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Hydrologic analysis of a limestone quarry using EPA's HELP Version 3.08 Model

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The Hydrologic Analysis of a Limestone Quarry
Using EPA's HELP Version 3.08 Model

By

Scott R. Bauer

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Civil Engineering

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2011

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This report, The Hydrologic Analysis of a Limestone Quarry Using EPA's HELP Version 3.08 Model, is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN CIVIL ENGINEERING.

Civil and Environmental Engineering

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Abstract

Aggregates were historically a low cost commodity but with communities and governmental agencies reducing the amount of mining the cost is increasing dramatically. An awareness needs to be brought to communities that aggregate production is necessary for ensuring the existing infrastructure in today's world. This can be accomplished using proven technologies in other areas and applying them to show how viable reclamation is feasible.

A proposed mine reclamation, Douglas Township quarry (DTQ), in Dakota Township, MN was evaluated using Visual Hydrologic Evaluation of Landfill Performance (HELP) model. The HELP is commonly employed for estimating the water budget of a landfill, however, it was applied to determine the water budget of the DTQ following mining. Using an environmental impact statement as the case study, modeling predictions indicated the DTQ will adequately drain the water being put into the system. The height of the groundwater table will rise slightly due to the mining excavations but no ponding will occur. The application of HELP model determined the water budget of the DTQ and can be used as a viable option for mining companies to demonstrate how land can be reclaimed following mining operations.

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1. Introduction

Aggregate mining has been conducted by society as long as civilization has been in existence. Humans have used rocks to hunt and build. Rocks were abundant, and were used with little concern about supply or availability. As society advanced the need for rocks increased but the general supply and availability were never an issue. Typically, quarries and underground mines could be located wherever a rock supply was needed. As towns and cities grew, the quarries and mines would simply be located as closed to the site as possible, to minimize cost and the difficulty of transporting rock. In time, rocks became aggregates and were bought and sold as used as a commodity with little change over the next thousand years. Aggregates have always been considered as a low cost, easily obtainable commodity. Today, aggregates are used extensively in our infrastructure. Due to wide spread urbanization, increasing transportation costs, and declining aggregate quality of aggregate reserves, the cost of aggregates are starting to dramatically increase. This will have a significant impact on society, which has relied on aggregates to be a low cost and easily obtainable commodity.

An additional issue is the environmental and societal impact of aggregate production. In the United States, the only natural resource that is mined and federally regulated, which covers both environmental and societal impacts, is surface coal mining. Coal mining is regulated under the Surface Mining Control and Reclamation Act (SMCRA) that was enacted in 1977 (Green, 1997). Metal mining has no federal regulation with the exception of the 1872 General Mining Law that was enacted to protect and adjudicate mining rights (Mining Engineering, 2010). Most states do regulate metal mining to offset environmental and societal impacts. For example, Michigan passed the Nonferrous Metallic Mining Regulations (Michigan, 2006) to regulate metal mining (with the exception of iron) in 2006. Aggregate mining, which typically includes sand, gravel and stone, has no federal regulations and only Minnesota and West Virginia have state-wide regulations governing aggregate mining. There are two likely reasons for the lack of regulations. First, the public and governmental agencies have generally viewed aggregate mining as being relatively environmental friendly since they do not involve the use of chemicals to produce aggregates. Second, and possibly more importantly, is that aggregates are a low cost commodity and generally mined by small operators that do not have the economic resources to conduct rigorous environmental assessment of their operations.

Today, aggregate production is coming under significantly more pressure as communities no longer view aggregate production neither as environmentally benign nor as being something they would like within or even near their communities. Many local governments, for example, have passed zoning regulations to restrict aggregate production to low population areas such as rural and farming areas. These communities, in many cases, object to aggregate being mined near them or even to use existing transportation corridors that might impact them. As a consequence, establishing aggregate production in almost any county or township in the country today has become difficult. This trend is well described in the literature as the "Not In My Back Yard" (NIMBY) syndrome (Burningham, 2000) and is becoming a very common problem for new aggregate quarries as well as existing quarries that are attempting to expand.

The problem is that society's need for low cost aggregate to maintain its existing infrastructure, as well as to develop sustainable alternatives, will unfortunately require increasing quantities of aggregates. For example, asphalt contains 95% aggregate consisting of sand and course aggregate. Concrete contains essentially 100% aggregate because the "cement" portion of concrete is made from limestone and shale, both produced in aggregate quarries, although processing limestone and shale into cement requires a significant amount of energy and does have a very large carbon footprint.

It is clear that to meet both environmental and societal needs for aggregates, attention must be given to developing better ways to evaluate aggregate quarries. One way is to use proven existing technologies in other areas but have been applied to aggregate production. One such area is in the analysis of the hydrologic impacts of quarries. Since there are relatively few or no reclamation regulations for quarries, many quarries are simply abandoned and fill with water[1]. This can lead to safety and environmental problems if the standing water becomes stagnant or of the quarry becomes a collection area for runoff from other sources.

One model that can be applied to hydrologic analysis of an aggregate quarry is EPA's Hydrologic Evaluation of Landfill Performance (HELP) model (Version 3.08). HELP is a proven model for conducting water balances of landfills, cover systems, and solid waste disposal and containment facilities (Schroeder et al. 1994b). Even though HELP is designed for landfills, the program could be used determine the water balance of a reclaimed quarry surface.

1.1. Report Objective

This report will investigate utilizing EPA's HELP model to assess the long term performance of a proposed aggregate quarry south of St. Paul, Minnesota in Douglas Township, Dakota County in regards to whether the quarry, which will be mined to a depth of about 90 feet (30 m) below the surrounding country side will remain dry or fill with water over time. The quarry, known as the Douglas Township Quarry, was being planned as a replacement quarry by Edward Kramer & Sons (EKS) to replace their large Burnsville Quarry located just south of the city of Minneapolis,

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[1] In general, many rock quarries will mine aggregate down to a water table and then stop, since the cost of mining below the ground water table is generally not cost effective.

MN. The Burnsville Quarry was a major aggregate supplier to the Twin Cities area for over 90 years and similar to many quarries developed in or near the surrounding metropolitan areas. The Burnsville Quarry is in close proximity to the Minnesota River, the I-35 Highway 13 interchange, the Minnesota Valley National Wildlife Refuge, the Port Cargill fuel tank storage farm, a railroad track that runs along the edge of the quarry, and a major power line and electrical substation, which runs through the quarry itself and the community of Burnsville, MN.

EKS's replacement quarry, the Douglas Township Quarry (DTQ), is located about 30 miles south east of St. Paul in a farming community. The layout of the quarry is shown in Figure 1. The quarry was opposed by the Township Board as well as most of the residence in the Township. In addition, the Township, being a rural township composed primarily of farms, did not have any zoning ordinances excluding nor regulating the development of quarries in the Township. In an attempt to protect the township, the board passed two requirements governing aggregate production. The first regulation stated that the quarry could not mine within ten feet of an aquifer, while the second rule was that the quarry had to be placed back into agricultural production after mining was completed. This meant that the quarry, which had a maximum planned depth of about 90 feet, would have to support farming typical of the area at the bottom of the quarry. A key issue then was determining the long term hydrology of the quarry.

In addition to the rules passed by Douglas Township, Minnesota also has the "Aggregate Protection and Planning Act" (Minnesota Statue 84.94), which was enacted in 1984 to "protect aggregate resource; to promote orderly and environmentally sound development; and to introduce aggregate resource protection into local comprehensive planning and land use controls." This legislation required that an environmental impact statement (EIS) be conducted for this quarry. An environmental impact statement was conducted but due to litigation on a number of issues, including the ability of Douglas Township to apply rules to aggregate mining, EKS subsequently decided against developing the quarry and therefore the quarry is no longer under consideration.

Information from the environmental impact statement from the formerly proposed Douglas Township Quarry was available to be used as a test case to evaluate using EPA's HELP Model to investigate the long term hydrology of the quarry if it were to be completed and reclaimed to sustain agricultural production.

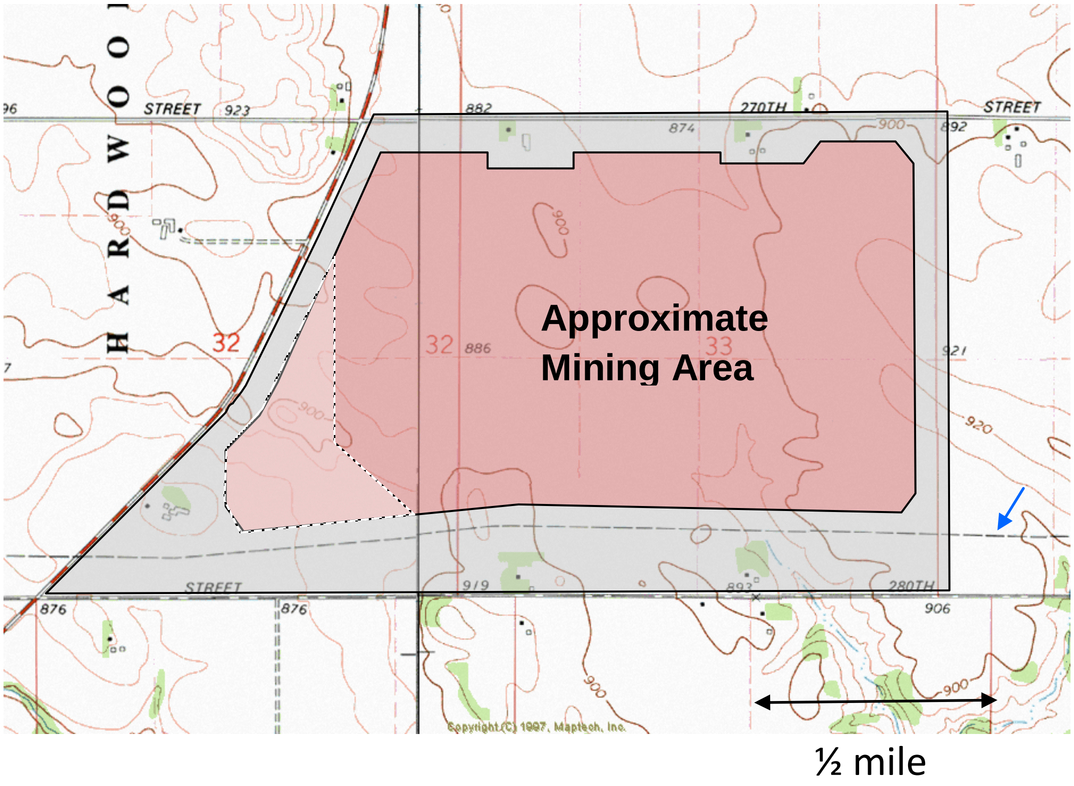


Figure 1 Douglas Township Quarry, Dakota County Minnesota.

2. EPA’s HELP Model

The passage of the 1984 “Resource Conservation and Recovery Act (RCRA)” gave EPA the authority to control hazardous waste from the "cradle-to-grave", which included the generation, transportation, treatment, storage, and disposal of hazardous waste. RCRA also set forth a framework for the management of non-hazardous solid wastes through the design and regulation of landfills where most hazardous and non-hazardous waste is stored.

With an ever expanding need for landfills, landfill design and performance is a key aspect for maintaining the long term viability of landfills. Understanding how landfills will perform over time is an important design issue especially in minimizing groundwater contamination. EPA’s HELP model was developed for assessing the hydrologic processes of landfills and analyzing the effectiveness of their design. If a landfill is not designed properly, leachate can reach the groundwater table damaging a potential water source. HELP model is required for obtaining landfill permits in the U.S (WHI, 2003). The program can be downloaded for free on the internet. The downloadable version has a DOS operating system.

To model landfill performance, several pieces of data must be assessed. HELP uses a quasi-two-dimensional hydrologic model which requires the following input data:

- Weather (temperature, precipitation, solar radiation, evapotranspiration parameters)
- Soil (field capacity, porosity, hydraulic conductivity, wilting point)
- Engineering design data (surface slope, leachate and runoff collection systems, liners)

HELP allows a landfill to use a multi-layered profile configuration with a combination of natural (soil) and geosynthetic materials such as geotextiles, geogrides, and geomembrane liners to be modeled. It also allows for horizontal drainage and alternate slope of profiles (e.g. leachate collection and removal systems, landfill cap) (WHI, 2003).

2.1. HELP Model Development

The HELP model was developed by Paul Schroeder, U.S. Army Engineer Waterways Experiment Station, and other collaborators at the U.S. Environmental Protection Agency (EPA) in 1982 (Berger 2000). The model was created to predict the two-dimensional water balance for landfills through cover and liner systems. The main purpose of the HELP model was to aid engineers in comparing design alternatives. Numerous versions of this program were released including Version 1 (1984), Version 2 (1988), Version 3 (1994), and Version 3.08, all based on the DOS operating system.

Due to the difficulty of running the DOS versions of HELP model, a company in Canada, Waterloo Hydrogeologic Inc. (WHI), which is now part of Schlumberger Water Services), designed a Windows interface for the HELP Version 3.08. It was released in May 1998 under the name Visual HELP version 1.101. WHI has since released Visual HELP 2.1 and the most recent version Visual HELP 2.2.

2.2. Hydrologic Processes

HELP model is a quasi two-dimensional (2D) model incorporating a one-dimensional (1D) lateral drainage model and 1D vertical drainage model. The model uses soil parameters, weather, and engineering design data as inputs. The hydrologic regime is divided between surface and subsurface processes. The surface processes consist of snowmelt, infiltration, runoff, and evapotranspiration. The subsurface processes consist of soil moisture storage, vegetative growth, leachate recirculation, lateral subsurface drainage, leakage through various liners such as soil, geomembrane, or composite liners, and unsaturated vertical drainage (Sophocleous et al. 2003).

2.3. Weather Generator

HELP uses three types of meteorological data that must be supplied as daily values. This data includes precipitation (snow), solar radiation, and mean air temperature. The data is then used to estimate the volume of water flowing into the landfill via surface runoff, vegetation growth and transpiration, evaporation, and infiltration during warm periods. During cold periods, the model can handle snow and ice generation in the landfill.

To estimate long periods of weather, e.g., 100 years, HELP model utilized a synthetic weather generator that was developed by the U.S. Department of Agriculture Agricultural Research Service (Richardson and Wright, 1984; Schroeder et al. 1994a). Following the release of Visual HELP 1.101, WHI received requests from clients to expand the Weather Generator to other regions of the world (WHI, 2003). A new global database was prepared, consisting of a GIS feature, for locating the closest stations worldwide. The database includes 10,000 stations around the world containing 14 years (1977-1991) of daily temperature and precipitation. This data was from the National Oceanic and Atmospheric Administration (NOAA) and GDS (Global Daily Summary). Due to the large amount of raw data, a large amount of studying and programming was performed. This helped with decoding the database files and creating filters to delete records with missing data (WHI, 2003).

Determining the solar radiation coefficients and evaporation parameters required using the United Nations Agriculture Organization Agroclimatological Data Series. Also, the Koppen world climate zoning scheme for determining regions with similar climates was utilized for establishing these parameters. The values for evapotranspiration were input for all the stored weather stations in the Weather Generator database (WHI, 2003).

2.4. Profile Design

In Visual HELP, the profile represents a one dimensional section of the landfill from the cover to the containment layers at the base of the landfill. The landfill is assumed to have the same cross-section throughout the base of the landfill along with sloped sides. The profile allows for a multitude of engineered components such as geomembranes, geonets, leachate collection and recirculation systems, and subsurface drainage that are being considered for the landfill. The layers can be sloped to resemble the shape of a typical landfill with sloped sides and a flat middle.

Visual HELP arranges the layers in the model based the hydraulic task they are supposed to perform, e.g., drainage and/or containment. The five types of layers that are available in HELP are (1) vertical percolation, (2) lateral drainage, (3) barrier soil liner, (4) geomembrane liner, and (5) support systems using geotextiles and geonets. Vertical percolation layers are commonly topsoil and waste while the lateral drainage layers are usually sand layers or geocomposites. Barrier soil liners are generally compacted clay layers while geomembrane liners, such as high or low density polyethylene, are used for containment. Lastly, geotextiles and geonets are used as separation and support layers.

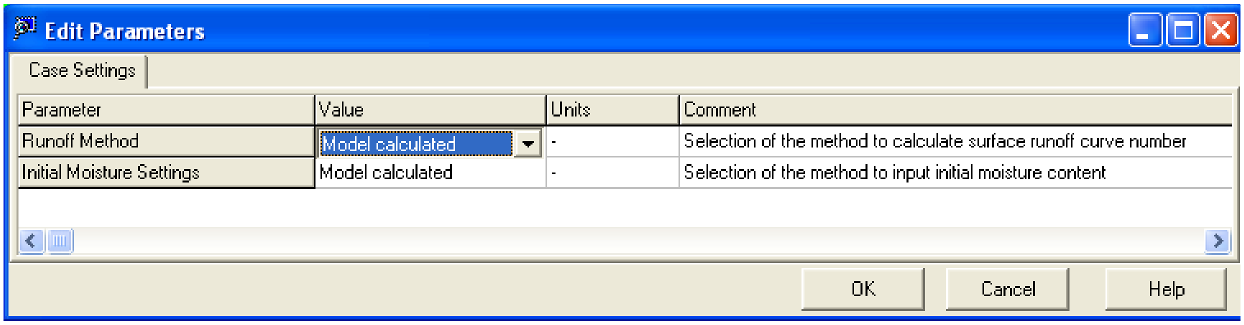
2.4.1. Case Settings

Visual HELP contains a set of parameters called Case Settings that are used to establish the initial water balance of the landfill. The case settings establish how much water is in the landfill initially and how the model will estimate the amount of water runoff from the landfill versus infiltration. Both settings are prescribed by the user selection or input.

To start, the runoff method must be selected. The HELP model utilizes the USDA Soil Conservation Service curve-number (CN) method to model the rainfall vs. runoff processes. The CN uses an empirical relationship to estimate infiltration or direct runoff due to rainfall. The CN is calculated as follows,

where S is the measure of the potential maximum soil moisture retention of rainwater after runoff begins. CN varies from 30 to 100 where 100 indicates no infiltration and 30 insinuates low potential for runoff. The model allows three options for prescribing the CN number (1) let the model calculate the CN number, (2) user specified CN numbers, and (3) user modified parameters.

Before a simulation can be run, the initial water content of each layer must be specified. Initial volumetric water contents for each layer are chosen by indicating either “model calculated” or “user specified” and “user modified.” If the user has obtained the volumetric water content of each layer then it can be specified. If moisture contents are unknown then HELP will designate reasonable values for initial moisture storage and simulate one year of landfill hydrology. The simulation will produce values of moisture storage for each layer and apply them as the initial values. The simulation will be again from the start of the year one. The input screen for this function is shown in Figure 2 below.

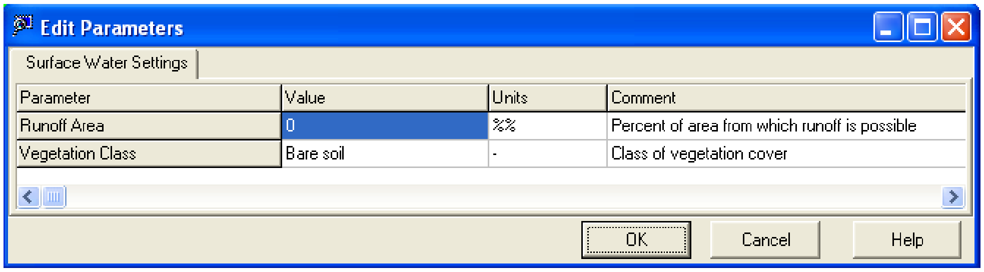


Parameter	Value	Units	Comment
Runoff Method	Model calculated	-	Selection of the method to calculate surface runoff curve number
Initial Moisture Settings	Model calculated	-	Selection of the method to input initial moisture content

Figure 2 HELP Case Settings parameters.

2.4.2. Surface Water Settings

Two parameters need to be modified or selected in surface water settings which are runoff area and vegetation class or curve number. The runoff area is input as a percentage of the allowable runoff area vs. total area of interest. All three scenarios allow the user to input the percentage of runoff area. For vegetation class, there are the five available selections: (1) bare soil, (2) poor stand of grass, (3) fair stand of grass, (4) good stand of grass, and (5) excellent stand of grass. If "model calculated" is prescribed for runoff method, HELP allows the user to choose the type of vegetation. The type of selected vegetation dictates the model input for curve number as shown in Figure 3. If the user chooses to "specify" or "modify" then a value for CN must be input manually. No vegetation classes are available when "user specified" or "user defined" is chosen.

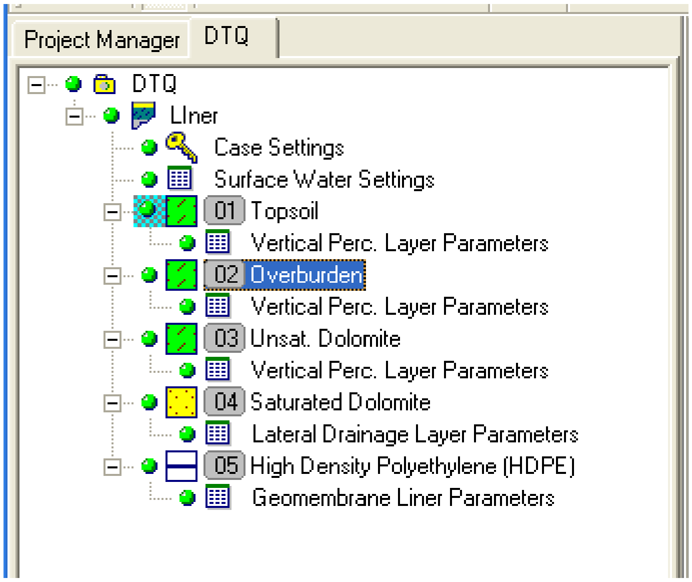


Parameter	Value	Units	Comment
Runoff Area	0	%%	Percent of area from which runoff is possible
Vegetation Class	Bare soil	-	Class of vegetation cover

Figure 3 HELP Surface Water Settings dialog box.

2.4.3. Editing and Modifying Layer

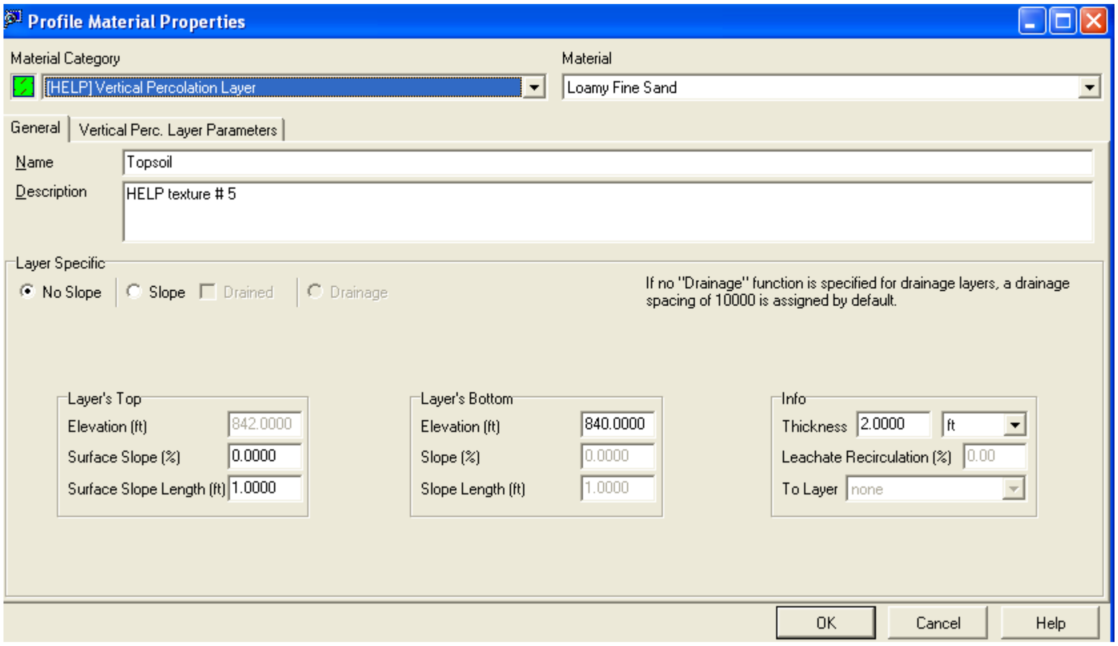
When creating a profile, HELP allows the user to choose the existing default HELP profile or create a new profile. For either selection, the user is able to insert, remove, resize, edit, split, and group the layers. After choosing the type of profile to start, choosing a fixed top or bottom elevation is necessary. Once an elevation is selected the Project Tree and Profile View appear. The profile can then be modified to the user's specifications.



- DTQ
  - LIner
    - Case Settings
    - Surface Water Settings
    - 01 Topsoil
      - Vertical Perc. Layer Parameters
    - 02 Overburden
      - Vertical Perc. Layer Parameters
    - 03 Unsat. Dolomite
      - Vertical Perc. Layer Parameters
    - 04 Saturated Dolomite
      - Lateral Drainage Layer Parameters
    - 05 High Density Polyethylene (HDPE)
      - Geomembrane Liner Parameters

Figure 4 HELP project tree dialog box.

Each layer is then altered to have the correct thickness and type of material. Once the proper thickness and material are chose for each layer, the parameters for each layer must be specified. All of the drainage layers use the following parameters (1) total porosity, (2) field capacity, (3) wilting point, (4) saturated hydraulic conductivity, (5) subsurface inflow, and (6) initial moisture content. Figure 5 shows a typical dialog box for the input parameters for topsoil, which is generally the top layer in a profile.



Material Category: [HELP] Vertical Percolation Layer

Material: Loamy Fine Sand

Name: Topsoil

Description: HELP texture # 5

● No Slope ○ Slope ☐ Drained ○ Drainage

If no "Drainage" function is specified for drainage layers, a drainage spacing of 10000 is assigned by default.

Layer's Top
Elevation (ft) 842.0000
Surface Slope (%) 0.0000
Surface Slope Length (ft) 1.0000

Layer's Bottom
Elevation (ft) 840.0000
Slope (%) 0.0000
Slope Length (ft) 1.0000

Info
Thickness 2.0000 ft
Leachate Recirculation (%) 0.00
To Layer none

Figure 5 HELP profile material properties window showing general inputs.

2.5. Running the Model and Viewing Outputs

With the profile finished HELP calculates the water balance for the landfill over a period of years. A typical time interval is 100 years. The model takes the initial conditions of the landfill, which at the beginning of the landfill, for example, might not have any waste in it, and therefore any rain or snow would (or should) go directly into a drainage layer to be removed from the landfill as leachate[2], with the amount of evaporation estimated and reduced from the total amount of water. As waste is deposited in the landfill say year two, the rainfall (and or snow) is calculated based on the synthetic weather generator. Part of the rainfall evaporates in year one but part of it is absorbed into the waste. The waste also has a given amount of moisture so the model must estimate how much of the moisture drains through the waste to the drainage layer to be removed as leachate. The model keeps track of the cumulative amount of moisture entering and leaving the landfill on a yearly basis through closure and beyond.

Key outputs from the model would be how much leachate is generated throughout the time period (and need to be treated) and how much will seep through the liner system into the ground since it is impossible to design a perfect lining system. For a properly designed landfill

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[2] Leachate is any liquid, mostly water that has been in contact with the landfill waste and containinated.

the system should come to equilibrium at one point where the surface containment system provides greater runoff than infiltration while the waste will reach field capacity.

A second important parameter determined by the HELP model is the amount of leachate that is "*ponding*" above the containment layers. If the drainage layers cannot adequately drain the water entering the landfill then the leachate will collect above the drainage layer. EPA regulations only allow 12 inches (30 cm) to pond above a containment liner. In areas with very high rainfall such as the Pacific Northwest, a much higher level of drainage would be required than for a dry area such as in Arizona.

The HELP model was therefore used to estimate the volume of water that would "pond" over a system of drainage and containments layer that could be modeled in a reclaimed quarry. The bottom of a reclaimed quarry would most likely consist of topsoil, overburden and rock. These units could be modeled as drainage units with various permeability and storage parameters. At some depth in the rock, most likely the ground water table, a containment layer could be placed. By running in a number of simulations given the estimated rainfall and the ability of the drainage layers to drain the water entering this system would either drain or pond on top of the containment layer. This ponding over time might rise about the rock, overburden and topsoil resulting in a pond forming in the quarry. On the other hand, if the drainage layers were adequate than no ponding would form.

The HELP model was then used to determine whether the Douglas Township Quarry would be able to support agricultural over a 100 year period. The remainder of this report describes this analysis.

3. Case Study – Douglas Township Quarry (DTQ)

Edward Kraemer & Sons, Inc. (EKS) leased 907 acres of agricultural land in Douglas Township, Dakota County MN to develop a limestone quarry. The proposed quarry is located approximately 30 miles southeast of St. Paul, MN as shown in Figure 6. Originally, The 907 acres were used for agricultural purposes but the land owners leased the property to EKS to mine the limestone. Of the 907 acres leased, only 675 were planned to be mined. EKS planned an open-pit (quarry) method to extract the aggregate. The anticipated life of the quarry is 99 years and the projected reserves are 96 million tons (Vitton, 2005).

After mining is completed, the site plan is to reestablish to its original use. An area of concern is the water will not drain adequately through the soil causing a pond or lake to occur. Without sufficient drainage throughout the leased property, reclamation would be unachievable.

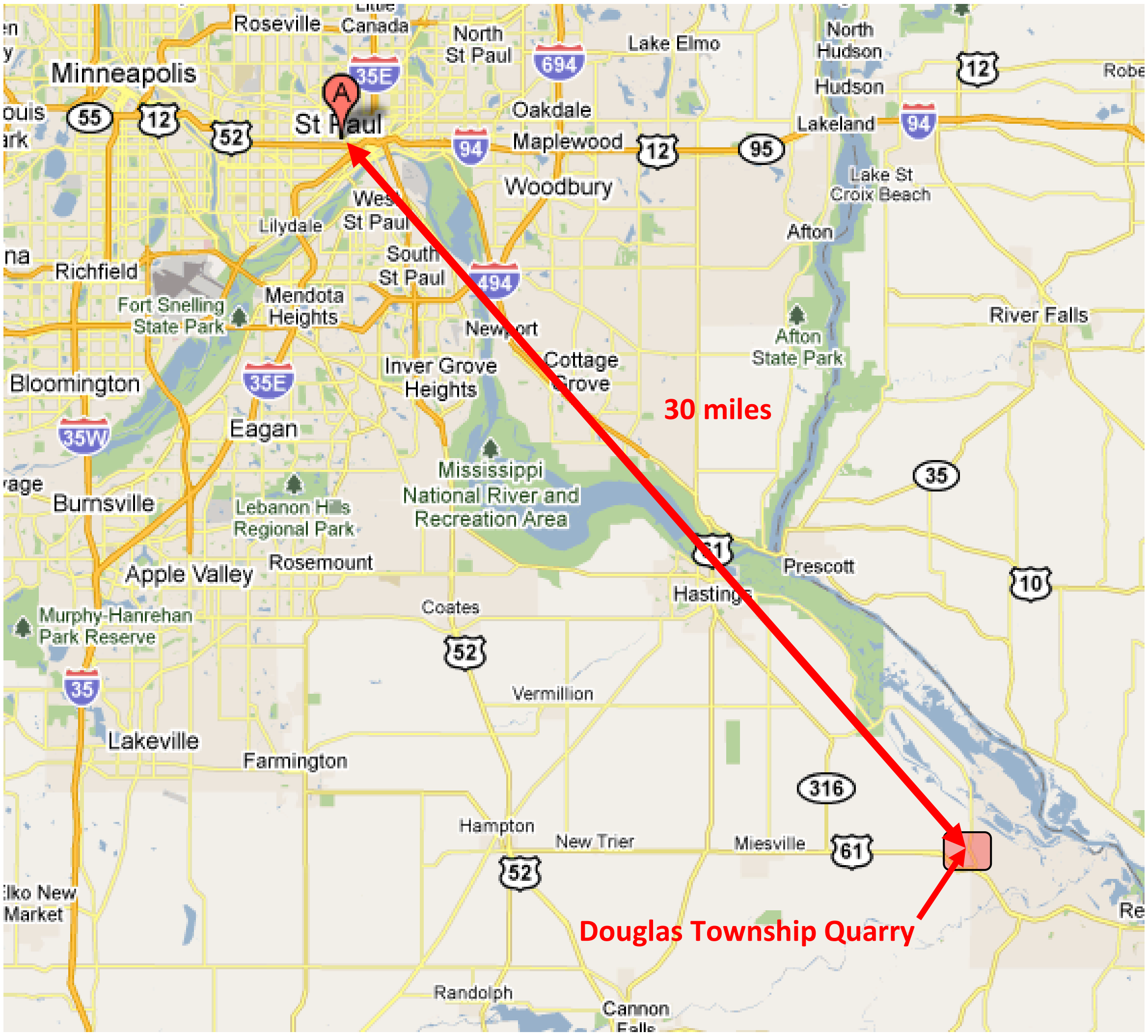
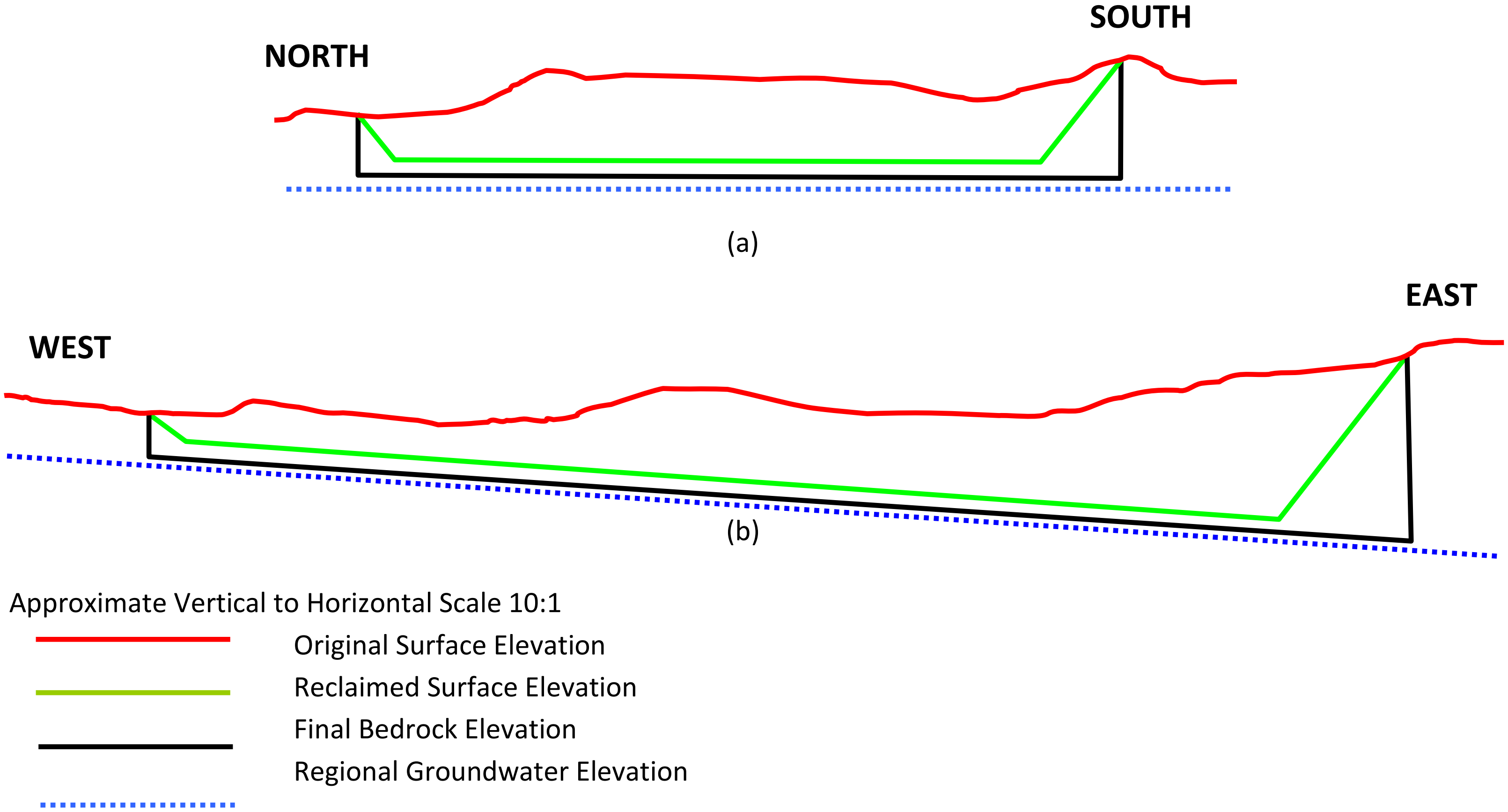


Figure 6 Location of the proposed Douglas Township Quarry Dakota County Minnesota.

Douglas Township has enacted ordinances that regulate the depth to groundwater table and operating times of the quarry. The quarry will be regulated to a mining depth of 10 feet above the regional water table, which was determined to slope across the quarry starting in the west and continuing easterly at a rate of 36 feet per mile. The floor of the quarry will follow the same slope of the groundwater table, maintaining the required minimum 10 foot distances as shown in Figure 7.



Note: Approximate Vertical to Horizontal Scale 10:1

Figure 7 Cross sections of the Douglas Township Quarry (a) north-south cross section, (b) East-west cross section.

After sufficient operational room was available, the proposal was to start reclamation of the quarry, returning the land to the original state of agricultural use. The final reclaimed surface will have a depression in the topography with no type of drainage outlet. With the quarry collecting and retaining the surface water runoff, subsurface drainage is vital for prevention of ponding to arise on the quarry floor.

The reclamation of the quarry is a relatively straight forward process. After removal of rock, overburden and any remaining waste produced in the mining operations will be laid over the quarry floor. Portions of the overburden will be used to slope the high vertical walls surrounding the quarry to a maximum of 12%. Once the overburden has settled, the topsoil will placed over the overburden and seeded immediately to avoid erosion.

3.1. Topsoil

Topsoil at the site will be removed prior to mining and either stockpiled for later use or directly reapplied for reclamation. In 1960 the Natural Resources Conservation Service (NRCS) conducted the *Soil Survey of Dakota County* which was then updated in 1983. The survey provided the topsoil types and acreage at the site of approximately 2.2 million yards of topsoil, an average depth of roughly two feet, will be removed, stockpiled, and then replaced upon the start of reclamation. The topsoil at the site is not expected to be sold because of the importance for reclaiming the land back to pre-mining conditions.

The initial topsoil will have to be stockpiled until the mining has progressed to a given point. The stockpiled topsoil has to be monitored ensuring that soil degradation is minimal, such as not stockpiling when it is frozen or wet. Stockpiles should be stacked no higher than 10 to 15 feet to prevent compaction. After the appropriate amount of mining has occurred, reclamation can begin in the western portion of the quarry applying the stockpiled topsoil. Once the stockpiles of topsoil are depleted, the topsoil can be stripped and reapplied directly on the reclaimed surface, avoiding stockpiling.

3.2. Overburden

Underneath the topsoil are unconsolidated glacial sediments consisting of sandy outwash deposits with no associated till deposit. The unconsolidated material averages 14 feet, roughly 15.2 million yards, in thickness based on the drilling logs provided by EKS (Vitton, 2005). Commonly, portions of quarry sands and gravels are sold, however, due to the anticipated reclamation, the overburden will remain in the quarry.

Approximately 10 million yards of overburden will be used to create the 12% slopes surrounding the quarry. The remaining overburden and waste produced waste produced in the mining operations will be replaced to an approximate depth of 8 feet instead of the original 14 feet.

3.3. Bedrock Geology

The bedrock is part of the upper layer of the Prairie du Chien group. The Prairie du Chien group is mainly composed of dolomites but also contains thin beds of sandstones. The thickness of the group is approximately 275 feet until contacting the Jordan Sandstone. The Jordan Sandstone consists of medium to coarse grained friable sandstone and is the principal aquifer in the area for domestic and irrigation use. Overlaying the Prairie du Chien group is the St. Peter Sandstone however the sand stone has been eroded away in the quarry site.

The group contains two formations: the Oneota Dolomite and the overlaying Shakopee Formation. The depth of the DTQ will not reach the Oneota Dolomite so the vertical and horizontal hydraulic conductivities of the Shakopee Formation are vital. Slug and pump tests were conducted on the Shakopee Formation in the Arden Hills and New Brighton area. The tests indicate vertical and horizontal conductivities of 1.75 ft/day (6.2×10^{-4} cm/sec) and 163 ft/day (5.8×10^{-2} cm/sec) respectively. “The Shakopee Formation and the upper part of the Oneota Dolomite have a high density and large cavities” (Runkel et al. 2003).

3.4. Long-term Drainage

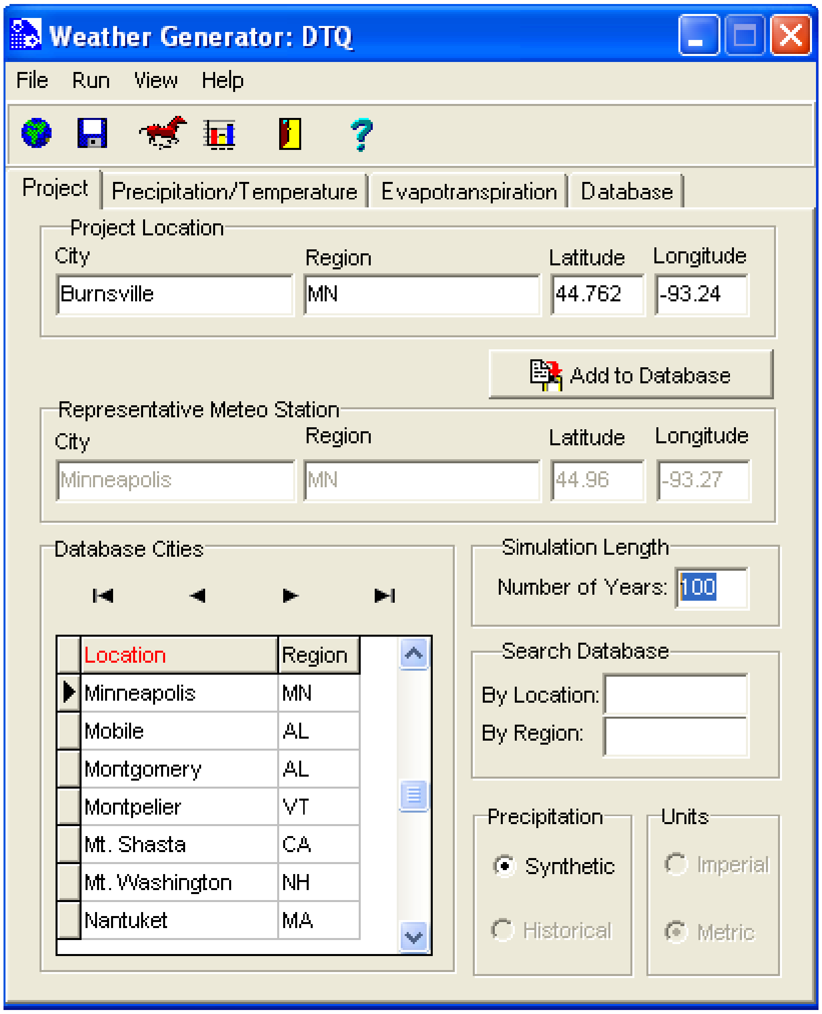
The reclaimed surface of the quarry will result in a depression for the topography of the area. Precipitation that falls on the reclaimed surface of the quarry will be retained because there is no mode of drainage. If the precipitation is not evaporated or consumed by vegetation it will percolate into the ground. As a result, permeability must be sufficient enough for water to infiltrate the ground.

The expected densities of the replaced topsoil and overburden will not be as high as they were in their original states due to placement and handling and hence should have increased permeabilities than the original permeability. In terms of the bedrock, it can be anticipated that an increase of vertical permeability will occur due to blasting operations increasing the amount fractures.

3.5. HELP Model Inputs

3.5.1. Burnsville's Weather Data

HELP's Weather Generator was the source for obtaining weather data. The Weather Generator obtained the climatic data recorded from Minneapolis, MN, located approximately 40 miles to the northwest, and applied those recordings to the EKS quarry. As stated earlier, HELP model employs a synthetic generation of daily values of precipitation, mean temperature, and solar radiation for inputs into the site.



Project Location

City	Region	Latitude	Longitude
Burnsville	MN	44.762	-93.24

Representative Meteo Station

City	Region	Latitude	Longitude
Minneapolis	MN	44.96	-93.27

Database Cities

Location	Region
Minneapolis	MN
Mobile	AL
Montgomery	AL
Montpelier	VT
Mt. Shasta	CA
Mt. Washington	NH
Nantuket	MA

Simulation Length

Number of Years: 100

Search Database

By Location:

By Region:

Precipitation

● Synthetic

○ Historical

Units

○ Imperial

● Metric

Figure 8 Weather generator dialog box.

3.5.2. Profile of DTQ

While designing the EKS quarry profile, it was unlike a typical design in HELP because it was investigating infiltration capacity of a reclaimed surface. The profile will not be utilizing a cap or a leachate recirculation system since there wasn't any refuse inside the quarry. All of the rainfall that will enter the quarry will percolate through the ground reaching the groundwater table, evaporate, or transpire through vegetation. When the water reaches the groundwater table, it will flow horizontally across the bedrock. Thus, it is imperative that adequate later drainage be present to allow water to infiltrate the subsurface without any long-term ponding occurring.

The designed profile was a five-layer system. The elevations, thicknesses, and permeabilities of each layer can be seen below in Figure 9. The topsoil, overburden, and unsaturated dolomite are assumed as vertical percolation layers. Once the water reaches the regional aquifer (saturated Shakopee Formation) flow will drain laterally. The geomembrane acts as a barrier that minimizes vertical flow through the saturated bedrock so a head could be determined.

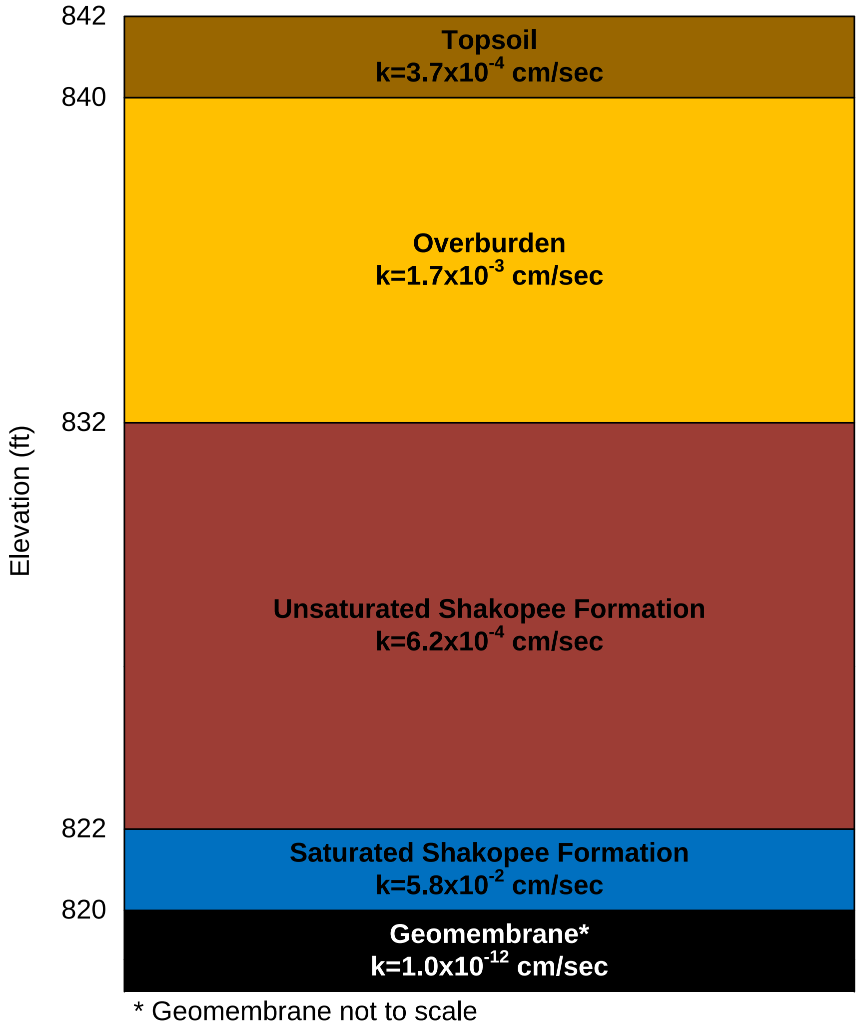


Figure 9 Cross sectional view of the Douglas Township quarry profile used in the HELP model.

The thickness of the topsoil was determined by the pre-mining depth of 2 feet. The remaining overburden and waste products will be placed to a depth of 8 feet. The conductivities of the topsoil and overburden are 3.7×10^{-4} and 1.7×10^{-3} cm/sec respectively. The conductivities and remainder of parameters for the layers were assigned by selecting loam and loamy sand as the materials of each layer respectively as shown in Table 1.

The bottom two layers are part of the Prairie du Chien group. The regulation to remain 10 feet above the regional groundwater table established the depth of the unsaturated Shakopee Formation. The bottom two feet of thickness are assumed as the lateral drainage depth. The conductivities of the unsaturated and saturated bedrock are 6.2×10^{-4} cm/sec and 5.8×10^{-2} cm/sec respectively (Runkel et al. 2003). The remainders of the parameters are assumed using the material municipal waste with channeling and dead zones because it closely matched the description of the bedrock Formation as shown in Table 1.

Table 1 Parameters of soil layers in the DTQ model

	Topsoil	**Overburden**	**Unsat. Shakopee**	**Sat. Shakopee**
Total Porosity (%)	0.463	0.437	0.1	0.1
Field Capacity (%)	0.232	0.105	0.032	0.032
Wilting Point (%)	0.116	0.047	0.013	0.013
Saturated Hydraulic Conductivity (cm/s)	3.70E-04	1.70E-03	6.20E-04	5.80E-02
Subsurface Inflow (mm/yr)	0	0	0	0

An “assumed” geomembrane was placed below the lateral drainage layer to collect water if the drainage was not sufficiently handling the infiltration water. The function was used to determine if soil layers above the geomembrane had adequate drainage so water would not pond on the reclaimed surface over long periods of time, i.e. 100 years. This is similar to a landfill because if the lateral drainage system in not sufficient to handle the leachate, the water level will start to rise. The geomembrane thickness is assumed by Visual HELP with an approximate thickness of 0.0033 feet. HELP also assumes a saturated hydraulic conductivity of 2×10^{-13} cm/sec which is acceptable for a geomembrane conductivity.

After creating the profile, Case Settings and Surface Water Settings needed to be established. Runoff method and initial moisture settings were both prescribed as model calculated for Case Settings. For the Surface Water Settings, the runoff area was input as 0% and the vegetation class prescribed was bare soil. The runoff area was determined to be 0% because the 12% surrounding slopes will collect and transfer any water runoff to the bottom floor of the quarry allowing for no potential water runoff. The vegetation class was selected as “bare soil” because it will allow for the highest amount of infiltrating water due to minimizing losses from evaporation and transpiration through vegetation. Additionally, the reclaimed surface will predominantly consist of bare soil during certain times throughout the year, especially in early spring and late fall, due to snowmelt and harvesting of crops.

4. Results and Discussion

After creating the DTQ model, Burnsville's weather was determined using a 100 year simulation in Weather Generator. The simulated weather and duration of time were applied to the DTQ model which determined the long-term hydrology of the DTQ quarry. The hydrology was investigated to determine if adequate drainage of the reclaimed quarry surface would allow for an agricultural restoration.

4.1. Annual Average Head on Geomembrane Liner

Analyzing the annual average height of heads on the geomembrane determined if the soil layers were capable of allowing the water to infiltrate without ponding. The incoming sources of water percolated through the DTQ profile sufficiently enough for a head to start forming on the geomembrane indicating no ponding. A head began forming on the geomembrane within the first year of the model and at the end of the third year an annual average head height of 1.31 feet was observed. Over the next four years annual average head values declined rather consistently to approximately 0.68 feet. Head values follow this cyclical pattern throughout the remainder of the simulation generating observed maximum and minimum average head values of 1.44 (year 49) and 0.25 (year 22) feet, respectively, as shown in Figure 10. The mean average annual head height above the geomembrane throughout the duration of the model was 0.80 feet.

The annual average heads above the liner throughout the simulation were minimal in comparison with the allowable head of 20 feet. The outcome is a long-term reclaimed surface that could endure agricultural production.

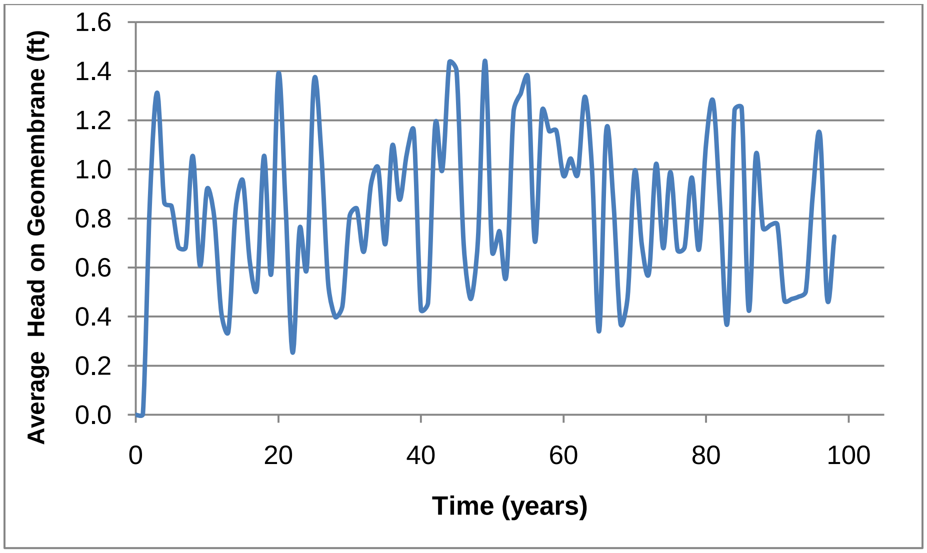


Figure 10 Average ponding (head) above the geomembrane for the DTQ model.

Two additional simulated weather datasets were applied to the DTQ profile using the Weather Generator. The locations chosen were Phoenix, AZ and Seattle, WA due to their unique weather conditions. Phoenix is an extremely dry climate which receives nominal rainfall and snowfall. Seattle, in contrast, receives large amounts of precipitation and snowfall. Simulating, and modeling, the two different locations could determine how the hydrology of the quarry is affected by differing weather.

Burnsville, Phoenix, and Seattle receive approximately 26.4, 7.1, and 36.0 feet/yr of precipitation respectively. The mean annual temperatures for the three locations were 7.1, 21.8, and 10.8 °C respectively. The varying temperatures and precipitation rates are representative in the average head heights above the geomembrane liner for each simulation.

With Phoenix receiving the smallest amount of precipitation, and presumably having the driest soil, the modeled average head above the liner was almost non-existent. Nearly all of the incoming water is lost due to evaporative forces. The elevated temperatures coupled with nominal rainfall events yield warm soils that evaporate rainfall expediently. Evaporative forces accounted for 99% of the rainfall removed from the system. Since all the rainfall is lost in the system before reaching the underlying soils layers, minimal percolation occurs and no head forms on the liner.

An annual average head of 2.45 feet above the liner was observed in the Seattle simulation, roughly a 300% increase of the DTQ modeled head. The maximum head for Seattle was 5.13 feet which is still in the range of allowable head. The head values are higher due to the increase in precipitation over the length of the simulation. With increased precipitation rates, moisture contents of soils are higher and soil temperatures are lower. As opposed to Phoenix, precipitation lost to evaporation was only 49% resulting in an increase of percolating water reaching the liner. The three different simulations are evidence DTQ is variable depending on weather as shown in Figure 11.

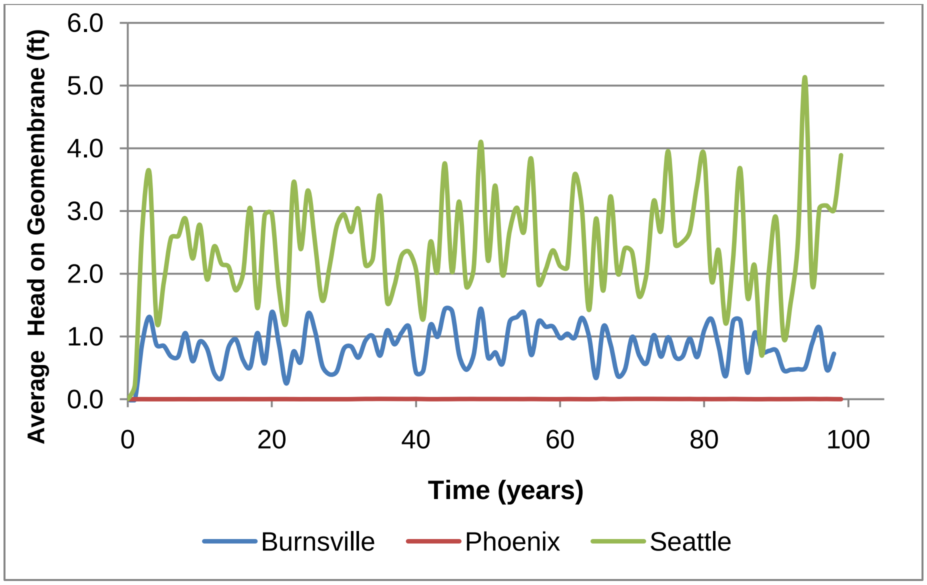


Figure 11 Ponding (head) for three different regions of the United States.

4.2. Water Storage in Layers

The water storage of each layer was evaluated for the DTQ model. Water storage is the total amount of water stored in each layer. The layer will retain a portion of the drainage dependent upon the various material characteristics.

The overburden has the largest amount of storage followed by the topsoil, unsaturated Shakopee Formation, and saturated Shakopee Formation in decreasing order as shown in Figure 9. Overburden contains the highest storage because the lower conductivity of the uderlying unsaturated Shakopee Formation. Water percolates more rapidly through the overburden as opposed to the Shakopee Formation which produces a ponding effect between the two layers because the conductivity is being decreased. The amount of total storage in the overburden is approxiamtely 1.4 feet, less than the permissible 10 feet of soil above.

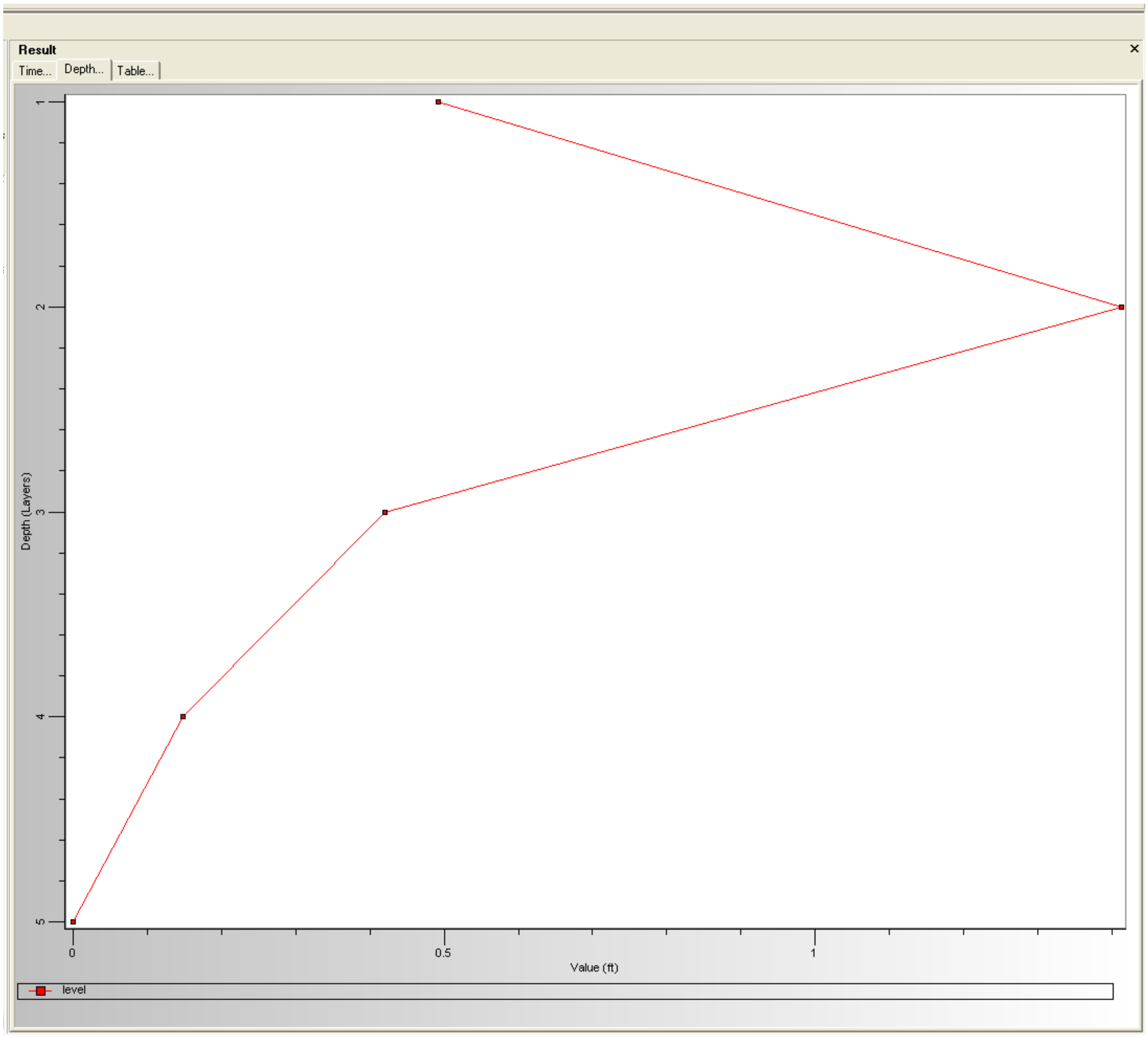


Figure 12 Final water storage for each layer in Douglas Township Quarry.

The final storage in each layer is acceptable so that no ponding will occur. The storage in the overburden is larger than the topsoil because a larger depth of the overburden will result in a larger volume of material that will retain water. Additionally, a portion of storage in the topsoil is lost to evaporation due to exposure of sunlight heating the soil. An increase in depth of the topsoil would directly result in an increase in the storage as shown in Figure 13.

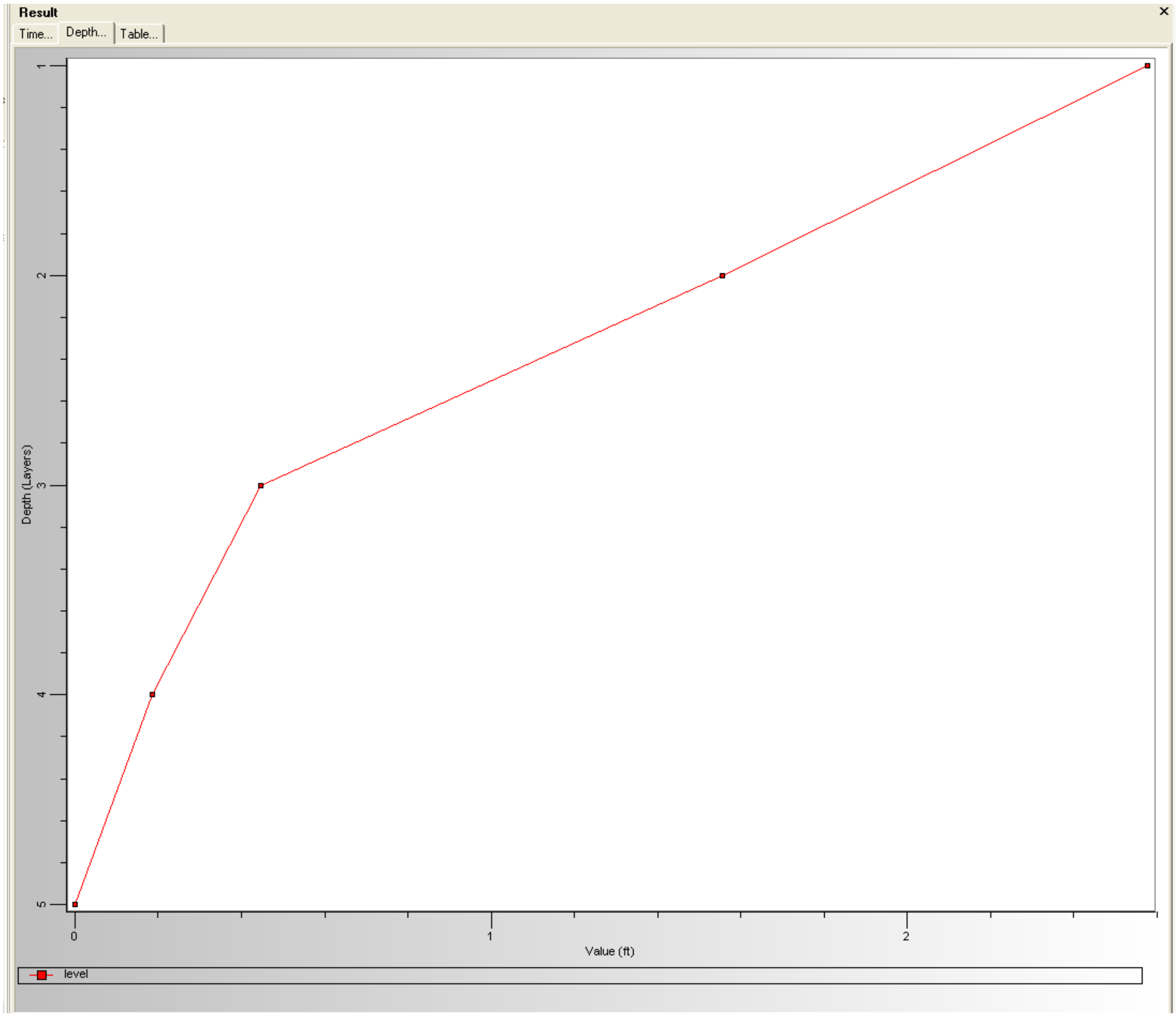


Figure 13 Storage of each layer after increasing depth of topsoil to 10 feet.

4.3. Initiating a Ponding Effect

Numerous simulations were run to determine a lateral drainage conductivity, of the saturated Shakopee Formation, that created a ponding situation. Determining the conductivity required varying the conductivity of the saturated soil until an approximate head height of 20 feet was obtained. A conductivity of 4.5 x 10^{-6} cm/s raised the head height above the liner nearly 20 feet as shown in Figure 14. A conductivity of that magnitude is classified as fine sediment such as silts and clays. The hydrogeology data obtained for the Prairie du Chien group determined large vertical and lateral drainage rates of the Shakopee Formation verifies ponding will not occur.

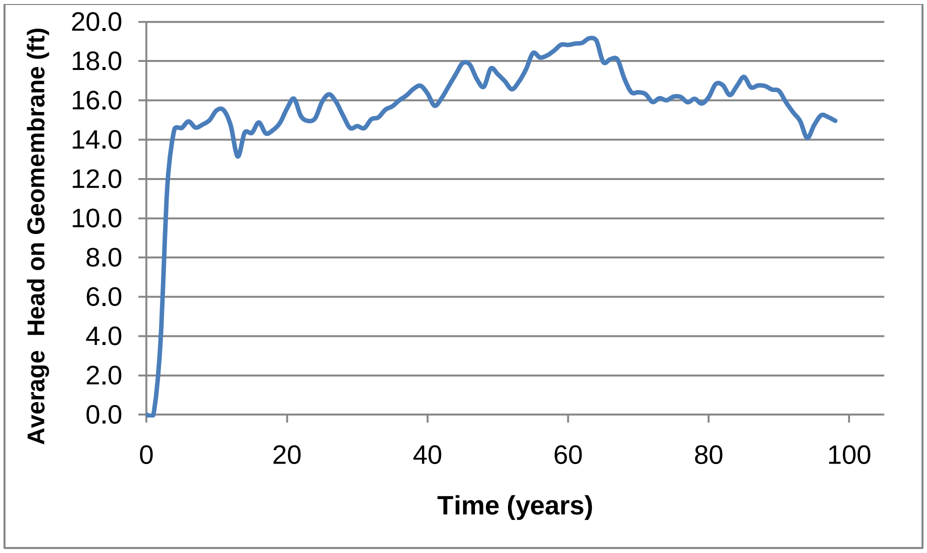


Figure 14 Head depths of the Douglas Township Quarry with ponding.

4.4. Douglas Township Quarry Site

Quarries commonly have an issue of dewatering during mining operations due to shallow groundwater table depths. Shallow water tables are problematic because after mining ceases and reclamation begins, the groundwater table will prefer to return to original elevation. This will result in ponding, or on a larger scale, formation of a lake because the depression left from mining will have a lower ground elevation than the original groundwater table.

Douglas Township's regulation of ensuring the depth of mining remains, at minimum, 10 feet above the groundwater table is significant because it ensures minimal disturbance of the groundwater table. If the water table is not being lowered or altered, disturbance of the water budget is minimized. The 10 feet of undisturbed Shakopee Formation above the groundwater table will allow adequate vertical percolation and later drainage because the in-situ height of the water table already representative of sufficient drainage. If the Shakopee Formation percolation and lateral drainage was insufficient, the depth of the water table would be closer to the ground elevation because the incoming water would not be able to infiltrate as effectively. However, the vertical and horizontal hydraulic conductivities of the Shakopee Formation will allow for adequate percolation of the water and, upon reaching the groundwater table, lateral drainage.

4.5. HELP Constraint

HELP assumes a homogeneous material throughout the entire layer consequently assuming consistent conductivities throughout and will not allow for the conductivity to vary over the length of the layer. Portions of the in-situ bedrock conditions will, in all probability, be heterogeneous across the entire quarry floor resulting in differing conductivities. Without being able to properly model varying conductivities within each layer, the bedrock could contain portions of blocked vertical drainage imitating a clay layer or lenses resulting in a spot ponding effect. Since HELP assumes homogeneity, the effect of spot ponding cannot be properly modeled.

5. Conclusion and Recommendations

Even though there are not any federal regulations regarding mining of aggregates, local governments are passing zoning regulations restricting aggregate production to protect their communities. Consequently, the once low cost commodity is dramatically beginning to increase because of increased transportation and cost of transportation, increased urban sprawl, NIMBY syndrome, etc. Aggregate is vital in maintaining the existing infrastructure and the demand for aggregates is only increasing. Awareness must be brought to developing ways of demonstrating to society that quarries are necessary and, with the proper regulations put in place by the community, reclamation is possible once mining operations are completed. One possible approach is to apply existing technologies that have been proven in different areas that could be applied to aggregate production. One such approach is using HELP model as a viable method for determining the long-term hydrology of quarries.

A model was created in HELP for the Douglas Township Quarry to determine if the reclaimed surface would allow for agricultural production. Various simulations were run to determine if the hydrology of the quarry would allow for a proper reclamation. The model predicted a maximum head height above the geomembrane liner of approximately 1.44 feet, significantly less than the 20 feet of allowable head before ponding would occur. Infiltration of surface waters should occur through the reclaimed surface and with no ponding occurring, the reclaimed surface would allow for agricultural production. However, short-term ponding may occur during extended wet periods or large rain events.

To ensure that the drainage properties of the reclaimed surface is sufficient, the surface, especially the surrounding slopes, should be vegetated immediately and an erosion control management should be put into place. Erosion of the slopes would cause an enormous sediment deposit that could cause a low conductivity soil to be overlying the topsoil. The lower conductivity of the fine sediment would not allow sufficient drainage to occur and would cause ponding to occur.

The HELP model is a proven method for determining the water budget of landfills and can be applied in other areas such as reclaimed quarry pits. HELP model estimated the amount of drainage to be sufficient for ponding not to occur but the model needs to be validated for surface mining. Using other surface mines around the state of Minnesota, other simulations could be used for determining the validation of the HELP model in verifying water budgets of quarries.

HELP was valuable in evaluating the reclaimed quarry hydrology by determining the various areas of the water budget. Mining companies can utilize HELP model in validating to communities, city officials, and regulatory agencies the long-term hydrology of the quarry and if a reclamation is feasible.

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