0.7	0.4	-1.6	0.9	1.4
February	-2.6	3.5	2.6	-0.1	-0.9	-1.2	-4.3	-0.1	2.8	1.0
March	1.2	6.1	4.1	4.3	4.1	4.7	6.1	0.8	7.5	4.9
April	10.1	11.5	9.4	13.4	9.4	11.5	9.9	9.7	10.8	9.3
May	13.9	15.8	14.8	14.6	13.1	14.3	15.8	13.6	13.6	13.8
June	18.0	19.6	18.8	16.5	17.8	18.4	18.6	17.2	17.8	18.1
July	22.4	20.2	19.5	19.8	21.1	18.1	20.0	20.9	20.7	22.0
August	16.3	19.7	19.1	19.8	18.4	19.6	19.9	19.5	17.1	22.6
September	16.4	12.4	13.5	16.2	12.8	16.0	15.0	13.0	14.9	14.9
October	11.0	8.0	9.4	8.4	6.7	8.6	8.7	9.8	10.6	8.8
November	6.4	2.2	6.0	5.7	6.3	2.4	5.9	5.1	7.0	6.1
December	2.4	-0.7	1.6	-0.2	-3.9	2.0	-1.7	1.7	2.0	2.7

4.3. Hooghoudt's Equation

Homogenous soil is hardly formed both on vertical neither in horizontal direction, by using soil maps or observe the homogeneity more like expectation. Pedologist defined, that one characteristic of soil is that certain degree of change has taken place in the profile, a deposit that is uniform from top to bottom will not be considered as a soil because no development of parent material has taken place (H. P. Ritzema, 2006). Related to that theory, several formulas have been developed based on each investigations.

Based on above theory, it is useful to assume the selected area as a steady – state condition which represented by figure 9 below. In this condition, Hooghoudt's Equation would be good to calculate the discharge (*q*) of the drainage system. Hooghoudt's Equation is based on steady – state or homogenous soil assumption, as this equation has been verified under nearly steady – state condition either under steady – state. This equation is adapted on dynamic condition, typically with good result for water (Mollerup, M., P. Abrahamsen, C. T. Petersen, 2014).

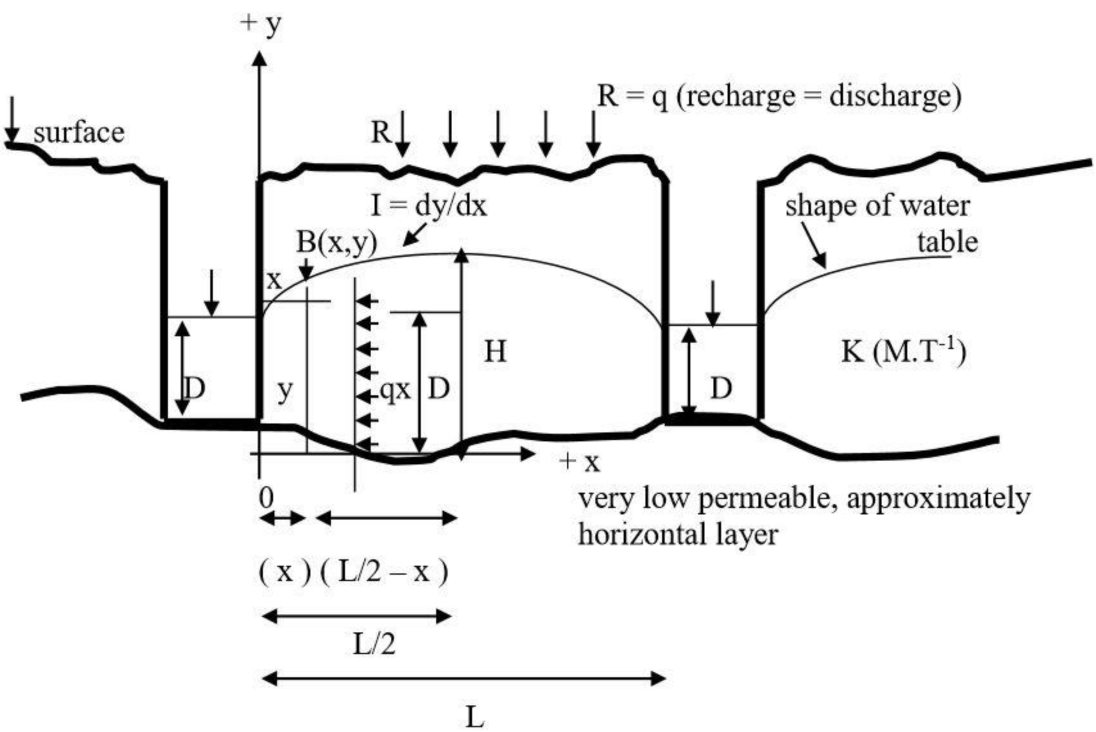


Figure 15. Scheme of steady – state drainage flow of open ditches under low permeability of soil (H. P. Ritzema, 2006)

When the design of rainfall is chosen high, the Hooghoudt's Equation results in a small drain spacing. The case of steady – state flow condition, the discharge rate *q* from a drain can be calculated with the Hooghoudt's Equation (Wiskow & Van Der Ploeg, 2003).

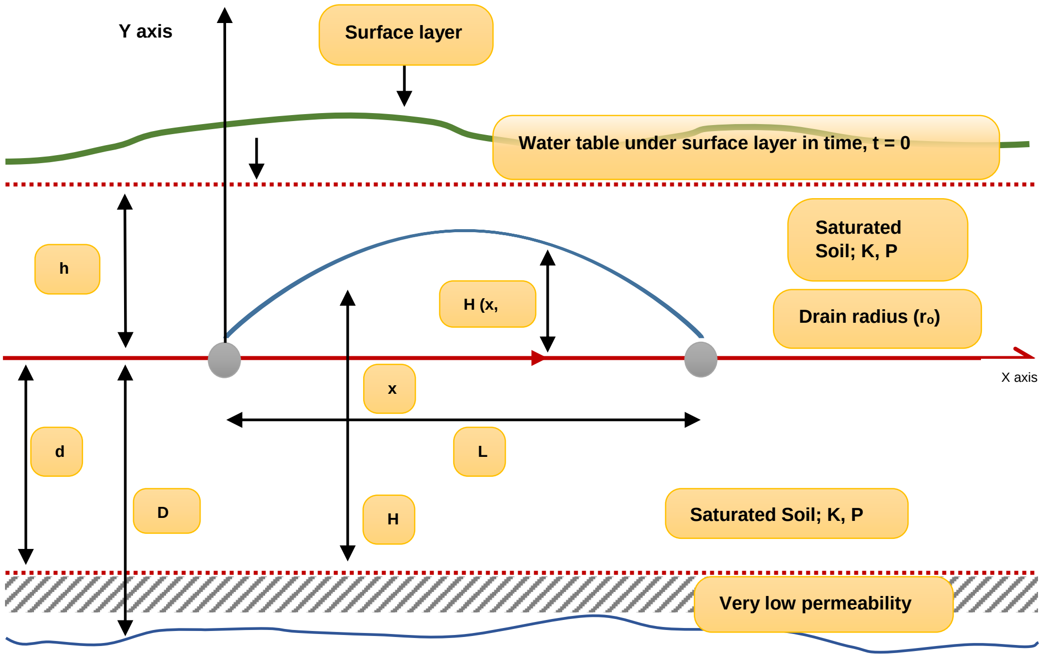


Figure 16. The height of water above drain h(x, t) with distance x > 0 from the drain at time t > 0, in condition of saturated unsteady drainage flow (Štibinger et al., 2015)

Most of tile drainage simulated by using Hooghoudt's Equation and Ernst method, in a condition, where the groundwater table will be higher than the position of drain pipes, water will flow towards the drain. Water flow in the soil will be described by Richard's equation and solved, resulting a solution also calculate the hydraulic conductivity at saturation state and continue with water flux calculation which can be determined by using Darcy's equation.

<u>Richard's equation for water flow:</u>

$$\frac{\partial \theta}{\partial t} = \nabla . \left(\boldsymbol{K}\,(\psi)\, \nabla\, (\psi + \mathrm{z})\right) - \Gamma_w \qquad (4)$$

Where θ is the volumetric water content, ψ is the pressure potential, and Γ_w is the sink term which includes root uptake and loss to the tile drains. Hydraulic conductivity matrix is expressed on $K(\psi)$, and z is the vertical coordinate.

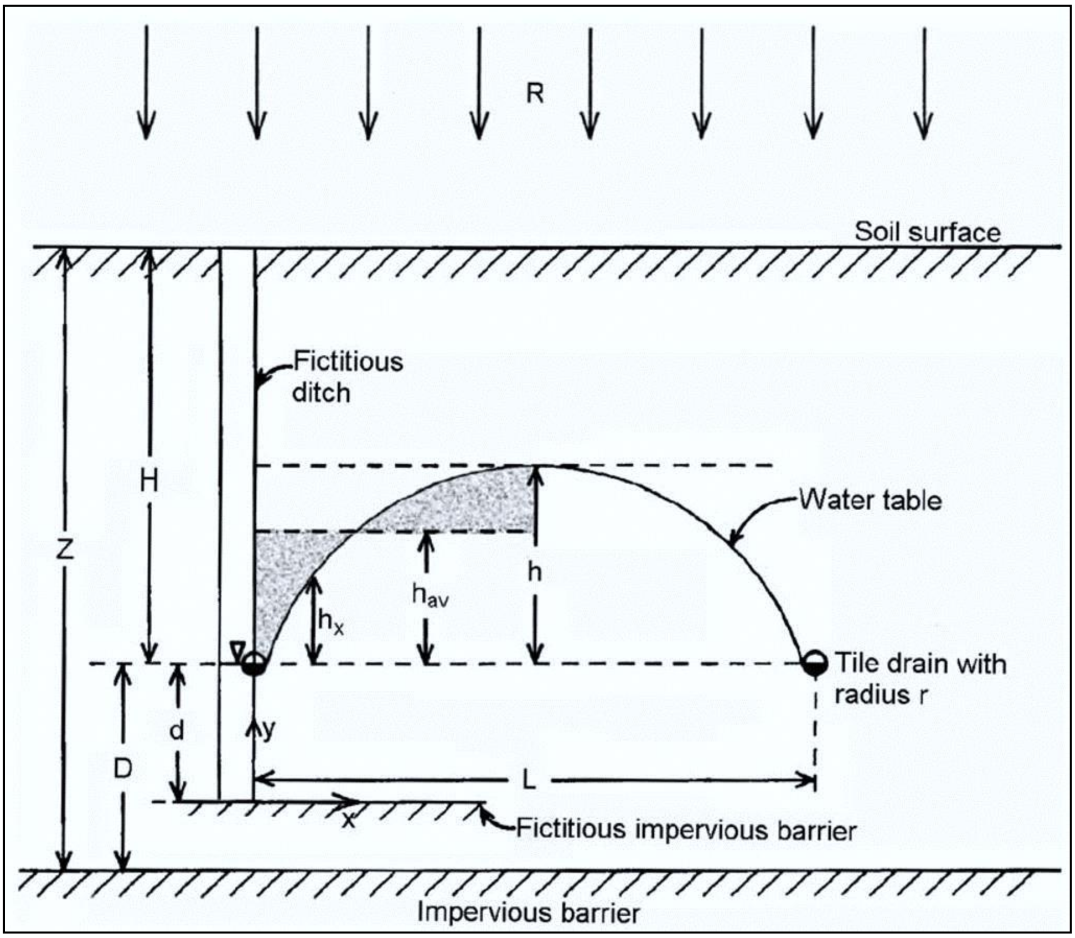


Figure 17. Schematic of homogenous soil (Wiskow & Van Der Ploeg, 2003)

<u>Darcy's equation for water flux:</u>

$$q = -K(\psi)\ \nabla.(\psi + z) \tag{5}$$

Where $\boldsymbol{q}$ is soil water flux density. According to *Mollerup et al.* (2014) the steady state drain flux per unit surface area $\boldsymbol{q}$ possible to be computed as:

$$q = \frac{8\,K_b\,d\,h + 4\,K_a\,h^2}{L^2} \tag{6}$$

Where $\boldsymbol{K_a}$ is the hydraulic conductivity of saturated layer above drain level and $\boldsymbol{K_b}$ is the hydraulic conductivity of saturated layer below drain level. The distance between drains represent as ***L***, with ***d*** is the equivalent drain depth depending on the vertical distance between drains and impermeable layer, ***D***. Midpoint of height of water table above drain is denoted as ***h*** and drain radius ***r***.

Ritzema (2006) also explains the derivation of Darcy's equation (equation 9) according to the Dupuit – Forchheimer theory, it describes the flow of groundwater (q) through a vertical plane (y) at a distance (x) from the ditch presented in these following equations.

$$q = K\,y\,\frac{dy}{dx} \tag{7}$$

It is clear that the continuity principle is valid with the flow going against to the positive direction of the x – axis (equation 10).

$$-\,K\,y\,\frac{dy}{dx} = -R\,\left(\frac{L}{2} - x\right) \tag{8}$$

Equation 10 could be written also like equation 11.

$$K\,y\,dy = R\,\left(\frac{L}{2} - x\right)dx \tag{9}$$

As the boundary condition has been created for x = 0 → y = D and for x = ½ L → y = H, where D is elevation of the water level in the drain and H is elevation of water table midway between the drains (H. P. Ritzema, 2006). Integration and substitution works here, in resulting the below equation (12):

$$K\,y\,dy = R\,\left(\frac{L}{2} - x\right)dx \tag{10}$$

From figure 15 as it was represented such the steady state schematization in drainage flow, the recharge *(R)* is identical with discharge (R = q). Based on that we can conclude the equation is:

$$L^2 = \frac{4\,K\,(H^2 - D^2)}{q} \tag{11}$$

This equation has been corrected for "ideal" drain pipe by Hooghoudt's where H – D = h and H + D = 2D + h, the height of the water table above water level is represented by h, and it is written as equation 6. Ritzema (2006) explained that equation (6) above is concluded if the drain level interface is between 2 soil layers, which are consisting 2 different hydraulic conductivities. He also mentioned that the ratio q: h called drainage criterion or drainage intensity, the higher the q: h ratio the more safety the system built. Thus the aim is to prevent high water table, the drainage criteria will not be discuss more as we will focus only on steady state equations (H. P. Ritzema, 2006).

4.4. Irrigation System

The last part of calculation will be related with irrigation system in the local area, where the input data will be based on result of drain spacing. Nearby the selected study area is situated a brook with water flow rate (Q) 3 m^3/ s. By using the result of L, it is possible to calculate evapotranspiration (Et).

By assuming the ditches will be full of water and by using mobile gate to control the water the integration and substitution work here and it is resulting in the equation as we will mention below.

From the boundary conditions in figure 18, by using Darcy equation (eq. 7) and continuity equation (eq. 14) and also substitution and derivation it is resulting in the equation (15).

$$q = v.S = v.y \tag{1}$$

$$q = K\,y\,\frac{dy}{dx} \tag{2}$$

Where Q represents the water flow in the area (m^3/s) and v is the velocity of the water flow (m/s). Based on the situation in the scheme with $dy = y_1 - y_2 > \theta$ and $dx = x_1 - x_2 < \theta$ is equal to $dy/dx < \theta$.

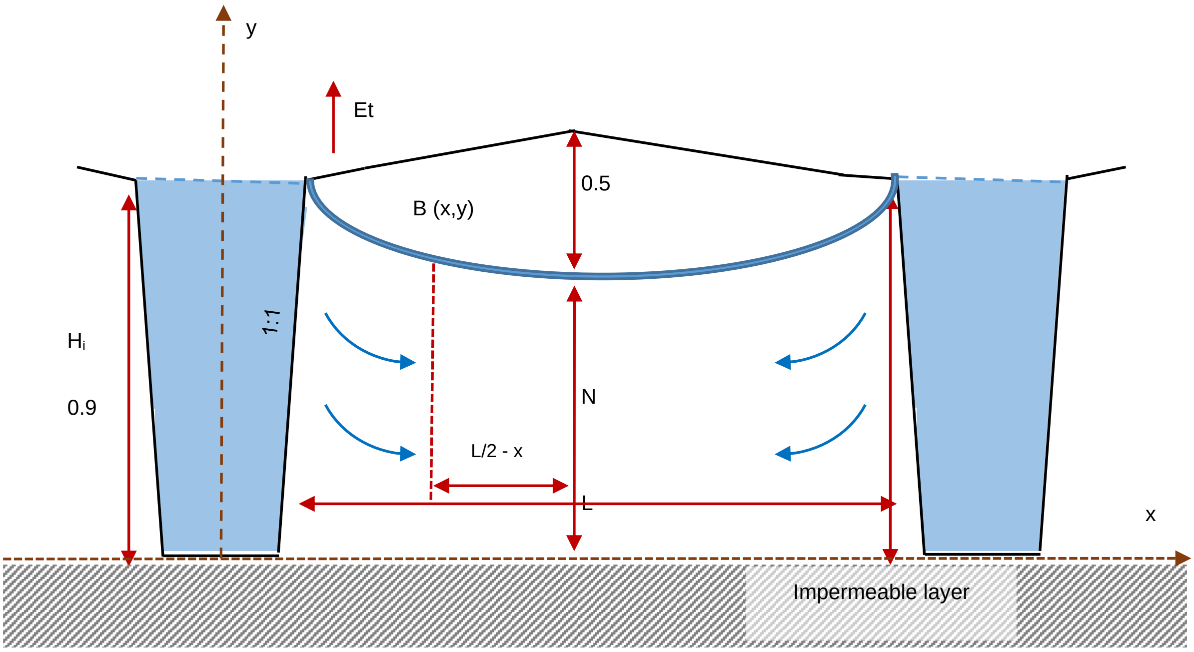


Figure 18. Schematic of full ditches with mobile gate applied in selected area Gbely Meadows - South Moravia, Czech Republic

$$-y\,dy = E_t \frac{L}{2}\,dx - E_t\,x\,dx \tag{3}$$

The direction of point B is going down along the axis y, that is why the B position is in the (x, -y). After substitution and integration, it is resulting in the final irrigation formula (eq. 17) to calculate the evapotranspiration (Et).

$$L^2 = \frac{4\,K\,({H_i}^2 - N^2)}{E_t} \tag{4}$$

Figure 18 represents the condition of the ditches when it is full of water controlled by the mobile gate, it is causing the water table with concave shape. The selected area on figure 14, the scale bar showed us approximate size of the area of drainage system around 36 hectare (ha). Evapotranspiration (Et) will be obtain by using equation (17) and it represents the range of data from dry period until wet period from local area in Gbely Meadows. We will need to calculate the amount of inflow water (Q) in selected area, in order to keep the water table at 0.5 m below surface. We can assume the inflow water should be at least or equal to the size of area (A) multiply by the evapotranspiration rate (Et) which represent in equation (18).

$$Q = A \, . Et \qquad (5)$$

5. Result

5.1. Drain Spacing

From previous study, we have data $K_a = K_b = 0.24$ m/day. The reason for this assumption ($K_a = K_b$), in this selected area based on Štibinger et al. (2015) the deeper the soil, the more low permeability it is (very low, *K neglected*). According to Štibinger *et al* (2015), estimation of hydraulic conductivity below drains pipe will be approximately 0.002 m/day (possible more low). The height of allowed water table (h) will be 0.3 m, and the height of ditches will be 0.9 m. The depth of aquiclude is about 1.5 m with drainage porosity 4.8% or equal to 0.048 (-).

Based on Ritzema (2006), to calculate the drain radius it is possible to use equation (20).

$$u = 2c + b \tag{6}$$

$$r_o = \frac{u}{\pi} \tag{7}$$

Detail width of the ditches bottom (b) is 1.0 m with slope 1:1, meanwhile ditches are filled with water inside with depth 0.15 m from bottom. From equation (12) the result for u is 1.42 m, and after substitution the result for drain radius (r_o) by using equation (13) is 0.45 m. Once all data is set, the next thing is to calculate drain spacing (L) using Hooghoudt's Equation.

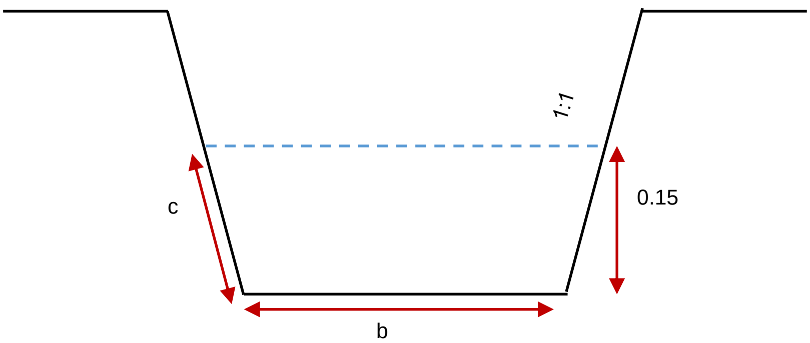


Figure 19. Schematic of ditches in selected area Gbely Meadows – South Moravia, Czech Republic

Table 6. Calculated drain spacing (L) related to prediction of recharge (R) in local area

R (mm/day)	L (m)
0.1	104
0.2	73
0.3	59
0.4	52
0.5	46
0.6	42
0.7	39
0.8	37
0.9	35
1.0	33
1.1	31
1.2	30
1.3	29
1.4	28
1.5	27
1.6	26
1.7	25
1.8	24
1.9	24
2.0	23
2.1	23
2.2	22
2.3	22
2.4	21
2.5	21
2.6	20
2.7	20
2.8	20
2.9	19
3.0	19
3.5	18
4.0	17
4.5	16
5.0	15

Range of the recharge has been estimated between 0.1 mm/day in dry period and approximately around 4 – 5 mm/day maximum rate in wet period. The range for drain spacing based on the calculation is resulted in figure 19 and it is represented with corresponding value based on the recharge, as we assumed in the beginning, that this condition is steady – state where Q = R or vice versa.

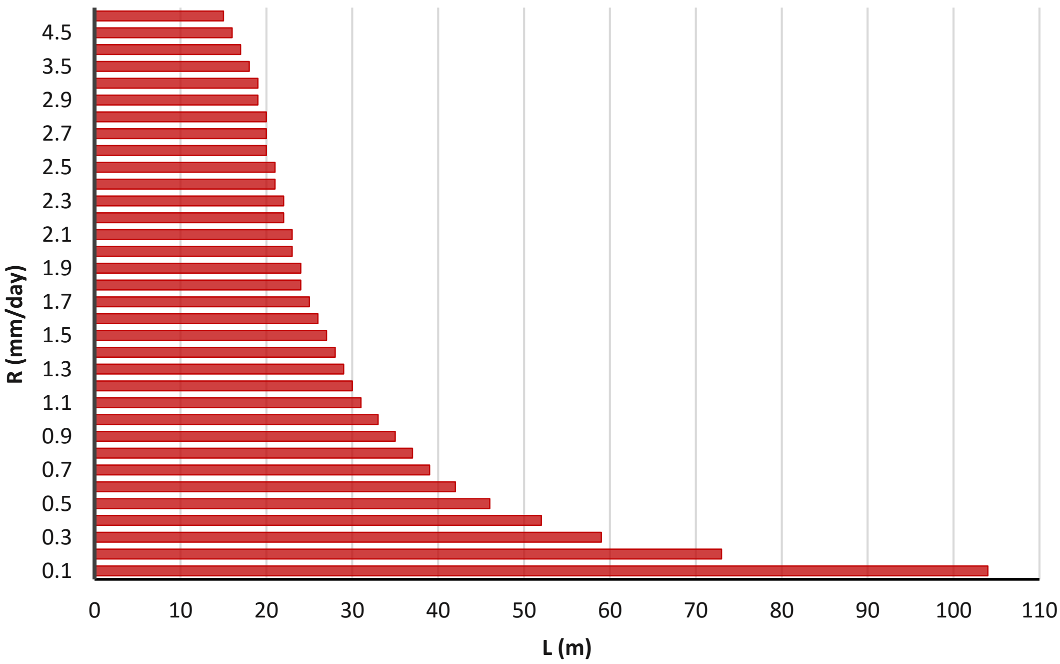


Figure 20. Relation between recharge (R) and drain spacing (L) in Gbely Meadows - South Moravia, Czech Republic

Prediction of highest recharge occurs in wet period, mostly after winter season usually in spring around March – April. As is presented in figure 20 the precipitation is increasing from February until March and decreasing again in April. This condition combines with snow melting is including surface runoff from higher area around, where it will end in the Morava River.

The source of precipitation and air temperature data were collected from the Czech Hydrometeorological Institute (CHMI) database, which has the record of all meteorological data over Czech Republic from 1961 – recently. Unfortunately they do not have the data from the selected area nor any city nearby.

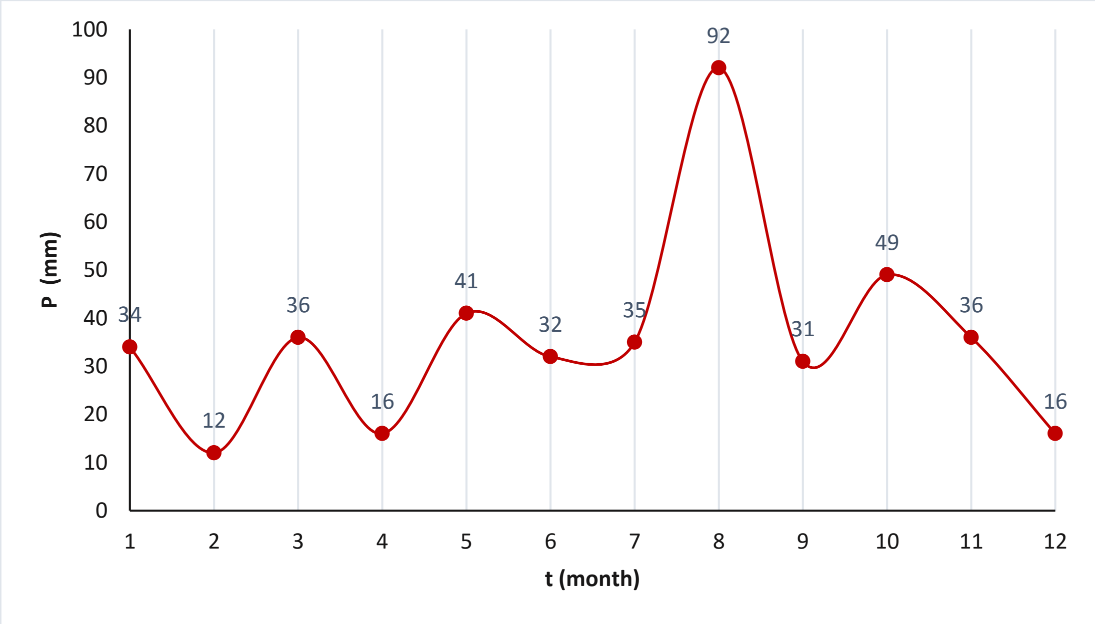


Figure 21. Monthly territorial precipitation (P) in year 2015 at South Moravia Region

5.2. Irrigation

Using the result of drain spacing from previous calculation and same hydraulic conductivity (K), H_i is representing the height of water in the ditches and N is the height from the midpoint of water table to the impervious layer. In this case, we are assuming the impervious layer will be the same depth with the bottom line of ditches. Initial data collected from previous study of Štibinger et al. (2015) are mentioning, that H_i or drain depth will be 0.9 m and distance between midpoints of concave water table to the impermeable layer represented as N will be 0.4 m. The depth for water table below surface soil is estimated in 0.5 m for concave shape water table. Table 7 represents the calculation, which is showing the result of Et and inflow water (Q). For area 36 ha, the minimum discharge is 2.10^{-4} m^3/s with L= 104 m. The maximum rate of discharge is $1{,}16\ .10^{-2}$ m^3/s with shorter L= 15 m.

Table 7. Minimum value of inflow water (Q) for area with specific drain spacing (L) and evapotranspiration (Et)

L (m)	Et (mm/day)	Q (m3/s)
104	0.06	0.000
73	0.12	0.000
59	0.18	0.001
52	0.23	0.001
46	0.29	0.001
42	0.35	0.001
39	0.41	0.002
37	0.46	0.002
35	0.51	0.002
33	0.57	0.002
31	0.65	0.003
30	0.69	0.003
29	0.74	0.003
28	0.80	0.003
27	0.86	0.004
26	0.92	0.004
25	1.00	0.004
24	1.08	0.005
23	1.18	0.005
22	1.29	0.005
21	1.41	0.006
20	1.56	0.007
19	1.73	0.007
18	1.93	0.008
17	2.16	0.009
16	2.44	0.010
15	2.77	0.012

6. Discussion

A case happened in 2000 in North Yorkshire town Ripon, United Kingdom (UK), they have a serious river floods and reservoir which led to further discussion (Posthumus et al, 2008). The result of the discussion about non – structural approaches to flood risk management called Making Space for Water, producing the Ripon Multi – Objective Pilot (Ripon – MOP). According to Posthumus et al. (2008) this project is to analyse how integrated solutions solves the issue between catchment including flood management, biodiversity, resource protection, land management, and public amenity.

This study has led us to the resulting discussion based on all theory and hypothesis about good drainage system design, focusing on drain spacing calculation. The fact that Hooghoudt's Equation was reliable enough to determine drain spacing (L) in a subsurface parallel tile drainage system (Mishra & Singh, 2007), has brought us a final result for this study. Figure 19 showed us how L and recharge (L) are corresponding to each other, the higher R value the narrow L has to be designed. Theoretically, L depends on the equivalent depth (d) (H. P. Ritzema, 2006). Luthin (1966) mentioned as a result of extensive experimentation in the Imperial Valley of California, here are list of few factors which has influence by R:

a) Irrigation head
b) Length of run
c) Slope
d) Soil type
e) Infiltration rate
f) Evapotranspiration (Et)
g) Seepage into or out of the area
h) Artesian pressure
i) Type of crop – rooting habits – depth of rooting
j) Frequency of irrigation
k) Soil moisture control at the time of irrigation

Ditches in drainage system design are also one of the factor to create a wider L, it is logical that some of excess water will flow to the ditches. Another case is to increase the water table, it is necessary to design smaller L. This case only happens in some special condition for example in a very dry area or low precipitation. There are three important sections in a drainage system according to Bohne et al. (2012) based on figure 21. First is (1) land equipped by a systematic open or subsurface drainage system, evacuate to (2) a ditch which is the second section acted as a recipient of the drains, and last part (3) is a structure within the ditches which can control the water level and discharge (Bohne et al., 2012). Sector number 3 in figure 21 is about mobile gate, which is able to control the amount of water entering a ditch. We will discuss further in the next point the condition, where the ditches are full of water controlled by mobile gate.

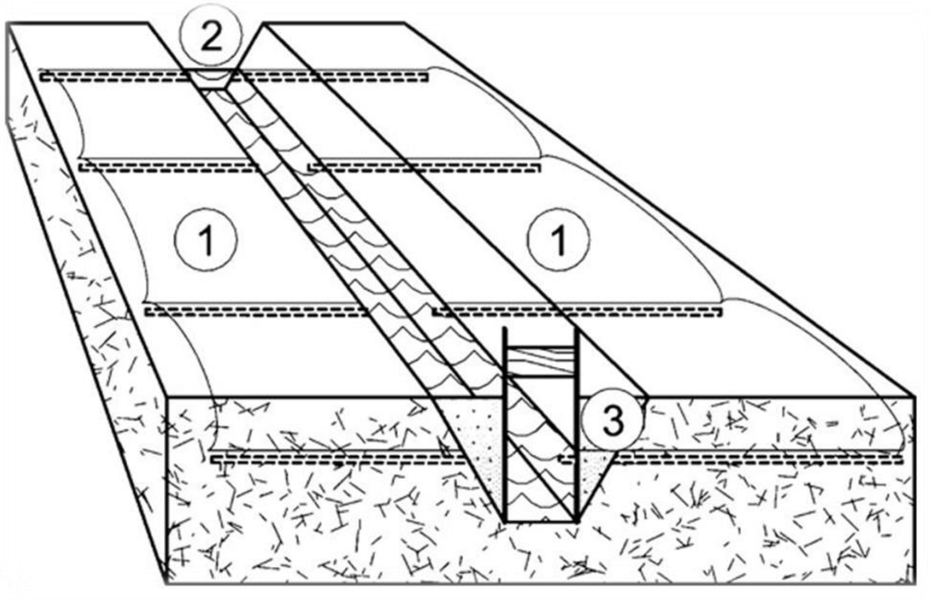


Figure 22. Assumption of the layout of drainage system section (Bohne et al., 2012)

It is fact that drainage ditches help to reduce the excess surface water. According to Monsieurs et al. (2015) drainage ditches are important for a land with heavy rain and sloppy. Ditches will capture excess surface water to help reduce the water logging in the surface and bad effect to the crop causing soil compaction, shallow root zone, etc. (Monsieurs et al., 2015). Build a ditches parallel with sloping area or landscape is a good solution to help lower the water table (Youngs & Rushton, 2009). Water table plays an important role for agriculture sector.

One study in Australia along the north – eastern tropical and subtropical coastline which is dominated by sugarcane field with typical shallow water table, shows that sugarcane are very sensitive to high water table (Yang, 2008). Yang (2008) also mentioned to design drainage system has to consider other hydrological factors. As mentioned above in the beginning that a good drainage system design is necessary. A proper drain spacing design based on the climate and other hydrological data, indeed could save a lot of money for farmers and especially better crop production.

From the past 10 years shown in table 8, that average of air temperature in South Moravia was fluctuating each year. Although it is clearly showed us that it is slowly increasing, and high probability in future could be higher. Below (table 8) presents the average rate of both precipitation and air temperature from South Moravia Region, we assume that the differences was not so big compare to the selected area.

Table 8. Territorial air temperature (T) and precipitation (P) 2006 – 2015 in South Moravia

Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
P (m/year)	0.61	0.60	0.48	0.68	0.78	0.44	0.50	0.60	0.62	0.43
T (ºC)	9.1	10.2	10.0	9.6	8.4	9.5	9.5	9.1	10.5	10.5

The precipitation data may seems vary but it is still assumed at normal state. Based on the table 8, the highest precipitation has occurred in 2010 which is also proofed in figure 21. It is one of the reason how important is a drainage system, which could fight against the floods. The flood which is affected in Czech Republic in the year 1997, 2002, 2006, 2009 and 2010, with local waterlogging areas on spring period of 2012 and 2013, showed us how important is a good water management in Czech Republic (Stibinger, 2013).

The reason for this because of the both result represent different area. Recharge prediction of Štibinger, et al. (2015) was collected in the local area, Gbely Meadows, and result from rationan method was calculated based on precipitation in wider area of South Moravia Region. Hence, it is not relevant to compare or adjust both recharge values. Table 8 which showed us the overall value of drain spacing could possibly relate to each recharge rate, and classified the result into few range options like it is mentioned in table 9.

Table 9. Range of calculated drain spacing (L) in corresponding with recharge value (R)

R (mm/day)	L (m)
0.5	46
1.0	33
1.5	27
2.0	23
2.5	21
3.0	19
4.0	17
5.0	15

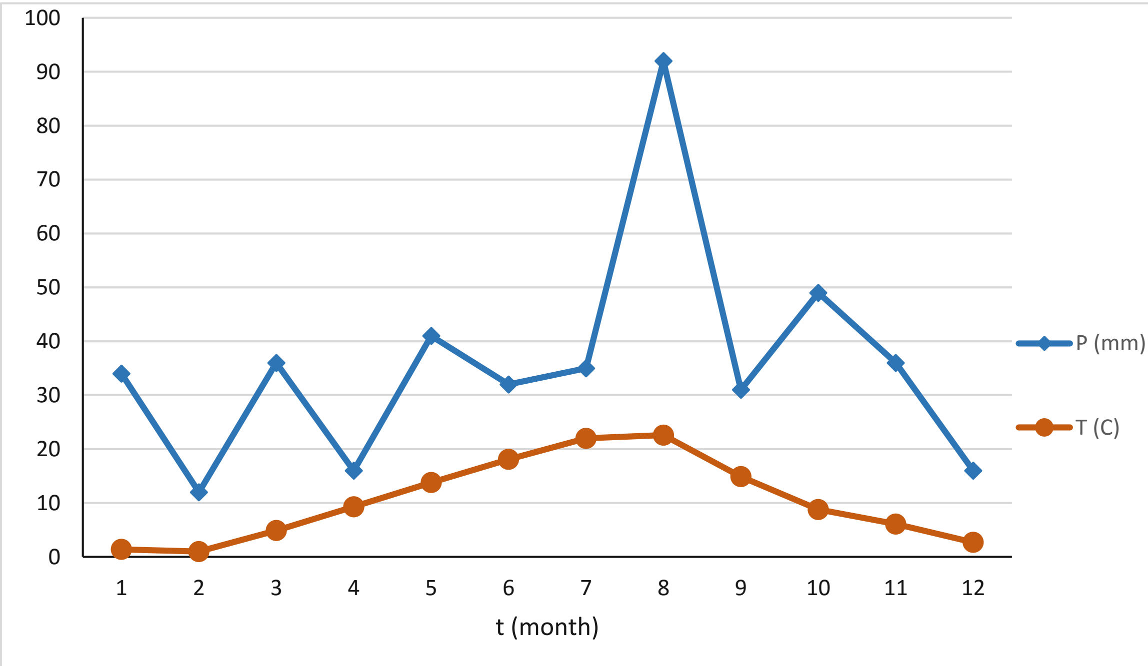


Figure 23. Monthly temperature (T) and precipitation (P) in 2015, South Moravia Region

The highest possibility of recharge in this area is 5 mm/day, which commonly occurs in wet period with heavy rainfall or snow melting period. The lowest recharge could be in 0.5 mm/day, the highest possibility is that it will occur during summer or dry period, when the temperature is raising and evapotranspiration is increasing. From the graph (figure 22) we can see when the possibility of dry and wet period is.

Figure 22 is made based on South Moravia Region in 2015 from Czech Hydrometeorological Institute (CHMI) database.

From the graph (fig. 22) heavy rain could occur between end of July ending in November and getting lower in December. This could be assumed as the wet period of this region. Start from May until beginning of July is the precipitation decreasing along with the increasing temperature. At this time, we could assume as dry period, where recharge is lower with high temperature causing high evapotranspiration.

Based on that hypothesis, an integrated irrigation system could be a good solution for this area. According to Štibinger, et al. (2015), there is a brook situated nearby the selected area with outflow water about 3 m^3/s. This brook will be able to irrigate the selected agriculture area when the dry season is coming. There is huge possibility, that the source of the water is also coming from the nearby Hydropower station located in Hodonín. There is a possibility to irrigate the area while dry period occurs, by connecting the water channel into the selected area and integrated with the drainage system (fig. 22).

Table 10 represents an overall result of calculated evapotranspiration value in regards of the drain spacing and estimation of minimum inflow water in local area. From that result (table 10), it is possible to shrink the range into few possible options of drain spacing, based on real situation on dry or wet period in local area. Figure 18 represents a condition, where the ditches are full of water and controlled by mobile gate. This case could happen during dry season or in summer, where rainfall is rarely occurred with high temperature causing high rate of evapotranspiration (Et).

Table 10. Minimum rate of inflow water (Q) in area with calculated drain spacing (L) and estimated evapotranspiration (Et)

L (m)	Et (mm/day)	Q (m^3/s)
46	0.29	0.001
33	0.57	0.002
27	0.86	0.004
20	1.56	0.007
15	2.77	0.012

At the minimum evapotranspiration rate (Et) at 0.29 mm/day for drain spacing (L) value in 46 m, we will need at least 0.001 m^3/s water flowing through the system. The inflow water from the brook will bring 3 m^3/s from the outlet and it will arrive in the system bringing at least half of the amount of water. Although it is still sufficient enough to irrigate the area.

For narrow drain spacing (L) in 15 m (table 12) with calculated evapotranspiration (Et) in 2.77 mm/day, the area needs at least inflow water (Q) 0.01 m^3/s. This condition could be best for area with low recharge or low precipitation and high temperature mean, which mostly occurs in dry period or summer. With this condition the brook will be still able to irrigate the area and keep the water table in 0.5 m below the surface.

Lack of moisture in soil could disturb the biochemical processes which affect the quality of health of the plants, that is why it is necessary to understand the demand of cultivated plants during their growth and development period (Kubeček, 2013). In worst case, while the water flow will be in the highest period such as in spring, the area will be still in safe condition by drainage system applied here. It is necessary to determine the amount of water to be drained out of the soil to keep satisfying the leaching requirement and keep the water table at the safe level (Luthin, 1966).

The idea is not just to design a water channel to irrigate the area, but also to design an efficient input water, which is necessary to be consider there. This could be best to combine it with an integrated system to control the efficiency of water usage, a combination of improved inlet structures (new sluices and channels), water metering, elimination of leaks, laser levelling of paddocks and construction of re – use systems to recycle excess surface irrigation runoff (Mosley & Fleming, 2009), could protect the efficiency of water for irrigation.

A study in northeast Italy explained that controlled drainage in winter and sub – irrigation in summer was tested as a strategy for continuous water table management along with benefits by optimizing water usage and also to reduce unnecessary drainage and nitrogen losses (Bonaiti & Borin, 2010). The second idea of this thesis is to improve the quality of the agriculture land and also improve the knowledges of the farmers and lead them to be more professional and more efficient. In one study is mentioned, that higher level of irrigation could increase the agricultural yields and improve the output per unit of input, it allows the farmers to obtain crops in the end (Calzadilla, Rehdanz, & Tol, 2010). The negative side for this, according to Calzadilla et al. (2010) is that from the economical perspective it could reduce the production costs and also the crop prices.

Beyond all those negative impact could possibly occur, it is still necessary to encourage our agricultural land and farmers by introducing a good system. European agriculture has decrease in number of farms, according to one study which was explained that the most significant effect on European agriculture was through the increasing frequency of extreme weather and changes in water availability (Giannakis & Bruggeman, 2015).

This could be a great initial idea to have more deep study about the real situation nowadays which got affected by the climate change, focusing on agricultural area all over the world. One study in Asia mentioned that temperature increasing by 1.5 °C could reduce crop net revenues by 13% of US$ 93 billion per year, and in India for example is predicted to suffer two thirds of the aggregate losses in Asia because of large share of crop net revenues are particularly high spring temperature (Mendelsohn, 2014).

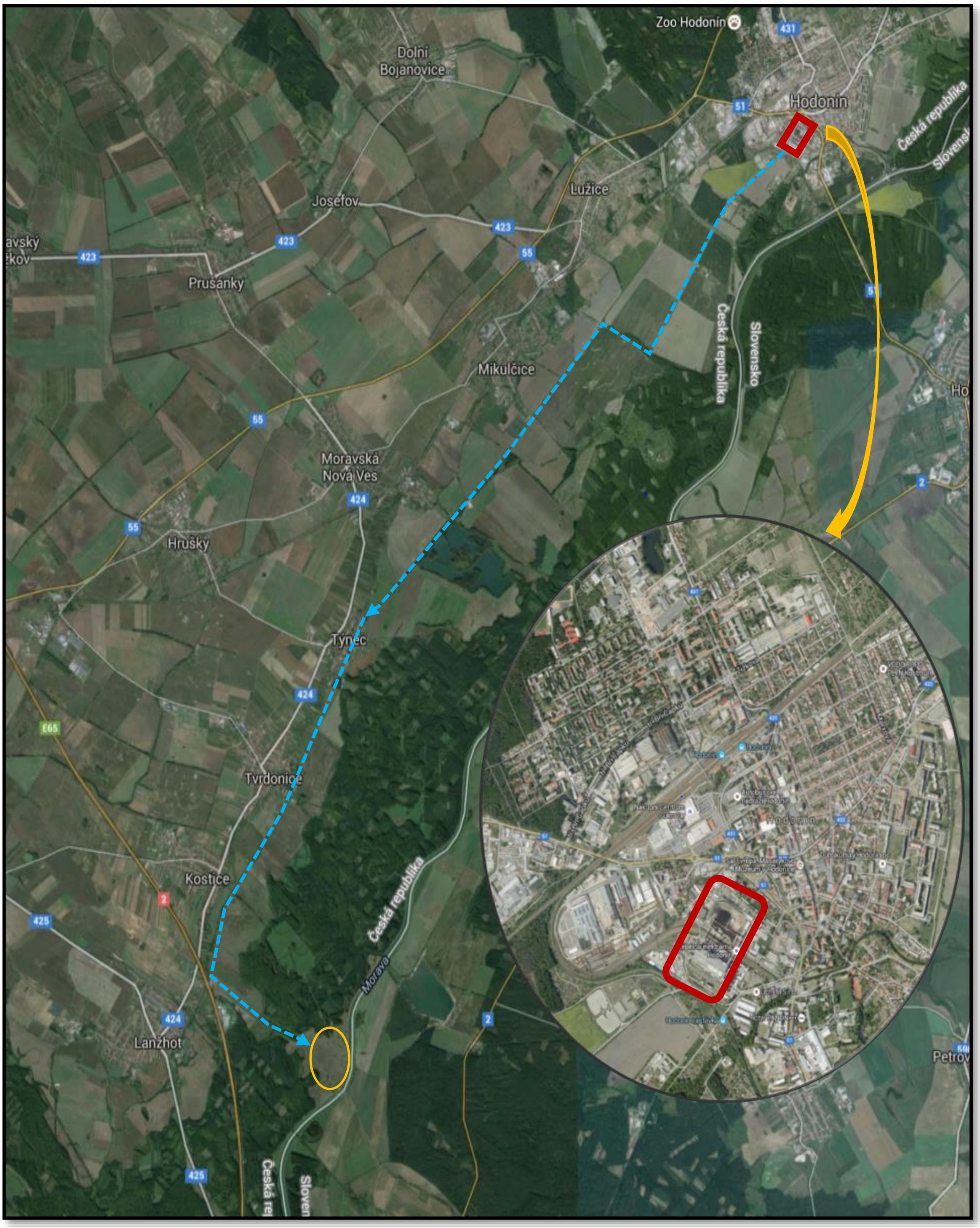


Figure 22. Proposed design of water network for irrigation from Hodonin Hydropower Station (red box) to selected study area, Gbely meadows (yellow circle)

7. Conclusion

This study is focused on the drain spacing design in regards of recharge rate in Gbely Meadows. But we also consider the local climate data connected with the integrated irrigation system, which can prevent any drought for the crop in future. This was aimed in case the temperature will keep increasing, along with low precipitation. To save the crops yield, it is necessary to consider an irrigation system which can be connected with the drainage system.

According to the literature review above, a method has been selected to calculate an appropriate value of drain spacing. We can estimate the highest and lowest rate of recharge from previous study of Štibinger et al. (2015) and based on precipitation according to the database of Czech Hydrometeorological Institute (CHMI). This range could be recommended to the local farmers, to improve the quality of the land.

Table 11. Recommended drain spacing (L) related to the possibility of recharge in local area

R (mm/day)	L (m)
1.0	33
1.5	27
2.0	23
3.0	19
4.0	17
5.0	15

For local farmers we can conclude that this area could be better if the drain spacing is not as narrow as the precipitation was not that high, but also not so wide as it could damage the crops production with high water table. This study could suggest a range of corresponding rate between recharge and drain spacing like mentioned in table 11. This will be up to farmers how will they desire to design their land. But in regards to the price of installation, we could suggest that drain spacing with wide 17 meter or 19 meter is probably sufficient enough to take care of the water table. Connecting with irrigation system, all drain spacing are still fine for receiving the water stream from the brook or from Hodonín Hydropower system (table 12).

Table 12. Minimum values of inflow water (Q) for irrigation related with drain spacing (L) and evapotranspiration (Et)

L (m)	Et (mm/day)	Q (m^3/s)
33	0.57	0.002
27	0.86	0.004
23	1.18	0.005
19	1.73	0.007
17	2.16	0.009
15	2.77	0.01

Related to the highest rate of Et which could possibly occurs in dry period, the water flow from brook (1 – 3 m^3/s) will still able to irrigate the area and keep the water table at the safe position (0.5 meter below surface soil). If we connecting with result from database of CHMI, although fluctuating but average temperature slowly increasing which can affect Et more higher. Also with the average precipitation from past 10 years is slowly decreasing. This condition could predict what will happen in future, which can possibly lead to drought. At this point, this integrated system especially the irrigation based on the calculation will be able to keep the land from drought.

This could be better for future study to calculate more wide the trend – line of climate data and using better hydrological model to get more valid result. Also could be better to calculate the local temperature and precipitation which will give more precise result in the end.

8. References

Bohne, B., Storchenegger, I. J., & Widmoser, P. (2012). An easy to use calculation method for weir operations in controlled drainage systems. *Agricultural Water Management*, *109*, 46–53. http://doi.org/10.1016/j.agwat.2012.02.005

Bonaiti, G., & Borin, M. (2010). Efficiency of controlled drainage and subirrigation in reducing nitrogen losses from agricultural fields. *Agricultural Water Management*, *98*(2), 343–352. http://doi.org/10.1016/j.agwat.2010.09.008

Bouarfa, S., & Zimmer, D. (2000). Water-table shapes and drain flow rates in shallow drainage systems. *Journal of Hydrology*, *235*(3-4), 264–275. http://doi.org/10.1016/S0022-1694(00)00280-8

Boucher, M. (2010). Rainfall Intensity - Duration - Frequency (IDF) Curves. *Contra Costa Coutry Flood Control & Water Conservation District*.

Calzadilla, A., Rehdanz, K., & Tol, R. S. J. (2010). The economic impact of more sustainable water use in agriculture: A computable general equilibrium analysis. *Journal of Hydrology*, *384*(3-4), 292–305. http://doi.org/10.1016/j.jhydrol.2009.12.012

Cooke, R. A., Badiger, S., & García, A. M. (2001). Drainage equations for random and irregular tile drainage systems. *Agricultural Water Management*, *48*(3), 207–224. http://doi.org/10.1016/S0378-3774(00)00136-0

Giannakis, E., & Bruggeman, A. (2015). The highly variable economic performance of European agriculture. *Land Use Policy*, *45*, 26–35. http://doi.org/10.1016/j.landusepol.2014.12.009

Hillel, D. (2004). *Introduction to Environmental Soil Physics*. *Elsevier Science (USA)* (Vol. XXXIII). USA. http://doi.org/10.1007/s13398-014-0173-7.2

Huang, M., Lee Barbour, S., Elshorbagy, A., Zettl, J. D., & Cheng Si, B. (2011). Infiltration and drainage processes in multi-layered coarse soils. *Canadian Journal of Soil Science*, *91*, 169–183. http://doi.org/10.4141/cjss09118

Ilek, A., & Kucza, J. (2014). A laboratory method to determine the hydraulic conductivity of mountain forest soils using undisturbed soil samples. *Journal of Hydrology*, *519*(PB), 1649–1659. http://doi.org/10.1016/j.jhydrol.2014.09.045

Jakub Štibinger, Miloslav Šlezingr, Pavel Kovář, Jiří Kulhavý, Alois Prax, Ladislav Menšík, Petr Vahalík, Pavel Hadaš, Vítězslav Hybler, Eva Kostková, Milan Sůva,

M. B. (2015). Biotechnická opatření pro úpravu vodního režimu ve vybraných lokalitách modelového území Pomoravské nivy. *FOREST-AGRO, Spol. S R.o., Hrušky*, 1–44.

Kirchner, J. W. (2009). Catchments as simple dynamical systems: Catchment characterization, rainfall-runoff modeling, and doing hydrology backward. *Water Resources Research*, *45*(2), 1–34. http://doi.org/10.1029/2008WR006912

Kubeček, M. (2013). *Irrigation and drainage of green roof for Leisure centre located in Hronov*. Czech University of Life Sciences.

Kumar, M., & Koga, K. (1995). Mole drainage : Prospective drainage solution to Bangkok clay soils. *Agricultural Water Management 28*, *4549*(0888), 253–270.

Lacroix, M., Wang, H. Q., & Blavoux, B. (1996). Water-table modelling to estimate irrigation losses: Application to the Lower Durance, France. *Agricultural Water Management*, *30*(3), 283–300. http://doi.org/10.1016/0378-3774(95)01227-3

Luthin, J. N. (1966). *Drainage Engineering*. United States: John Wiley & Sons, Inc.

Mendelsohn, R. (2014). The impact of climate change on agriculture in Asia. *Journal of Integrative Agriculture*, *13*(4), 660–665. http://doi.org/10.1016/S2095-3119(13)60701-7

Mishra, G. C., & Singh, V. (2007). A new drain spacing formula. *Hydrological Sciences Journal*, *52*(2), 338–351. http://doi.org/10.1623/hysj.52.2.338

Mollerup, M., P. Abrahamsen, C. T. Petersen, and S. H. (2014). Comparison of simulated water, nitrate, and bromide transport using a Hooghoudt-based and a dynamic drainage model. *Water Resource Research*, 1080–1094. http://doi.org/10.1002/2012WR013318.Received

Monsieurs, E., Poesen, J., Dessie, M., Adgo, E., Verhoest, N. E. C., Deckers, J., & Nyssen, J. (2015). Effects of drainage ditches and stone bunds on topographical thresholds for gully head development in North Ethiopia. *Geomorphology*, *234*, 193–203. http://doi.org/10.1016/j.geomorph.2015.01.011

Mosley, L. M., & Fleming, N. (2009). Reductions in water use following rehabilitation of a flood-irrigated area on the Murray River in South Australia. *Agricultural Water Management*, *96*(11), 1679–1682. http://doi.org/10.1016/j.agwat.2009.06.001

Naz, B. S., Ale, S., & Bowling, L. C. (2009). Detecting subsurface drainage systems and estimating drain spacing in intensively managed agricultural landscapes, *96*, 627–637. http://doi.org/10.1016/j.agwat.2008.10.002

Pickels, G. W. (1941). *Drainage and Flood - Control Engineering* (2nd Editio). United States: McGraw-Hill Book Company, Inc.

Posthumus, H., Hewett, C. J. M., Morris, J., & Quinn, P. F. (2008). Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. *Agricultural Water Management*, *95*(7), 787–798. http://doi.org/10.1016/j.agwat.2008.02.001

Riley, K. D. (2006). *Hydrological modification of subsurface drainage systems*. Iowa State University.

Ritzema, H. P. (2006). *Drainage Principles and Applications* (third Edit). Wageningen, Alterra: ILRI Publication.

Ritzema, H., & Wösten, H. (2002). Hydrology of Borneo's Peat Swamps. *STRAPEAT Status Report*, (April), 1–17.

Sheler, R. J. (2013). *The impact of agricultural drainage systems on hydrologic responses*. MS (Master of Science) thesis, University of Iowa.

Singh, R., Helmers, M. J., & Qi, Z. (2006). Calibration and validation of DRAINMOD to design subsurface drainage systems for Iowa's tile landscapes. *Agricultural Water Management*, *85*(3), 221–232. http://doi.org/10.1016/j.agwat.2006.05.013

Skaggs, R. W., Youssef, M. A., & Chescheir, G. M. (2006). Drainage design coefficients for eastern United States. *Agricultural Water Management*, *86*(1-2), 40–49. http://doi.org/10.1016/j.agwat.2006.06.007

Stibinger, J. (2013). Estimation of Transient Drainage Discharge from Subsurface Pipe Drainage System in City Park Next to Mseno Dam (Czech Republic). *Agricultura Tropica et Subtropica*, *46*(2). http://doi.org/10.2478/ats-2013-0011

Stibinger, J. (2015). Drainage Retention Capacity (DREC) of Krisak Mountain Meadows Agricultural Area (Jizera Mountains, Czech Republic) for Mitigation of Negative Impacts of Climate Change. *Agriculture and Agricultural Science Procedia*, *4*, 186–194. http://doi.org/10.1016/j.aaspro.2015.03.022

Tancreto, A. E. (2015). *Comparison of Hydrologic Model Performance Statistics Using Thiessen Polygon Rain Gauge and NEXRAD Precipitation Input Methods at Different Watershed Spatial Scales and Rainfall Return Frequencies*. University of North Florida.

Wang, X., Mosley, C. T., Frankenberger, J. R., & Kladivko, E. J. (2006). Subsurface drain flow and crop yield predictions for different drain spacings using DRAINMOD. *Agricultural Water Management*, *79*(2), 113–136. http://doi.org/10.1016/j.agwat.2005.02.002

Wesstro, I., & Messing, I. (2007). Effects of controlled drainage on N and P losses and N dynamics in a loamy sand with spring crops. *Agricultural Water Management*, *87*, 229–240. http://doi.org/10.1016/j.agwat.2006.07.005

Wesström, I., Messing, I., Linner, H., & Lindström, J. (2001). Controlled Drainage—Effects on Drain Outflow and Water Quality. *Agricultural Water Management*, *47*, 85–100. http://doi.org/10.1016/S0378-3774(00)00104-9

Wheater, H., & Evans, E. (2009). Land use, water management and future flood risk. *Land Use Policy*, *26*(SUPPL. 1), 251–264. http://doi.org/10.1016/j.landusepol.2009.08.019

Wiskow, E., & Van Der Ploeg, R. R. (2003). Calculation of drain spacings for optimal rainstorm flood control. *Journal of Hydrology*, *272*(1-4), 163–174. http://doi.org/10.1016/S0022-1694(02)00262-7

Yang, X. (2008). Evaluation and application of DRAINMOD in an Australian sugarcane field. *Agricultural Water Management*, *95*(4), 439–446. http://doi.org/10.1016/j.agwat.2007.11.006

Youngs, E. G., & Rushton, K. R. (2009). Steady-state ditch-drainage of two-layered soil regions overlying an inverted V-shaped impermeable bed with examples of the drainage of ballast beneath railway tracks. *Journal of Hydrology*, *377*(3-4), 367–376. http://doi.org/10.1016/j.jhydrol.2009.08.034

9. List of Figures

10. List of Tables