Student thesis series INES nr 318

Water drainage from a Swedish waste treatment facility and the expected effect of climate change

Niklas Olén

2011

Department of Earth and Ecosystem Sciences

Physical Geography and Ecosystems Analysis

Lund University

Sölvegatan 12

Niklas Olén (2011). Water drainage from a Swedish waste treatment facility and the expected effect of climate change
Master degree thesis, 30 credits in *Atmospheric Sciences & Biogeochemical Cycles*
Department of Earth and Ecosystem Sciences, Physical Geography and Ecosystems Analysis, Lund University

Water drainage from a Swedish waste treatment facility and the expected effect of climate change

Niklas Olén

Master degree thesis (2011)
30 credits
In *Atmospheric Sciences & Biogeochemical Cycles*

Supervisor, Lund University:
Dr. Veiko Lehsten
Supervisor Borås Energi och miljö:
Sofia Carter

Department of Earth and Ecosystem Sciences, Physical Geography and Ecosystems Analysis,
Lund University

Abstract

The waste treatment facility, Sobacken, is located south of Borås, Sweden. At Sobacken there is a lake built to collect the leachate from the area. Leachate is a term for water that has the potential of carrying environmentally hazardous substances, in this case water that might have passed through waste.

This thesis focused on the development of a hydrological model that from common climate variables is able to model the water level of the leachate lake. The model was based on the theory that all incoming precipitation for the catchment will either end up in the leachate lake or are removed by either evapotranspiration or groundwater recharge. The water will then either be pumped out of the leachate lake or be removed as open water evaporation.

Since the area of the catchment was unknown this was estimated with a GIS analysis made with elevation data. The land area of the catchment was 349 477 m^2.

The model was used to investigate how the water level of the leachate lake will be affected by a proposed climate change scenario. The climate scenarios used for this thesis were A1B, A2, and B1.

The model gave reasonable results compared to other studies and showed for all three of the climate scenarios an increasing trend of the average leachate lake water level. This indicates that the lake will not be sufficiently large to handle the increment of leachate in the future. This in turn would lead to an overflow of leachate into the environment which has to be prevented.

Keywords: Leachate; Landfill; Waste treatment facility; hydrological model; climate change; Sweden;

Sammanfattning

Sobacken som är en miljöanläggning ligger i söder om Borås. Inom miljöanläggningen finns det en artificiell damm som är bygg för att ta hand om lakvattnet från anläggningen. Lakvatten är det vatten som har potential för att bära miljöfarliga ämnen, i detta fall ämnen som vattnet kan ha tagit upp då det passerade avfallet på miljöanläggningen.

Denna avhandling fokuserades på att ta fram en hydrologisk modell som med hjälp av vanliga väderobservationer kan modellera vattennivån i lakvattendammen. Modellen bygger på teorin att all nederbörd för avrinningsområdet kommer hamna i antingen lakvattendammen, grundvattnet eller avdunsta. Det vatten som hamnar i lakvatten dammen kan vidare endast försvinna genom utpumpningen eller som avdunstning från vattenytan.

Eftersom arean av avrinningsområdet är av stor vikt i modellen beräknades denna med hjälp av en GIS analys av höjddata. Resultatet av detta gav att avrinningsområdet var ca 350 000 m^2.

Modellen användes för att undersöka hur vattennivån i lakvattendammen påverkas av att klimatet förändras i enlighet med klimatscenario A1B, A2 och B1.

Resultatet modellen gav var rimligt och gav visade en ökande trend för vattennivån för alla tre klimatscenarion. Detta gav en indikation på att lakvattendammen inte kommer klara den framtida ökningen av inkommande vatten.

Nyckelord: Lakvatten, deponi, avfallsanläggning, hydrologisk modell, klimatförändring, Sverige;

Contents

Variable list

A_c = Area of the catchment [m^2]
A_l = Area of lake [m^2]
AW_i = Available water, day i [mm / day]
C_p = Specific heat at constant pressure, 1.013 10^{-3} [MJ / kg °C]
c_w = Specific heat of water [kJ/kg °C]
d_r = Inverse relative distance between earth and sun [rad]
E_a = Drying power of the air [MJ/m^2 day]
e_a = Vapor pressure of the air [mm]
e_s = Saturation vapor pressure at air temperature [mm]
ET_a = Actual evapotranspiration [mm/day]
ET_f = Evapotranspiration factor
ET_i = Evapotranspiration, day i [mm water / day]
ET_p = Potential evapotranspiration [MJ / m^2 day]
$f(u_2)$ = Wind speed function
FSD_d = Thawing period [days]
G_{sc} = Solar constant 0.0820 [MJ / m^2 min]
INF_i = Infiltration into soil, day i [mm water / day]
J = Day number that will be 1 for January 1 and 366 for December 31.
k_Q = Site dependent groundwater recharge factor
k_{reg} = Regression constant 1
L_f = Latent heat of fusion [kJ/kg]
L_{in} = Incoming long wave radiation [MJ/m^2 day]
LL_i = Amount of water in lake, day i [m^3]
L_{out} = Outgoing long wave radiation [MJ/m^2 day]
MF = Melt factor [mm water / °C day]
M_i = Snowmelt, day i [mm water / day]
M_{nri} = Snowmelt non-rain, day i [mm water/ day]
M_{reg} = Regression constant 2
P = Pressure [kPa]
P_i = Precipitation, day i [mm / day]
PO_i = Pumped outflow day i [m^3/day]
P_{ri} = Precipitation as rain, day i [mm water / day]
P_{si} = Precipitation as snow, day i [mm water / day]
Q_i = Groundwater recharge, day i [mm water / day]
R_a = Extra terrestrial radiation [MJ/m^2 day]

Rf = Runoff fraction
R_i = Runoff [mm/day]
R_i = Runoff, day i [m^3/day]
R_n = Net radiation [MJ / m^2 day]
R_{nl} = Net long wave radiation [MJ/m^2 day]
R_s = Incoming measured solar radiation [MJ/m^2 day]
$R_{s,\ 1st\ Dec}$ = Measured average daily solar radiation 1st December of data [langleys]
$R_{s,Dec}$ = Estimation of locations normal total solar radiation in December [langleys]
R_{so} = Clear sky radiation [MJ/m^2 day]
$R_{so,dec}$ = Clear sky solar radiation of location [langleys]
SC_i = Snow cover, day i [mm water / day]
SFF = Soil flow factor
SF_i = Soil water flow to lake, day i [mm water / day]
S_{in} = Incoming short wave radiation [MJ/m^2 day]
S_{out} = Outgoing short wave radiation [MJ/m^2 day]
SWC_i = Soil water content, day i [mm water]
SWC_{max} = Maximum water soil can contain [mm]
T_i = Average daily temperature, day i [°C]
T_{max} = Maximum daily temperature [°C]
$T_{max,K}$ = Maximum absolute temperature [K]
T_{min} = Minimum daily temperature [°C]
$T_{min,K}$ = Minimum absolute temperature [K]
u_2 = Daily average wind at elevation 2 m [m/s]
u_z = Wind speed at z m, [m/s]
WF = Water flow from biogas production constant at 130 [m^3/day]
z = Elevation above ground for wind speed measurement [m]
z_s = Elevation above sea level [m]
α = Albedo
γ = Psychrometric constant [kPa/°C]
Δ = Slope of the saturation vapor pressure curve at air temperature [kPa/°C]
δ = Solar declination [rad]
ε = Ratio molecular weight of water vapor and dry air, 0.622
λ = Latent heat of vaporization [MJ / kg]
σ = Stefan Boltzmann's constant $4.903\ 10^{-9}$ [MJ/m^2 day]
φ = Latitude [rad]
ω_s = Sunset hour angle [rad]

1 Introduction

This thesis is a hydrological analysis of Sobacken made for the company Borås Energi och miljö AB (BEM). Sobacken is a waste treatment facility in Borås municipality, Sweden, owned by BEM.

To be able to handle the leachate from the waste treatment facility, BEM has built a lake where it is collected. The leachate from the lake is pumped to a water treatment facility where it is processed.

The hydrological analysis was focused on the properties controlling the inflow to the leachate lake and how it will be affected by a future climate change. This was done by developing a hydrological model that from common climatic variables can model the water inflow to the leachate lake. The model was also able to estimate the amount of water that needs to be pumped to the water treatment facility and hence calculate the water level change.

Climate projections were at last used as input to model how a projected climate change would affect the leachate lake water level and the amount of water pumped to the water treatment facility.

1.1 Borås Energi och Miljö AB

Borås energi och miljö is responsible for waste, energy, water and sewer services within and around Borås municipality. It is owned by Borås city and has around 250 employees (Borås Energi och Miljö).

1.2 Problem description

The main problem of this thesis is concerning the leachate lake that is built to collect leachate before pumping it to a water treatment plant. Because of limitations from the water treatment plant they are only allowed to pump 42 m^3/hour of leachate to the water treatment plant. This leads to the leachate lake getting potentially flooded.

To understand how the inflow of water to the leachate lake is controlled, this thesis was focused on developing a hydrological model.

Before the hydrological model could be developed, the size of the area draining to the leachate lake was needed. Once the watershed area was determined, a hydrological model could be developed relating common climate variables, available for the area, to the pumped outflow from the lake.

1.3 Study area

The location of this study is Sobacken which is located within Borås municipality about 8 km south of Borås city center. The population of Borås municipality is around 103 000 and it is currently the 13th biggest municipality in Sweden (Statistiska Centralbyrån, 2011). Borås municipality is located in Västra Götaland County about 60 km west of Gothenburg.

1.3.1 Sobacken

Sobacken is a waste treatment facility where many different types of waste are retrieved and handled as seen in Figure 1. One example of this is that the citizens of Borås are sorting food waste in a black plastic bag and other combustible domestic waste in a white plastic bag. The plastic bags are then collected by garbage trucks and transported to Sobacken where they are optically sorted. The food waste will be turned into biogas and the white bag with combustible domestic waste will be burned and used as district heating.

At Sobacken hazardous waste is registered and sorted to allow a more efficient transport to recycling or final destruction.

Sobacken was built to drain the contaminated water from the area to a constructed leachate lake shown in Figure 1. The exact size of the area that drains to the leachate lake was calculated within this thesis. Excess water that originates from the biogas production will flow through a pipe directly to the leachate lake too.

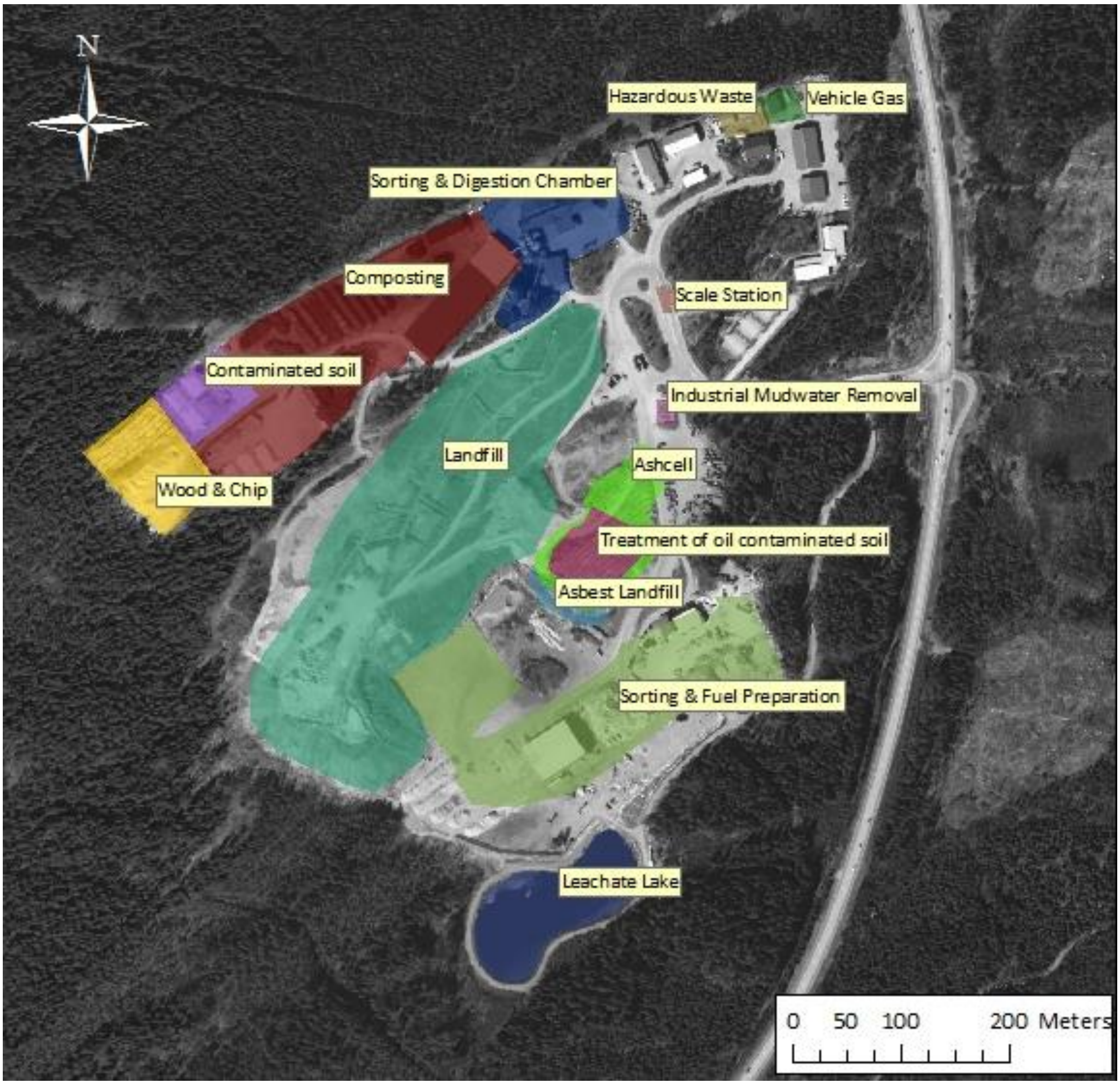

Figure 1, Map Showing Sobacken and its different activities. Source: Lantmäteriet[1] (n.d.) for aerial photo and Borås energi och miljö activity polygons.

---

[1] © Lantmäteriet Gävle 2011. Medgivande I 2011/0086

1.4 Objective

The objective of this thesis was to

- Determine the area of the watershed that drains to the leachate lake
- Develop a hydrological model for Sobacken that relate climate variables to pumped outflow from the leachate lake.
- Show how the lake will be affected by future climate change by using climate projection data as an input to the model

1.5 Hypothesis

To be able to formulate a good hypothesis one needs to consider everything what has been addressed in chapter 1 of this thesis. With that in mind the hypotheses of this thesis were:

With common climate variables as input it is possible to parameterize a valid hydrological model to simulate pumped outflow required from the leachate lake.

The leachate lake at Sobacken will be affected by future climate change.

2 Theory

2.1 Water balance of Sobacken

The natural water balance of the landfill can be seen in Figure 2. The only natural source of water input to the system is precipitation. Once entered the system the water naturally escapes as evapotranspiration or recharges the groundwater.

For Sobacken there will also be an input and output of water from anthropogenic activities. The excess water used for biogas production will flow to the lake and water will be pumped from the lake to a water treatment facility.

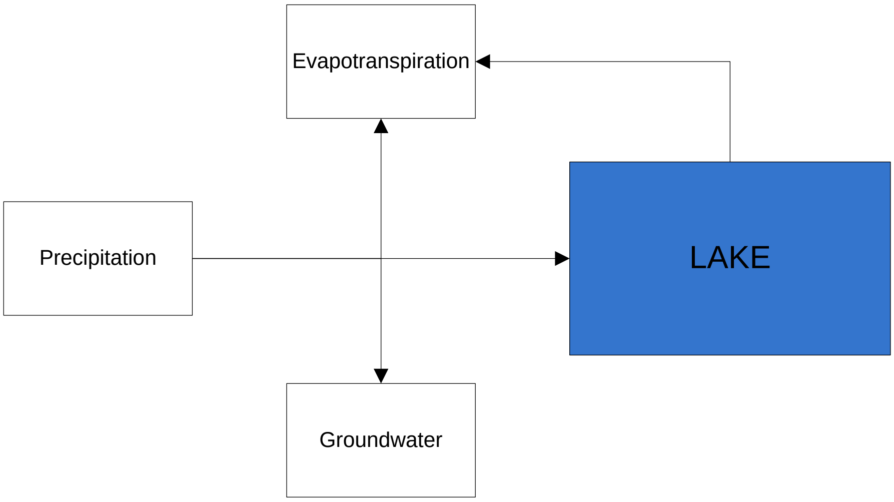

Figure 2, Water balance of landfill. Precipitation is input to the system. Evapotranspiration and groundwater recharge is output of system

2.2 Evapotranspiration

Evaporation is the process where liquid water is turned into water vapor and thereby removed from its initial source. This can take place at many different surfaces, for example at a lake surface or at the surface of the soil.

The change from liquid to vapor takes place when energy is introduced into the system. This is often in the form of solar radiation but can also come from temperature changes (Allen, Pereira, Raes, & Smith, 1998). The main force that controls the removal of water vapor from the surface is the difference between the water vapor pressure of the surface that is evaporating and the pressure of the air close to the surface (Allen, et al., 1998). Hence the air will slowly become saturated and the process will be slowed down and stopped if the wet air is not replaced. The replacement of the wet air is related to the wind speed.

Transpiration is the process where the water in plants is removed to the atmosphere. The most common way that plants loose water is through their stomata (Allen, et al., 1998). The stomata are pores in the plant leaf used to take up carbon dioxide and release oxygen. When the plant has the stoma open that water vapor can escape to the atmosphere.

The sum of the evaporation and transpiration is equal to the evapotranspiration. And the main climatic factors controlling it are temperature, wind and solar radiation.

2.3 Albedo

Albedo is a measure of the reflective power of the surface, i.e. the amount of incoming solar radiation that is reflected by a surface (Chapin, Matson, & Mooney, 2002). The albedo can differ much depending on the surface properties. For example the albedo of grassland is between 0.16 and 0.23 and the albedo of fresh snow can be as much as 0.75 to 0.95 (Chapin, et al., 2002). Hence fresh snow, can reflect, as much as 95 percent of the incoming solar radiation. The albedo is always a value between zero and one. It is zero when all incoming radiation is absorbed and one when all incoming radiation is reflected.

2.4 Climate change

The climate change will affect the climate variables controlling the hydrology and it was therefore of interest to study how the climate will change.

It was by IPCC (Meehl et al., 2007) stated that because of the climate change and the temperature increment, related to the increase of greenhouses gases, northern Europe will have a higher frequency of climate extremes including an increase of the number of extreme precipitation events. When the regional climate model RCA3 with climate scenario A2 was applied by SMHI (SMHI Rossby Center, 2007a) on Nordvästra Götaland County the result showed that the number of days per year with precipitation larger than 10 mm will at the end of the 22nd century have increased with 36% compared to the average value for the years 1961-1990. The result also shows that the precipitation is likely to increase with 15 percent (SMHI Rossby Center, 2007b). The temperature increment compared to the 1961-1990 average is likely to be as an average 6°C increment for winter months and a 5 °C increment for the rest of the year (SMHI Rossby Center, 2007c).

2.4.1 Climate scenarios

Since it is hard to know how the world will change and affect greenhouse gas (GHG) emissions and the climate, a number of different scenarios have been formed to model the future for different possible outcomes. The scenarios are divided into different storylines (Nakicenovic & Intergovernmental Panel on Climate Change. Working Group III., 2000). For this thesis the storylines A1B, A2 and B1 were used. The GHG emissions and its corresponding changes in surface temperature for each scenario can be seen in Figure 3.

A1 is a storyline where the world will undergo a very fast economic growth with a population peak around year 2050. The A1 storyline is also divided into various sub groups depending on how the technology is developed, where A1B is a scenario where there is a equal balance between fossil and non-fossil energy sources (Nakicenovic & Intergovernmental Panel on Climate Change. Working Group III., 2000).

A2 is a storyline that describes a very heterogeneous world with a small but constant increase in global population. The technological development is much slower in this storyline compared to the others, which leads to the GHG emissions for A2 are increasing the most as seen Figure 3.

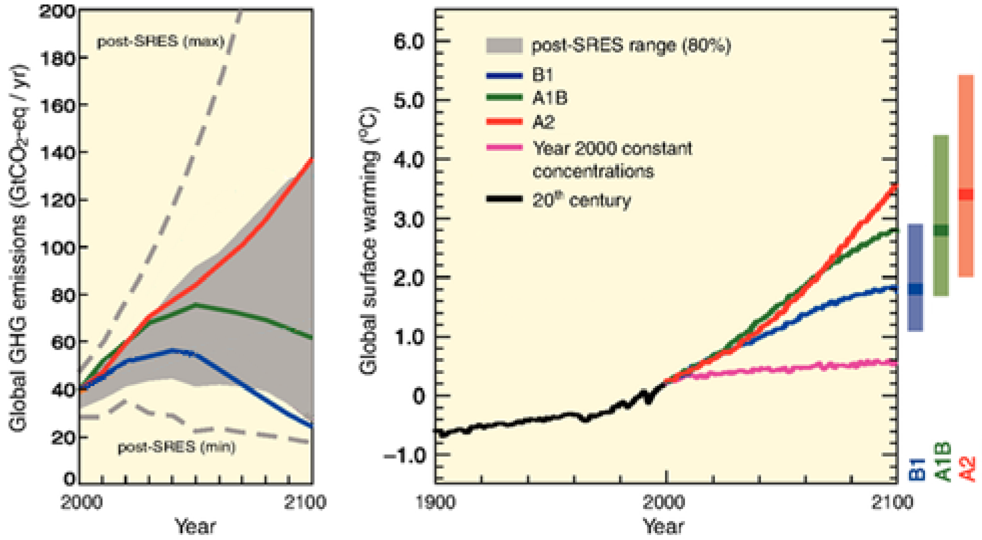

Figure 3, Left figure: Global green house gas (GHG) emissions for the different scenarios, Right figure: Global surface warming for the different climate scenarios, bars to the right shows the best estimate. Both figures adapted from Meehl et al. (2007).

B1 is a storyline which is equal to A1 in many ways but differs in that it is focused more on global solutions to economic-, social-, and environmental-sustainability which will make the GHGs emissions decrease around year 2050 as seen in Figure 3 (Nakicenovic & Intergovernmental Panel on Climate Change. Working Group III., 2000).

2.5 Climate projections models

To be able to make a complete simulation of the future climate a global climate model needs to be used because everything on the earth is connected. But since this takes a lot of computer power a low resolution is used. To be able to use the model for a more regional purpose as in this thesis a regional climate model is introduced. A regional climate model gives a result with a higher resolution on a regional scale and is using a global climate model to define its boundary conditions.

The climate model used to calculate the climate scenario data in this thesis are the regional climate model, RCA3 (Kjellström et al., 2005), with the boundary conditions from the global general circulation model, ECHAM5 (Roeckner et al., 2003).

The regional climate model, RCA3, is a model developed by SMHI Rossby Center that includes processes related to the interactions between the atmosphere and the land surface (Kjellström, et al., 2005).

The ECHAM5 model is an atmospheric general circulation model developed by the Max Planck institute for meteorology (Roeckner, et al., 2003).

2.6 Statistical methods and MatLab tools

2.6.1 MatLab, Linear regression (*polyfit*)

The cubic regression used in this thesis was the MatLab[2] function *polyfit*. Polyfit is a function that estimates the coefficients in a polynomial function of a certain degree, n, in a way that makes the sum of the square of the error minimized (Mathworks, 2011b). To make the polyfit function estimate a cubic fit a degree of 3 is used. Which means that in this case polyfit tries to fit the function seen in equation 1 by changing the values for the constants a, b, c, and d.

$$y = ax^3 + bx^2 + cx + d \qquad (1)$$

2.6.2 MatLab, Least square none linear (lsqnonlin)

The least square none linear (lsqnonlin) tool is a part of the optimization toolbox in MatLab used to optimize parameters.

Lsqnonlin solves a least-square nonlinear problem by starting at the user defined input, guess of parameters, and then try to find the minimum of the sum of squares of the function used as input (Mathworks, 2011a). The function also needs a lower and upper bound of the parameters as input.

2.7 Geographical information system (GIS)

Geographical information system (GIS) is a computer based system that is used for storing, modifying, analyzing and displaying data related to locations on the earth. In other words a way to digitally handle and analyze maps and properties related to a location.

2.7.1 Topo to raster tool

The topo to raster tool within ArcGIS[3] is a tool that from contour lines, elevation points, lake polygons, and stream lines interpolates a hydrological correct digital elevation model (DEM) (ESRI, 2011a).

---

[2] MatLab is a registered trademark and is a numerical computing environment

[3] ArcGis is a registered trademark and is a geographical information system

2.7.2 Hydrology toolset

The hydrology toolset is a toolset within ArcGIS spatial analyst that was used to extract hydrological information from a hydrological correct DEM (ESRI, 2011b).

3 Data

This section of the report concerns the data that was used throughout the thesis.

3.1 GIS data

To calculate the area of the watershed that drains to the leachate lake, geographical information about the landfill and its surrounding was collected from BEM. The geographical data available at BEM that was used for this thesis were elevation, base maps, land activity and water and sewer maps. All the data was as in the projected coordinate system SWEREF99 1330. The geographical data from BEM was converted from cad files into shape files that were more suitable for an ArcGIS analysis.

3.2 Climate data

The climatic data used in this report is shown in Table 1.

Table 1, accessed and used data

Variable	Resolution	Time period	Source	Comment
Precipitation	Daily	2009-2011	Borås city	
Wind speed	Daily	2009-2011	Borås city	Average
Temperature	Daily	2009-2011	Borås city	Average, Max, Min
Radiation	Daily	2009-2011	Borås city	Incoming
Precipitation	Daily	2000-2011	SMHI	For Borås
Pumped volume	~Weekly	2007-2011	BEM	From the lake
Snow depth	Daily	2009-2011	SMHI	Only wintertime

The pumped volume is the pumped outflow as a meter reading. In order to have an estimation of the daily outflow, the outflow between each meter reading was considered to be constant.

3.3 Climate scenario data

The climate scenario data was acquired from SMHI (SMHI et al., 2009) and consisted of scenario data from regional climate model RCA3 with boundary conditions from the global climate model ECHAM5.

The climate scenario data had a resolution of 50 km and was acquired for the area containing Borås and Sobacken. The climate parameters included precipitation, temperature, wind speed and solar radiation all with time resolution one month.

The data was downloaded three times one for each of the climate scenarios used, which was A1B, A2 and B1, and had a length from year 1981 to year 2100.

4 Method

This section of the report is divided into a section about the method used when determining the watershed area, and the method for developing the hydrological model.

4.1 Determination of watershed area

The watershed area was of importance since it will influence the amount of water reaching the leachate lake. It was calculated by using the elevation dataset acquired from BEM to create a hydrological correct digital elevation model (DEM) with the topo to raster tool in ArcGIS (see section 2.7.1 for more information).

The DEM was created using 1 meter elevation contour lines, elevation points, and the leachate lake polygon as input.

After the DEM was created it was checked for errors and updated to be correct. This was done by applying the sink tool that identified every sink of the DEM, a sink is defined as a single cell where all the surrounding cells flow into that cell. For this purpose all of the sinks were removed, since we need a DEM where the water can flow without disturbance.

The flow direction and flow accumulation tools were applied to the DEM.

Since the watershed tool needed a pour point as input, a new point layer was created where a point was created at the leachate lake but close to the observed high value of flow accumulation. This was done in a way to allow using the snap pour point tool with good results.

The point layer created was used together with flow accumulation raster as input in the snap pour point tool moving the point to the cell with the highest flow within 20 meters.

The watershed area was calculated as the area that drains to the point created or in other words to the leachate lake.

The watershed area was at last validated against known geographical properties about the area that changed the outcome of the result. An example of this is that a drainage pipe from a point source outside is draining into the calculated area, making the area that drains to the outside source a part of the total drainage area.

The flow chart used to calculate the watershed area in ArcGIS can be seen in Figure 4.

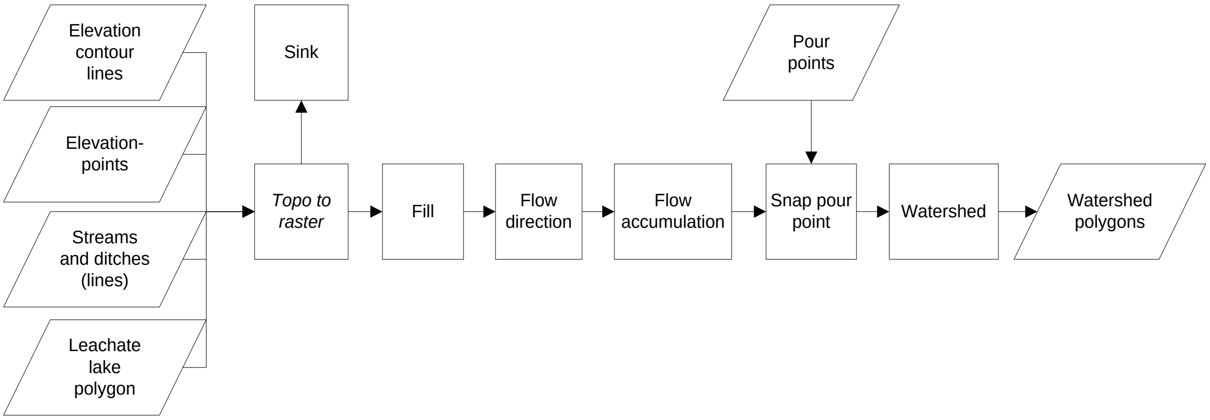

Figure 4, Flowchart of the work order used to determine the watershed area of Sobacken. Square is representative for a tool in ArcGIS and parallelogram is input data.

4.2 Model development

The hydrological model was designed to relate common climatic variables to the inflow to the leachate lake.

This was done by first developing a conceptual model for the inflow which was based on the theory that all incoming precipitation for the catchment will either end up in the leachate lake or will be removed by evapotranspiration or groundwater recharge. This can also be described with an equation, see below (2)

$$LL_i = LL_{i-1} + \frac{(P_i - ET_a - Q_i)}{1000} \cdot A_c \qquad (2)$$

Where

LL_i = Amount of water in lake, day i [m^3]

P_i = Precipitation, day i [mm / day]

ET_a = Actual evapotranspiration, day i [mm / day]

Q_i = Groundwater recharge, day i [mm / day]

A_c = Area of the catchment) [m^2]

Though the hydrological model is based on equation 2, the complete form of the model is more complex as displayed in the flowchart in Figure 5.

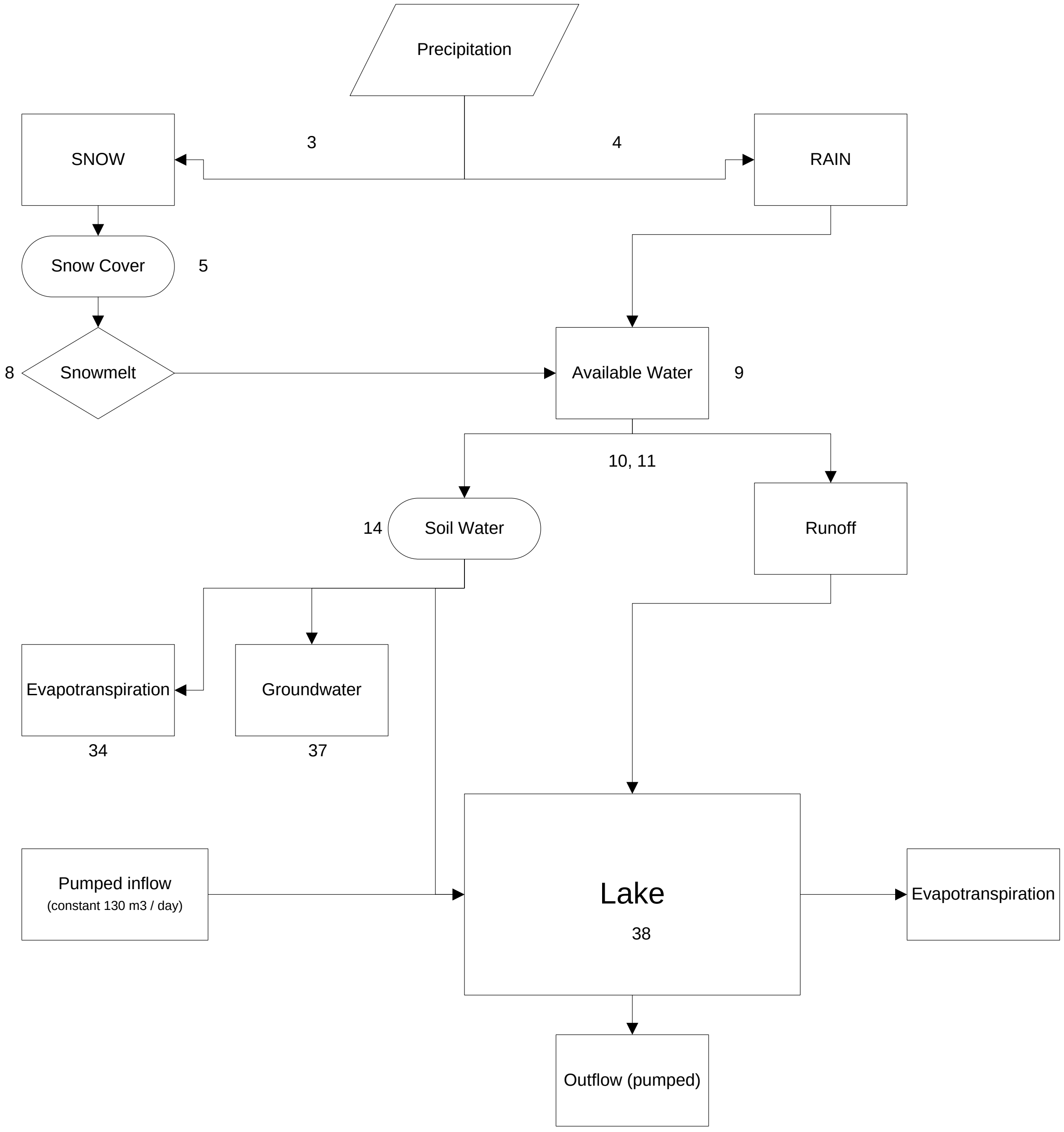

Figure 5, Design of the conceptual hydrological model made for Sobacken. Numbers is indicating the equation number of that part of the model.

4.2.1 Conceptual model development

Precipitation was, with the help of daily average temperature, divided into rain or snow, in the model as seen in top of Figure 5. In order to determine the suitable daily average temperature that will divide precipitation into either snow or rain, the average daily temperature was plotted against an increase in snow depth as seen in Figure 6. From Figure 6 we can see that only a minority of snow events (increase in snow cover) are associated with a daily average temperature of above 0°C (2 of 28 or 7.5%) are showing an increase in snow depth at a daily average temperature above 0°C. Hence 0°C was used as a breaking point between rain and snow as seen in equation 3 and 4.

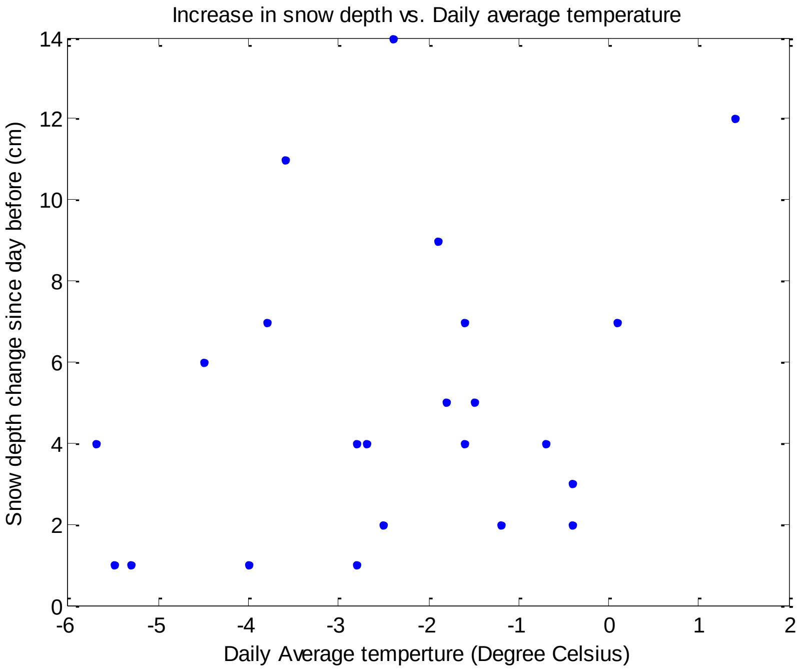

Figure 6, Increase in snow depth against daily average temperature for Borås. Daily snow depth measurements from SMHI and daily average temperature from Borås city data. Data from periods 20091101-20100215 and 20101101-20110215

$$P_{si} = \begin{cases} 0 & if\ T_i \geq 0 \\ P_i & if\ T_i < 0 \end{cases} \qquad (3)$$

$$P_{ri} = \begin{cases} P_i & if\ T_i \geq 0 \\ 0 & if\ T_i < 0 \end{cases} \qquad (4)$$

Where

P_{si} = Precipitation as snow, day i [mm water / day]
P_{ri} = Precipitation as rain, day i [mm water / day]
T_i = Average temperature, day i [°C]

From this the snow cover for each day can be calculated with the use of equation 5.

$$SC_i = P_{si} - M_i \qquad (5)$$

Where

SC_i = Snow cover, day i [mm water]
M_i = Snowmelt, day i [mm water / day]

The snow cover was only allowed to have values greater than or equal to zero. If snow cover was equal to zero that means that there was no snow cover present and would not be until precipitation was coming as snow again. The snowmelt in equation 5 was calculated in two different ways depending on whether rain was occurring. If it rains on the snow the snowmelt was a function of the amount of rain and the temperature of the rain (Andersson, 2006) as shown in equation 6. This was based on the fact that energy is released from the rain as it is cooled down by the snow. The release of energy will melt the snow. The temperature of the rain was in this case considered to be equal to the average daily temperature as seen in equation 6, which is used to calculate the rain snowmelt.

$$M_{ri} = \frac{c_w \cdot P_{ri} \cdot T_i}{L_f} = 0.0125 \cdot P_{ri} \cdot T_i \qquad (6)$$

Where

M_{ri} = Snowmelt rain, day i [mm water / day]
c_w = specific heat of water [kJ/kg °C] = 4.18
L_f = Latent heat of fusion [kJ/kg] = 334

To calculate the non-rain snowmelt the model used a melt factor together with temperature as seen in equation 7. This is, according to the manual of the snow-17 model (Andersson, 2006), a common way to calculate the non-rain snowmelt.

$$M_{nri} = M_f \cdot T_i \qquad (7)$$

Where

M_{nri} = Snowmelt non-rain, day i [mm water/ day]

M_f = Melt factor [mm water / °C day]

Equation 7 is a simplified version of the way snowmelt is calculated in HELP (Hydrological Evaluation of Landfill Performance) model (Schroeder et al., 1994). Martinec & Rango (1986) used for the melt factor, M_f, values between 4 and 6. According to Schroeder et al. (1994) the melt factor will be different depending on the time of the year, but at latitudes close to 60N or higher it will always be around its minimum value. The minimum value used by Schroeder et al. (1994) is 2.0 mm water / °C day which is the factor used in this model.

The snowmelt for a day was then either the non rain snow melt or the rain snowmelt as seen in equation 8.

$$M_i = \begin{cases} M_{ri} & if\ M_{ri} > 0 \\ M_{nri} & if\ M_{nri} > 0 \end{cases} \qquad (8)$$

Once the snowmelt for a day was calculated the model was ready to calculate the available water, that is water that is free to runoff or infiltrate the soil. This calculation is shown in equation 9.

$$AW_i = M_i + P_{ri} \qquad (9)$$

Where

AW_i = Available water, day i [mm / day]

If there was a snow cover, all the precipitation that came that day would affect the snow melt and hence P_{ri} would be equal to zero. If there was no snow cover, a snowmelt was impossible and M_i would be equal to zero.

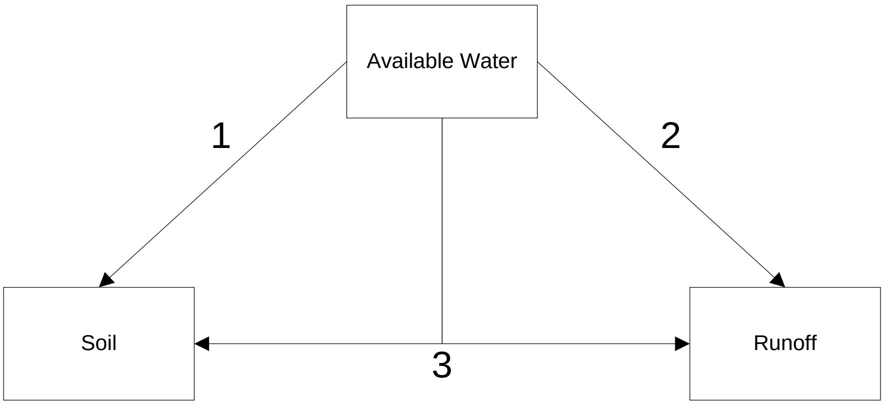

Figure 7, Design of how the available water is divided in the model. 1: all the water infiltrate the soil, 2: All to runoff and 3: divided between the two.

The available water was then either runoff, infiltrated by the soil or both as seen in Figure 7. Because Sobacken is man-made and has some paved areas with drainage and wells, a fraction of the available water was always treated as runoff. Also if the soil water reached field capacity the excess water was treated as runoff.

Last, if the soil was frozen, all the available water was treated as runoff. Based on this the runoff and the infiltration was calculated by using equation 10 below.

$$R_i = \begin{cases} AW_i & \text{if frozen soil} \\ Rf \cdot AW_i & \text{if none frozen soil} \end{cases} \qquad (10)$$

Where

Rf = Runoff fraction

R_i = Runoff [mm/day]

As mentioned above, if the soil water content reaches its maximum and there is available water left (after filling up the soil and calculating the runoff), the excess water will then be treated as runoff which can be calculated with equation 11 instead of 10.

$$R_i = AW_i - (SWC_{max} - SWC_{i-1}) \qquad (11)$$

Where

SWC_i = Soil water content, day i [mm water]

The calculation of the freezing and thawing of the soil is based on the method used in Schroeder et al. (1994). First one calculates the thawing period, FSD_d. The thawing period is the amount of days it takes for the soil to thaw after the average daily temperature goes above zero and is dependent on the latitude as seen in equation 12. The amount of days for thawing will in this model not change and therefore only a single value for the thawing period was needed.

$$FSD_d = 35.4 - 0.154 \cdot R_{s,Dec} \qquad (12)$$

Where

FSD_d = Thawing period [days]

$R_{s,Dec}$ = Estimation of locations normal total solar radiation in December [langleys]

The estimation of a locations normal total solar radiation is based on both the potential solar radiation in December (i.e. clear sky solar radiation, R_{so}) and on the measured average daily solar radiation of December, the first year of the measured data as seen in equation 13. The unit ‘langleys’ was converted to MJ/m^2 by multiplication with 0.04184.

$$R_{s,Dec} = 0.5\left(R_{s,1st\ Dec} + 0.75R_{so,dec}\right) \qquad (13)$$

Where

$R_{s,\ 1st\ Dec}$ = Measured average daily solar radiation 1st December of data [langleys]

$R_{so,dec}$ = Clear sky solar radiation of location [langleys]

The soil was considered to enter a frozen state if the average temperature for the last 30 days was below zero degrees Celsius. The unfreezing and refreezing of the soil was calculated with the help of a counter function which also prevented the soil to refreeze immediately after a thaw.

The counter was set to be zero when the soil became frozen for the first time of that winter season. If the average daily temperature was above zero, one was subtracted from the counter (minimum value of zero) and if the average temperature was above zero one was added.

When the counter was equal to the thawing period the soil was considered to be unfrozen again and the counter was set to (FSD_d+2)/3 as done in Schroeder et al. (1994).

The soil was considered to be frozen again if the counter was equal to zero and the average temperature for the last 30 days was below zero.

The water that ends up as runoff will be considered to flow to the leachate lake because of the design of the landfill. The water that goes into the soil will either evapotranspirate, flow to the lake or end up in the groundwater. Based on this the soil water content was calculated by using equation 14.

$$SWC_i = SWC_{i-1} + INF_i - ET_i - SF_i - Q_i \qquad (14)$$

Where

INF_i = Infiltration into soil, day i [mm water / day]
ET_i = Evapotranspiration, day i [mm water / day]
SF_i = Soil water flow to lake, day i [mm water / day]
Q_i = Groundwater recharge, day i [mm water / day]

The infiltration is the amount of available water that was left after a part of it was treated as runoff as seen in Figure 7.

The evapotranspiration was calculated by first calculating the potential evapotranspiration with equation 15 which is an equation originally formulated by Penman (1948) but modified by Brutsaert and Stricker (1979). The potential evapotranspiration gives the maximum amount of water that the atmosphere is able to take up at a specific location and a specific time of the year. The potential evapotranspiration was then used to calculate the actual evapotranspiration using equation 36.

$$ET_p = \frac{\Delta R_n}{\Delta + \gamma} + \frac{\gamma E_a}{\Delta + \gamma} \qquad (15)$$

Where

ET_p = Potential evapotranspiration [MJ / m^2 day]
Δ = Slope of the saturation vapor pressure curve at air temperature [kPa/°C]
R_n = Net radiation [MJ / m^2 day]

γ = Psychrometric constant [kPa/°C]
E_a = Drying power of the air [MJ/m^2 day]

The potential evapotranspiration ET_p can easily be transformed into the dimension [mm water / day] by multiplication with 0.408 (Allen, et al., 1998). The drying power of the air, E_a, was calculated with equation 16.

$$E_a = 2.45 \cdot f(u_2)(e_s - e_a) \qquad (16)$$

Where

$f(u_2)$ = wind speed function
e_a = vapor pressure of the air [mm]
e_s = saturation vapor pressure at air temperature [mm]
2.45 = Conversion from [mm/day] to [MJ/m^2 day]

The wind speed function was a part of the calculation of the drying power of the air, E_a, and is shown in equation 17 (Brutsaert & Stricker, 1979). The wind speed function was made in such a way that if e_a and e_s have the dimension of mm and the wind speed, at two meter, in m/s, E_a will have the dimension of mm/day. A conversion from mm/day to MJ/m^2 day was therefore included in equation 16, since E_a was needed in equation 15.

$$f(u_2) = 0.35(1 + 0.54 \cdot u_2) \qquad (17)$$

Where

u_2 = Daily average wind speed at elevation 2 m [m/s]

If the wind speed measurement was not made at an elevation of 2 meters it was adjusted to it with equation 18 (Allen, et al., 1998). Equation 18 is for a reference grass surface but it was sufficient to be used for this model.

$$u_2 = u_z \cdot \frac{4.87}{\ln(67.8z - 5.42)} \qquad (18)$$

Where

u_z = Wind speed at z m, [m/s]
z = Elevation above ground for wind speed measurement [m]

Since the saturation vapor pressure of the air was not measured it needs to be estimated. This can be done by using the daily maximum and minimum air temperature (Allen, et al., 1998) as seen in equation 19.

$$e_s = \frac{e^0(T_{max}) + e^0(T_{min})}{2} \qquad (19)$$

Where

T_{max} = Maximum daily temperature [°C]

T_{min} = Minimum daily temperature [°C]

And

$$e^0(T) = 0.6108 \cdot e^{\frac{17.27T}{T+237.3}} \qquad (20)$$

The vapor pressure of air, e_a, was estimated by assuming that the dew point temperature was close to the daily minimum temperature as done by Allen et al. (1998) because of the lack of humidity measurements. This gave equation 21 for the estimation of vapor pressure of the air, e_a.

$$e_a = e^o(T_{min}) \qquad (21)$$

The slope between the saturation vapor pressure and the temperature, Δ, from equation 15 was calculated with equation 22 (Allen, et al., 1998).

$$\Delta = \frac{4098 \cdot 0.6108 e^{\frac{17.27T_i}{237.3+T_i}}}{(T_i + 237.3)^2} \qquad (22)$$

The psychrometric constant which is a relation between the partial pressure of the water in the air and the air temperature was calculated with equation 23 (Allen, et al., 1998).

$$\gamma = \frac{c_p P}{\varepsilon \lambda} \qquad (23)$$

Where

C_p = Specific heat at constant pressure, 1.013 10^{-3} [MJ / kg °C]

P = Pressure [kPa]

ε = Ratio molecular weight of water vapor and dry air, 0.622

λ = latent heat of vaporization [MJ / kg]

The specific heat, C_p, at constant pressure is the energy needed to increase the air temperature of one kilogram air with one degree Celsius. The specific heat depends for example on the temperature but at average conditions the value of $1.013 \ 10^{-3}$ [MJ / kg °C] can be used (Allen, et al., 1998).

The latent heat of vaporization, λ, which is the energy needed to convert water from liquid form to vapor, is in Allen et al. (1998) constant at 2.45 MJ / kg, but was calculated with equation 24.

$$\lambda = 2.501 - 0.002361 \cdot T_i \tag{24}$$

The pressure, P, was estimated based on the elevation above sea level with equation 25 (Allen, et al., 1998).

$$P = 101.3 \cdot \left(\frac{293 - 0.0065 \cdot z_s}{293}\right)^{5.26} \tag{25}$$

The model as developed so far is now complete with the exception of net radiation.

Because only the solar radiation was measured, the long wave and the outgoing shortwave radiation needed to be estimated.

Net radiation, R_n, in equation 26 is the sum of all incoming and outgoing radiation. It will be negative if outgoing radiation is larger than incoming and positive if incoming radiation is larger than outgoing radiation.

$$R_n = (L_{in} - L_{out}) + (S_{in} - S_{out}) \tag{26}$$

Where

L_{in} = Incoming long wave radiation [MJ/m^2 day]

L_{out} = Outgoing long wave radiation [MJ/m^2 day]

S_{in} = Incoming short wave radiation [MJ/m^2 day]

S_{out} = Outgoing short wave radiation [MJ/m^2 day]

Since outgoing shortwave radiation will just be a fraction of the incoming i.e. the radiation that was not absorbed by the surface we can rewrite equation 26 to remove outgoing short wave radiation, S_{out} , and instead introduce the albedo.

$$R_n = (L_{in} - L_{out}) + S_{in} \cdot (1 - \alpha) \qquad (27)$$

Where

α = Albedo

A typical value of the albedo is around 0.2 but it can increase to values between 0.6 and 0.8 when there is snow on the ground (Markvart & Castañer, 2003). The albedo used within this model was 0.3. This was calculated by using the winter 2010 when there were about 3 months of snow and 9 months with bare ground. The albedo was 0.6 and 0.2 for snow and bare ground respectively. The yearly average albedo used for each day of the model was then estimated as shown below.

$$\frac{0.6 \cdot 3 + 0.2 \cdot 9}{12} = 0.3$$

Since the incoming shortwave radiation is measured, only the long wave incoming and outgoing radiation was missing from equation 27. Allen et al. (1998) suggested equation 28 to be able calculate the net long wave radiation when it is not a measured variable.

$$(L_{in} - L_{out}) = R_{nl} = \sigma\left(\frac{T_{max,K}^4 + T_{min,K}^4}{2}\right)\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \qquad (28)$$

Where

R_{nl} = Net long wave radiation [MJ/m^2 day]

σ = Stefan Boltzmann's constant 4.903 10^{-9} [MJ/m^2 day]

$T_{max,K}$ = Maximum absolute temperature [K]

$T_{min,K}$ = Minimum absolute temperature [K]

R_s = Incoming measured solar radiation [MJ/m^2 day]

R_{so} = Clear sky radiation [MJ/m^2 day]

The clear sky radiation, R_{so}, was calculated with equation 29 (Allen, et al., 1998).

$$R_{so} = (0.75 + 2 \cdot 10^{-5} z_s) R_a \qquad (29)$$

Where

z_s = Elevation above sea level [m]
R_a = Extra terrestrial radiation [MJ/m^2 day]

The extra terrestrial radiation, R_a, which is the radiation of the sun on top of the atmosphere, was calculated with equation 30 using known parameters. The extra terrestrial radiation depends on the latitude, time of the year, and the solar declination (Allen, et al., 1998).

$$R_a = \frac{24 \cdot 60}{\pi} G_{sc} d_r [\omega_s \cdot \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \qquad (30)$$

Where

G_{sc} = Solar constant 0.0820 [MJ / m^2 min]
d_r = inverse relative distance between earth and sun [rad]
ω_s = sunset hour angle [rad]
φ = latitude [rad]
δ = solar declination [rad]

The inverse distance between the earth and sun, and the solar declination was calculated with the help of equations 31 and 32 respectively (Allen, et al., 1998).

$$d_r = 1 + 0.033 cos\left(\frac{2\pi}{365}J\right) \qquad (31)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365}J - 1.39\right) \qquad (32)$$

Where

J = Day number that will be 1 for January 1 and 366 for December 31.

The sunset hour angle, ω_s, was calculated with the latitude, φ, and the solar declination, δ, as shown in equation 33 (Allen, et al., 1998) .

$$\omega_s = arccos[-\tan(\varphi)\tan(\delta)] \qquad (33)$$

The model now had every component of equation 15 and the potential evapotranspiration could be calculated. From the potential evapotranspiration the actual evapotranspiration was calculated with equation 34.

$$ET_a = ET_p \cdot SWC_i \cdot ET_f \tag{34}$$

Where

ETa = Actual evapotranspiration [mm/day]
ETf = Evapotranspiration factor [1/mm]

The main reason behind the evapotranspiration factor, ET_f, was to control how much the ground could evaporate based on the soil water content. The reasoning behind this is that if the soil water content was at its maximum allowed value, the actual evaporation would be equal to the potential evaporation. From this we can calculate the evapotranspiration factor by rewriting equation 32 into the following relationship (equation 35).

$$ET_p = ET_p \cdot SWC_{max} \cdot ET_f \quad => \quad ET_f = \frac{1}{SWC_{max}} \tag{35}$$

The soil water flow to the lake, SF_i, as seen in equation 14, was in this model considered to be a fraction of the available soil water as shown in equation 36. It was made this way so that the soil flow was bigger if the soil contained more water and was equal to zero if the soil was completely dry.

$$SF_i = SFF \cdot SWC_i \tag{36}$$

Where

SFF = Soil flow factor

The groundwater recharge, Q, was calculated with equation 37 (Neilson, 1995) and was dependent on the soil moisture but in a slightly different way than the evapotranspiration (equation 34).

$$Q_i = k_Q \left(\frac{SWC_i}{SWC_{max}}\right)^2 \tag{37}$$

Where

k_Q = Site dependent groundwater recharge factor
SWC_{max} = Maximum water soil content [mm]

The model now had an equation or description of every component that affects the amount of water that will reach the leachate lake.

The inflow to the lake was in the model the sum of soil flow, runoff, water flow from biogas production, and the precipitation on the lake. The lake then looses water either as pumped outflow or as evaporation from the open water surface. The evaporation from the open water surface is considered to be equal to the potential evapotranspiration. This gave that the amount of water in the lake at any time step was calculated using equation 38.

$$LL_i = LL_{i-1} + \frac{(SF_i + R_i)}{1000} \cdot A_c + \frac{A_l \cdot P_i}{1000} - \left(PO_i + \frac{ET_p \cdot A_l}{1000}\right) + WF \qquad (38)$$

Where

A_l = Area of lake [m^2]

PO_i = Pumped outflow day i [m^3/day]

R_i = Runoff, day i [m^3/day]

WF = Water flow from biogas production constant at 130 [m^3/day]

The water flow from the biogas production, WF seen in equation 38, is released to the leachate lake. Since this is not measured on a regular basis the value used is based on the total water from year 2010. The total water flow from year 2010 is divided with 365 to get an estimation of the daily flow from the biogas production to the leachate lake.

The model used equation 38 to calculate the amount of water in the leachate lake at any time step. This was done by using daily temperature, wind speed, solar radiation, and precipitation as input climatic variables.

4.2.2 Parameterization of model

In order to get the model tuned to explain the outflow from the leachate lake in a correct way a parameterization was carried out.

The parameterization was done as a two step process so that different length of the datasets could be used for the different steps. Since the pumped outflow is a measured parameter only the first half of the data was used for the parameterization. The second half of the data was used to validate the parameterization.

Because the inflow is not a measured parameter it could not be evaluated in the same way as the pumped outflow and therefore the complete time series was used for the parameterization.

The first step of the parameterization was the parameterization of the inflow and was made by looking at the water level change in the leachate lake and not letting it take unreasonable high or low values. This was done by using the Matlab function *lsqnonlin* to minimize the sum of the square of the differences between the observed and the modeled leachate lake water level. The minimum and maximum allowed values for the parameter, seen in Table 2, where achieved by both looking at the literature (Bengtsson, Bendz, Hogland, Rosqvist, & Åkesson, 1994; Ministry of Agriculture, 2002) but also by running the parameterization several times and decreasing the interval in order to get a faster and more accurate guess from lsqnonlin since it is not possible to run infinite amount of times.

Table 2, Interval of the value that the constants are allowed to take within the first step of the model parameterization.

Constant	Minimum	Maximum	Equation	Description
kq	0	0.01	31	Groundwater recharge
SWCmax	100	800	31	Maximum allowed soil water content
SFF	0.0001	0.2	30	Soil flow factor
Rf	0.1	1	10	Runoff fraction factor

The second parameterization separated the data in two data sets, one for the parameterization and one for the evaluation. The first data set was used to calculate the amount of water in the leachate lake and the Matlab function *polyfit* was used to make a cubic regression. The cubic regression *f(x)* was then altered as seen in equation 39.

$$f_2(x) = \frac{f(x)}{k_{reg}} + M_{reg} \qquad (39)$$

Where

$f_2(x)$ = Altered cubic regression

$f(x)$ = Cubic regression

k_{reg} = Altering regression constant

M_{reg} = Altering regression constant 2

The best values for k_{reg} and M_{reg} were determined by using the MatLab *lsqnonlin* function (described in section 2.6.2) and by allowing both constants to take values in a specified range, seen in Table 3. This was done so that the cubic regression made on the leachate lake water amount fitted as well as possible to the pumped outflow.

Table 3, Interval of the value that the constants are allowed to take within the second step of the model parameterization.

Constant	Minimum	Maximum	Equation	Description
M_{reg}	0	0.01	PA1	Altering regression constant
k_{reg}	150	300	PA1	Altering regression constant 2

4.2.3 Validation of model

Since the inflow to the leachate lake is not a measured parameter, the calculated value could not be validated against reality. Instead, each of the components which controlled the inflow to the lake was validated against expert knowledge and literature. The components affecting the inflow to the leachate lake and thereby evaluated were runoff, soil flow, evaporation, groundwater recharge, and maximum soil water content.

The pumped outflow was however a measured parameter and can therefore be validated against the modeled outflow. This was not a straightforward process since the amount of water in the leachate lake of every time step is dependent not only on the inflow to the lake but also to the pumped outflow.

It was solved by letting the modeled pumped outflow (altered cubic regression in Figure 7) at the last time step of the regression be an estimation of the outflow from that time step to the next (dotted line in Figure 7).

From the estimated outflow (dotted line in Figure 7) and the modeled inflow to the leachate lake, new values of the leachate lake water volume were calculated. The new values were added to the time series with the leachate lake water volume and a new cubic regression was made.

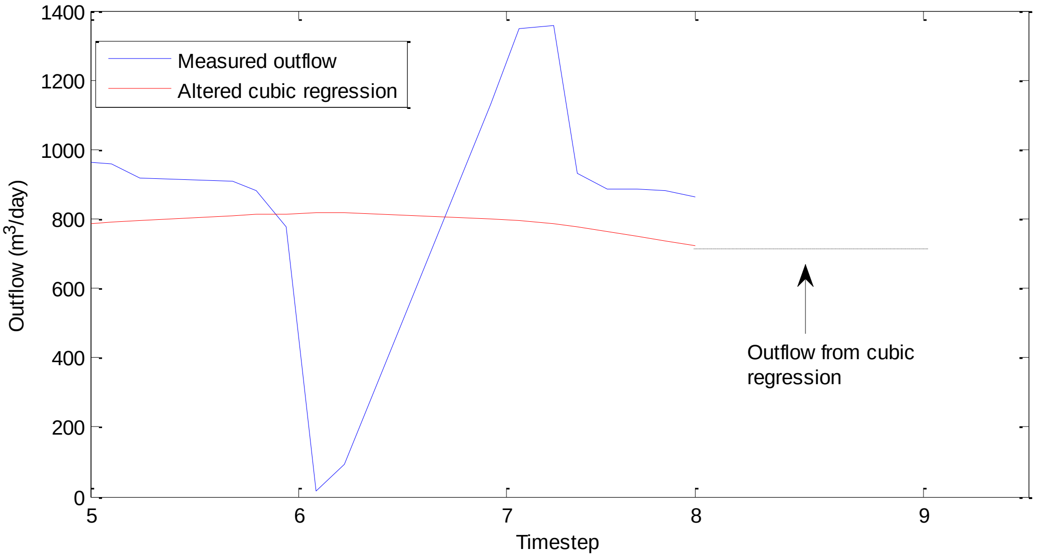

Figure 8, Shows how the outflow is calculated from this cubic regression. This by assuming that the outflow from the leachate lake at the last time step was equal to the outflow until the next time step occurs.

From the new regression in combination with k_{reg} and M_{reg}, a modeled outflow from the lake was for the next time step calculated in the same way as before, hence once again assuming that the outflow at the last time step of the regression was considered as the outflow for the period until the next time step.

This process was then repeated until every times step of the validation period was processed.

The process that was repeated for every time step of the validation was

1. Cubic regression of the leachate lake water volume.
2. Modification of the cubic regression with k_{reg} and M_{reg}.
3. Assume value at the end of regression equal to modeled pumped outflow until next time step.
4. Calculation of leachate lake water volume for the period between the time steps.
5. Added new leachate lake water volume values to previous time series (return to step 1).

The time steps used were not constant since the measured pumped outflow is not measured at a regular interval. Hence the calculated outflow which was compared against the measured was needed for similar temporal resolution.

At last the measured outflow was compared with the model calculated outflow and in this way validated.

4.2.4 Applying climate projections

To be able to see how the leachate lake and the hydrology of the landfill will be affected by climate change, climate projection data for the scenarios A1B, A2 and B1 was used as model input data.

Since the climate projection data was as a monthly mean it was first transformed into daily values. This was done by calculating the yearly anomaly from the 1981 to 2010 (30 years) average value. The yearly anomaly was calculated for the period year 2011 to 2100, which is the climate scenario period used.

The anomalies for the temperature were calculated as absolute values and for precipitation, wind, and radiation as ratios. This was done since temperature is the only variable that is allowed to take negative values.

The two years of daily data from SMHI and Borås City were then repeated 45 times to have a length of 90 years. For each year of the 90 year time series the anomaly corresponding to the same year was used to change the measured values. This was done by for the temperature adding the temperature anomaly and for the precipitation, wind, and radiation multiplying the anomalies.

Once the climate projection data was modified to be as daily values it was used within the model. The pumped outflow was then calculated and validated in the same way as above (section 4.2.3 last part).

Applying climate projections to the model as input was allowed to estimate how the leachate lake will be affected by climate change for the different climate scenarios.

5 Results

5.1 Watershed calculation

The first result of the watershed area was corrected against geographical data that could not be included in the first calculation. It was done by minimizing the error of the watershed area and included the removal of the area that drains to the ditch shown in Figure 9.

The reason for the removal of the area that drains to the ditch is that the southeast end of the ditch goes into an underground pipe, thereby removing the water from the watershed connected to the leachate lake.

The final result of the watershed area calculation is shown in Figure 9. The area that drains to the leachate lake is **360 237 ± 100 m^2**. This value has then been used throughout the model to estimate the total amount of precipitation that potentially arrives in the leachate lake from the area.

The geographical analysis of the area also gave that the area of the leachate lake is 10 760 ± **100** m^2. Since the watershed area used within the model only was land area the leachate lake area was subtracted from the watershed area giving the result of the land area of the watershed to **349 477 ± 100 m^2**

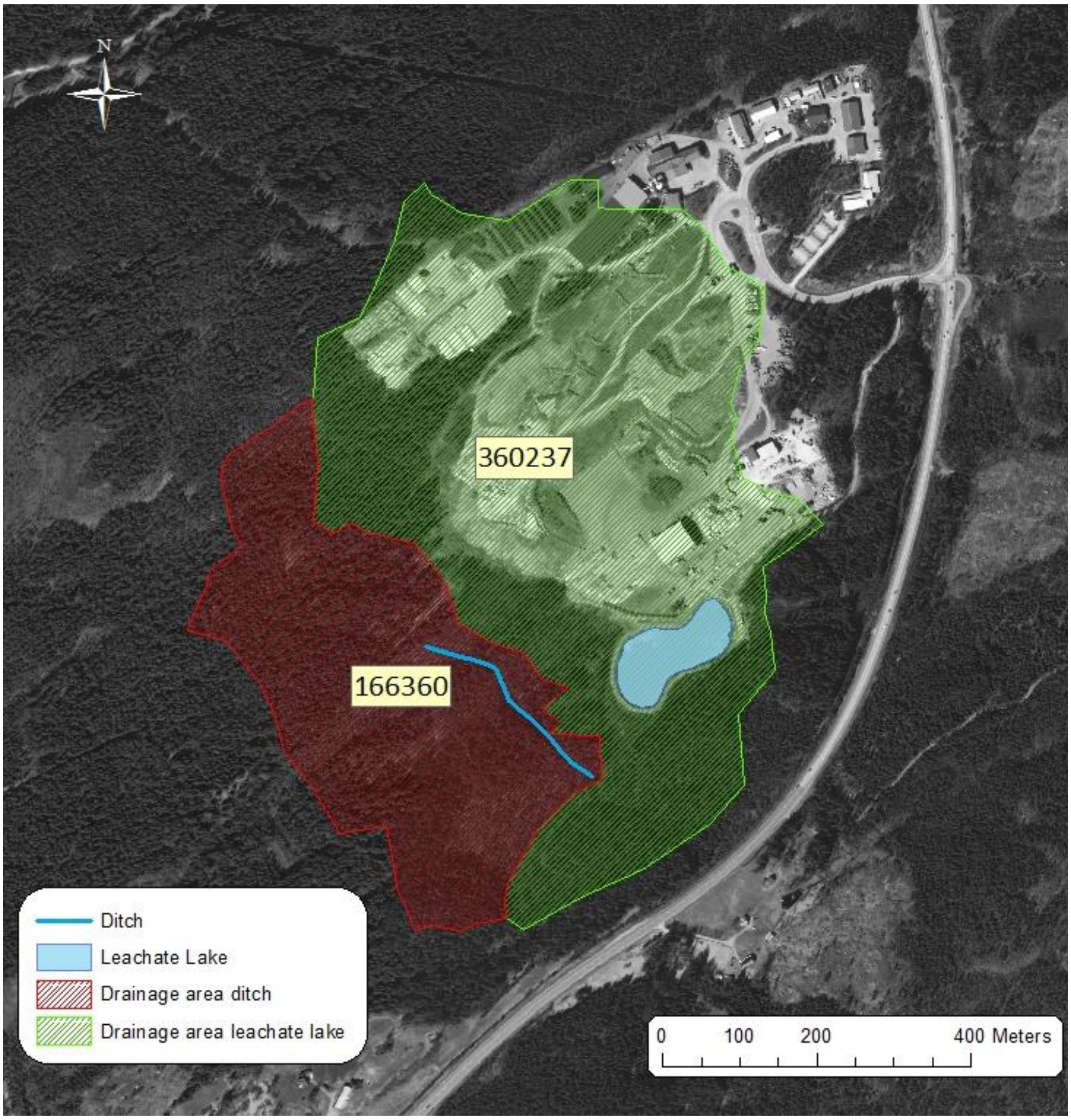

Figure 9, Watershed for Sobacken and ditch, the total area (m^2) is given inside polygons. Source: Aerial photo from Lantmäteriet[4]

---

[4] © Lantmäteriet Gävle 2011. Medgivande I 2011/0086

5.2 Parameterization of Model

5.2.1 Parameterization of constants controlling inflow

The first part of the parameterization was carried out by visually controlling if the fluctuations of the water level height of the leachate lake were within a reasonable range. As seen in Figure 10 it was fluctuating but a water level of +2 meters is reasonable because of the dimensions of the leachate lake. The leachate lake has a maximum water depth of about 5 meters so the -3 meters water level change is also reasonable.

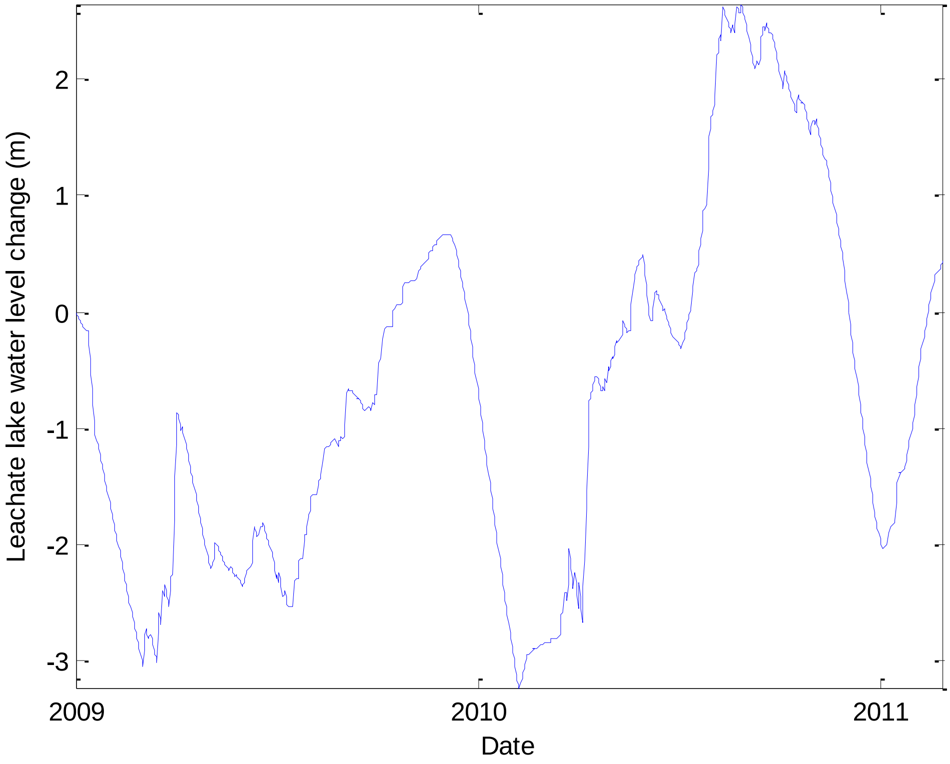

Figure 10, Shows the leachate lake water level (m) change for the period 2009-01 to 2011-02.

Since the modeled lake water level cannot be compared against measured data it was of great importance to compare each of the parameterized constants against current knowledge to determine their accuracy.

According to BEM the landfill is located in a place where the groundwater recharge is very small, a small value of k_q was suspected. The soil flow factor, SFF, of 0.0046 implies that 0.46 percent of the soil water will flow to the leachate lake each day. Since the soil water flow is an extremely slow process dependent on the conductivity of the soil the soil flow should be fairly constant and small.

Table 4, Results from the parameterization of the inflow

Constant	Parameterization value	Dimension	Equation
k_Q	0.0099	[-]	31
SWC_{max}	353	[mm water]	31
SFF	0.0046	[-]	30
Rf	0.2296	[-]	10

Bengtsson et al. (1994) stated that for a 4 meter layer of a landfill 1000 mm water is needed for it to reach its field capacity, in other words 250 mm (1000/4) water is needed for a layer of 1 m landfill to reach its maximum allowed soil water content. If we compare this to the value of 353 mm from the parameterization it seems that the parameterization gave a value that is in the correct range since waste is a very diverse material.

The drainage area of 350 000 square meter is however containing 40 percent landfill, 16 percent roads and buildings, and 44 percent vegetation. The main soil type of the vegetation is sandy loam which has a field capacity of 125 mm water per meter soil (Ministry of Agriculture, 2002).

This makes the maximum soil water content of 353 mm reasonable. And if we assume that the maximum soil water content of road and buildings equal to zero the average field capacity of Sobacken should according to literature (Bengtsson, et al., 1994; Ministry of Agriculture, 2002) be

$$SWCmax_{litterature} = 125 \cdot 0.44 + 250 \cdot 0.4 + 0 \cdot 0.16 = 155 \frac{mm\ water}{m\ soil}$$

Since the maximum soil water content in the model is for the complete soil depth (i.e. soil depth is unknown) the value of 353 mm is probably for more than one meter of soil. This makes the comparison with literature only an indication if the value was in the correct range. The value of 353 mm water compared to 155 mm water / m soil shows that it was in the correct range hence making the value reasonable.

According to the parameterization the runoff factor, Rf, is 0.23 which means that 23 percent was always treated as runoff. This seemed like a good value since there are drainage and ditches that influenced the runoff by increasing it.

5.2.2 Parameterization of outflow

The result for the parameterization of k_{reg} and M_{reg} is showed in Table 5. To verify the correctness of these values a short calculated example is shown below.

Table 5, Result from the parameterization of the relationship between amount of water in leachate lake and pumped outflow.

Constant	Parameterization value	Dimension	Equation
M_{reg}	1150	[-]	PA1
k_{reg}	38.3	[-]	PA1

The arrow between the top and bottom figure in Figure 11 marks the time step where the example was calculated. The cubic regression line in the top figure at the place of the arrow gives a value of approximately -20000m^3. So if we apply the parameterized values on

-20000m^3 as seen in equation 39 the result should be close to the measured outflow.

$$Approx_{measured} = -\frac{20000}{38.3} + 1150 = \mathbf{627.4\ m^3}$$

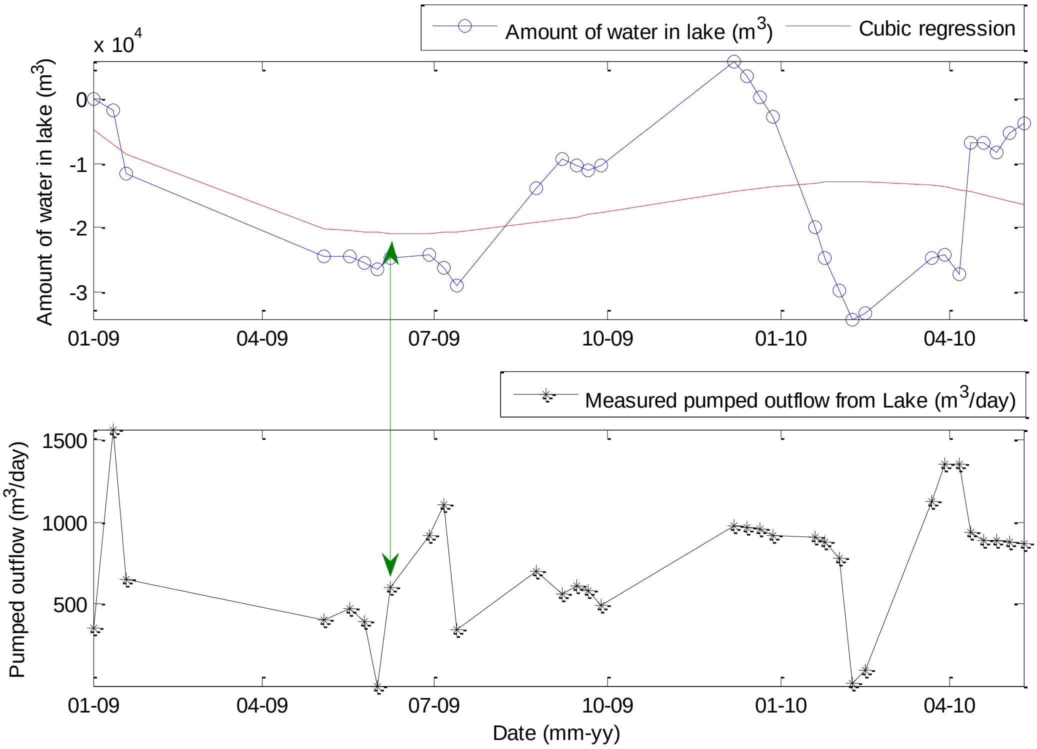

Figure 11, Top figure: Amount of water in the lake (m^3) and a cubic regression of that data. Bottom figure: The measured pumped outflow. Arrow in between is marking the place for the calculated example done.

And as seen in the bottom figure of Figure 11 the value 627.4 m^3 is lower than the measured outflow but in the correct range.

The parameterization of M_{reg} and k_{reg} was also evaluated against the second half of the data and the result of this can be seen in Figure 12. The mean outflow for the second period is 890 [m^3 / day] and 929 [m^3 / day] for measured and calculated outflow respectively. This gave the indication that the model gave good values of the outflow compared to the measured values on a longer time scale. But as seen in Figure 12 the model was not able to model any of the quick changes of the pumped outflow but worked better for an average outflow seen over a longer time period. Hence the response time of the model was too long.

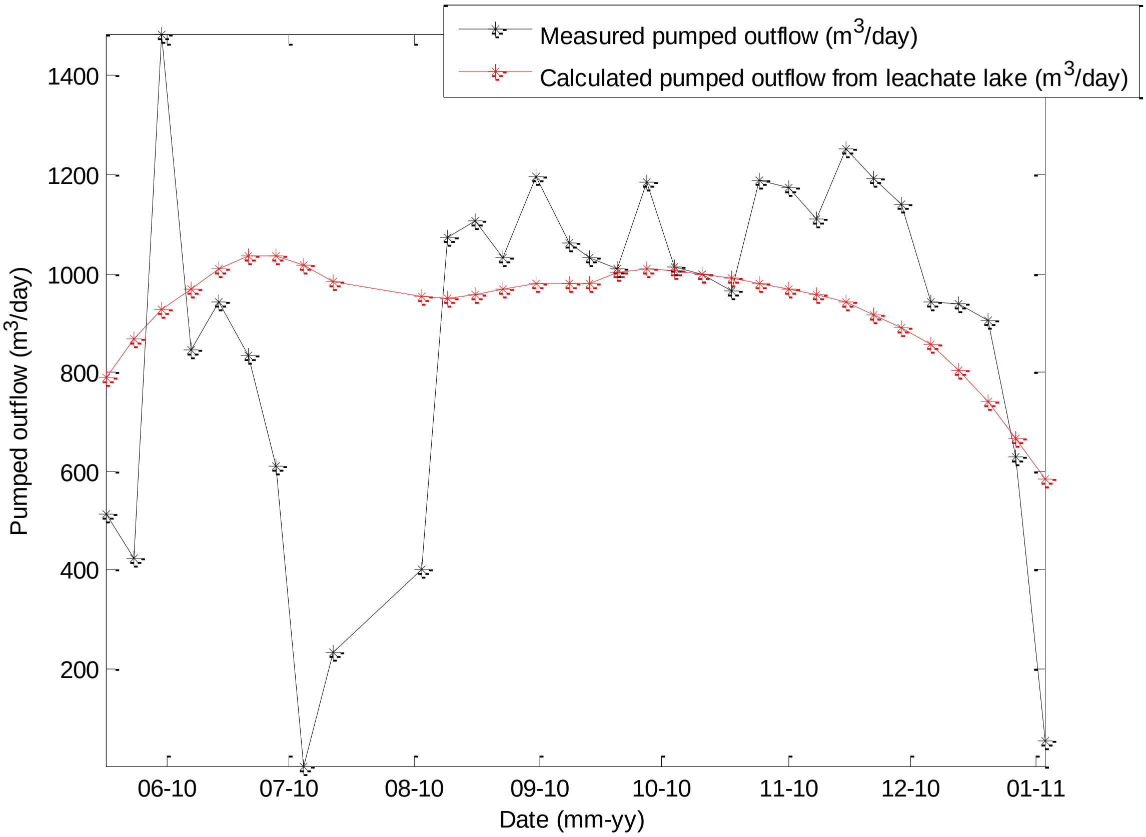

Figure 12, Validation of the relationship between calculated outflow (modified regression line) and measured outflow.

5.3 Model test run results

To validate the model a first test run was made to assure that there was no water within the model that was not accounted for. This was done by running the model and assuring that all the water can be accounted for. The result of the test run showed that all the water for both 2009 and 2010 could be accounted for as seen in Table 6 when comparing the row *sum of above* with the row for *precipitation*.

The reason for the big difference between 2009 and 2010 is mainly that 2009 was the starting year of the model and as seen much of the water goes into soil water storage which would not be the case in reality. The reason for not implementing a first guess of the soil water content is that it would just increase all the soil water content values, that including the maximum allowed value making the first guess redundant. So therefore this spin up effect was not to be avoided.

The evapotranspiration for 2010 can however be compared against the value from Bendz & Bengtsson (1996) where the evaporation from a landfill in Malmö (240 km south of Borås) consist of 27 percent of the water input. This indicates that the calculated evapotranspiration at Sobacken for year 2010 (29.6 %) was in the same range.

Table 6. All components of the model as a summation for year 2009 and 2010 and as a percentage of the precipitation. The storage in snow and soil water is calculated as the amount at the end of each year subtracted with the amount in the beginning of each year and is therefore allowed to be negative.

	2009		**2010**	
	[m^3]	*% of precip.*	*[m^3]*	*% of precip.*
Runoff	96086	27.4%	119200	34.1%
Soil flow	61708	17.6%	112090	32.0%
Evapotranspiration	50846	14.5%	103540	29.6%
Groundwater recharge	205	0.1%	572	0.2%
Soil water storage	74690	21.3%	29335	8.4%
Snow storage	67077	19.1%	-14971	-4.3%
Sum of Above	**350612**	100%	**349766**	100%
Precipitation	**350612**		**349766**	

5.4 Climate projection results

In Figure 13 the 10 year average yearly precipitation and the 10 year average temperature for each of the scenarios are displayed. All the scenarios show a trend of increasing temperature and precipitation, which is also stated by SMHI Rossby center (2007b; 2007d), with the highest increase for scenarios A1B and A2.

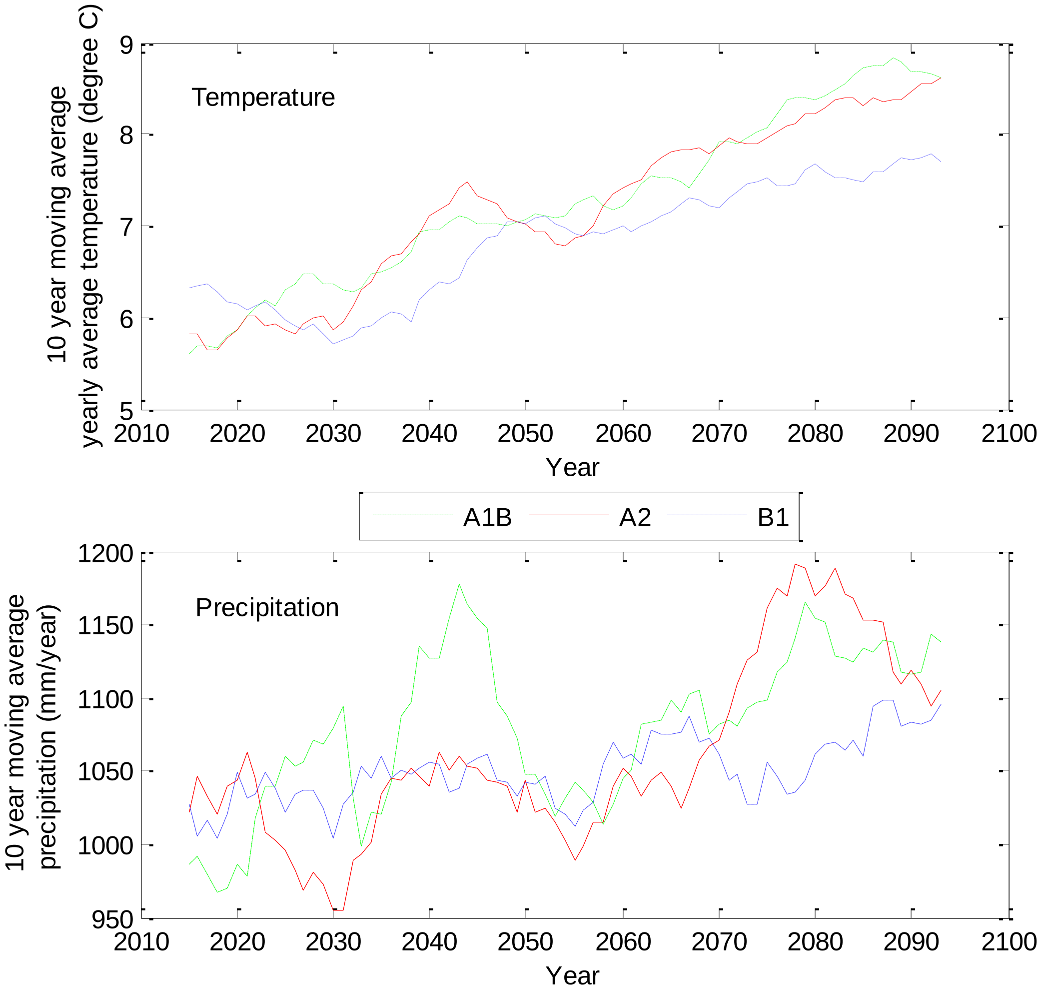

Figure 13, Top panel: 10 year moving average yearly temperature for scenarios A1B, A2 and B1. Bottom panel: 10 year moving average yearly precipitation. Both figures for years 2010 to 2100. Data from Kjellström et al. (2009).

When using the A1B scenario data as input data, the model showed that there will be an increasing trend of the leachate lake water level as seen in Figure 14, since the linear regression trend shows a positive trend. The variability within the data is however very large.

As seen in Figure 15, the model result for scenario A2 shows similarly to A1B an increasing trend of the assumed 10 year average lake water level when compared to the average for year 2010 to 2020. Once again the results showed a high variability.

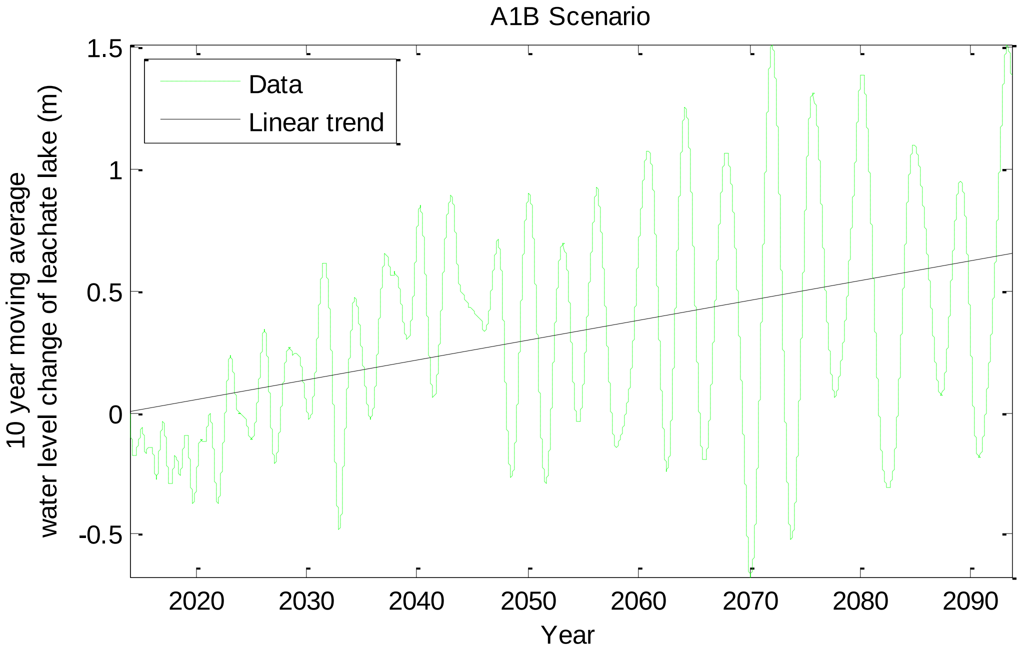

Figure 14, Scenario A1B, change from 2010-2020 (2015) average value in water level of leachate lake (m) as a 10 year moving average and a linear regression.

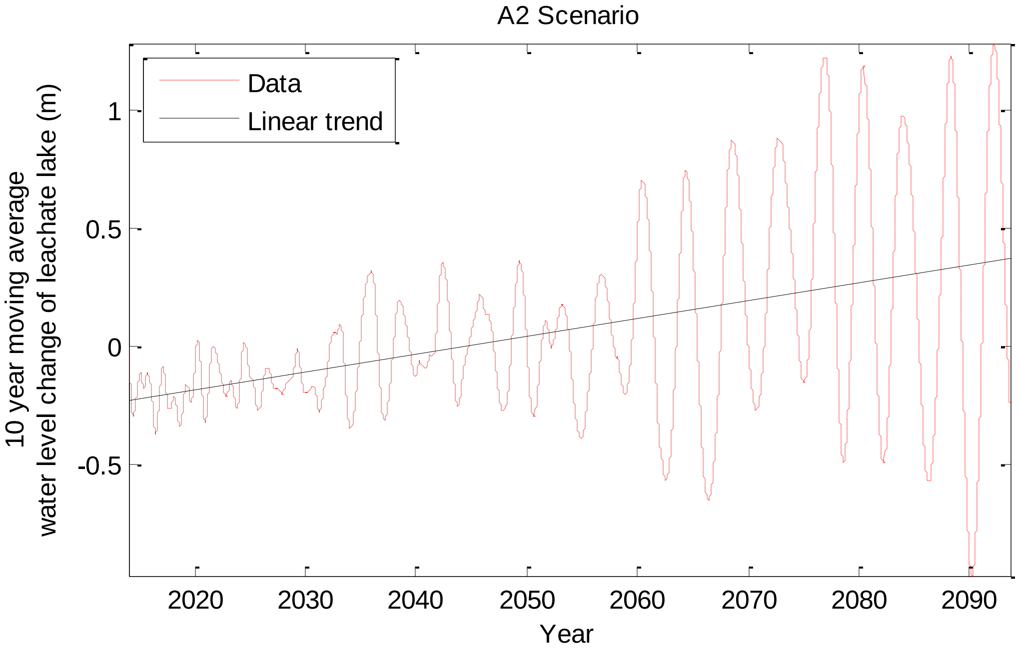

Figure 15, Scenario A2, change from 2010-2020 (2015) average value in water level of leachate lake (m) as a 10 year moving average and a linear regression.

For the B1 scenario the result, as seen in Figure 16, shows an increasing trend of the calculated 10 year average lake water level change from the average lake water level for the years 2010-2020.

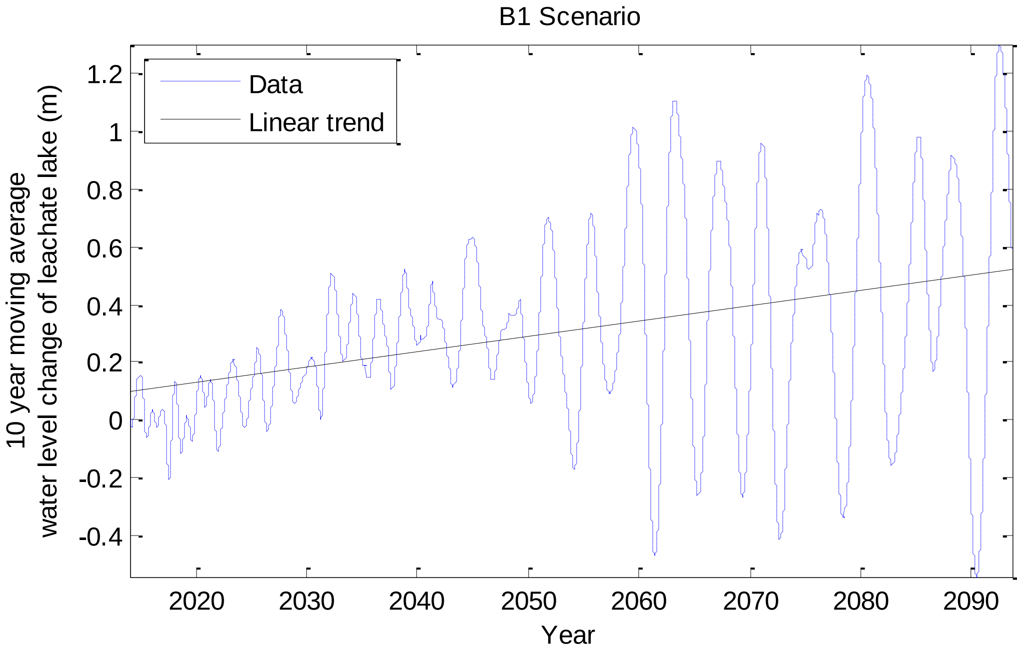

Figure 16, Scenario B1, change from 2010-2020 (2015) average value in water level of leachate lake (m) as a 10 year moving average and a linear regression.

In short, when the climate projection data was used in the model, the results showed for all the scenarios an increasing trend for the water level of the leachate lake.

In order to verify that the scenario results gave similar values of the modeled pumped outflow from the leachate lake the modeled outflow is shown in Figure 17. The average pumped outflow was 350 670, 347 370 and 343 490 m^3/year for A1B, A2 and B1 respectively.

Since the pumped outflow for each scenario was in the same order of magnitude the climate scenario results for each of the projections were valid to be compared against each other.

As displayed in Figure 18, the slope for climate scenario B1 is the smallest of the three.

Since the slope of the linear trend-line for climate scenario B1 in Figure 18 is smaller than for the other climate scenarios (A1B and A2), the calculated increase of the leachate lake water level is smallest for climate scenario B1.

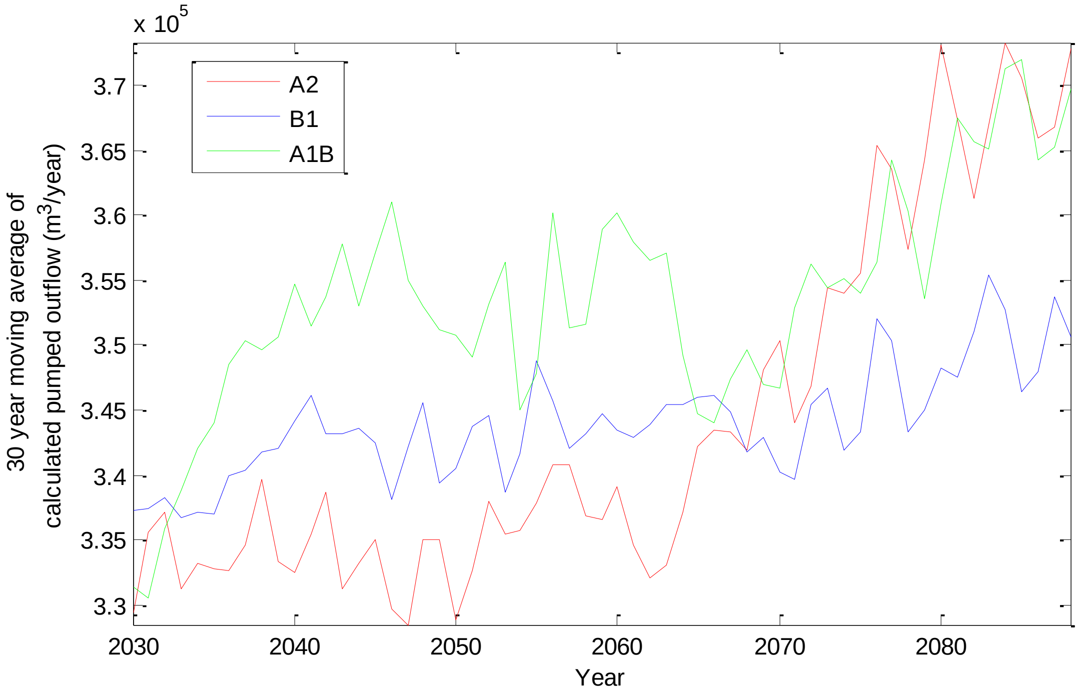

Figure 17, 30 year moving average of calculated pumped outflow from the leachate lake (m^3/year) for each climate scenario used.

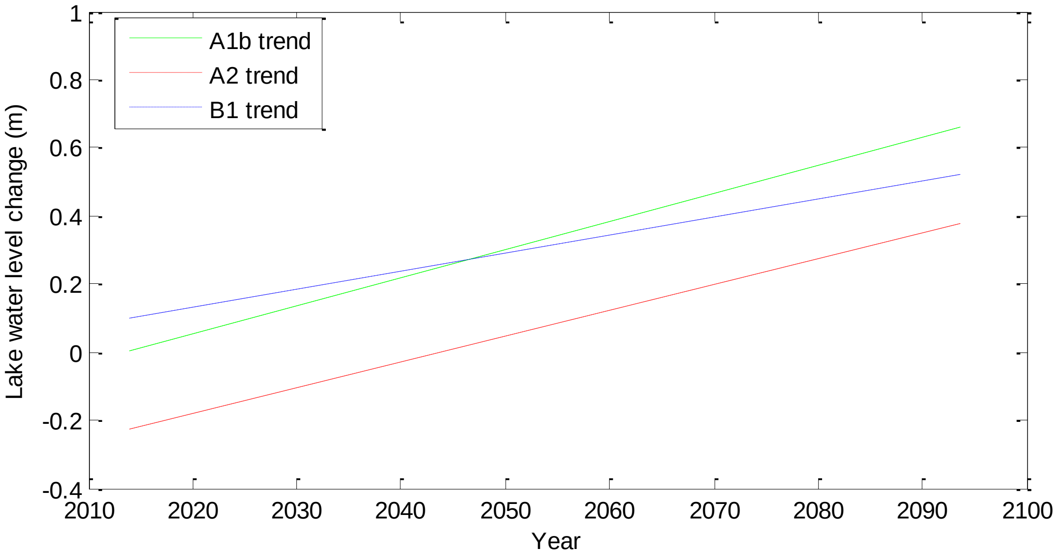

Figure 18, Shows the linear trend lines from Figure 14, Figure 15, and Figure 16 for comparison.

6 Discussion

This thesis was carried out in order to see how a proposed climate change would affect the water level of the leachate lake at the waste treatment facility, Sobacken. The result is of great importance in order for BEM to be able to make the correct changes to the leachate lake and its surroundings.

The evapotranspiration, groundwater recharge, runoff and soil flow are reasonable compared to the literature (Bendz & Bengtsson, 1996; Bengtsson, et al., 1994; Ministry of Agriculture, 2002). The model gave also a reasonable result for year 2010.

The analysis of the scenario data as input in the model showed that there will be an increasing trend of the lake water level regardless of the applied climate scenario (A1B, A2, and B1). The leachate lake will be affected by climate change but how much depends on the change of the GHG emissions and that will affect the climate, which is still very uncertain. But since the results for all three of the scenarios showed an increasing trend, the most likely change is that the amount of water that reaches the leachate lake will increase during this century.

Since BEM is allowed to pump 42 m^3 per hour from the leachate lake which is equal to 367 920 m^3 per year, it is possible to increase the amount of water pumped from the lake and by that counteract a possible water level increase. However, since the modeled pumped water for scenario A1B and A2 is above the maximum allowed value by the end of the 22nd century (Figure 17) it will not be possible to increase the pumped water amounts any further. This indicates that other measures need to be taken to decrease the amount of water to be pumped from the leachate lake. Additionally one has to take into consideration, that the model had a rather slow response and that the temporal variability of the climate is also expected to increase (Trenberth et al., 2007), hence I consider my model estimates rather conservative. Since this model does not consider any climate extremes such as a extreme rain event the results may differ when including extremes in the input data.

The model gave good results when compared to similar studies. Graham et al. (2007) for example came to the conclusion that there is an indication of an overall increment of the runoff for Lule river basin (northern Sweden) when studying future climate scenarios. This is in agreement with the results for this thesis since an increment of runoff will lead to an increment of the water ending up in the leachate lake.

The first challenge when developing the model was the fact that the modeled inflow to the leachate lake could not be validated against any measured data. This in combination with the short data series made the parameterization and validation of the inflow impossible. But since the evaporation seemed to be in the same range as value found in literature I valued this as an indication that the model worked.

Since the soil flow, runoff and groundwater recharge is highly dependent on the location it was hard to evaluate these values. It was however clear that any change in groundwater recharge will influence the evapotranspiration, since they are the only sources where the water naturally can be removed from the system. Because of this the evaluation of the evapotranspiration was also an evaluation of the groundwater recharge.

The short time series were the reason that the initialization period of the model covered a large part of the available data set. Since it took time for the soil water content to reach an acceptable value this had an effect on the result as seen for the year 2009 of the model test run. The starting value of the soil water content was chosen to be zero because it was not possible to within this thesis estimate a correct value. Limitations with the model made a starting guess of the soil water content only shift the zero soil water content level upwards. Because of this it was better to leave it at zero and take the result of the first year as an initialization period of the soil water content.

The parameterization was done as a two step process to be able to use different lengths of the datasets. Since the inflow to the leachate lake is not a measured parameter, its parameterization could use the full length of the dataset. For the pumped outflow, which is measured, half of the dataset would be needed to validate the parameterization hence only half could be used for the parameterization.

The reasons for maximizing the datasets used was because of the low extend of the dataset. Therefore I decided that it would be better to be able to use as much as possible than to make it as a one step process.

All in all the parameterization of the water inflow to the leachate lake needs to be validated against measured leachate lake water level in order to increase the level of accuracy of the validation. Which could be done relatively easily in a subsequent study if the required measurements are taken for several years.

Something that has not been addressed completely in this thesis is the amount of water that is used for the biogas production and released to the leachate lake. Since this amount is not measured on a regular basis the amount used for this thesis is a constant value (130 m^3 / day) based on the amount released in year 2010. The value is a good estimation of the reality for the years 2009-2010 but it is impossible to say if that would change in the future and therefore it was not possible to use any other estimation.

The pumped outflow can in reality not be constantly held at its maximum allowed value, of 42 m^3 / hour, because the pump needs a certain water level to operate, which is not reached throughout the year. This was however not considered within the model and it should be noted that when the results of the pumped outflow are close to its maximum allowed value, it might not be possible to pump that amount of water to the treatment facility.

The conversion from monthly to daily resolution of the climate scenario data was done so that the model could be used in a correct way. This has been done mainly since the snowmelt and frozen soil calculations depend on daily values. The method used for the conversion was chosen because of its simplicity and because that the result it gave was good enough and other applications, e.g. dynamic vegetation models have used a similar method. Since the results for the climate scenarios were seen as an indication for how the water level of the leachate lake might be affected by climate change, it was only important that the climate scenario data had the correct trend.

7 Outlook

The model developed in this thesis was site specific done for the waste treatment facility Sobacken but could easily be used at another site by changing the input data. The data that needs to be changed are the climatic data but also the site specific data such as elevation and albedo. The calculation of the thawing period is also a site specific parameter that needs to be recalculated with equation 12 and 13.

To improve the results of the model there are several things that could be changed within the model and the input data. The model could be improved if the parameterization of the inflow to the leachate lake could be made with real data of the leachate lake water level.

In order to improve the calculation of the potential evapotranspiration it should be verified against field data which was not possible in this thesis. Such verification should is required to change the outcome of the calculation of the potential evapotranspiration to better match the reality.

To further improve the model a more complex version of the soil/waste and its layers should be considered.

8 Conclusion

It was possible from common climate variables as input to parameterize a valid hydrological model for Sobacken that was able to simulate the pumped outflow required from the leachate lake. This leads to the conclusion that the first hypothesis:

With common climate variables as input it is possible to parameterize a valid hydrological model to simulate pumped outflow required from the leachate lake.

is verified.

Since the model for climate scenario A1b, A2, and B1 data showed an increasing trend of lake water level this leads to the conclusion that the second hypothesis:

The leachate lake at Sobacken will be affected by future climate change.

also is verified.

9 References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Available from http://www.fao.org/docrep/X0490E/X0490E00.htm

Andersson, E. (2006). Snow Accumulation and Ablation Model – SNOW-17. Retrieved from http://www.nws.noaa.gov/oh/hrl/nwsrfs/users_manual/part2/_pdf/22snow17.pdf

Bendz, D., & Bengtsson, L. (1996). Evaporation from an active, uncovered landfill. *Journal of Hydrology*, *182*(1-4), 143-155.

Bengtsson, L., Bendz, D., Hogland, W., Rosqvist, H., & Åkesson, M. (1994). Water balance for landfills of different age. *Journal of Hydrology*, *158*(3-4), 203-217.

Borås Energi och Miljö. (no date). Om företaget. Retrieved 2011-03-14, from http://www.borasenergimiljo.se/vanstermeny/omforetaget/

Brutsaert, W., & Stricker, H. (1979). An advection-aridity approach to estimate actual regional evapotranspiration. *Water resources research*, *15*(2), 443-450.

Chapin, F. S., Matson, P. A., & Mooney, H. A. (2002). Principles of terrestrial ecosystem ecology (pp. 73-74). New York: Springer.

ESRI. (2011a). ArcGIS 9.3. Topo to raster (3D analyst). Retrieved 2011-05-24, from http://resources.esri.com/help/9.3/arcgisdesktop/com/gp_toolref/3d_analyst_tools/topo_to_raster_3d_analyst_.htm

ESRI. (2011b). Desktop 9.3 Help. An overview of the Hydrology tools. Retrieved 2011-05-24, from http://webhelp.esri.com/arcgiSDEsktop/9.3/index.cfm?TopicName=An_overview_of_the_Hydrology_tools

Graham, L. P., Andréasson, J., & Carlsson, B. (2007). Assessing climate change impacts on hydrology from an ensemble of regional climate models, model scales and linking methods -- a case study on the Lule River basin. *Climatic change [: an interdisciplinary, international journal devoted to the description, causes and implications of climatic change]*, *81*(1), 293-307.

Kjellström, E., Bärring, L., Goolvik, S., Hansson, U., Jones, C., Samuelsson, P., et al. (2005). A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3). *SMHI Reports Meteorology and Climatology 108*, 54 pp

Lantmäteriet. (n.d.). Digitala Kartbiblioteket. Retrieved 2011-03-15, from https://butiken.metria.se/digibib/index.php

Markvart, T., & Castañer, L. (2003). Practical handbook of photovoltaics : fundamentals and applications (pp. 5-66). New York: Elsevier Advanced Technology.

Martinec, J., & Rango, A. (1986). Parameter values for snowmelt runoff modelling. *Journal of Hydrology, 84*(3-4), 197-219.

Mathworks. (2011a). Lsqnonlin, Least square nonlinear, . Retrieved 2011-05-12, from http://www.mathworks.com/help/toolbox/optim/ug/lsqnonlin.html

Mathworks. (2011b). Polyfit, Polynomial curve fitting. Retrieved 2011-05-12, from http://www.mathworks.com/help/techdoc/ref/polyfit.html

Meehl, G. A., Stocker, T. F., Collins, W. D., Friedlingstein, P., Gaye, A. T., Gregory, J. M., et al. (2007). Global Climate Projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Ed.), *Climate Change 2007: The physical Scienece Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Ministry of Agriculture, F. a. F. (2002). *Water conservation factsheet: Soil water storage capacity and available soil moisture*. Retrieved from http://www.agf.gov.bc.ca/resmgmt/publist/600Series/619000-1.pdf.

Nakicenovic, N., & Intergovernmental Panel on Climate Change. Working Group III. (2000). *Summary for policymakers in:Special report on emissions scenarios : a special report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge ; New York: Cambridge University Press.

Neilson, R. P. (1995). A Model for Predicting Continental-Scale Vegetation Distribution and Water Balance. *Ecological Applications, 5*(2), 362-385.

Roeckner, E., Bäuml, G., Bonaventura, L., Brokopf, R., Esch, M., Giorgetta, M., et al. (2003). *The atmospheric general circulation model ECHAM 5. PART I: Model description*: Max-Planck-Institute for Meteorology.

Schroeder, P. R., Dozier, T. S., Zappi, P. A., McEnroe, B. M., Sjostrom, J. W., & Peyton, R. L. (1994). *The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3*.

SMHI, Kjellström, E., Hansson, U., Jones, C., Nikulin, G., Strandberg, G., et al. (2009). Changes in the wintertime temperature climate as deduced from an ensemble of regional climate change simulations for Europe. *Rossby Centre Newsletter*, 9-15.

SMHI Rossby Center. (2007a). Klimat I framtiden, extrem nederbörd Nordvästra Götaland. from http://www.smhi.se/sgn0106/leveranser/sverigeanalysen/

SMHI Rossby Center. (2007b). Nederbördsförändring, Nordvästra Götaland. from http://www.smhi.se/sgn0106/leveranser/sverigeanalysen/index.php?distrikt=3&target=nede&v=17

SMHI Rossby Center. (2007c). Temperaturförändring per årstid, Nordvästra Götaland. from http://www.smhi.se/sgn0106/leveranser/sverigeanalysen/index.php?distrikt=3&target=mtps&v=2

Statistiska Centralbyrån. (2011). Folkmängd, top 50, 31 December 2010. from http://www.scb.se/Pages/TableAndChart.aspx?id=228197

Trenberth, K. E., Jones, P. D., P., A., Bojariu, D., Easterling, A., Klein Tank, A., et al. (2007). Observations: Surface and Atmospheric Climate Change. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller (Eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge; New York: Cambridge University Press.

10 Acknowledgment

Many thanks to Veiko Lehsten, my supervisor at Lund University, for helping me with the academic part of my thesis and for all the good meetings we had.

Also many thanks to Sofia Carter, my supervisor at Borås Energi och Miljö, for sharing your knowledge about Sobacken and for all the time you used helping me. This thesis would not have been possible without you.

Further I would like to thank Maria Rydberg and Miljöbron for their help getting in contact with Borås Energi och Miljö.

A special thanks to Sara Boke for all the encouragement and help throughout my thesis.

At last I would like to thank all the employees at Borås Energi och Miljö that helped me for their time and help.

Appendix 1 (Description of attached CD)

In order to run the model and get some example plots start *mainprogram.m* with MatLab. Mainprogram.m will use a series of scripts and data files that are included on the CD. A short description of each file included is shown below.

Files included

Mainprogram.m – The file that runs everything

Opticons.m - Optimization of the constants used in the hydrological model modeling the inflow to the leachate lake

Hydromodel.m - Main Model

Penman.m - Calculates the potential evapotranspiration ETp

NetRad.m – Calculates the net radiation

frozenSoil.m – Calculates if the soil is frozen or not

Precip.m – Determines if the precipitation is rain or snow

Flow.m – Modifies the data of the measured outflow from the leachate lake

Flow2.m – Modifies the data of the measured outflow (different output than from flow.m)

Optreg.m – Optimization of M and k

calcOutflow.m – Calculates the outflow from the leachate lake

HydromodelScenario.m – Model for scenario data

doy.m – Converts date to day number of that year

Modeldatashort.mat – Data file includes precipitation, wind, temperature, solar radiation, and measured pumped outflow. All with the same length

PUMP2.mat – Data file of raw measured pumped outflow data

SA1B.mat – Data file with scenario A1B data for year 1981-2100

SA2.mat – Data file with scenario A2 data for year 1981-2100

SB1.mat –Data file with scenario B1 data for year 1981-2100

Appendix 2 (Matlab code)

Main program

Running everything

```
%%
clc
clear all
% define parameters and constants
global landarea lakearea Elev Albedo wasteflow Lakewater dateN PLW L2 LWfit PdateN
Poutflow
Elev=140; %define elevation of area (m)
Albedo=0.3; %Define albedo of area
lakearea=10760; %lakearea in m2
landarea=360237; %watershed area in m2
wasteflow=130; % flow from biogas in m3/day

% Optimization of constants runoff factor (runoffF), Soil flow factor (SFF),
groundwater recharge factor (kq), and maximum soil water content (SWCmax)
x0(1)=0.25; %runoff start guess
x0(2)=0.1; %SFF start guess
x0(3)=0.001; %kq start guess
x0(4)=300; %SWCmax start guess
lb=[0.1 0.001 0 100]; %lower limit of parameters
ub=[1 0.2 0.01 800]; %upper limit
[x,resnorm] = lsqnonlin('Opticons',x0,lb,ub); %returns vector x with optimized
parameters and resnorm with norm of residuals
clear lb ub x0 resnorm %remove variables not needed anymore

% Run with the optimized constants so that plots can be made
[Lakewater, Qm3, ETam3, SFm3, Runoffm3, Inflowm3, ETl] = Hydromodel(x(4),x(3) ,
x(2), x(1));

% Room for figures
figure(1)
plot(dateN,(Lakewater-Lakewater(1))./lakearea)
datetick('x')
axis tight
xlabel('Date')
ylabel('Leachate lake water level change (m)')
%  Optimization of constants altering cubic regression
x1(2)=900; %guess of Mreg
x1(1)=50; %guess of kreg
lb1=[0 100]; %lower limit
ub1=[75 1500]; %upper limit
[x2,resnorm] = lsqnonlin('Optreg',x1,lb1,ub1); %returns vector x2 with optimized
parameters
clear x1 lb1 ub1 resnorm %remove variables not needed anymore

% Calculate the outflow from the lake with the cubic regression method
% For second half of the data
[Coutflow, Lakewater2, CoutflowDateN] = CalcOutflow(x2(2), x2(1), Lakewater(1:L2),
Inflowm3, ETl, LWfit, PLW, L2, dateN, PdateN);
%Coutflow is calculated outflow
%CoutflowDateN is datenumber of calculated outflow
%Lakewater2 is the new lakewater vector but is just Lakewater(1:L2) made
%longer so data 1:L2 is calculated with the measured outflow

% Room for figures
clear Lakewater
% For Scenario data
q=1; %Which scenario to run see below
```

```
[SCENQm3, SCENETam3, SCENSFm3, SCENRunoffm3, SCENInflowm3, SCENETl, SCENLakewater,
SCENcalcout] = HydromodelScenario(x(4),x(3) , x(2), x(1), x2(1), x2(2), q);
%last input of hydromodel scenario is defining which scenario to be used
% 1 = A1B
% 2 = A2
% 3 = B2

if q==1   %% load correct scenario data based on Scenarionr
    load SA1B.mat
elseif q==2
    load SA2.mat
elseif q==3
    load SB1.mat
end
p=1; %For loop to make 10 year moving average
for i=3650:length(SCENLakewater)
    YLakewater(p)=mean(SCENLakewater(i-3649:i));
    YdateN(p)=mean(S.dateN(i-3649:i));
    p=p+1;
end

%Room for figures SCENARIO
figure(2)
pf=polyfit(YdateN,(YLakewater-YLakewater(1))./lakearea,1);
plot(YdateN,(YLakewater-YLakewater(1))./lakearea,'--g')
hold on
plot([YdateN(1) YdateN(end)],[pf(1)*YdateN(1)+pf(2) pf(1)*YdateN(end)+pf(2)],'-k')
hold off
datetick('x')
axis tight
legend('Data','Linear fit','Location','NorthWest')
xlabel('Year')
ylabel('10 year moving average water level change of leachate lake (m)')
if q==1
    title('A1B Scenario')
elseif q==2
    title('A2 Scenario')
elseif q==3
title('B1 Scenario')
end
```

Opticons

Optimization of the constants used in the hydrological model modeling the inflow to the leachate lake

```
%% Opticons
%%
% Optimization of the constants used in the hydrological model modeling
% the inflow to the leachate lake
function F=Opticons(x)
global lakearea %declare global variables
runoffF=x(1);
SFF=x(2);
kq=x(3);
SWCmax=x(4);
[Lakewater, Qm3, ETam3, SFm3, Runoffm3, Inflowm3, ETl] = Hydromodel(SWCmax, kq,
SFF, runoffF);

F=Lakewater./lakearea;
```

Hydromodel

Main model

```
%% Hydromodel
%%
function [Lakewater, Qm3, ETam3, SFm3, Runoffm3, Inflowm3, ETl] =
Hydromodel(SWCmax, kq, SFF, runoffF)

%Load data needed and run functions needed and define global variables
global landarea lakearea Elev Albedo wasteflow dateN
    load Modeldatashort.mat
AvTemp=(BC.MaxTemp+BC.MinTemp)./2; %Make average temperature from max and min
[degree C]
[Rainprecip, Snowprecip]= precip(AvTemp, SMHI.SumPrecip); %Give precip as either
snow or rain depending if T>0 or T<0
FS=frozenSoil(AvTemp, dateN); %Calculate if the soil is frozen Frozen soil 1=yes
0=no
ETp=Penman(BC.MaxTemp, BC.MinTemp, BC.AvSun, dateN, Elev, Albedo, BC.AvWind, 12);
outflow=Flow(PUMP.counter, dateN); % pumped outflow from lake [m3/day]
ETf=1/SWCmax; % evapotranspiration factor is defined
MFr=0.0125; % Melt factor rain days
MF=2; % Melt factor non-rain

%define length of needed variables
 AW=zeros(1,length(dateN)); %Define length of variable
 runoff=zeros(1,length(dateN)); %Define length of variable
 SF=zeros(1,length(dateN)); %Define length of variable
 SWC=zeros(1,length(dateN)); %Define length of variable
 ETa=zeros(1,length(dateN)); %Define length of variable
 sno=zeros(1,length(dateN)); %Define length of variable
 Q=zeros(1,length(dateN)); %Define length of variable
 Melt=zeros(1,length(dateN)); %Define length of variable
 Lakewater=zeros(1,length(dateN)); %Define length of variable
 SFm3=zeros(1,length(dateN)); %Define length of variable
 Runoffm3=zeros(1,length(dateN));  %Define length of variable
 Inflowm3=zeros(1,length(dateN)); %define lenght of variable
 Lakerain=zeros(1,length(dateN));

 %Run model
 for i=2:length(dateN) %loop through whole period
    if sno(i-1)>0
        if Rainprecip(i)==0 && AvTemp(i)>=0
            Melt(i)=MF*AvTemp(i);                %None rain melt mm/day
        elseif Rainprecip(i)>0 && AvTemp(i)>=0
            Melt(i)=MFr*Rainprecip(i)*AvTemp(i); %Rain melt mm/day
        end
        sno(i)=sno(i-1)+Rainprecip(i)+Snowprecip(i)-Melt(i); %accumulated snow
cover in mm
    else
        sno(i)=Snowprecip(i);                    %if no snow cover sno is equal to
snow precipitation
    end
    if sno(i)<0 %sno cover not allowed to be below zero. (could happend if melt is
calculated to large)
        Melt(i)=Melt(i)+sno(i); %decrease the melt
        sno(i)=0; %and set snow cover to zero
    end
    if Melt(i)>0
        AW(i)=Melt(i); %If we have melt the available water will be equal to that
    elseif Melt(i)<=0
        AW(i)=Rainprecip(i); %if no melt available water is equal to rain.
    end
    if FS(i)==1 %if frozen soil
        SWC(i)=SWC(i-1); %soil water content is same as day before
```

```
        runoff(i)=AW(i); %all Available water is runoff
    elseif FS(i)==0 %not frozen soil
        runoff(i)=runoffF*AW(i); %runoff is always a fraction of AW mm/day
        AW1=AW(i)-runoff(i); %AW left after runoff mm/day
        SF(i)=SWC(i-1)*SFF; %soil flow is dependent on factor and SWC day before 
mm/day
        Q(i)=kq*(SWC(i-1)/SWCmax)^2; %groundwater recharge mm/day
        ETa(i)=SWC(i-1)*ETf*ETp(i); %actual evapotranspiration mm/day
        if ETa(i)>ETp(i)
            ETa(i)=ETp(i); %actual evapotranspiration not allowed to be larger than 
potential
        end
        SWC(i)=SWC(i-1)+AW1-ETa(i)-SF(i)-Q(i); %Soil water content is calculated mm
        if SWC(i)>SWCmax %if SWC larger than maximum allowed value
            runoff(i)=runoff(i)+SWC(i)-SWCmax;  %add excess to runoff
            SWC(i)=SWCmax; %set SWC as max
        end
    end
    if SWC(i)<0 %SWC not allowed to be negative
        SWC(i)=0;
    end
    ETl(i)=ETp(i)*lakearea/1000;   %evaporation from lake m3
    Lakerain(i)=(Rainprecip(i)+Snowprecip(i))*lakearea/1000; %precipitation that 
falls directly on lake
    Runoffm3(i)=(landarea-lakearea)/1000*runoff(i); %mm to m3
    SFm3(i)=(landarea-lakearea)/1000*SF(i); % mm to m3
    Qm3(i)=(landarea-lakearea)/1000*Q(i); % mm to m3
    ETam3(i)=(landarea-lakearea)/1000*ETa(i); % mm to m3
    Inflowm3(i)=SFm3(i)+Runoffm3(i)+Lakerain(i);  %inflow to the leachate lake (m3)
    Lakewater(i)=wasteflow+Lakewater(i-1)+Inflowm3(i)-ETl(i)-outflow(i); %Amount of 
water in lake
 end
```

Penman

Calculates the potential evapotranspiration ETp

```
%% Penman
% Calculates the potential evapotranspiration ETp
function [ETp]= Penman(MaxTemp, MinTemp, AvSun, dateN, elev, albedo, AvWind, zwind)
% Run net radiation
Rn=NetRad(MaxTemp, MinTemp, AvSun, dateN, elev, albedo); % [MJ m-2 day-1]

% Penman-Monteith calculation (ETp) [mm/day]
Tmean=(MinTemp+MaxTemp)./2; %Average temperature from Tmax+Tmin/2 [degree C]
AvWind2=AvWind.*4.87/log(67.8*zwind-5.42); %windspeed at 2m (m/s) converted from 
windspeed at zwind m
P=101.3*((293-0.0065*elev)/293)^5.26; %Pressure calculated from elevation (kPa)
delta=(4098*0.6108*exp(17.27.*Tmean./(Tmean+237.3)))./((Tmean+237.3).^2);%slope 
vapour pressure curve [kPa / degree C] (eq 13)
lambda=2.501-0.002361.*Tmean; %latent heat of vaporisatiom [MJ/kg];
gamma=1.013*10^-3*P./(0.622.*lambda); %pshychrometric constant [kPa / degree C] (eq 
8)
G=0; %Soil heat flux [MJ m-2 day-1]

ea=(0.611*exp(17.27.*MinTemp./(MinTemp+237.3))).*1000.*0.0075; % actual vapour 
pressure FAO 56 eq 48 [mm]
es=((0.6108.*exp(17.27.*MaxTemp./(MaxTemp+237.3))+0.6108.*exp(17.27.*MinTemp./(MinT
emp+237.3)))/2).*1000.*0.0075; %actual vapour pressure (eq 12) [mm]
fu2=0.35*(1+0.54.*AvWind2); %Windspeed function
Ea=2.45.*fu2.*(es-ea); %Drying power of air [MJ m-2 day-1]    2.45 converts mm/day 
to MJ m-2 day-1
```

```
ETp=delta.*Rn./(delta+gamma)+gamma.*Ea./(delta+gamma); %from Penman but read in 
brutsaert & stricker
ETp=ETp.*0.408; %From MJ m-2 day-1 to mm/day
for i=1:length(ETp)
    if ETp(i)<0
        ETp(i)=0; % ETp not allowed negative
    end
end
```

NetRad

Calculates the net radiation

```
%% NetRad
% Calculates the net radiation
function [Rn] = NetRad(MaxTemp, MinTemp, sun, dateN, elev, albedo)

yeardaynr=doy(dateN); %get a day of the year number for every date
%Calculation of extraterrestrial radiation Rad.Ra [MJ m-2 day-1]
%Ra is the solar radiation recieved at the top of the atmosphere at a given
%latitude for a given time of year
%Formulas and constants from FAO56
%constants
Gsc=0.0820; %Solar constant MJ/(m2*min)
phi=3.14/180*57.65; %latitude in radians
%calculations of Ra
dr=1+0.033*cos(yeardaynr.*2*pi/365); %Inverse relative distance earth and sun
sigma=0.409*sin(2*pi/365.*yeardaynr-1.39); %solar decimation [radians]
ws=acos(-tan(phi).*tan(sigma)); %sunset hour angle [radians]
Ra=24*60/pi*Gsc.*dr.*(ws*sin(phi).*sin(sigma)+cos(phi).*cos(sigma).*sin(ws));
%%%%%
%Net longwave radiation (Rad.Rnl) calculation from FAO 56 [MJ m-2 day-1]

Rso=(0.75+2*10^-5*elev).*Ra; %Clear sky solar radiation [MJ m-2 day-1]
Rs=sun.*0.0864; %Incoming solar radiation convertion from [W m-2] to[ MJ m-2 day-1]
for i=1:length(Rs) %Make sure that Rad.RsRso=Rs/Rso is not bigger than 1 if so set 
to 1.
    if (Rs(i)/Rso(i))>1
        RsRso(i)=1;
    else
        RsRso(i)=Rs(i)/Rso(i);
    end
end
ea=0.611*exp(17.27.*MinTemp./(MinTemp+237.3)); % actual vapour pressure FAO 56 eq 
48
TmaxK4=(MaxTemp+273.16).^4; %Max temperature in Kelvin to the power of 4
TminK4=(MinTemp+273.16).^4; %Min temperature in Kelvin to the power of 4
s=4.903*10^-9; %Stefan Boltzmann constant [MJ K-4 m-2 day-1]
Rnl=s.*(TmaxK4+TminK4)./2.*(0.34-0.14.*sqrt(ea)).*(1.35.*RsRso-0.35);
%%%%%
%Net shortwave radiation calculation Rad.Rns [MJ m-2 day-1)
Rns=(1-albedo).*Rs;
%%%%%%
%Net radiation Rad.Rn
Rn=Rns-Rnl;
```

doy

Calculates the day number of that year

```
function [dayofyear] = doy(dateIn)
% Returns the daynumber of the year from input as datenumber
dayofyear=zeros(1,length(dateIn));
for i=1:length(dateIn)
    dateV=datevec(dateIn(i));
    dateV(1,2:3)=1;
    yearN=datenum(dateV);
    dayofyear(i)=dateIn(i)-yearN+1;
end
```

Frozen soil

Calculates if the soil is frozen or not

```
%% Frozen soil
% Calculates if the soil is frozen or not
function [soilf] = frozenSoil(AvTemp, dateN)
%If temperature been below 0 degrees for 26 days this will mean a frozen
%soil. 26 is from HELP model function to calculate days it takes to thaw
%soil dependent on location.
%function returns vsalue 1 for days with frozen soil and 0 for days
%without. need daily values
soilf=zeros(1,length(AvTemp));
p=0;
f=0;
thawT=26;
A=datevec(dateN);
for i=30:length(AvTemp)
   if nanmean(AvTemp(i-29:i))<0 && p==0
       soilf(i)=1;
       p=1;
   end
   if p==1;
       if AvTemp(i)>0
           f=f+1;
       elseif AvTemp(i)<0
           f=f-1;
       end
       if f<0
           f=0;
       end
        if f==thawT
            soilf(i)=0;
            f=round((thawT+2)/3);
            p=2;
        else
            soilf(i)=1;
        end
   elseif p==2
       if AvTemp(i)>0
           f=f+1;
       elseif AvTemp(i)<0
           f=f-1;
       end
       if f<0
           f=0;
       end
        if f==0
            soilf(i)=1;
```

```
            p=1;
        else
            soilf(i)=0;
        end
   end
      if A(i,2)==6 && A(i,3)==15
          p=0;
      end
end
```

precip

Determines if the precipitation is rain or snow

```
%% precip
% Determines if the precipitation is rain or snow
function [Rain, Snow]= precip(AvTemp, SumPrecip)
%dependning if its below or
%above 0 degrees celsius.
Rain=zeros(1,length(SumPrecip));
Snow=zeros(1,length(SumPrecip));
for i=1:length(AvTemp)
    if AvTemp(i)<=0
        Snow(i)=SumPrecip(i);
    else
        Rain(i)=SumPrecip(i);
    end
end
Rain(isnan(Rain))=0; %NaN to zero
Snow(isnan(Snow))=0; %NaN to zero
```

Flow

Modifies the measured outflow from leachate lake

```
%% Flow
% Modifies the measured outflow from leachate lake
function [flow] = Flow(counter, dateN)
%Loop below change the measured outflow to unit of m3/day and gives every day
%of the time period a value of outflow
p=1;
for i=1:length(counter)
    if counter(i)>0
       time(p)=dateN(i);
       value(p)=counter(i);
       p=p+1;
    end
end
q=1;
for i=1:length(time)-1
    tim=daysact(time(i),time(i+1));
    for p=1:tim
         flo(q)=(value(i+1)-value(i))/tim;
        dateN2(q)=time(i)+p;
        q=q+1;
    end
end
q=1;
for i=1:length(dateN)
    if q<=length(flo) && dateN(i)-dateN2(q)==0
        flow(i)=flo(q);
        q=q+1;
```

```
    else
        flow(i)=0;
    end
end
```

Flow2

Modifies the measured outflow from leachate lake but this time with two outputs

```
%% Flow2
% Modifies the measured outflow from leachate lake
function [flow, dateN2] = Flow2(counter, dateN)
%Loop below change the measured outflow to unit of m3/day and gives every day
%of the time period a value of outflow
p=1;
for i=1:length(counter)
    if counter(i)>0
       time(p)=dateN(i);
       value(p)=counter(i);
       p=p+1;
    end
end
q=1;
for i=1:length(time)-1
    tim=daysact(time(i),time(i+1));
    for p=1:tim
         flow(q)=(value(i+1)-value(i))/tim;
        dateN2(q)=time(i)+p;
        q=q+1;
    end
end
```

Optreg

Optimization of M and k

```
%% Optreg
%%
%  Optimization of M and k
function F=Optreg(x)
global Lakewater dateN PLW PdateN Poutflow L2 LWfit %define global variables
M=x(2);  %define M as x(2)
k=x(1); %define k as x(1)

% Make pump values ok to be compared
load PUMP2.mat % load measured pumped outflow meter value
PdateN=PUMP.dateN;
for i=1:length(PUMP.dateN)-1 %convert meter value to average daily outflow (m3/day)
Poutflow(i)=(PUMP.counter(i+1)-PUMP.counter(i))/(PUMP.dateN(i+1)-PUMP.dateN(i));
PdateN(i)=PUMP.dateN(i); %datenumber for corresponding date
end

%Lakewater calculation
p=1;
L=length(PdateN); % L = number of Pumped outflow values
L2=round(L/2);  % divide L by 2 and round to integer.
for i=1:length(dateN) %go through Lakewater
    if p<=L2 && dateN(i)==PdateN(p) %use only first half of data (=up to L2)
        PLW(p)=Lakewater(i); % Lakewater amount of each day where we have a
measured pumped outflow value. (m3)
        p=p+1;
```

```
    end
end
q(1,:)=PdateN(1:L2)-PdateN(1)+1;
pfLW=polyfit(q,PLW,3); % cubic polyfit of q against PLW
LWfit=pfLW(1).*q.^3+pfLW(2).*q.^2+pfLW(3).*q+pfLW(4); %calculate a value of the
fitted function for each timestep

F=Poutflow(1:L2)-((LWfit./k)+M); % measured outflow subtracted with fitted function
divided by k and M added
```

CalcOutflow

Calculates the outflow from the leachate lake

```
%% CalcOutflow
%  Calculates the outflow from the leachate lake
function [Coutflow, Lakewater, CoutflowDateN] = CalcOutflow(M, k, Lakewater,
Inflowm3, ETl, LWfit, PLW, L2, dateN, PdateN)
global wasteflow
A=length(Lakewater)+1; % set A to length of Lakewater plus 1
a=1;
p=length(PLW)+1; %p equal to the length of the 'lakewater at each timestep'
for q=A:length(dateN)
    Lakewater(q)=wasteflow+Lakewater(q-1)+Inflowm3(1,q)-ETl(q)-(LWfit(end)/k+M);
%calc lakewater with LWFit calculated below. For first time LWfit is from Optreg
    if p<=length(PdateN) && dateN(q)==PdateN(p) % for each time the timestep of
lakewater (which is daily) is equal to the timestep of the time of the measured
outflow
        PLW(p)=Lakewater(q); %increase length of PLW with one value
        xv=(PdateN(1:L2+a)-PdateN(1)+1)';
        pfLW2=polyfit(xv,PLW,3);
        LWfit=pfLW2(1).*xv.^3+pfLW2(2).*xv.^2+pfLW2(3).*xv+pfLW2(4); %make a new
polyfit from the longer vector
        Coutflow(a)=LWfit(end)/k+M; % calculate the outflow from the last value of
fitted function
        CoutflowDateN(a)=dateN(q); %date number of that outflow
        p=p+1;
        a=a+1;
    end
end
```

HydromodelScenario

Model for scenario data

```
%% HydromodelScenario
% Model for scenario data
function [Qm3, ETam3, SFm3, Runoffm3, Inflowm3, ETl, Lakewater, calcout] =
HydromodelScenario(SWCmax, kq, SFF, runoffF, k, M, Scenarionr)

% Load data needed and run functions needed and define global variables
global landarea lakearea Elev Albedo wasteflow
if Scenarionr==1   %% load correct scenario data based on Scenarionr
    load SA1B.mat
elseif Scenarionr==2
    load SA2.mat
elseif Scenarionr==3
    load SB1.mat
end
```

```
AvTemp=(S.MaxTemp+S.MinTemp)./2; %Make average temperature from max and min [degree
C]
[Rainprecip, Snowprecip]=precip(AvTemp, S.SumPrecip); %Give precip at either snow
or rain depending if T>0 or T<0
FS=frozenSoil(AvTemp, S.dateN);
ETp=Penman(S.MaxTemp, S.MinTemp, S.AvSun, S.dateN, Elev, Albedo, S.AvWind, 10); %
mm / day
ETf=1/SWCmax; % evapotranspiration factor is defined
MFr=0.0125; % Melt factor rain days
MF=2; % Melt factor non-rain

% Model
 AW=zeros(1,length(S.dateN));
 runoff=zeros(1,length(S.dateN));
 SF=zeros(1,length(S.dateN));
 SWC=zeros(1,length(S.dateN));
 ETa=zeros(1,length(S.dateN));
 sno=zeros(1,length(S.dateN));  %% Make variables correct length
 Q=zeros(1,length(S.dateN));
 Melt=zeros(1,length(S.dateN));
 Inflowm3=zeros(1,length(S.dateN));
 SFm3=zeros(1,length(S.dateN));
 Runoffm3=zeros(1,length(S.dateN));

for i=2:length(S.dateN)
    if sno(i-1)>0 %snow on the ground
        if Rainprecip(i)==0 && AvTemp(i)>=0 % if rain on snow melt
            Melt(i)=MF*AvTemp(i);
        elseif Rainprecip(i)>0 && AvTemp(i)>=0 %snowmelt non-rain
            Melt(i)=MFr*Rainprecip(i)*AvTemp(i);
        end
    sno(i)=sno(i-1)+Rainprecip(i)+Snowprecip(i)-Melt(i); %snow accumulation
    else
        sno(i)=Snowprecip(i); %no snow on the ground sno cover equal to snowprecip
    end
    if sno(i)<0
        Melt(i)=Melt(i)+sno(i); % snow cover not allowed to take neg values
        sno(i)=0;
    end
    if Melt(i)>0
        AW(i)=Melt(i);
    elseif Melt(i)<=0
    AW(i)=Rainprecip(i);
    end
    if FS(i)==1 %if frozen soil
            SWC(i)=SWC(i-1); %soil water content is same as day before
            runoff(i)=AW(i); %all Available water is runoff
    elseif FS(i)==0 %not frozen soil
            runoff(i)=runoffF*AW(i); %runoff is always a fraction of AW mm/day
            AW1=AW(i)-runoff(i); %AW left after runoff mm/day
            SF(i)=SWC(i-1)*SFF; %soil flow is dependent on factor and SWC day
before mm/day
            Q(i)=kq*(SWC(i-1)/SWCmax)^2; %groundwater recharge mm/day
            ETa(i)=SWC(i-1)*ETf*ETp(i); %actual evapotranspiration mm/day
            if ETa(i)>ETp(i)
                ETa(i)=ETp(i);
            end
            SWC(i)=SWC(i-1)+AW1-ETa(i)-SF(i)-Q(i); %Soil water content
            if SWC(i)>SWCmax %if SWC larger than maximum allowed value
                runoff(i)=runoff(i)+SWC(i)-SWCmax;  %add excess to runoff
                SWC(i)=SWCmax; %set SWC as max
            end
     end
         if SWC(i)<0 %SWC not allowed to be negative
            SWC(i)=0;
         end
        ETl(i)=ETp(i)*lakearea/1000;    %m3/day
```

```
        Lakerain(i)=(Rainprecip(i)+Snowprecip(i))*lakearea/1000; %m3/day
        Runoffm3(i)=(landarea-lakearea)/1000*runoff(i); %m3/day
        SFm3(i)=(landarea-lakearea)/1000*SF(i); %m3/day
        Qm3(i)=(landarea-lakearea)/1000*Q(i); %m3/day
        ETam3(i)=(landarea-lakearea)/1000*ETa(i); %m3/day
        Inflowm3(i)=SFm3(i)+Runoffm3(i)+Lakerain(i);    %m3/day
end


% make pumped outflow values ok and calculate the outflow in m3/day
load PUMP2.mat
[outflow, dateNoutflow]=Flow2(PUMP.counter, PUMP.dateN); %convert outflow values to
daily
clear PUMP
Lakewater(1)=0;
q=2;
datevec(dateNoutflow)
for i=2:length(S.dateN)
   if q<=(length(dateNoutflow)/2)
       if S.dateN(i)==dateNoutflow(q)
        Lakewater(q)=wasteflow+Lakewater(q-1)+Inflowm3(i)-ETl(i)-outflow(q);
%calc Lake water for half of period with measured data
        q=q+1;
       end
    end
end
xv=1:length(dateNoutflow)/2;
pfLW=polyfit(xv,Lakewater,3); %make polyfit
LWfit=pfLW(1).*xv.^3+pfLW(2).*xv.^2+pfLW(3).*xv+pfLW(4); %get values for the
polyfit
p=1;
A=length(Lakewater)+1; %set A to be length of Lakewater plus 1
for i=A:length(S.dateN)-109 %%% Model the outflow m3/day and calculate the monthly
lakewater changes m3
    xv=1:A+p-2;
    pfLW=polyfit(xv,Lakewater,3);
    LWfitend=pfLW(1)*xv(end)^3+pfLW(2)*xv(end)^2+pfLW(3)*xv(end)+pfLW(4);
    calcout(p)=LWfitend/k+M; %m3/day
    if calcout(p)<0;
        calcout(p)=0;
    end
    Lakewater(i)=wasteflow+Lakewater(i-1)+Inflowm3(i)-ETl(i)-calcout(p); %calculate
the Lakewater
    p=p+1;
end
```

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (www.nateko.lu.se/masterthesis) och via Geobiblioteket (www.geobib.lu.se)

The student thesis reports are available at the Geo-Library, Department of Physical Geography and Ecosystem Science, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden. Report series started 1985. The complete list and electronic versions are also electronic available at the LUP student papers (www.nateko.lu.se/masterthesis) and through the Geo-library (www.geobib.lu.se)

285 Cansu Karsili (2013) Calculation of past and present water availability in the Mediterranean region and future estimates according to the Thornthwaite water-balance model

286 Elise Palm (2013) Finding a method for simplified biomass measurements on Sahelian grasslands

287 Manon Marcon (2013) Analysis of biodiversity spatial patterns across multiple taxa, in Sweden

288 Emma Li Johansson (2013) A multi-scale analysis of biofuel-related land acquisitions in Tanzania - with focus on Sweden as an investor

289 Dipa Paul Chowdhury (2013) Centennial and Millennial climate-carbon cycle feedback analysis for future anthropogenic climate change

290 Zhiyong Qi (2013) Geovisualization using HTML5 - A case study to improve animations of historical geographic data

291 Boyi Jiang (2013) GIS-based time series study of soil erosion risk using the Revised Universal Soil Loss Equation (RUSLE) model in a micro-catchment on Mount Elgon, Uganda

292 Sabina Berntsson & Josefin Winberg (2013) The influence of water availability on land cover and tree functionality in a small-holder farming system. A minor field study in Trans Nzoia County, NW Kenya

293 Camilla Blixt (2013) Vattenkvalitet - En fältstudie av skånska Säbybäcken

294 Mattias Spångmyr (2014) Development of an Open-Source Mobile Application for Emergency Data Collection

295 Hammad Javid (2013) Snowmelt and Runoff Assessment of Talas River Basin Using Remote Sensing Approach

296 Kirstine Skov (2014) Spatiotemporal variability in methane emission from an Arctic fen over a growing season – dynamics and driving factors

297 Sandra Persson (2014) Estimating leaf area index from satellite data in deciduous forests of southern Sweden

298 Ludvig Forslund (2014) Using digital repeat photography for monitoring the regrowth of a clear-cut area

299 Julia Jacobsson (2014) The Suitability of Using Landsat TM-5 Images for Estimating Chromophoric Dissolved Organic Matter in Subarctic Lakes

300 Johan Westin (2014) Remote sensing of deforestation along the trans-Amazonian highway

301 Sean Demet (2014) Modeling the evolution of wildfire: an analysis of short term wildfire events and their relationship to meteorological variables

302 Madelene Holmblad (2014). How does urban discharge affect a lake in a recreational area in central Sweden? – A comparison of metals in the sediments of three similar lakes

303 Sohidul Islam (2014) The effect of the freshwater-sea transition on short-term dissolved organic carbon bio-reactivity: the case of Baltic Sea river mouths

304 Mozafar Veysipanah (2014) Polynomial trends of vegetation phenology in Sahelian to equatorial Africa using remotely sensed time series from 1983 to 2005

305 Natalia Kelbus (2014) Is there new particle formation in the marine boundary layer of the North Sea?

306 Zhanzhang Cai (2014) Modelling methane emissions from Arctic tundra wetlands: effects of fractional wetland maps

307 Erica Perming (2014) Paddy and banana cultivation in Sri Lanka - A study analysing the farmers' constraints in agriculture with focus on Sooriyawewa

D.S. division

308 Nazar Jameel Khalid (2014) Urban Heat Island in Erbil City.

309 Jessica, Ahlgren & Sophie Rudbäck (2014) The development of GIS-usage in developed and undeveloped countries during 2005-2014: Tendencies, problems and limitations

310 Jenny Ahlstrand (2014) En jämförelse av två riskkarteringar av fosforförlust från jordbruksmark – Utförda med Ekologgruppens enkla verktyg och erosionsmodellen USPED

311 William Walker (2014) Planning Green Infrastructure Using Habitat Modelling. A Case Study of the Common Toad in Lomma Municipality

312 Christiana Marie Walcher (2014) Effects of methane and coastal erosion on subsea-permafrost and emissions

313 Anette Fast (2014) Konsekvenser av stigande havsnivå för ett kustsamhälle- en fallstudie av VA systemet i Beddingestrand

314 Maja Jensen (2014) Stubbrytningens klimatpåverkan. En studie av stubbrytningens kortsiktiga effekter på koldioxidbalansen i boreal barrskog

315 Emelie Norhagen (2014) Växters fenologiska svar på ett förändrat klimat - modellering av knoppsprickning för hägg, björk och asp i Skåne

316 Liisi Nõgu (2014) The effects of site preparation on carbon fluxes at two clear-cuts in southern Sweden

317 Julian Will (2014) Development of an automated matching algorithm to assess the quality of the OpenStreetMap road network - A case study in Göteborg, Sweden

318 Niklas Olén (2011) Water drainage from a Swedish waste treatment facility and the expected effect of climate change