MODELING SMALL RESERVOIRS IN THE GREAT PLAINS TO ESTIMATE OVERFLOW AND GROUND-WATER RECHARGE

by

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B.S., University of Agricultural Sciences, Bangalore, India, 1986
M.S., University of Agricultural Sciences, Bangalore, India, 1990

AN ABSTRACT OF A DISSERTATION

Submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Biological and Agricultural Engineering
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2009

ABSTRACT

Small reservoirs catch and store water for long periods and they decrease streamflow and increase ground-water recharge. A field monitoring program provided the measured water depth for four years in several reservoirs in the Republican River Basin where there are concerns about their aggregate effects in the basin.

The daily water budget operation for one reservoir was developed. Daily seepage rates were estimated by using precipitation, inflow and evaporation which was assumed equal to grass reference evapotranspiration (ET_0), that average 120 to 150 cm/yr, along with the measured stage-storage and stage-surface area relationships. Two computer simulation modules, written in FORTRAN 95, were developed to estimate 1) overflow and gross seepage and 2) potential for ground-water recharge underneath the reservoir. Required daily input data are precipitation, ET_0, and inflow from the watershed area. Required reservoir site characteristics include stage-storage and stage-surface area relationships, a standard seepage rate (S_0) at 14 different levels in the reservoir, soil-water and plant-growth characteristics and a monthly crop-residue factor.

The gross seepage module calculates water depth that determines daily overflow, the water-surface area for evaporation and the head of water on the 14 levels to cause seepage losses. If a level is not inundated, seepage is zero. If a level is inundated less than 0.3-m, S_0 is used. When the water head (h_L) on a level exceeds 0.3 m, the seepage rate (S_L) is increased by, $S_L = S_0 * (h_L/0.3)^{0.25}$. This relationship was chosen after testing several exponent values between 0 and 1.

The modules were calibrated on one reservoir and verified on two others in northwestern Kansas. Results showed runoff from the watersheds averaged about 1.2 to 1.6 cm/yr from the average annual precipitation of 46 to 62 cm. The three reservoirs reduced streamflow at the reservoir site by 74 to 97%, but 90 to 95% of the retained runoff was calculated to contribute to ground-water recharge.

Several sensitivity analyses for model inputs were done. Results showed that, the ratio of the average annual inflow volume from the watershed area to the reservoir storage volume was the most sensitive input variable tested.

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Dedication

Dr. James K. Koelliker

for his humanity and leadership

CHAPTER 1- Introduction

Water is an important natural resource resulting in existence of all living being on the planet earth. Judicious use and proper management of the water is more important today than before. We are extracting more water for human and animal consumption and also for crop production. Unless water is used properly, there is a threat to having sufficient and safe water for irrigating cropland and other human uses for future generations. For this reason there is more responsibility for water resource engineers and scientists to find the ways and the means to preserve and conserve this precious natural resource.

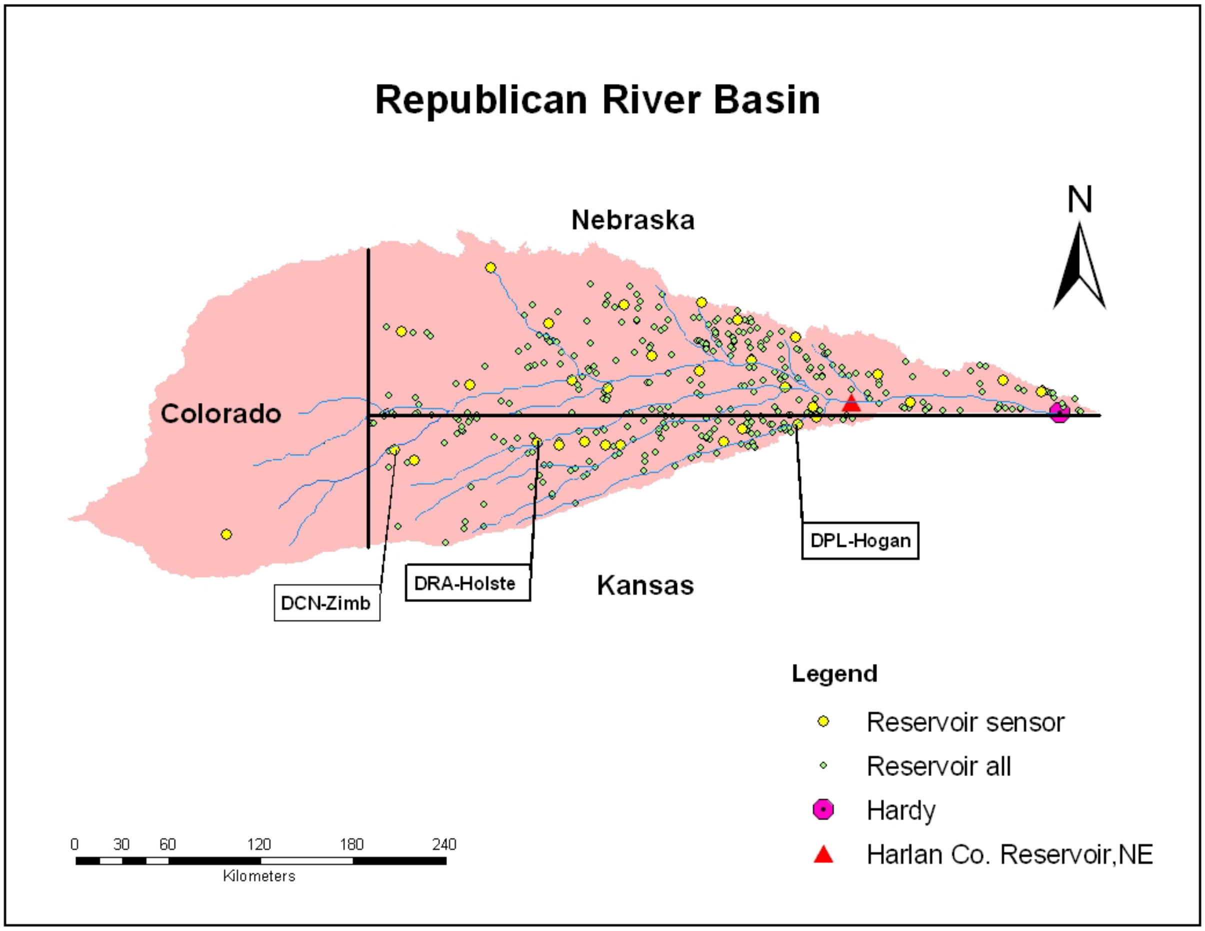
Small reservoirs play a considerable role in storing water for a reasonable time. These reservoirs are constructed to retain water for many purposes include stock water drinking, flood retardation, and for aesthetics. Construction of these small reservoirs influences watershed hydrology to a certain extent. The purpose of the present study is to examine and quantify their effect on the overflow and potential ground-water recharge in Great Plains of the United States.

The study area, the Republican River Basin, is located in the Great Plains of the United States in parts of Colorado, Kansas, and Nebraska. Surface water yield in the Basin above Hardy, Nebraska (Fig. 1.1), is declining. A compact between the three states (Republican River Compact Administration report 2008) was approved in 1942 that allocates the streamflow among the three states. The original compact also defined the amount of water, but the amount that now occurs has been reduced substantially. The State of Kansas threatened to sue the State of Nebraska because of the decline in water that has been available to Kansas, particularly at the lower end of the Basin.

Republican River Basin an Overview

The Republican River Basin begins in Eastern Colorado, flows through Northwest Kansas into Southwest Nebraska, flows back into North central Kansas near the town of Hardy, Nebraska, and finally flows into Milford Reservoir in north central Kansas. The main stem of the Republican River is formed by the junction of the North Fork of the Republican River and Arikaree River near Haigler, Nebraska (from the website of Republican River Basin Administration).

Figure 1.1. Republican River Basin above Hardy, Nebraska (Kansas Geospatial Community Commons)



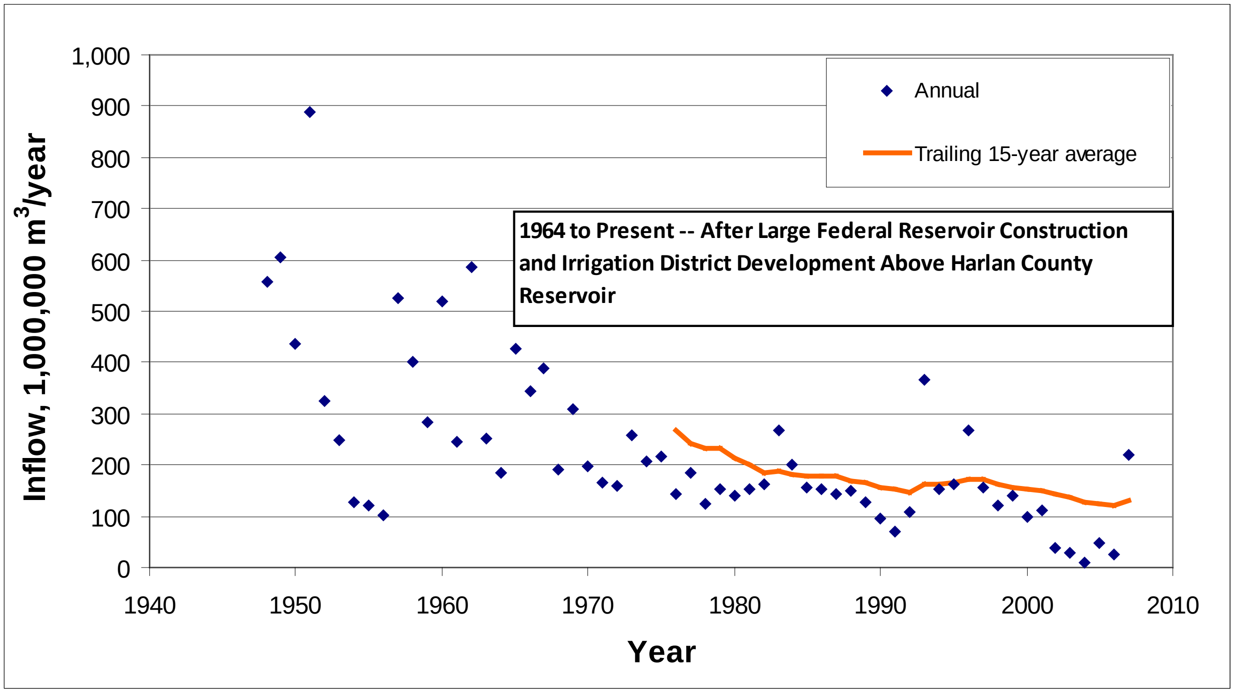
The river generally flows in an easterly direction for 720 kilometers before it joins the Smoky Hill River at Junction City, Kansas to form the Kansas River, a major tributary to the Missouri River. The Republican River drains an area of 64,700 square kilometers.

The continental climate in the Basin is semi-arid in the west and transitions to sub-humid in the eastern part. Mean annual precipitation increases from 40 cm in the west to about 75 cm in the east. Annual grass reference evapotranspiration, ET_0, is about 120 to150 cm.

The important soil and water conservation measures including the construction of conservation terraces and small non-federal reservoirs are of special interest. In particular, small reservoirs catch and store runoff water that often serves as water supplies for pasture and rangeland. Retained water is lost by seepage that may add to ground-water recharge and by evaporation.

Since the last quarter of the 19th century, the overall impact of agricultural activities has resulted in substantial native prairie grassland being converted to cultivated land and much of the remainder is used for grazing. The transformed landscape in the Great Plains initially resulted in increased runoff and water and wind erosion that has led to adoption of best management practices including construction of field terraces and numerous reservoirs of both small and large size. Irrigation in later years, along with these practices, has resulted in a decreasing trend in streamflow. This is evident from the inflow behavior to the Harlan County Reservoir, Nebraska located near the lower end of the Republican River Basin in Nebraska (Fig.1.2).

Figure 1.2. Annual inflow into the Harlan County Reservoir, Nebraska (USGS stations 06848500 + 06844500)



A project is underway to quantify the contribution of land terracing and small, non-federal reservoirs on streamflow and potential ground-water recharge that is supported by the U.S. Bureau of Reclamation with cooperation from the states of Colorado, Kansas and Nebraska. In the study area of the overall project, 716 small, non-federal reservoirs have been identified.

Small reservoirs influence the watershed water budget to a certain extent. So, it is important to determine their effects on watershed hydrology and to assess the ground-water recharge contribution in terms of net seepage, and to quantify their effect on streamflow in the form of overflow from the reservoir at the reservoir site. Quantifying these two effects of small reservoirs is the main goal of this dissertation.

Some of the earlier studies of the effect of small reservoirs on water yield are discussed here.

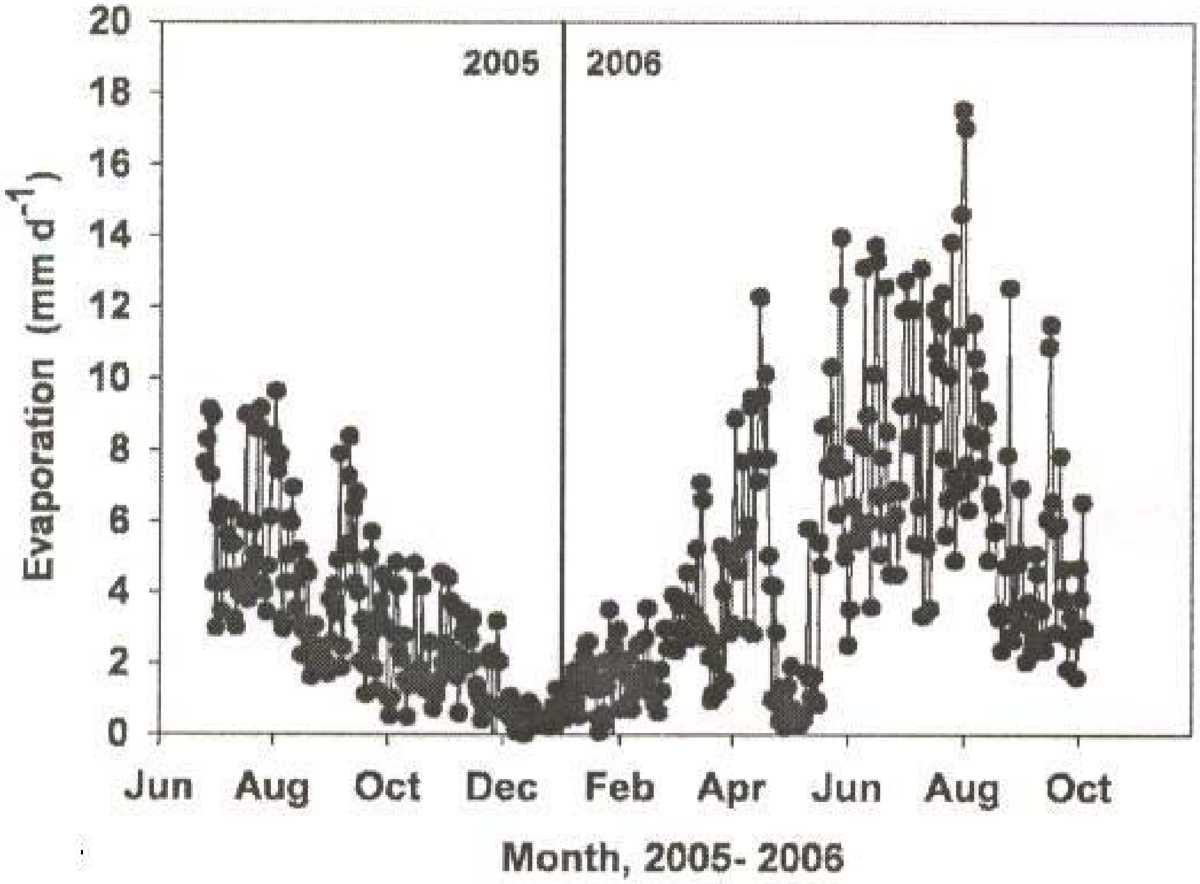
Duesterhaus et al. (2007) studied on water balance of a stock-watering pond in the Flint Hills of Kansas. They reported that, the main water loss from the pond was by evaporation that accounted for 64% of the total water lost annually during their measurement period, June 2005 to October 2006. Seepage, cattle consumption, and transpiration accounted for the remaining 36%. The results for daily evaporation losses for this study are shown in the Figure 1.3. Soils at the site have considerably more clay content than those in my study area.

Eisenhauer et al. (1982) studied two flood-retarding reservoirs in south central Nebraska to estimate their potential for ground-water recharge. The average seepage rate for the two reservoirs was 1.27 to 1.50 cm/day. Water depth in one of the reservoirs varied from 2 to 5 m and averaged about 3 m during the 8-month study period and storage volume at the principal spillway crest was about 33,000 and 81,000 m^3. Soils at the sites were not described; however, I believe they would have greater clay content that would reduce seepage rates to levels that are lower than for reservoirs in the Republican River Basin. Also, these reservoirs would have more water in them a greater portion of the time than would reservoirs further west in my study area.

Sauer and Masch (1969) studied the effects of floodwater retarding structures on water yield in Texas. They calculated the annual surface water yield using annual data for a seven-year period. The results of the study revealed that for watershed with less than 1.8 cm of annual runoff, the surface water yield was reduced by 100%. When the runoff exceeded this level then they developed a curve which predicts the reduction in yield which was presented in Koelliker et al. (1981) (See Fig. 1.4).

Peterson (1956) found that stockwater ponds on the Cheyenne River above Angostura Reservoir in South Dakota controlled 46 percent of the amount that flowed into the reservoir over a 4-year study period. He believed this area to be as highly developed with stockwater ponds as anywhere in the U.S.

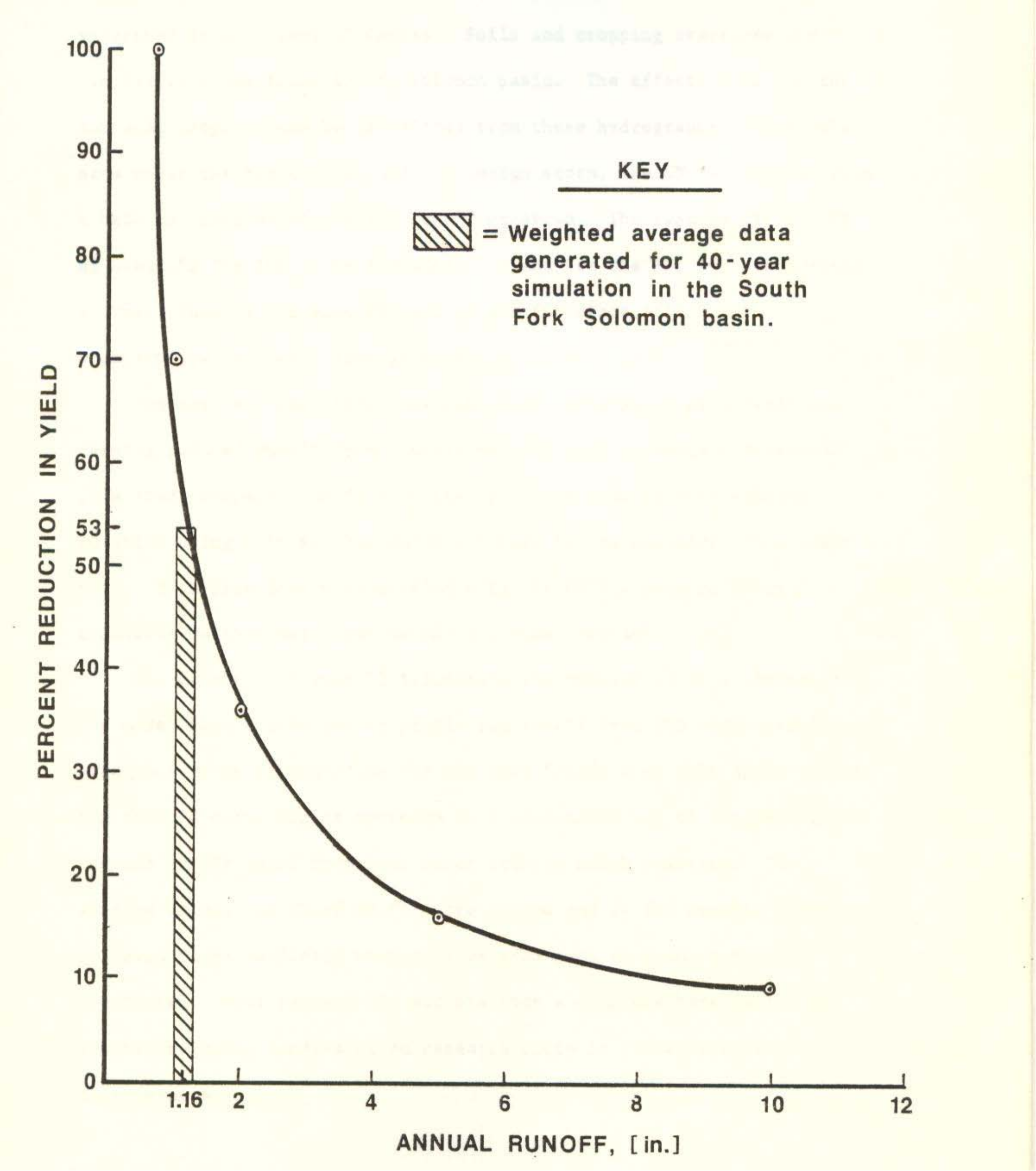
Figure 1.3. Evaporation loss from the pond during June 2005 to October 2006 at Flint Hills, Kansas (Duesterhaus et al., 2007)



Sharp et al. (1966) attempted to develop a procedure to estimate the effects of structural measures of contouring, terracing and stockwater dams on watershed yield; however, they could not document changes sufficiently to develop an exact method. They did, however, present a rational approach which was a valuable foundation on which to build a better method.

Koelliker et al. (1981) reported that, reservoirs are built for stockwater supplies in pasture and rangeland trap much of the runoff from their watersheds. They are generally built in drainage ways that flow intermittently. They also reported that, the impact of stockwater ponds on water yield could be significant.

Figure 1.4. Reduction in water yield due to reservoirs as a function of annual runoff in the watershed (Sauer and Mausch, 1969, adapted and found in Koelliker et al., 1981)



Koelliker et al. (1981) developed a simulation model which accounts for changes in land uses and soil and water conservation practices and estimates their effects on water yield on an annual basis that was presented as methodology to assess the effect of agricultural soil and water conservation practices on water yield. Their study in South Fork Solomon River basin above Webster Reservoir, KS found that there was a continuous reduction in water yield in the basin. Figure 1.4 shows the reduction in water yield in the South Fork Solomon river basin that agreed well with the relationship developed by Sauer and Mausch (1969).

The main goal of this dissertation is to quantify the effects of small reservoirs on streamflow in the form of overflow from the reservoir and ground-water recharge. The present study was conducted in the Republican River Basin situated in the Great Plains by selecting a small reservoir which was continuously monitored with a water-depth sensor. Other required data were collected from weather stations nearby to estimate unknown parameter seepage of the pond water balance.

In order to make reasonable estimates for the dispensation of the inflow small reservoirs, I must develop a daily water balance for the reservoir pool area. Assessing the impact of a reservoir must include quantifying the amount of inflow from the contributing area, precipitation onto the reservoir water surface and evaporation from it, along with overflow and seepage from the reservoir. In particular, my method must be able to estimate the effective net seepage from a small reservoir with widely varying temporal water depths and dry periods. Here, I define net seepage as water that percolates below the rooting depth of plants that grow in the reservoir pool area that becomes potential ground-water recharge at the site.

Objectives

The overall objective of this dissertation is to examine the effect of small reservoir on streamflow and potential ground-water recharge at the reservoir site at various locations in the Republican River Basin. Specific objectives are to

1. develop a method to examine the daily water-depth record of a small reservoir to estimate the average daily seepage rate,
2. develop and apply a computer simulation module to estimate overflow and gross seepage rates from a small reservoir at various depths within the reservoir with varying water depths,
3. develop and apply a computer simulation module to estimate the net seepage rates from a small reservoir at various locations within the reservoir,

4. combine the results of 2 and 3 to determine the effect of the reservoir net seepage (potential ground-water recharge) at the reservoir site and net reduction in streamflow at the reservoir, and
5. examine the sensitivity of various factors about the reservoir site on the effect on overflow and net seepage at the reservoir site.

A total of 716 non-federal reservoirs have been constructed in the Republican River Basin, out of which 6 are in Colorado, 148 in Kansas, and 562 are in Nebraska. Many of these reservoirs do not have principal or pipe spillways. Watershed areas for these reservoirs range from about 30 ha to more than 2,000 km^2, most however are nearer to about 250 ha.

Thirty-two of these reservoirs are being monitored by using water-depth sensors of which 11 reservoirs are in Kansas (Appendix A, and Figure 1.1). Water depth in the reservoirs is reported hourly to the nearest 0.3 cm, with sensors provided by the Bureau of Reclamation. The eleven reservoirs in Kansas are operated by the Kansas Division of Water Resources (DWR). All of these reservoirs have been surveyed by Kansas DWR personnel and they have developed information about storage volume and surface area at each water depth. Also, the spillway discharge characteristics have been determined. Thus, the continuous water-depth measurements can be used to provide a continuous accounting of the water volume, surface area, and overflow discharge for these reservoirs.

The analysis of the information from the reservoirs is being done as a part of a cooperative grant project between Kansas State University, KS and the University of Nebraska-Lincoln, NE which is funded by the U.S. Bureau of Reclamation. The work in this dissertation is a direct result of and is a work product of this project. My research was funded by this project.

To accomplish the specific objectives of my dissertation the following chapters are presented:

In Chapter 2, specific objective 1 is addressed. Chapter 3 presents my work to specific objective 2. Chapter 4 covers specific objectives 3 and 4. In Chapter 5, my work to examine the sensitivity of the results (specific objective 5) is presented. Finally chapter 6 contains conclusions, and recommendations for further work and improvements.

CHAPTER 2- Estimation of Seepage Losses From the Reservoir

Using Water-Level Records to Estimate Reservoir Operations

During the study period, 2004-2009, to obtain field information about the water depth in the reservoirs, continuously-recording, water-depth sensors were installed and operated to measure the water depth in 32 reservoirs (Fig. 1.1). The sensors records provided the water depth above the bottom of the reservoir and they were collected and stored on an hourly basis. The monitoring program was operated by the three cooperating states.

For this study, three sensor-monitored reservoirs were selected as identified on Figure1.1. These three were selected because of a more continuous presence of water and I was more familiar with their watershed characteristics and I followed their operations most closely. They also represent a range of different precipitation and land-use characteristics.

The water-depth record is influenced by factors that include reservoir characteristics of stage-storage volume, stage-surface area and stage-discharge relationships, site soil characteristics, precipitation on and evaporation from the free-water surface area, and water used from it along with the change in depth can be used to estimate the daily seepage amount by calculating a daily water balance. Input parameters include inflow from the watershed area and precipitation onto the free-surface area. Outflow parameters include evaporation from the free-water surface, seepage, overflow through the spillway and water use from the reservoir. Change in storage volume (ΔV), m^3, was determined by using the change in depth and the stage-storage volume relationship. Seepage (S), m^3, was estimated by summing the daily values using following relation:

$$S = P + I - E - O \pm \Delta V \tag{2.1}$$

Where,

P = Precipitation from the nearest reporting station times free-water surface area, m^3

I = Inflow (sum of runoff and drainage), m^3

E = Weighted ET_0 for the nearest station(s) times free-water surface area, m^3

O =Estimated overflow from recorded water depth and spillway characteristics, m^3

For the daily water balance, the first water-depth sensor record after 12:00 a.m. was used as the daily water depth in the reservoir. It was observed from the water-level data that inflow was only occasional and uncertain and precipitation occurred only about one day in five. Seepage and evaporation, however, were known to occur each day. Water used from the reservoir was limited to consumption by livestock and I determined as described below that was minimal and it has not been included in the analysis. This resulted in more unknowns than relationships to determine seepage and inflow independently. Therefore, I carefully examined the water-depth record to estimate seepage each day. On days with no inflow or precipitation, seepage was estimated by change in depth minus evaporation. Evaporation was assumed to be equal to ET_0. On days with inflow that produced an increase in water depth that was more than would result from precipitation minus evaporation and seepage, inflow was estimated by adjusting the seepage amount such that it remained a reasonable amount compared to the preceding day unless there was a large inflow. Then, the amount of seepage had to be estimated by my best judgment. Overflow amounts, when they occurred, were determined by examining the hourly water-depth record and the stage-discharge relationship. This approach was less than satisfying methodology but it was the only approach that the field data would allow. This approach is expected to provide reasonably good results for the operation of these reservoirs.

DPL- Hogan

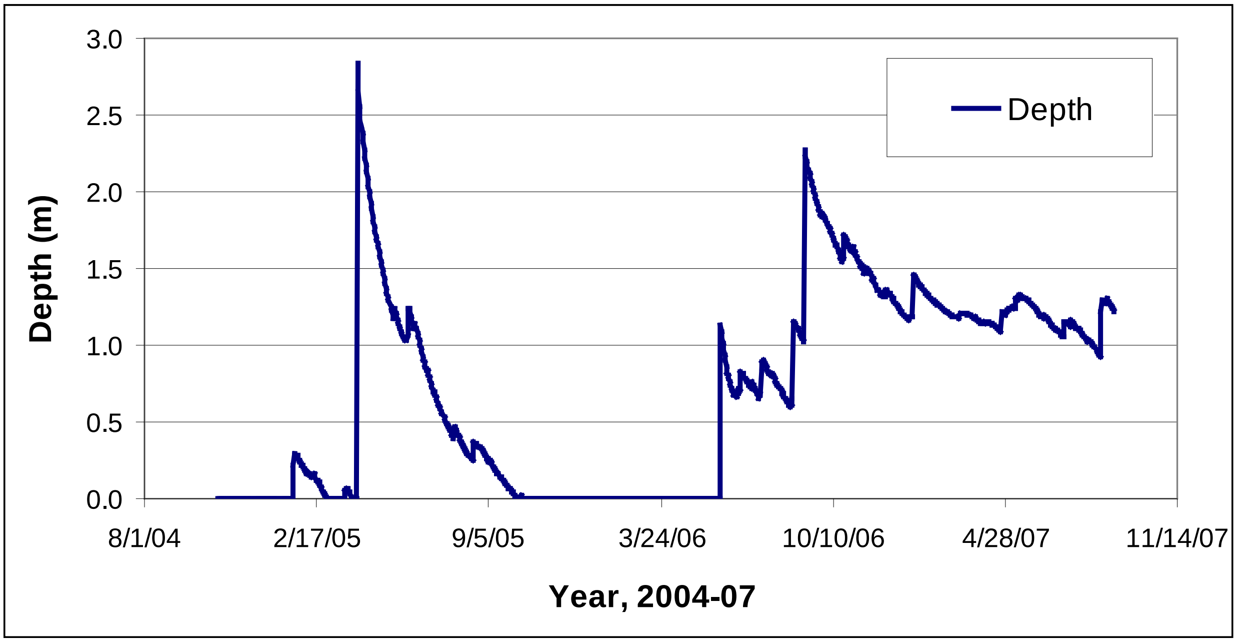
The reservoir chosen for development of this analysis is DPL-Hogan which is located in Phillips County, Kansas (Fig.1.1). It has a watershed area of 33 ha and its surface area at minimum water depth is 0.03 ha at maximum area at a water depth of 2.84 m is 0.41 ha. Land use in the watershed area is characterized by pastured rangeland. The storage volume in the reservoir at the 6.1-m wide earthen spillway level of 5,378 m^3 is equal to 1.6 cm over its watershed area. A weighted average annual ET_0 between Colby, KS and Scandia, KS was used for the site. Soil is characterized by Uly and Penden silt loam in hydrologic soil group B with 7 to 20% slopes (NRCS, 2008). Soil has good permeability of 1.5 to 4.8 cm/hr. Precipitation data was obtained from the nearest station Long Island, KS. Details for the reservoir DPL-Hogan are shown in the Table 2.1, and the temporal change in water during study period 2004 to 2007 is shown in the Figure 2.1.

The reservoir was one of two water sources for about 30 cattle in the approximately 80-ha fenced area around the reservoir. Cattle were in the area only during the grazing season that was about 150 days. Water consumption by cattle averages about 0.03 m^3/day (Guyer, 1977). If all 30 cattle drank from the reservoir, total water use for a day would be about 0.9 m^3. With a reservoir depth of 0.9 m the surface area is 1,390 m^2 the cattle consumption would equal less than 0.1 cm from the reservoir which is less than the 0.3-cm (0.01-ft) increment from the water-depth sensor record.

Table 2.1. Reservoir characteristics of DPL-Hogan

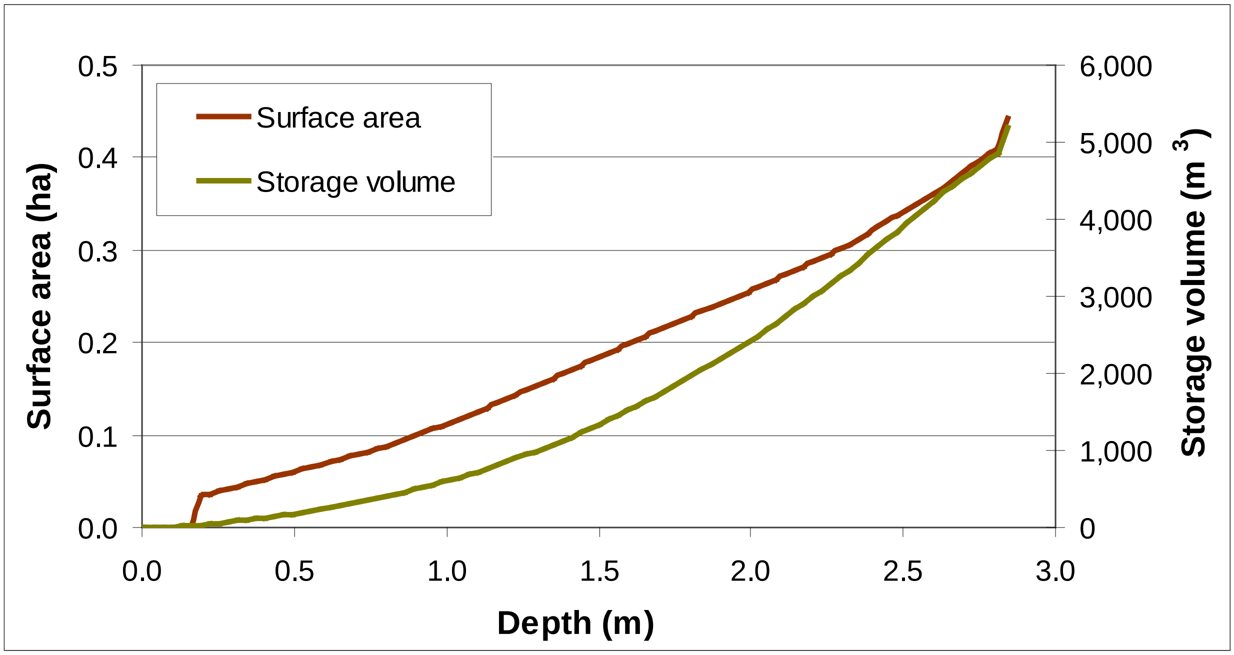
Characteristics	
Volume at spillway (m^3)	5,378
Area at spillway (ha)	0.41
Depth at spillway (m)	2.84
Average annual precipitation (cm)	62
Average annual ET_0 (cm)	130

Figure 2.1. Temporal change in depth of water in the reservoir DPL-Hogan, 2004-07



A water balance spreadsheet was developed to solve Equation 2.1 on a daily basis. The spreadsheet contains a Lookup table so that the volume in storage can be determined each day, as well. Hourly water-depth sensor data was extracted to obtain the water depth at midnight to facilitate the daily balance. The water depth versus water-storage volume and surface-area relationships provided were used to develop stage-storage volume and stage-surface area relationships in the Lookup table so that exact values are provided automatically for each day. These relationships are plotted in Figure 2.2.

Figure 2.2. Stage-storage volume and stage-surface area relationship of the reservoir DPL-Hogan



As Equation 2.1 shows, seepage was determined by adding rainfall on the reservoir surface, estimating runoff from the watershed area, deducting evaporation from the reservoir surface, and determining the change in water storage from the previous day. Runoff water from the watershed area was estimated for days when it occurred by inspection so that seepage rate versus time was reasonably consistent. Reservoir rainfall, evaporation and seepage were expressed both in depth (cm) and in volume (m^3). A sample of the daily water balance spreadsheet is shown in the Table 2.2.

Table 2.2. A typical daily reservoir water balance for DPL-Hogan for a large inflow event

Date	Depth (m)	Area (ha)	Volume (m^3)	P (m^3)	I (m^3)	E (m^3)	O (m^3)	S (m^3)	S (cm)
4/5/05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4/6/05	2.83	0.43	5,065	0.00	8,222.64	3.99	2,674.03	479.62	22.02
4/7/05	2.66	0.37	4,424	0.00	0.00	8.95	0.00	632.15	15.52
4/8/05	2.56	0.35	4,115	0.00	0.00	11.91	0.00	297.21	8.07
4/9/05	2.47	0.34	3,832	0.00	0.00	7.62	0.00	275.05	7.88
4/10/05	2.42	0.33	3,650	0.00	0.00	12.29	0.00	169.43	5.07
4/11/05	2.38	0.32	3,529	50.37	0.00	2.34	0.00	169.17	5.20
4/12/05	2.33	0.31	3,348	0.00	0.00	4.06	0.00	177.66	5.63
4/13/05	2.27	0.30	3,192	0.00	0.00	3.27	0.00	152.50	4.99
4/14/05	2.23	0.29	3,063	0.00	0.00	3.00	0.00	125.54	4.21

Since seepage and evaporation are continuous whenever there was water impounded in a reservoir, the sum of the two could be reasonably estimated on most days. In the study area, average annual values of ET_0 agree reasonably well with the average annual evaporation from small reservoirs provided by the USDA NRCS as shown on p. 45 in Viessman et al. (1977) of about 135 cm. Since I had ET_0 values available on a daily basis, I used them directly to estimate daily evaporation. So, daily ET_0 was added to the daily loss of water depth during days with no precipitation or inflow to estimate seepage using Equation 2.1.

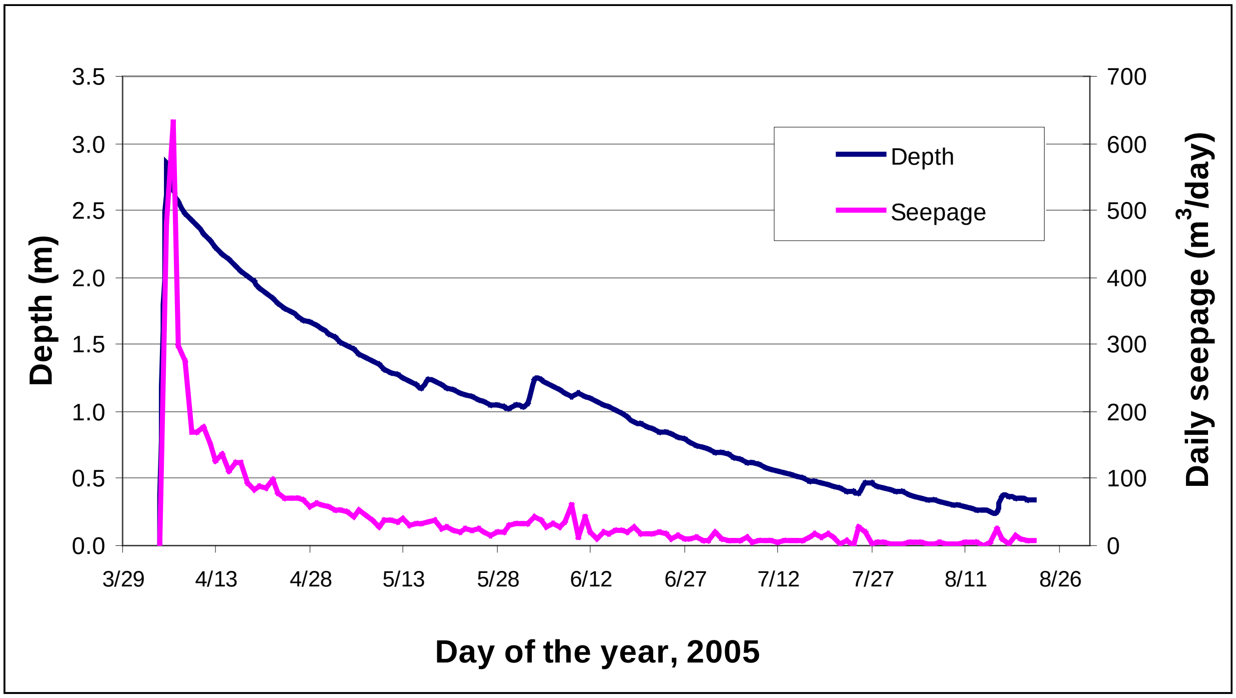
Examination of the Water depth Record to Estimate Daily Gross Seepage

One large inflow event on April 5, 2005 from a 9.5-cm rainfall event that produced an estimated 9,300 m^3 of runoff filled the reservoir and produced an estimated overflow of 3,370 m^3. This event, and the subsequent period with essentially no more inflow, provided me with the opportunity to observe seepage rates for the full range of depths for the reservoir.

Temporal change in water depth and seepage volume for the large inflow event resulting from the inspection of the daily water-level record for DPL-Hogan are shown in Figure 2.3.

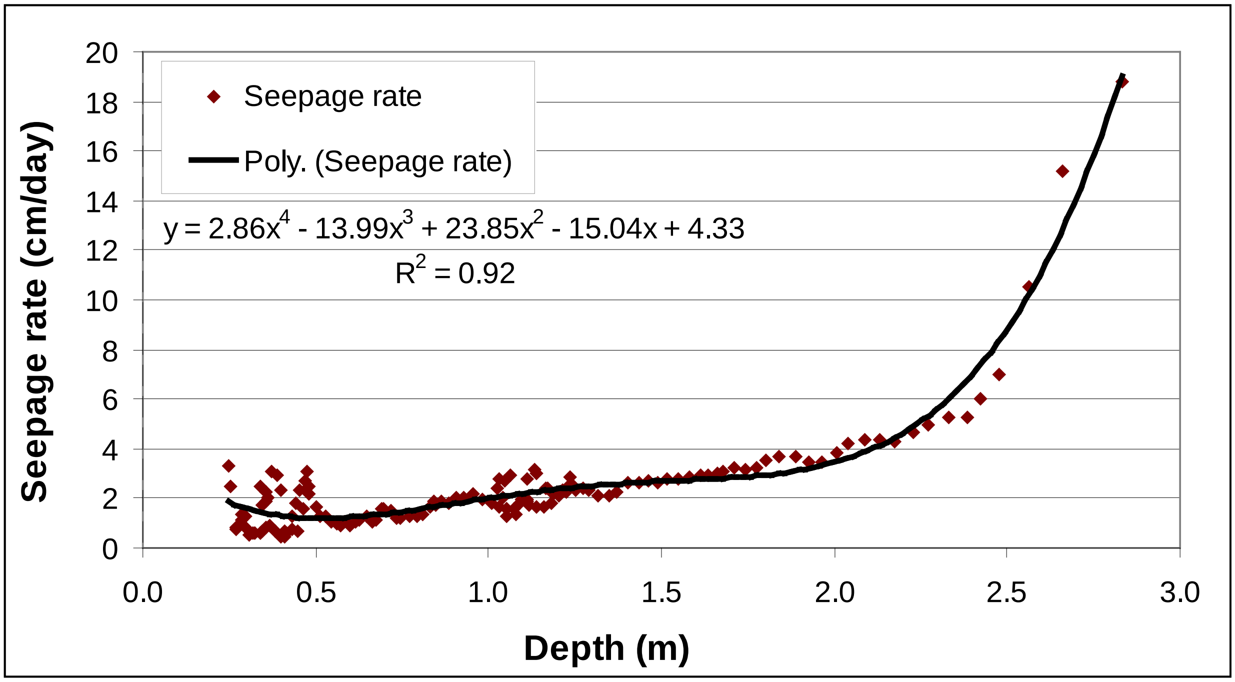
Calculated daily seepage volume was converted to depth by dividing the calculated volume of seepage by the surface area for the day to estimate daily seepage rate. These results are shown in Figure 2.4.

Figure 2.3. Temporal change in depth of water in the reservoir and calculated daily seepage volume for DPL-Hogan for a large inflow event period in 2005 (source: Water-depth data provided by the Kansas Division of Water Resources)



It was noticed that, there was a linear relationship between seepage rate and water depth in the reservoir. However, on some days the seepage rate did not agree with this trend. This is because of uncertainties in the input variables. The precipitation data was used from the weather station located 6 km away from the reservoir site. ET_0 was used from the Scandia and Colby which were also located away from the site and therefore, the two stations ET_0 values were weighted on the distance from the reservoir site. Inflow was another input parameter estimated from the water-depth sensor readings. This was complicated by the fact that inflow occurred from runoff events occurred at the same time as precipitation. In addition, seepage rates changed when the water depth increased. Thus, I had to make estimates of both inflow and seepage for those days. The water-depth sensor's precision in measurement was another factor affecting daily water budget calculations.

Figure 2.4. Calculated daily seepage rate versus water depth in DPL-Hogan for the 2005 large inflow event



Clearly, the average seepage rate decreased as the water depth in the reservoir decreased. I believe the high rate of seepage is mostly from higher rates of infiltration into the sides of the reservoir that are only infrequently inundated and probably due somewhat to the additional hydraulic head on the bottom parts of the reservoir.

The resulting water balance for the period, April 6 to August 22, 2005 is shown in Table 2.3. For this period, overflow amounted to 36% of total inflow. Precipitation onto the water surface was small compared to inflow and equaled about 67% of the calculated evaporation from the water surface. Thus, gross seepage was the only way that nearly all of the water retained in the reservoir was lost. Since gross seepage is such an important part of the water budget for these ponds, understanding how much of it might become potential ground-water recharge is important.

The results of this technique indicate that, there is a relatively-linear relationship between depth of water in the reservoir and seepage rate in the lower half of the reservoir. These areas are inundated much more frequently than the upper areas of the reservoir and have lower seepage rates because of a combination of accumulation of fines and some surface sealing caused by biological growth.

Table 2.3. Water balance for DPL-Hogan for the period, April 5 to August 22, 2005

Inputs	All volumes in m^3 *
Inflow from the watershed	10,040
Precipitation on water surface	430
Total	10,470
Outputs	
Overflow	3,640
Evaporation from water surface	640
Gross seepage	6,100
Cattle consumption (unknown & small)	0
Total	10,380
Change in storage	100

*All volumes rounded to nearest 10 m^3.

If all that were needed was the total seepage volume or seepage losses from the reservoir relationship in Figure 2.4 could be used. For the purposes of my work, however, estimates of the net seepage that would move below the rooting depths of plants that grow in the reservoir pool area when there is no inundation are needed. So, I need to know the amount of gross seepage at different levels within the reservoir pool area. Then, I can simulate the water balance that results from the seepage at the various levels during inundation periods along with the water balance when plant growth occurs and removes water from the soil down to the rooting depth of plants. Of course, too, I need to examine the transition as wetting and drying occurs over the year(s). In Chapter 3, I will develop my method to estimate gross seepage at different levels in the reservoir, calibrate it for DPL-Hogan, and the apply it at two other reservoirs to verify it. Then, in Chapter 4, I will develop my method to estimate net seepage on each level within the reservoir to provide my best estimate of net seepage and potential ground-water recharge.

CHAPTER 3 -Gross Seepage Module Development and Application

Introduction

Computer simulation models have their own advantage in representing natural operations. They have become more important since they can be adapted to a very wide range of field conditions. In this regard, watershed simulation model development is no exception. There are many good watershed models that have been developed and being used by both scientific community and other users.

The present study is interested in estimating the reduction in streamflow and the increase in ground-water recharge contribution from small reservoirs. Computer simulation can help to achieve this goal. The details of a gross seepage module are presented in this chapter.

The present reservoir simulation model is divided into three modules - an inflow module, a gross seepage module, and a net seepage module. The inflow module is the part of POTYLDR model and runoff from the Hydrologic response unit (HRU) is the input for the gross seepage module along with precipitation on to the water surface. The gross seepage module is important to determine the dispensation of inflow at the reservoir site among the outflows of seepage, evaporation, and overflow in the operation of a reservoir. Also, the gross seepage module provides a way to estimate seepage losses at different locations within the reservoir which is important to know so that estimates of net seepage losses or potential ground-water recharge can be made. The details of the development of the net seepage module are discussed in the Chapter 4.

POTYLDR Model Description

POTYLDR is a unit area, physically based water balance model that simulates watershed water balance of wide range of land uses and cropping pattern. It also simulates the water balance for small reservoirs. Results from up to 18 separate land uses can be aggregated to estimate the streamflow and ground-water recharge from a small watershed. The original Potential Yield Model was developed by Koelliker et al. (1981) to simulate water budget of representative tracts of land. It was developed for conditions found in the High Plains of Kansas. Later, the model was converted to PC format in 1986. It was used without modification until

1993, and it was revised by splitting meteorological data files into one for precipitation and another for maximum and minimum daily temperatures. Irrigation was also added and can be simulated on of the land uses in the sub-basin. The original model name was changed to Potential Yield Revised (POTYLDR). This model simulates the water yield on daily basis. This model allows for different land uses and estimates the water yield on monthly or annual basis for a given watershed area. Runoff curve numbers are used to partition daily precipitation into runoff and infiltration. The output from the simulation includes ASCII files includes precipitation excess, percolation and seepage from pond and irrigation use on each land use. These files can be output on a monthly or annual basis. To improve their results and operation components which estimate potential evapotranspiration, runoff, interception, and snow have been modified.

It runs on a daily water budget of the inputs of precipitation and outputs of evaporation, evapotranspiration, surface runoff and recharge and the resulting daily change in water amounts in the interception account, soil water volume, accounts for each combination of conditions at the various locations within the basin. The overall POTYLDR served as the basic operational framework for the present small reservoir water budget simulation model to estimate inflow to a reservoir for long-term estimates.

User-Specified Inputs to Gross Seepage Module

The gross seepage module solves Equation 2.1 on a daily basis and requires daily data inputs of inflow from the watershed area, precipitation depth and evaporation depth. The reservoir characteristics of stage-surface area and stage-storage volume relationships are input in a step-wise fashion since it is needed to estimate gross seepage at various locations within the reservoir storage area. To estimate gross seepage at different depths, the reservoir storage area is divided into 14 level sections or stages (Fig. 3.1). The measured reservoir stage-storage volume and stage-surface area relationships for one of the three reservoirs studied are compared graphically with the relationships used in the gross seepage module in Figure 3.2. Since the reservoir is modeled with 14 level sections the user must define the height from the bottom of the reservoir and surface area for each level section. Also, the estimated daily seepage rate in cm/day at 0.3-m or less of hydraulic head (S_0) for each level is needed. Figure 3.3 shows the estimated values of S_0 for all 14 levels in the reservoir DPL-Hogan (described in Chapter 2). To account for the influence of water head on seepage rate for each level (S_L, L =1 to 14), a default exponent of 0.25 on the head of water greater than 0.30 m (h_L) is used. If $h_L > 0.3$ m, then

$$S_L = S_0 * (h_L/0.3)^{0.25} \tag{3.1}$$

For the entire modeling process, seepage and infiltration are assumed to move only vertically resulting in only one-dimensional soil-water movement.

The model begins with an initial depth of water in the reservoir and it performs the daily water balance on a volumetric basis.

Figure 3.1. Reservoir representation of level sections to estimate gross seepage rates for different depths and areas

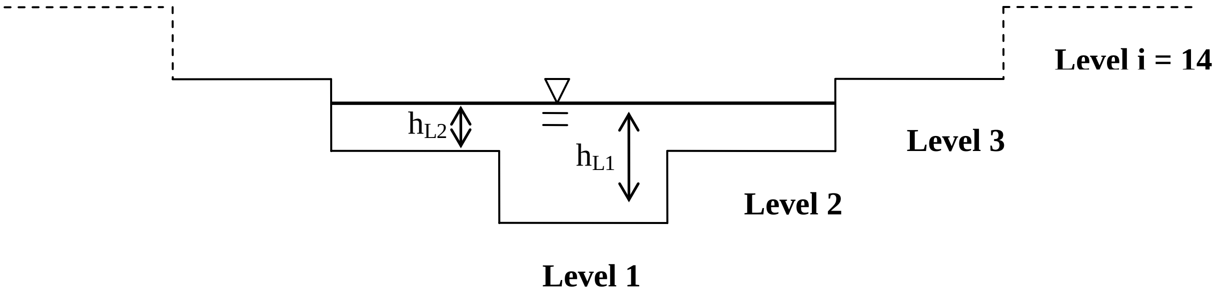


Figure 3.2. Stage-storage volume and stage-surface area relationships for the reservoir DPL-Hogan from field data and as represented in the input the gross seepage module

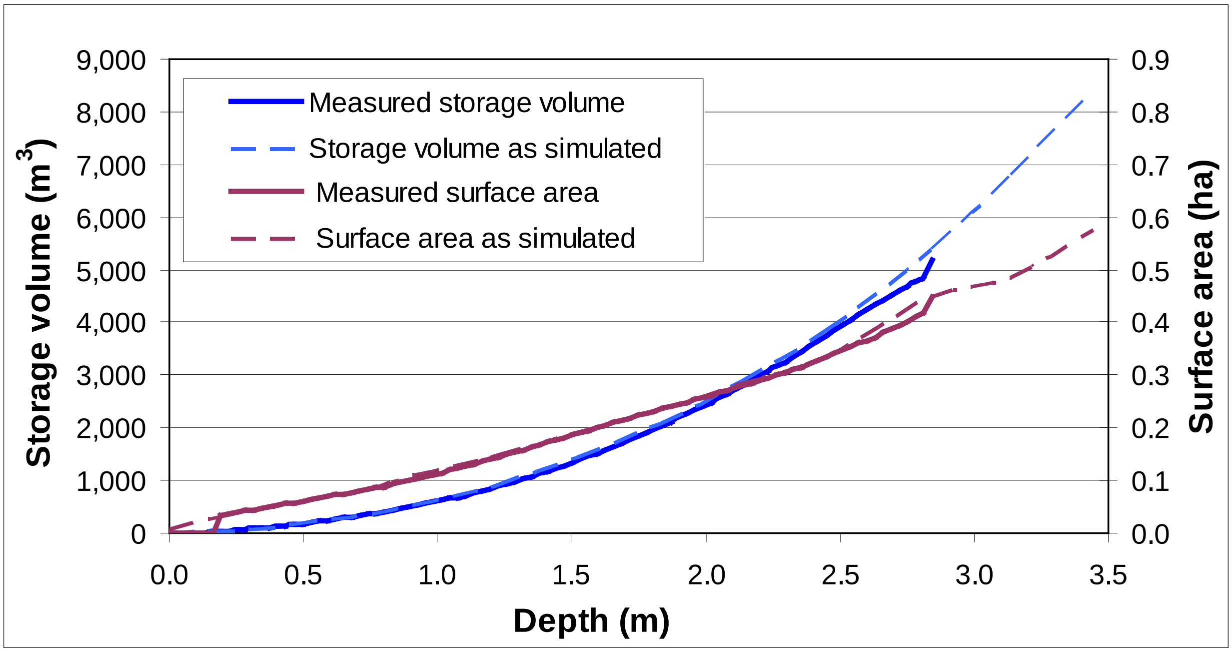
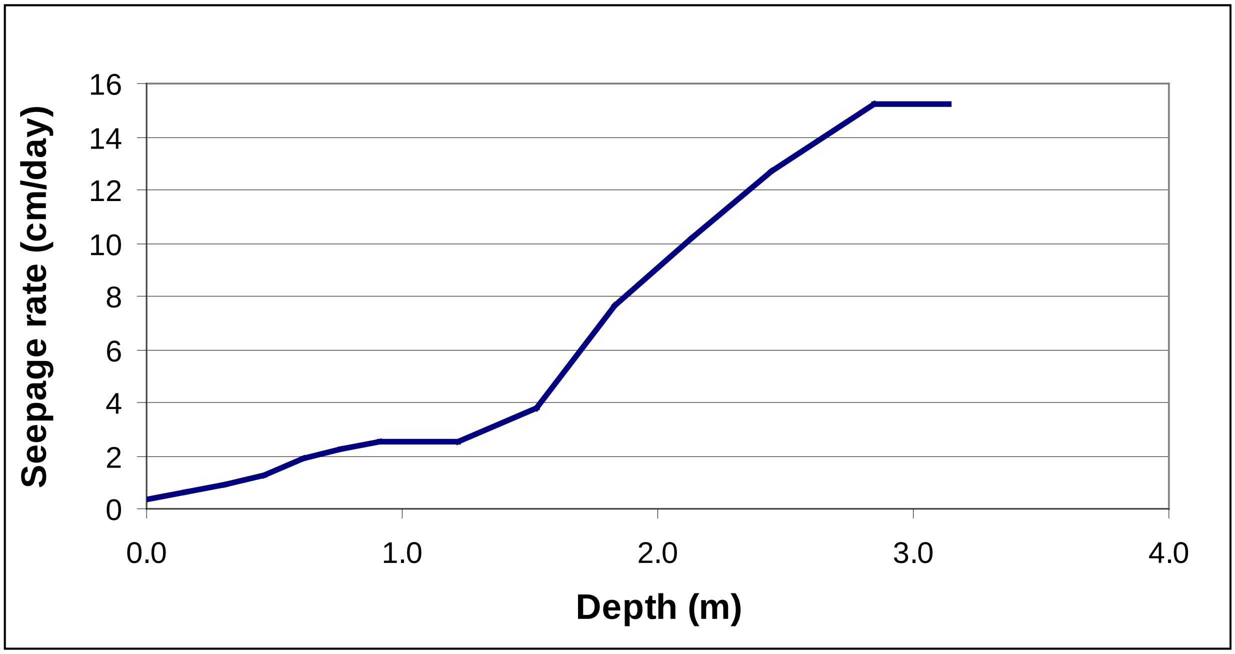
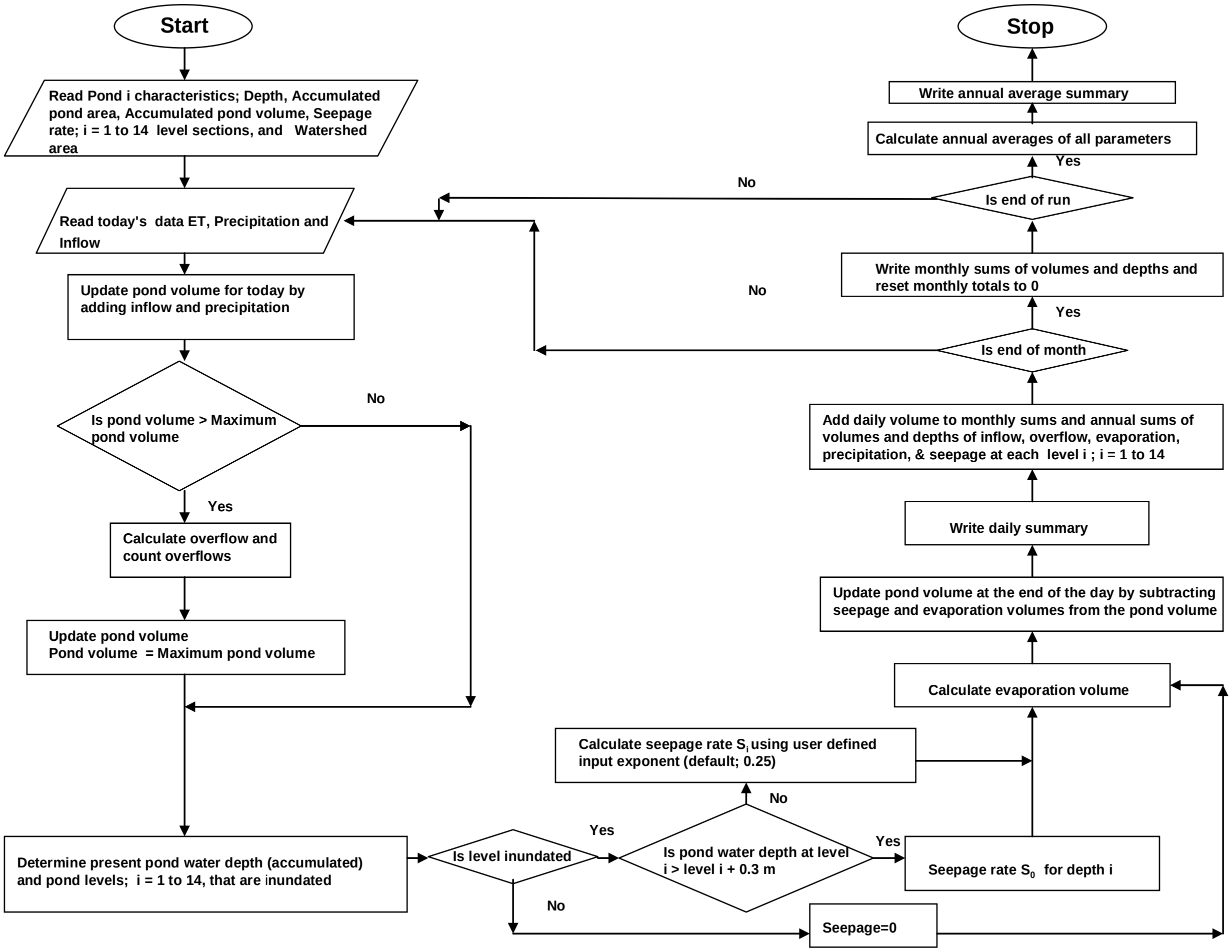


Figure 3.3. Seepage rate at 0.3-m head versus depth from the bottom of the reservoir DPL-Hogan



Precipitation onto the reservoir water-surface area and inflow from the watershed area are the inputs and evaporation from the free-water surface, overflow through the spillway and seepage volume from each level section are the outputs of the reservoir water budget. The seepage rate calculation is based upon depth of inundation of each level section. Those level sections that are not inundated at the beginning of the day are assumed to contribute runoff at the same volume per unit area as the watershed. ET_0 was used as the estimated evaporation from the free-water surface. Distance-weighted average of ET_0 values from nearby stations of Scandia and Colby, KS were used. Precipitation data from the nearest meteorological station, Long Island, KS was used. The model reads all daily inputs at the beginning of the day and updates the depth in the reservoir at the beginning of each day by taking the depth at the end of the previous day and adding the input of inflow and precipitation and estimates the new water depth and any overflow to determine which level sections are inundated. Then, it calculates seepage from each level and evaporation from the reservoir water surface over all levels that are inundated. Finally, it calculates the depth at the end of the day after removing evaporation losses and seepage from each level that is inundated and the proceeds to the next day. The details of the module operation are shown in the Figure 3.4.

Figure 3.4. The general algorithm for gross seepage module



Overflow Calculation

The maximum depth or capacity of reservoir to hold water was based on the location of the spillway. The spillway location for the module is at the water depth of the 13th level section. Partitioning between overflow through the spillway and temporary storage above the spillway is used to estimate the overflow volume and the average water depth for those days with overflow.

The event with overflow was determined after careful observation of the hourly water-depth sensor data. Whenever the water depth exceeds the maximum reservoir depth that is spillway height, it was considered as the overflow event. To estimate the water depth for days with overflow, two-thirds of the difference between the calculated water depth and the spillway

(Level 13) and the depth at Level 14 was deducted every day from the depth at Level 13 until the water depth came back down to the water depth at the spillway (Level 13). This assumption was made after estimating the amount of water flowing over the spillway. It is assumed that the spillway is an earthen rectangular weir. The weir formula was used to calculate the amount of water that flowed over the spillway. At the end of days with overflow, the exact amount of overflow was calculated by solving the water balance after seepage and evaporation were determined for the day and assuming that the water depth was at the spillway (Level 13) at the end of the day.

Seepage Calculation

Gross seepage into each level section is estimated after checking the water depth in the reservoir. If the level is not inundated, no seepage occurs. If the level section is inundated less than 0.3 m, the estimated seepage rate S_0 is used. If the level section that is inundated more than 0.3 m, the estimated seepage rate, S_L, is calculated using Equation 3.1.

Two separate output files are generated from the gross seepage module. One of them prints a daily record that lists gross seepage from each of the 14 levels, precipitation, ET_0, inflow depth, and reservoir level which is used as input to the net seepage module. The other output is a monthly water budget for the reservoir that can be used to estimate the effect of the reservoir on streamflow and gross potential ground-water recharge with and without the reservoir at the reservoir site.

Information about the reservoir DPL-Hogan, selected for the study is presented in the Chapter 2. Table 3.1 shows the information about the reservoir that is required as input to the gross seepage module.

As earlier discussed in the Chapter 2, DPL-Hogan was one of two water sources for about 30 cattle in the approximately 80-ha fenced area around the reservoir. Cattle were in the area only during the grazing season that was about 150 days. Water consumption by cattle averages about 0.03 m^3/day (Guyer, 1977). If all 30 cattle drank from the reservoir, total water use for a day would be about 0.9 m^3. With a reservoir depth of 0.9 m the surface area is 1,390 m^2 the cattle consumption would equal less than 0.1 cm from the reservoir which is less than the 0.3-cm increment from the water-depth sensor record. Total maximum water consumption for the grazing season was estimated to be small, on the order of 180 m^3, and all of was not from the reservoir. My estimate is that no more than 100 m^3 was consumed by the cattle. This is well within the uncertainty of my other assumptions, so I did not include it in the gross seepage module calculations.

Table 3.1. DPL Hogan Pond geometry

Level sections	Depth (m)	Area accumulated (ha)	Volume accumulated (m^3)	Seepage rate at 0.3-m head (cm/day)
1	0.00	0.028	0	0.38
2	0.15	0.042	25	0.64
3	0.30	0.055	86	0.89
4	0.46	0.068	160	1.27
5	0.61	0.082	259	1.91
6	0.76	0.099	370	2.22
7	0.91	0.139	530	2.54
8	1.22	0.184	900	2.54
9	1.52	0.229	1,233	3.81
10	1.83	0.273	2,048	7.62
11	2.13	0.324	2,824	10.16
12	2.45	0.413	3,737	12.70
13	2.84	0.443	5,378	15.24
14	3.14	0.480	6,759	15.24

Calibration of Gross Seepage Module

The gross seepage module was first calibrated by applying it to the reservoir, DPL-Hogan. Then, two other reservoirs, DCN-Zimb and DRA-Holste, were operated with the modules to examine visually how well results from the module agreed with their observed water depths during the measurement period.

Initial calibration was done for the period, April 5 through October 22, 2005, when water depths in the DPL-Hogan reservoir started at spillway level and dropped to zero.

Daily values of precipitation, ET_0, inflow, and measured water depth were input along with the reservoir characteristics represented by the 14 level sections which included their height above the bottom, surface area and estimated seepage rate at 0.3-m of hydraulic head. Outputs of calculated water depth in the reservoir from each run were compared visually with the measured record of water depth and the average difference between measured depth and simulated depth was calculated. For the calibration period, the average difference (measured – simulated) in water depth was only 1.3 cm.

A major assumption in the gross seepage module is that the seepage rate for each level increases when the depth of water above it increases. To account for the influence of water head on seepage rate, the default exponent of 0.25, as shown in Equation 3.1, was assigned to the gross seepage module. To evaluate the accuracy of this exponent value, a test was conducted to select be exponent that gave the best fit. The exponent values of 0.0, 0.25, 0.50, and 1.0 were assigned to the head to modify the seepage rate assigned to each level. Simulation runs for the 199-day period April 6 to October 22, 2005 that followed the major inflow event on April 5, 2005 were made. The comparative changes in water depth in the reservoir DPL-Hogan with each exponent are shown in Figure 3.5. Among all exponents tested, 0.25 had the best visual fit with the measured water depth. The daily differences between measured and simulated water depth for the exponent of 0.25 are presented in the Figure 3.6. Also as shown in Table 3.3, the sum of squares of the differences (measured – simulated) between daily depths was the smallest for the exponent 0.25. I therefore, concluded that, the exponent 0.25 is the best value could be used to estimate seepage rate when the head of water is more than 0.3 m above the bottom of each level section.

The sum of squares of the difference between measured and simulated water depth for the different exponents tested are presented in the Table 3.2. It can be observed that, when the value 0.25 was used as the exponent, the difference of sum of square was minimum compared to other exponents used. I therefore, used 0.25 as the exponent for head of water over the bottom of the each level section to estimate seepage rate.

Figure 3.5. Comparison of the results of predicted water depth versus time for different exponent values on the head of water above the level sections used to estimate seepage rate

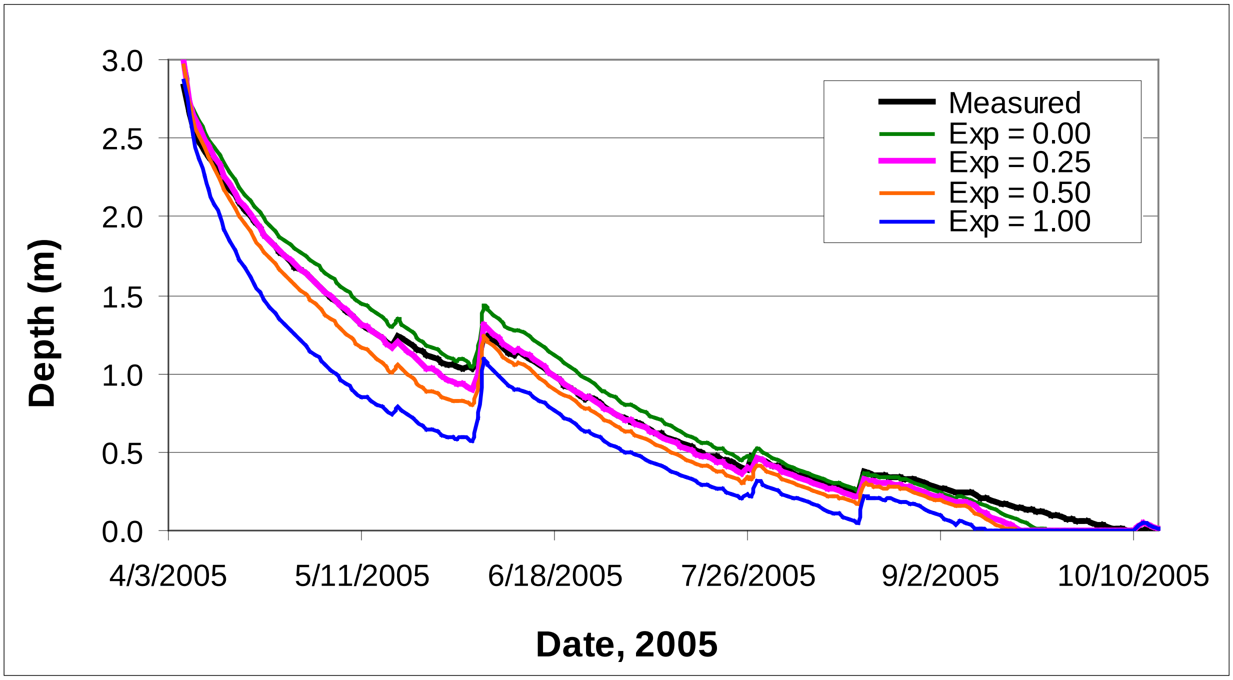


Figure 3.6. Difference (measured – simulated) in daily reservoir water depth when the head exponent = 0.25 was used on each level to modify the seepage rate when the simulated water depth was greater than 0.3 m

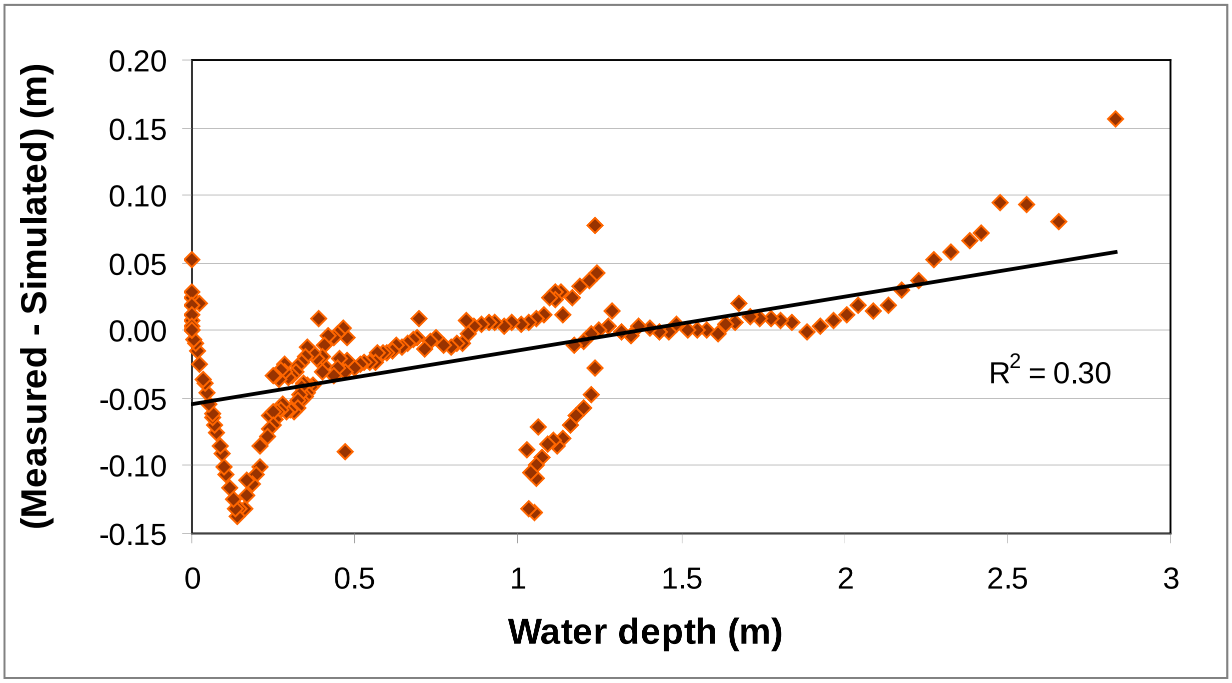
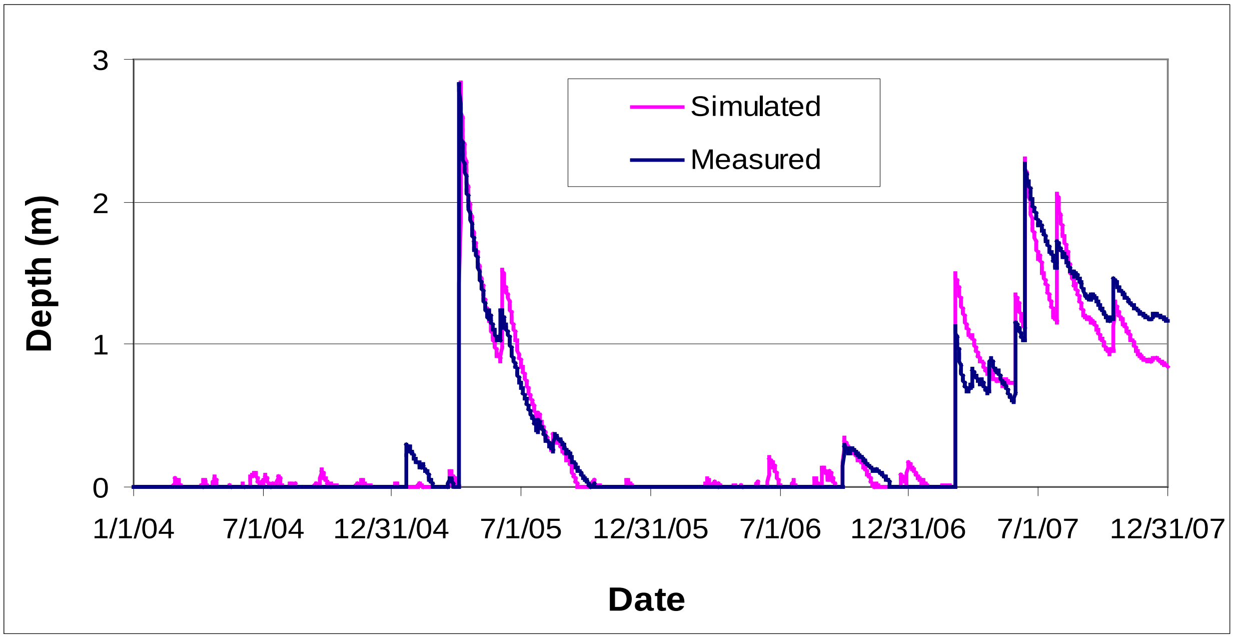


Table 3.2. Results of sum of squares of difference (measured – simulated) in daily reservoir water depths to determine the best exponent on head for water depths when the head exponent was changed from 0 to 1.

	Head exponent			
	0.00	0.25	0.50	1.00
Sum of squares of differences between measured and simulated reservoir water depth, m^2	1.52	0.58	2.25	14.05

Subsequently, the simulation for DPL-Hogan was run for four years. Table 3.3 includes the water balance for DPL-Hogan for the 4-year calibration period. The results are similar to the event period discussed in the Chapter 2 with the exception that no additional overflow occurred. Gross seepage was computed to be 94% of the inflow retained in the reservoir. Also, Figure 3.7 shows the daily measured and simulated water depths for the period. Results were very good and the average difference between measured and simulated daily water depth for DPL-Hogan was 1.0 cm.

Figure 3.7. Simulated versus observed water depth comparison for reservoir, DPL-Hogan, 2004-07



Verification of Gross Seepage Module

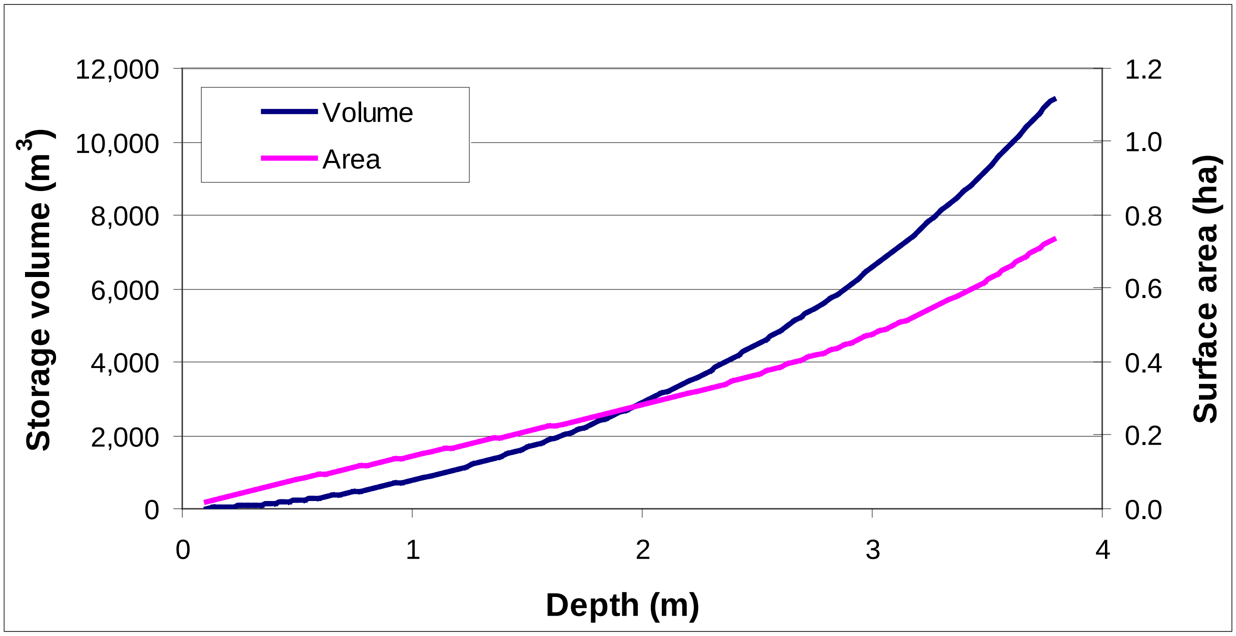
The other two reservoirs DCN-Zimb and DRA-Holste were selected for model verification. The process of model verification involved comparing the model simulation results with measured water-depth data.

Description of the Reservoirs

DCN-Zimb

This reservoir is located in the north-western most part of Kansas (See Fig. 1.1). Precipitation data, obtained from the nearest station St.Francis 8NW, located 6 km from the reservoir, was used. Annual average precipitation is 46 cm. DCN-Zimb has a watershed area of 29.9 ha with average land slope of seven percent. Figure 3.8 shows the stage-storage volume and stage-surface area relationship for the reservoir. One third of the watershed area is cropland with level-closed end terraces in poor condition and the remaining two thirds is grazed pasture/range. Soils are characterized as Colby silt loam with good permeability of 1.5 to 4.8 cm/hr. ET_0 was taken as 97% of the Colby station. The reservoir surface area at spillway level is 0.48 ha.

Figure 3.8. Stage-storage volume and stage-surface area relationship for reservoir DCN-Zimb

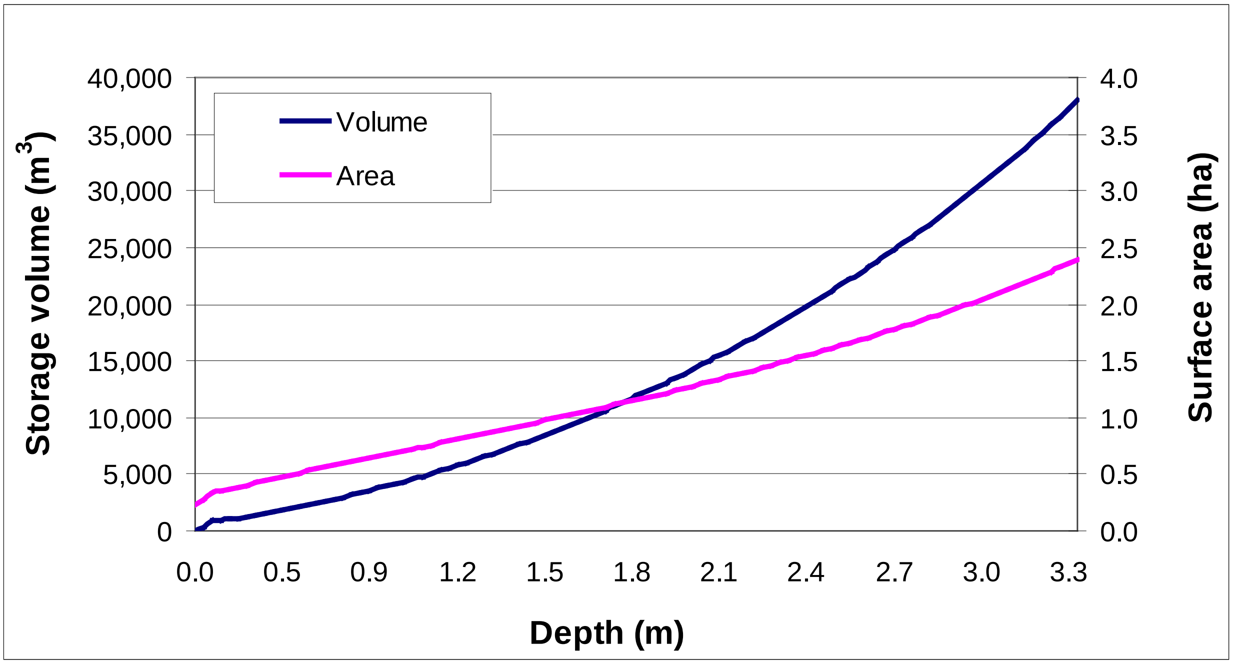


DRA-Holste

DRA-Holste is located in the Rawlins County (See Fig.1.1) and has a watershed area of 174 ha. Precipitation data was obtained from the nearest station at Atwood 8SSE, located 10 km from the reservoir. Annual average precipitation is 55 cm. Soils at the site have good permeability of 1.5 to 4.8 cm/hr**.**

Land use in the 174-ha watershed area is characterized by about half cropland with level, closed-end terraces in good condition and half pastured rangeland. A weighted average of ET_0 between Colby, KS and Scandia, KS was used for the site and average annual is 154 cm. The reservoir surface area at spillway level is 1.83 ha. The stage-storage volume and stage-surface area relationships for the reservoir are shown in Figure 3.9.

Figure 3.9. Stage-storage volume and stage-surface area relationships for reservoir DRA-Holste



Verification process

In order to get my model fit to the observed water depth data, I had to input the reservoir characteristics as required by the gross seepage module. An important unknown, however was the seepage rate for the two reservoirs. First, I looked at soil types which are listed in Table 3.3.

They are from NRCS Soil Survey (2008) data. Based on the soil series, I approximated the percentage of sand, silt, and clay that is shown in Table 3.3. Then, I used soil water characteristics from texture relations presented by Saxton et al. (1986) to obtain approximate hydraulic conductivity as shown in the Table 3.3. The values of approximate hydraulic conductivity were obtained by the ratio of sand, silt, and clay content of the soils of the reservoir sites. By this procedure, all three reservoirs would be expected to have essentially the same seepage rates. Initially, I used the same seepage rates for DCN-Zimb and DRA-Holste. I found however that, DCN-Zimb agreed well except at the lower levels. So, I adjusted seepage rate for levels 1-4. That was the only seepage rate adjustment I made for DCN-Zimb.

For DRA-Holste, I found that when I used the same seepage rates as for DPL-Hogan the simulated water level dropped much more slowly than the observed water-depth sensor data. Then, I examined the temporal change following the major inflow event to each o the three reservoirs. To compare the three, I calculated the slope of the temporal change in depth versus time for all the reservoirs by examining the slope of depth versus time of the curves shown in the Figures 3.7, 3.10, and 3.11 for DPL-Hogan, DCN-Zimb, and DRA Holste, respectively. The rates I found are shown in the Table 3.3. They showed that, DPL-Hogan and DCN-Zimb were reasonably close. On the other hand, the rate for DRA-Holste was about four times greater than the average of other two. Therefore, I adjusted the seepage rates for all levels in DRA-Holste

Table 3.3. Soil characteristics of the three reservoirs and estimated seepage rate comparisons.

Reservoir	Soil series	Approx. sand/silt/clay (percent)	Approx.[a] hydraulic conductivity (cm/hr)	Slope of [b] seepage depth vs. time (cm/day)
DPL-Hogan	Uly Penden	25/45/30	1.2	4.0
DCN-Zimb	Colby	30/47/23	1.3	6.7
DRA-Holste	Colby	30/47/23	1.3	22.5

[a] Saxton et al. (1986)

[b] From the following inflow event to each reservoir, see Figs. 3.7, 3.10, and 3.11

Figure 3.10. Simulated versus observed water depth comparison for reservoir DCN-Zimb, 2004-07

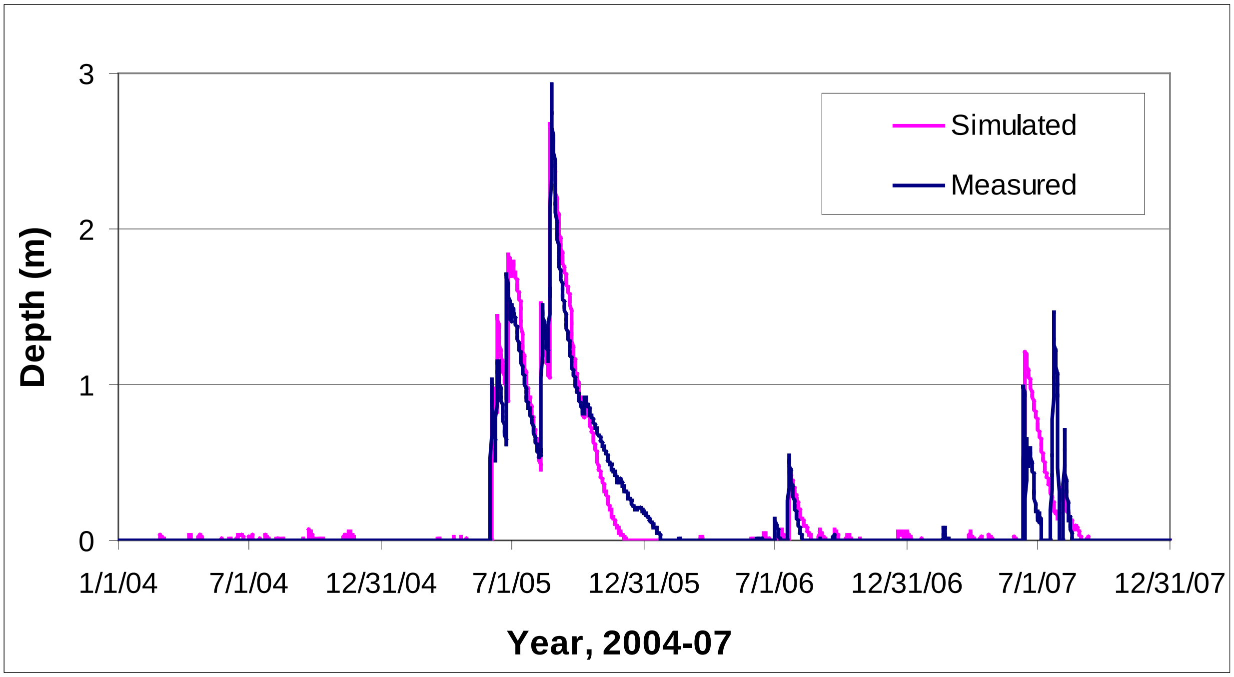
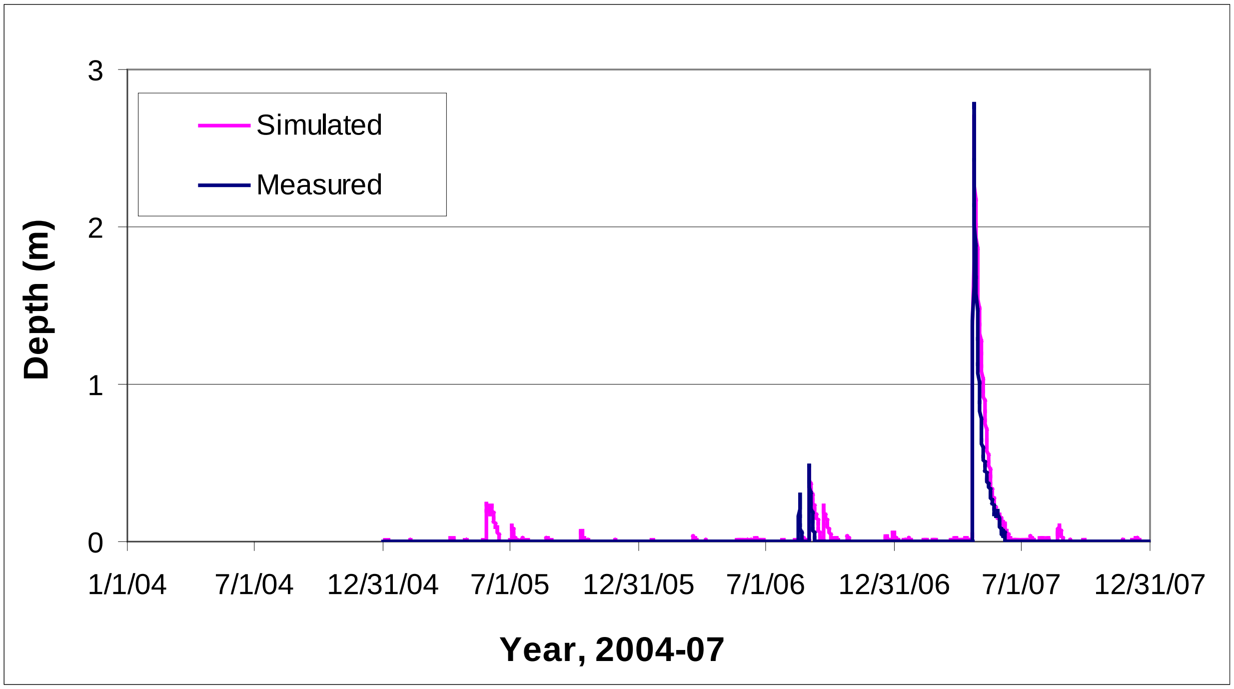
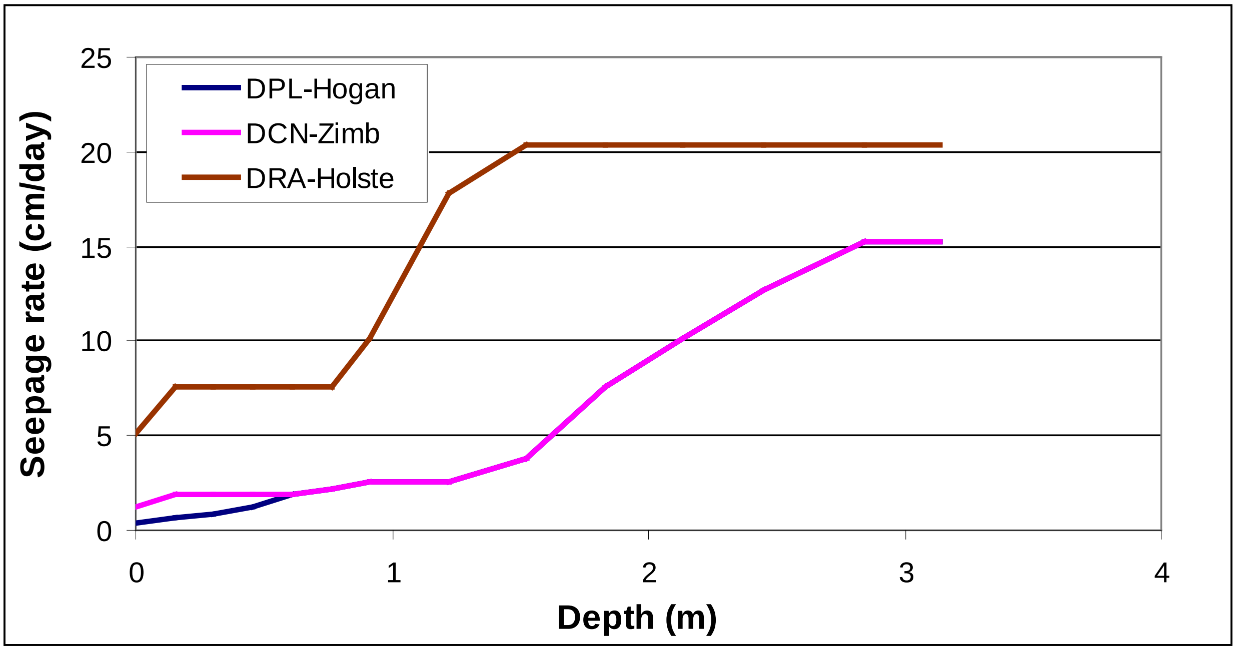


Figure 3.11. Simulated versus observed water depth comparison for reservoir, DRA-Holste, 2004-07



upward by about five times in the lower five levels, four in the middle levels and two in the top levels to obtain good agreement between simulated and measured water depths. This amount of adjustment upward was much greater than I expected. Finally, I realized that DRA-Holste was constructed differently than other two. It was built as a part of the construction of Highway US-36 by filling the stream valley. This resulted in little disturbance of the surface soils in the reservoir storage area. So, the soils in the reservoir area are more typical of the surface soils than of those that would be found if the embankment had been built by excavating the materials from reservoir storage area. Hence, the higher seepage rates that were necessary to obtain good agreement between simulated and measured water depths can be justified. Figure 3.12 shows the seepage rate versus depth used in the three reservoirs for calibration and verification simulations.

Figure 3.12. Seepage rate versus depth used in the three reservoirs for calibration and verification simulations.



Figures 3.10 and 3.11 show comparisons of the measured and simulated water depths during the field measurement period. The average difference between measured and simulated daily water depth for DCN-Zimb was 4 cm and for DRA-Holste it was 1 cm. Days with zero depths are included in the averages. These results showed that the gross seepage module worked

well for other reservoirs and should be useful for evaluating other reservoirs. Finally, Table 3.4 includes the simulated water balance for these two reservoirs.

Table 3.4. Simulated water balance for the three reservoirs used for the study, 2004-07

Inputs	All volumes in m^3 *		
	DPL-Hogan	DRA-Holste	DCN-Zimb
Inflow from the watershed	19,600	96,310	19,210
Precipitation on water surface	2,560	9,480	1,870
Total	22,160	105,790	21,080
Outputs			
Overflow	3,370	24,820	650
Evaporation from water surface	3,080	8,060	3,190
Gross seepage	15,700	72,920	17,240
Cattle consumption (unknown & small)	0	0	0
Total	22,150	105,800	21,080
Change in storage	-43	0	0
Delta difference	-32	0	0
Delta difference in %	-0.1	0.0	0.0

*All volumes rounded to nearest 10.

Results and Discussion

Effect of Reservoirs on Streamflow and Gross Seepage at the Reservoir Site

The details of water budget estimation with and without reservoir scenarios for all three reservoirs are presented in the Table 3.5. It was observed that contribution to streamflow without the reservoir was significant. With the reservoir in place, streamflow from the reservoir watershed was reduced by 83% to 97%. This was calculated by dividing the difference between total inflow from the watershed area without the reservoir and the overflow with the reservoir in place by the total inflow from watershed area without the reservoir. For DPL-Hogan the values from Table 3.5 in m^3 are (19,870-3,370)/19,870 that equals 83.0%. The gross seepage at the reservoirs ranged from 93% at DCN-Zimb to 100% at DRA–Holste. Gross seepage was calculated by dividing gross seepage by the difference between inflow and overflow with the reservoir in place. For DCN-Zimb for the values in Table 3.5 in m^3 are 17,240/ (19,210-650) that equals 93.0%.

Table 3.5. Comparative water input and output with and without reservoir at the three sites during the study period, 2004-07

Inputs	All volumes in m^3 *					
	DPL-Hogan		DRA-Holste		DCN-Zimb	
	Without reservoir	With reservoir	Without reservoir	With reservoir	Without reservoir	With reservoir
Inflow from the watershed	19,870	19,600	97,280	96,310	19,460	19,210
Precipitation on water surface	-	2,560	-	9,480	-	1,870
Total	19,870	22,160	97,280	105,790	19,460	21,080
Outputs						
Overflow	19,870	3,370	97,280	24,820	19,460	650
Evaporation from water surface	-	3,080	-	8,060	-	3,190
Gross seepage	-	15,700	-	72,920	-	17,240
Cattle consumption (unknown & small)	-	0	-	0	-	0
Total	19,870	22,150	97,280	105,800	19,460	21,080
Change in streamflow	-16,500		-72,460		-18,810	
Change in streamflow (%)	-83.0		-74.5		-96.7	
Increase in gross seepage	15,700		72,920		17,240	

*All volumes rounded to nearest 10.

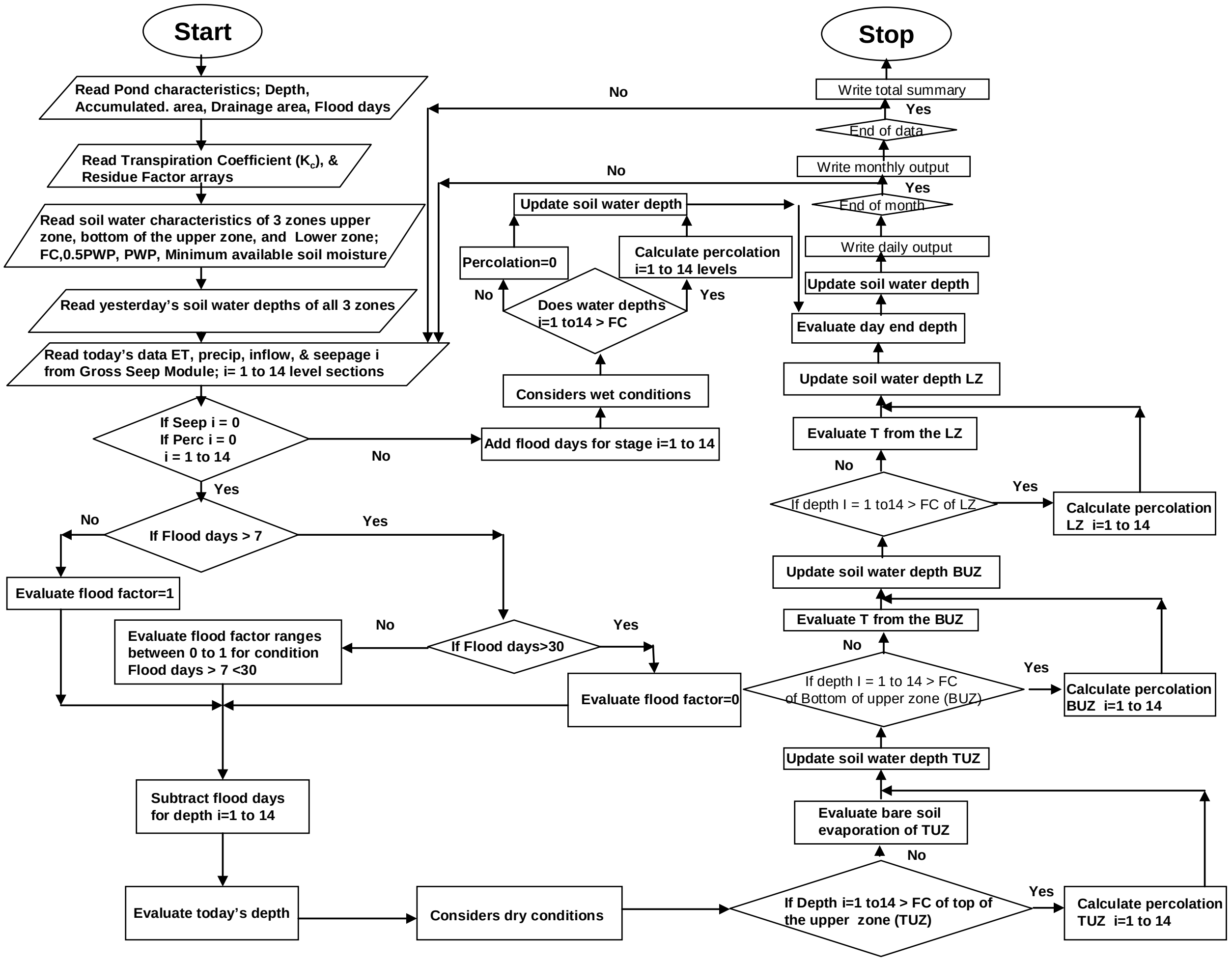
Now I have estimates of gross seepage for each of the levels. In Chapter 4, I will develop and present how I estimate net seepage.

CHAPTER 4 - Net Seepage Module Development and Application

Net Seepage Module

The net seepage module is designed to simulate net seepage on a daily basis. Net seepage is defined as the water that percolates out of the bottom of the rooting zone of the plants that can be expected to grow on each of the 14 levels in the reservoir. This water can become ground-water recharge from the reservoir. A flowchart for the net seepage module operation is shown in Figure 4.1. Appendix C contains the FORTRAN 95 coding for the net seepage module.

Figure 4.1. The general algorithm for net seepage module



Soil Physical System and Soil-Water Movement

The soil profile on each level is divided vertically into three zones. They are the top of the upper zone (TUZ) equal to 10.2 cm, the bottom of the upper zone (BUZ) equal to 20.3 cm, and the lower zone (LZ) that has thickness of 120 cm (Fig. 4.2). The TUZ receives water from infiltration from precipitation when not inundated and seepage when inundated and loses water only by bare soil evaporation and runoff when not inundated and by percolation to the BUZ whenever the water content of the TUZ exceeds field capacity (FC). The BUZ receives percolated water from the TUZ and loses water by transpiration (T) when conditions are suitable for plant growth and by percolation to the LZ whenever the water content exceeds FC. The LZ receives percolated water from the BUZ and loses water by T when conditions are suitable for plant growth and by percolation out of the LZ whenever the water content exceeds 90% of field capacity. Water is assumed not to move up to the layer above it and back from percolation that moves below the LZ. Table 4.1 shows the soil-water characteristics for silt loam type soil.

Figure 4.2. Assumptions made for vertical movement of water in the soil profile for net seepage module

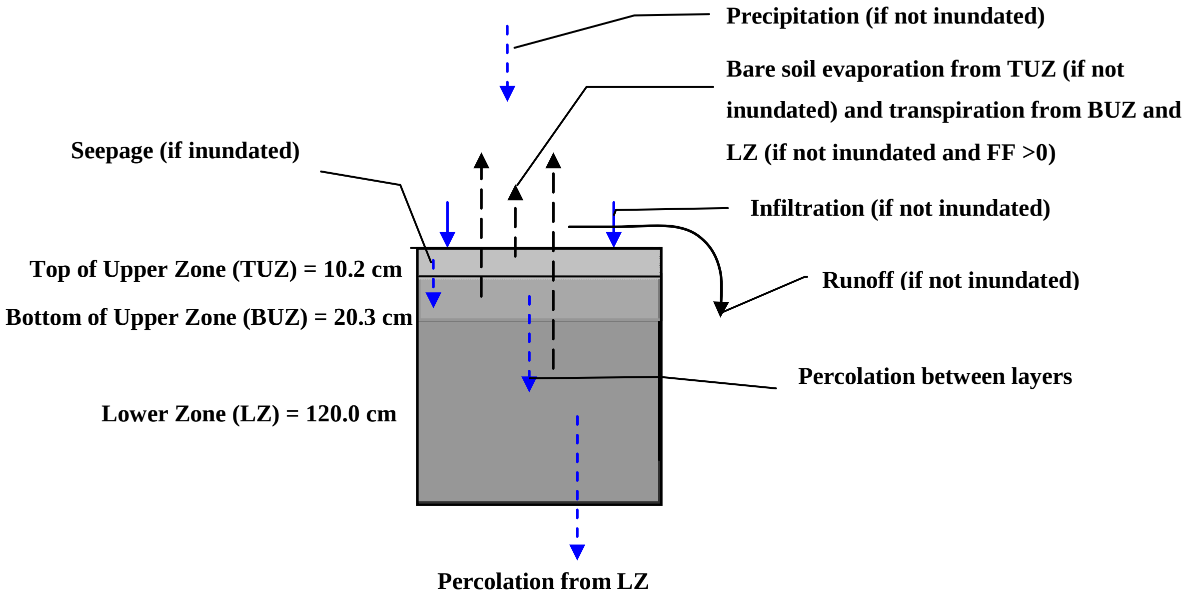


Table 4.1. Soil-water characteristics of silt loam type soil

Soil zone	Soil zone thickness (cm)	Water content at (cm/zone)			
		FC	90% FC	PWP	50% PWP
TUZ	10.2	3.6	NA	2.0	1.0
BUZ	20.3	7.2	6.5	4.0	NA
LZ	120.0	42.7	38.0	24.4	NA

Bare Soil Evaporation

Water loss by bare soil evaporation (BSE) may occur whenever the soil is not inundated. The process is described by the two-stage process found in FAO Irrigation and Drainage Paper 56 (Allen et al., 1998). The first-stage, when the soil is wet, BSE occurs at a constant rate equal to the amount of ET_0 that reaches the surface. A term, soil evaporation reduction coefficient (K_r), equals 1. This occurs when available soil water (ASW) content is above 70% of FC. Second-stage evaporation occurs when the hydraulic properties of the soil limit the evaporation rate and the K_r is less than 1. Second-stage evaporation begins when the ASW falls below a threshold limit of 70% of ASW. Between 70% FC down to a water content of 50% of permanent of wilting point (PWP), K_r is reduced linearly from 1.0 to 0.

The process uses soil-water content characteristics that are equivalent to about a 10-cm layer of soil, TUZ, from which all water that is lost by BSE is removed. Also, my model assumes that no water is taken from this layer by plant transpiration. When water content is above FC, all excess water percolates to the BUZ at the end of each day.

The water lost by BSE is calculated by Equation 4.1.

$$BSE = ET_0 * K_r * (1-K_c) * (1-RF) \tag{4.1}$$

Where,

K_c = plant transpiration coefficient, - (described in the next section)

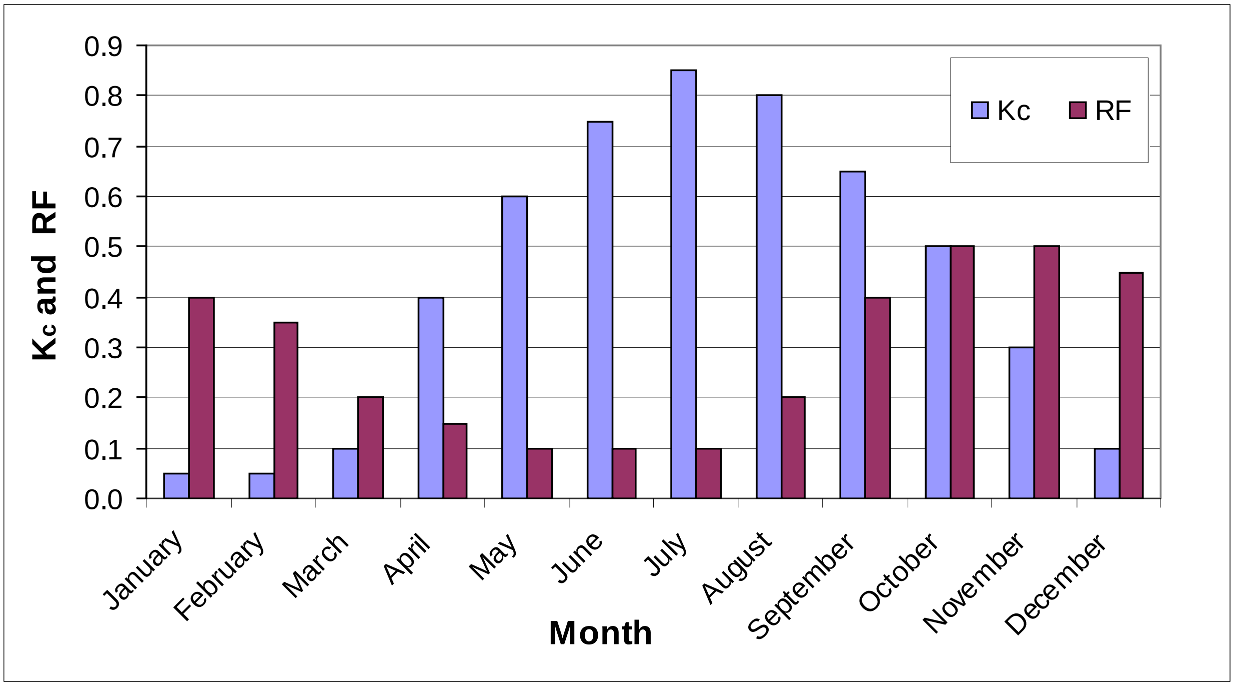
RF = residue factor, -

RF is another important factor that affects BSE. The blanket of residue cover on the soil surface influences both energy and water exchange between the soil surface and atmosphere. The model assumes there is more residue cover during non-growing parts of the year compared to active growing season. The monthly assigned values for RF are shown in the Figure 4.3.

Transpiration

Active plant grow removes water from the BUZ and LZ by T during active plant growing season whenever a level is not inundated except during periods following flooding events. The details of flooding effects are presented in the next section.

Figure 4.3. Plant transpiration coefficient, K_c and residue factor, RF assigned for different months of the year for model simulation



The portion of ET_0 left after the amount that used for BSE is defined as ET_{rem}. $ET_{rem} = ET_0 - BSE$. Water removed by T from the BUZ, T_{BUZ}, is calculated by,

$$T_{BUZ} = ET_{rem} * K_c * TF * SWC_{BUZ} * T_{fr} \quad (4.2)$$

Where,

TF = transpiration factor that defines the effects of flooding on plant water use, - (described in the next section)

SWC_{BUZ} = the soil-water coefficient for the BUZ,-

SWC_{BUZ} is the factor that accounts for the effects of soil-water content on T. SWC_{BUZ} is 1.0 when the ASW is greater than 30% of FC. Between 30% FC and PWP, SWC_{BUZ} is reduced linearly from 1.0 to 0.

T_{fr} = is the fraction of T taken from the BUZ when there is adequate ASW to satisfy T_{BUZ}. The model uses a value of 0.20.

If the SWC_{BUZ} is less than 1.0, then T_{BUZ} is reduced by the SWC_{BUZ}. The amount that T_{BUZ} is reduced on those days is passed down as additional demand for T from the LZ.

The amount of T from the LZ, T_{LZ}, is calculated exactly the same as T_{BUZ}, except that SWC_{LZ} is based upon the ASW of the LZ, and T_{fr} is equal to 0.8. Also, if the full amount of T_{BUZ} is not satisfied for a day, the additional demand for T from T_{BUZ} is added to the quantity, (ET_{rem} * K_c * TF) to increase the demand for T_{LZ}.

$$T_{LZ} = [ET_{rem} * K_c * TF + (1-SWC_{BUZ})]* SWC_{LZ} * T_{fr} \tag{4.3}$$

Effects of Flooding or Inundation on Transpiration

There are three distinct scenarios we can expect in modeling the effects of inundation on vertical soil-water movement.

First, whenever a level is inundated, no BSE or T occurs from that level.

The second scenario is when an area is not inundated, but recent inundation has been of long enough duration to affect T. BSE occurs as calculated according to Equation 4.1. T is affected by the TF as shown in Equations 4.2 and 4.3. For each day that inundation continues on a level, a flood factor (FF) equal to the total number of days the particular level has been inundated, to a maximum of 60 days, accumulates. If the FF is less than 7 days, then TF=1 and T resumes at the full rate for the day as soon as inundation ceases. When inundation ceases, FF is reduced by 1 each day until it reaches 0. When the FF greater than 30 days, TF=0. When the FF is more than 7 and less than 30 days, TF is calculated for the day by,

$$TF = [(30 - 7) - (FF - 7)] / (30 - 7) \tag{4.4}$$

The third scenario, during the periods when inundation is not occurring and FF is less than 8 and TF=1. Therefore, the water budget operations on the level are not affected by past flooding.

Estimating Net Seepage

The net seepage module uses the daily outputs from the gross seepage module (See Chapter 3) as daily inputs to estimate net seepage as depths of water. The daily inputs are gross seepage on each of the 14 level sections along with precipitation and ET_0, and inflow from the watershed to the reservoir. The user must provide the monthly WUC and RF plus soil water content parameters for all three zones. The user must also input the reservoir characteristics of accumulated area at the water depth of all 14 level sections.

The module first checks whether the level section is inundated or not. If the input data shows seepage greater than 0, the level is inundated. The number of flood days on each level is updated depending upon whether the level is inundated and this information is used to estimate the flood factor as discussed earlier.

The net seepage module cannot be calibrated directly since I do not have any measurements of soil water content. However, I can make judgments about the reasonableness of the results, particularly for Level 14 which is above the maximum water depth and is never inundated. Results for DPL-Hogan to show what results were found for the reservoir and for the various levels within the reservoir are presented here. The same 4-year period that was simulated for the gross seepage module was used for this simulation. Because of the amount of change in the soil water content of the 150-cm deep soil profile, results for net seepage may be affected slightly by the change in storage in the soil. Table 4.2 shows the simulated 4-year average water balance for the 14 different levels within the reservoir. Recall that Level 14 is above the maximum water depth and it represents the level where no seepage is added. The results for Level 14 show that there was no percolation during the four years. Essentially equal amounts of BSE and T resulted and the sum which is actual evapotranspiration totaled 96% of the precipitation. Both runoff and increase in soil water content equaled two percent.

Net seepage was calculated to have occurred on all 13 levels that were inundated as least part of the time during the four years because all levels received some gross seepage. Figure 4.4 compares gross and net seepage graphically for the 14 levels. The total height of the bar for each level is gross seepage and the lesser amount inside the bar is the net seepage for each level. The results show that both gross and net seepage were both maximum at Levels between 4 and 7, and both amounts were lower in the lower and upper levels of the reservoir. Level 1 has a lower net seepage percentage because it has a lower seepage rate that reduces gross seepage when it was inundated and also, when precipitation onto the pond occurred when the reservoir was empty all precipitation was accounted for in the inflow for the day by the gross seepage module. Thus, precipitation on Level 1 is 0. Since Level 1 was usually affected by the FF, any day with precipitation added a day to the FF.

Table 4.2. Water balance predicted by the net seepage module at different levels in the reservoir DPL- Hogan, 2004-07

Level	Depth above bottom (m)	Gross seepage[a] (cm)	P [a] (cm)	Net seepage [b] (cm)	Bare soil evaporation (cm)	AET (cm)	Runoff (cm)	Change in soil water (cm)	Net seepage [b] (%)
1	0.00	384	0	292	46	27	0	19	76
2	0.15	404	116	371	73	56	0	19	92
3	0.30	489	135	467	78	59	0	19	96
4	0.46	641	146	627	80	60	0	19	98
5	0.61	888	153	879	82	61	0	19	99
6	0.76	898	156	885	87	62	0	19	99
7	0.91	805	169	791	95	70	0	19	98
8	1.22	410	198	398	110	81	0	18	97
9	1.52	294	219	276	117	106	1	13	94
10	1.83	272	227	247	120	123	1	7	91
11	2.13	145	236	129	122	123	1	5	89
12	2.44	76	244	66	123	124	2	5	86
13	2.83	15	245	5	124	124	2	5	35
14	3.14	0	255	0	124	121	5	5	-

[a] Precipitation on to the soil surface when the level was not inundated. For Level l (bottom of the reservoir), all precipitation was accounted for as inflow by the gross seepage module.

[b] All percolation out of Lower Zone

This resulted in more of the ET_0 being used by bare soil evaporation that resulted in more of the gross seepage being lost from Level 1. In the upper levels, net seepage was less than in the middle levels because when inflow events occurred, more of the gross seepage was used to fill the soil profile because the soil was usually drier than the soil in the middle levels.

The net seepage module estimated that a total of 14,860 m^3 of the gross seepage amount of 15,700 m^3 for DPL-Hogan moved below the LZ during the 4-year study period. Results for 4 years run are shown in Figure 4.4. This amount to 95% of the gross seepage being estimated to be net seepage below the rooting depth and potential ground-water recharge. Average annual net seepage was 3,715 m^3. Subsequently, the two modules were run for 37 years of historical data for DPL-Hogan to see if the performance of the modules to estimate net seepage would be similar to those of the 4-year study period. The results for the 37-year run are shown in Figure 4.5. It is evident from the results that, the ratio of net seepage and gross seepage at different levels was similar to the results for the 4-year run of observed data. Here, 93% of the gross seepage was estimated to be lost as net seepage. The average annual net seepage amount was 2,890 m^3 for the 37-year run.

Net Seepage Module Performance

Table 4.3 gives an idea of how much portion of gross seepage became net seepage from three reservoirs. It is evident that, 90% to 95% of gross seepage was percolated down from the bottom of the lower zone and became potential ground-water recharge. The highest percent of contribution was observed in the reservoir DPL-Hogan which may be due to presence of water during most of the study period.

To understand the soil-water evaporation contribution from bare soil from the TUZ and T from the plant species from the BUZ and LZ, the results of a simulation run for a one-year period on Level 5 (0.61-m above the reservoir bottom) are shown in Figure 4.6. The figure is broken into 3-month sections so that conditions during the year can be shown more clearly. The open bar is the ET_0 for the day. BSE is shown as the bottom portion of the bar and T is stacked on top of BSE for each day to show estimated actual evapotranspiration total for each day. The days with no bars in the graph show that the water depth in the reservoir was above Level 5. For these days evaporation from the open water surface is estimated by the gross seepage module and there

Figure 4.4. Simulated gross and net seepage at different depths of the reservoir DPL-Hogan, 2004-07

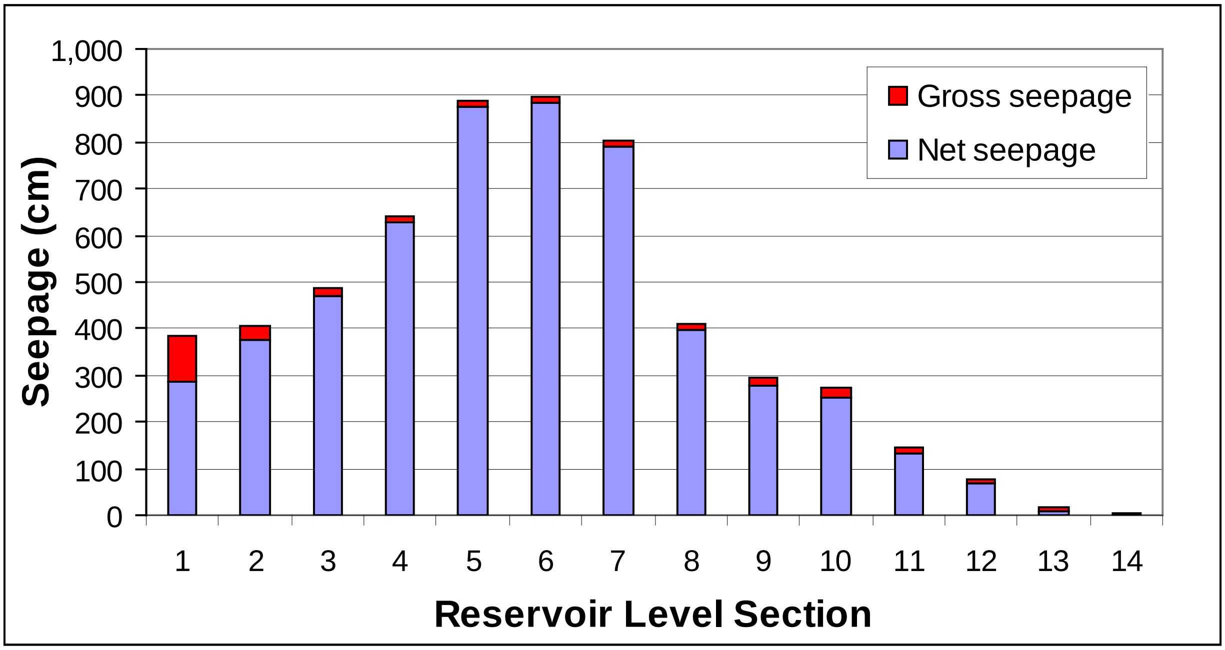


Figure 4.5. Simulated gross and net seepage at different depths of the reservoir DPL-Hogan, 1971-2007

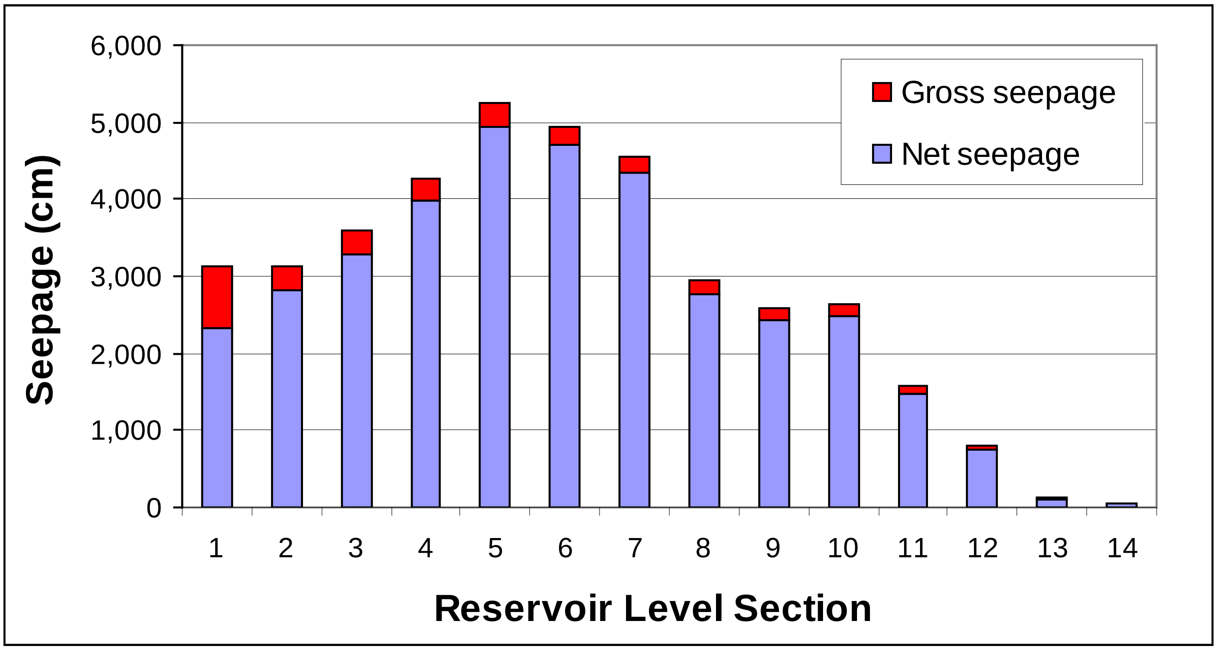


Table 4.3. Comparison of net seepage to the gross seepage, 2004-07

	DPL-Hogan	DRA-Holste	DCN-Zimb
Gross seepage	15,700	72,920	17,240
Net seepage	14,860	68,340	15,540
Net seepage to Gross seepage (%)	94.6	93.7	90.1

Figure 4.6. Simulated bare soil evaporation and transpiration on Level 5 of the reservoir DPL-Hogan during different periods, 2005

Figure 4.6.1. January-March, 2005

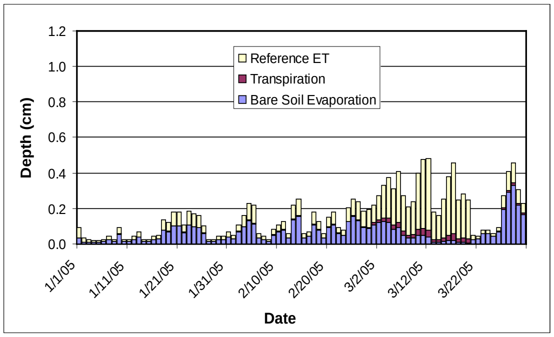


Figure 4.6.2. April-June, 2005

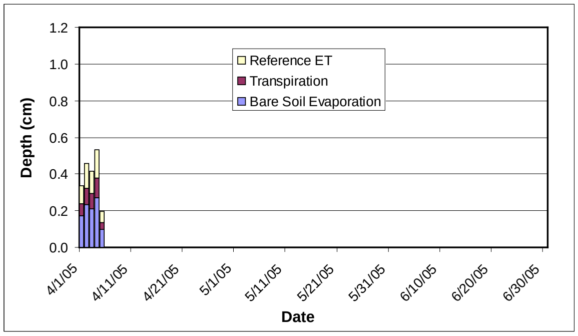


Figure 4.6.3. July-September, 2005

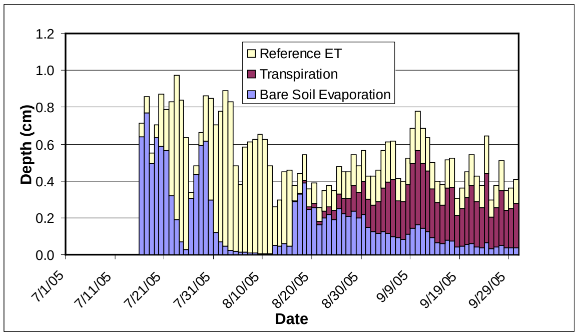
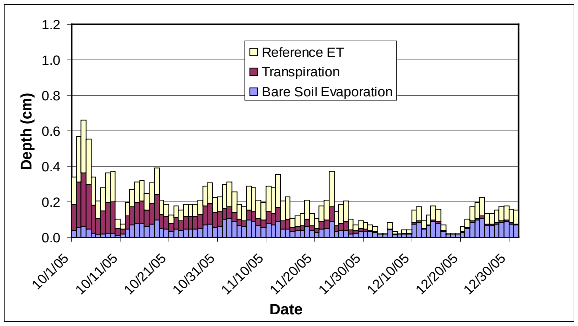


Figure 4.6.4. October-December, 2005



would not be any T or BSE. Recall that evaporation is calculated by the net seepage module according to the assumptions I made and discussed in detail in the earlier chapters. Irrespective of the level section of the reservoir, considering a given time period, in this case it is year 2005, accounting for evaporation showed that, T and BSE were prevalent except during April through the middle of July when Level 5 was flooded. BSE occurred throughout the year except for flood days. Because the K_c was low in the first part of the year, T was low then. Later after flooding stopped, T remained low until late August while the model predicted plant recovery from flooding. Then, T was active. Other factors affecting BSE and T were decrease in the $K_{c,}$ later in the year, increase in RF later in the year, and less availability of soil moisture later in the fall.

To illustrate the estimated daily actual evapotranspiration from the top, middle and lower levels of the reservoir, during a particular period of a year, results from the simulation run from April to June of the year 2005 for Level sections 12, 5 and 1 are shown in Figure 4.7. Level 12, except for few days when it was flooded, both BSE and T occurred. The condition is similar to a terrestrial system throughout the period. One the higher levels chances of inundation are rare. Level 5 shows no BAE or T after the major inflow event on April 5, 2005 because of the resulting inundation through the period. At the middle levels the presence of water for longer periods discourages plant growth, but I would expect BSE or T to be occasional as the water depth in the reservoir fluctuates over time. On Level 1, both BSE and T occur only a small amount of the time because Level 1 is inundated whenever there is any water in the reservoir. This particular period in Figure 4.6 during 2005 is unusual. During the 2004-07 period, Level 12 was inundated only 7 days as shown in Figure 4.7.1. Level 5 was inundated about 30% of the time. Finally, Level 1 had water covering it more than 50% of the time.

Results and Discussion

Results from the net seepage module run for a 37 years simulation for the reservoir DPL-Hogan are discussed here. The historical weather data from the nearest weather station during 1971 to 2007 was used for the simulation. Figure 4.8 shows the accumulation of gross and net seepage during the period. The relative amount of net seepage to gross seepage was consistent through the simulation period. Gross seepage was quite event driven by inflows.

Figure 4.7. Simulated bare soil evaporation and transpiration on different level sections of the reservoir DPL-Hogan during April-June, 2005

Figure 4.7.1. Level 12

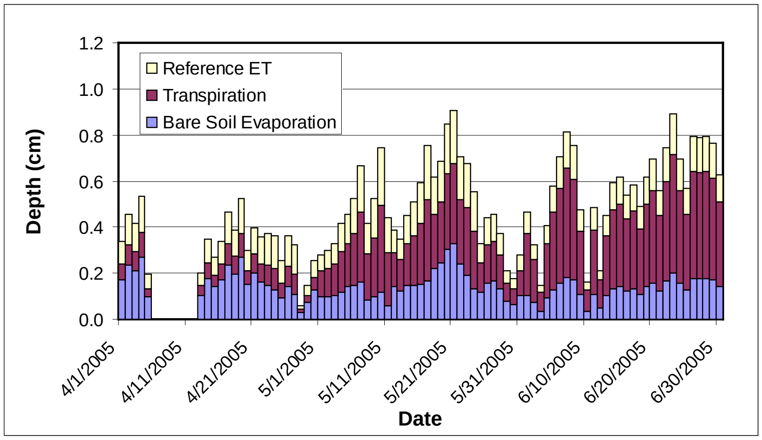


Figure 4.7.2. Level 5

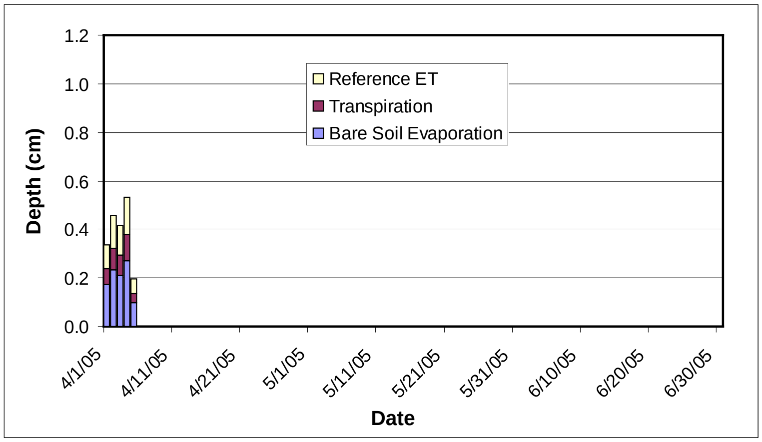


Figure 4.7.3. Level 1

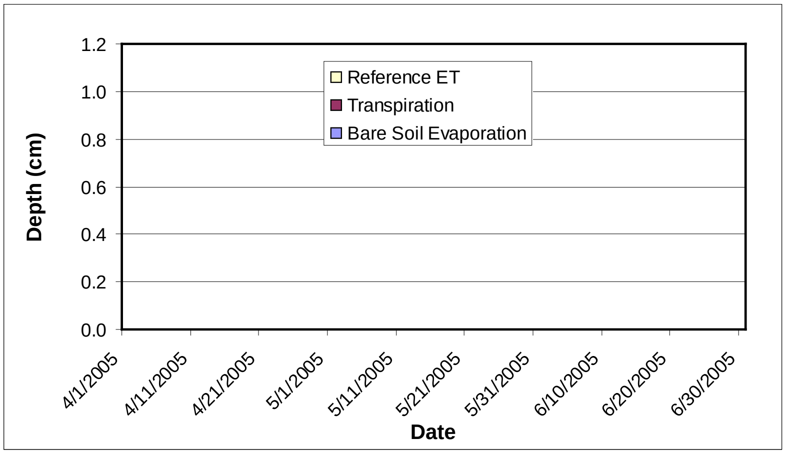
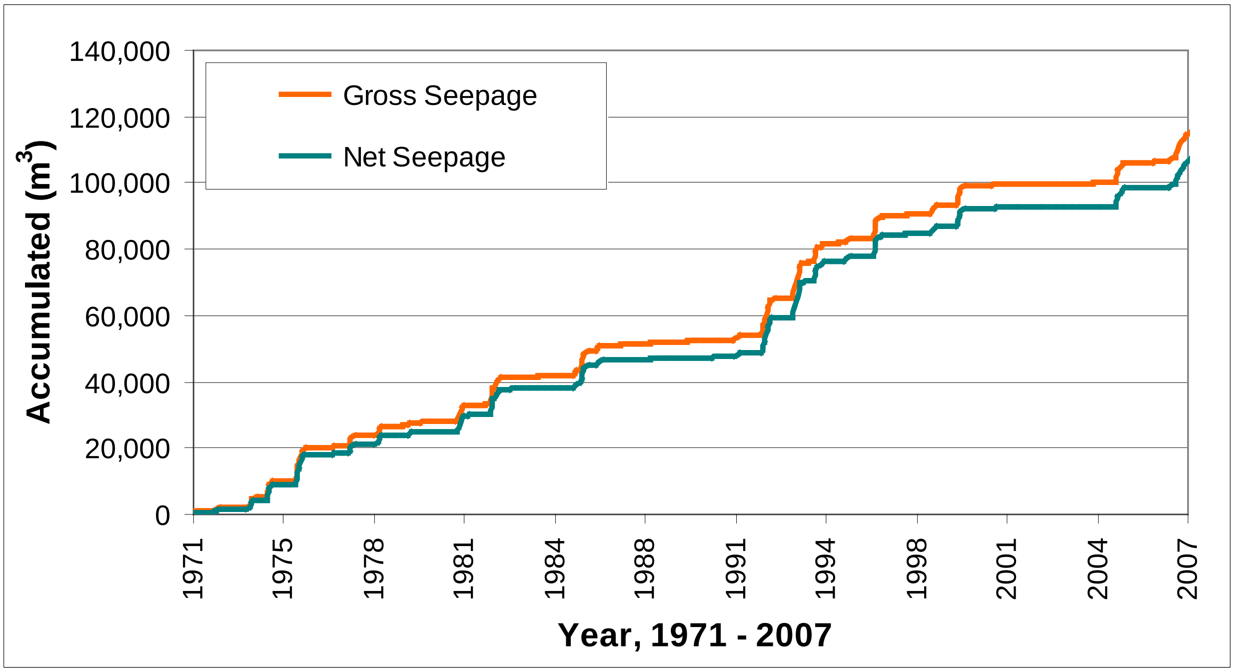


Figure 4.8. Monthly accumulated gross and net seepage of the reservoir DPL-Hogan, 1971-2007



The water added to the reservoir as calculated by the gross seepage module is shown in Figure 4.9. The inflow is mainly from about ten large events during the 37-years period. Also there are about five periods longer than two years when little inflow occurred. Precipitation onto the reservoir surface was equal about 15% of the inflow from the watershed. It too, shows some relatively long periods of little accumulations because the reservoir was essentially empty during these periods so little water surface area was present to receive precipitation onto it.

Water losses for the period are shown in Figure 4.10. Net seepage was the dominate loss as has been discussed earlier. Overflow occurred seven times in the 37-year period, about as expected for an earthen spillway. Evaporation from the pond surface was by far the smallest loss and it barely exceeded the precipitation amount onto the water surface of the reservoir.

Finally, Figure 4.11 shows all additions and losses for the reservoir on a single graph. Again, note how closely evaporation losses compare to precipitation additions for the reservoir. Also, note that net seepage is the main loss from the reservoir.

Figure 4.9. Monthly accumulated additions to the reservoir DPL-Hogan, 1971-2007

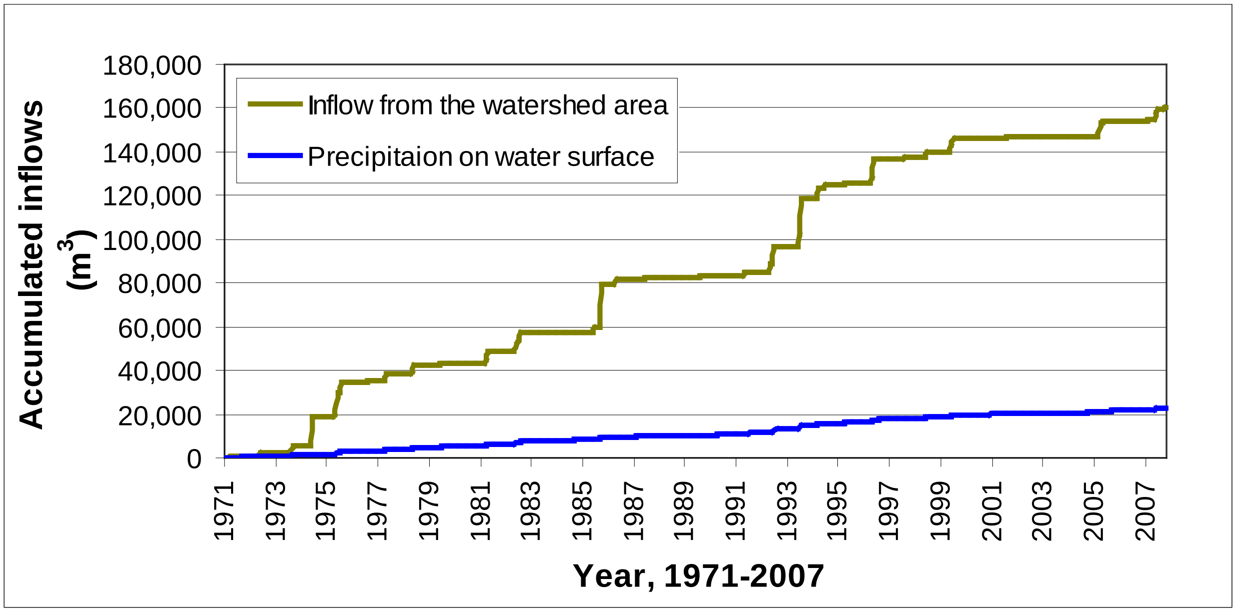


Figure 4.10. Monthly accumulated losses from the reservoir DPL-Hogan, 1971-2007

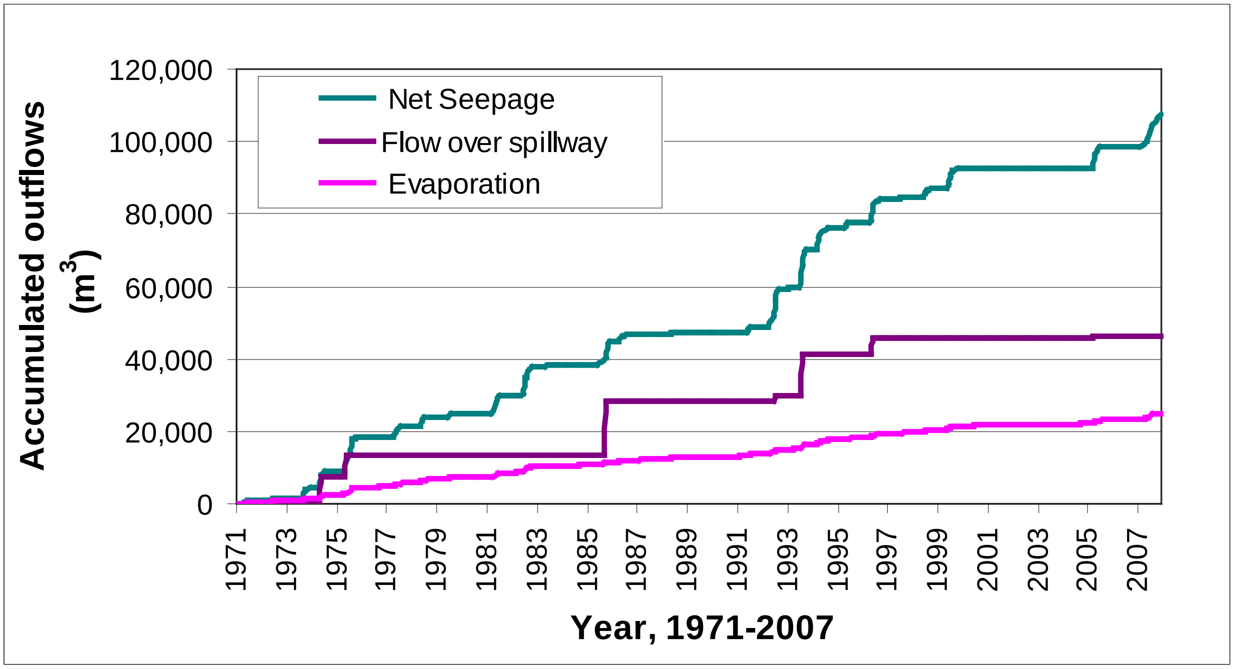
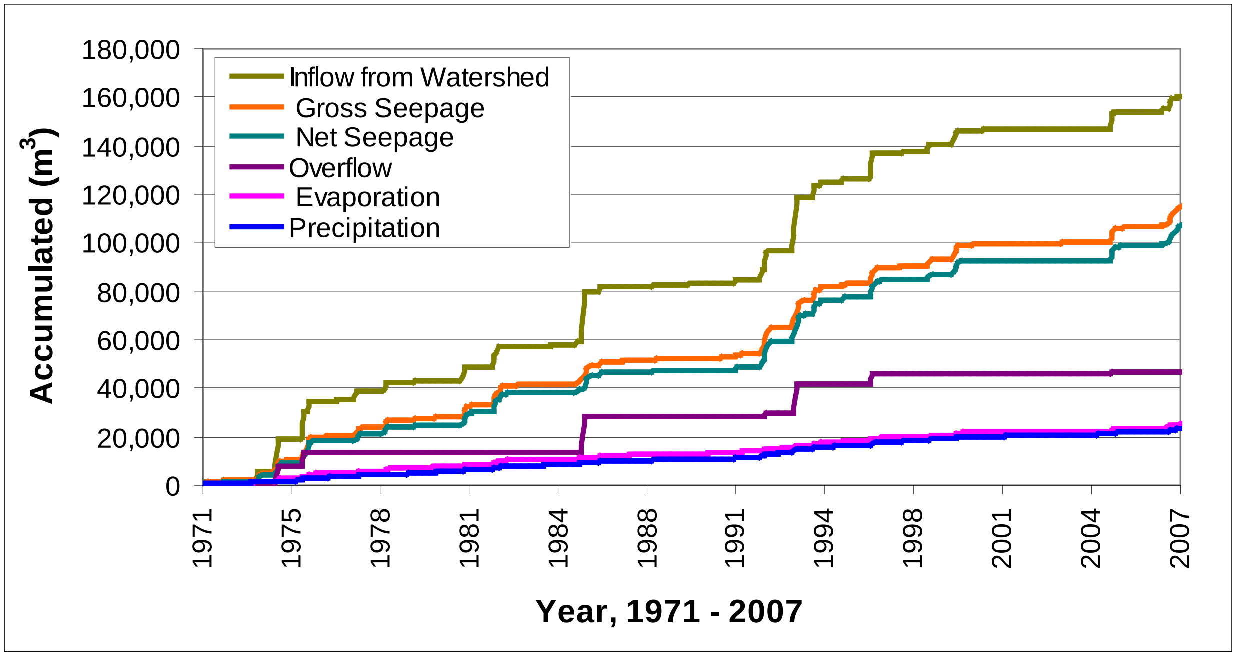


Figure 4.11. Monthly accumulated water budget parameters of the reservoir DPL-Hogan, 1971-2007



CHAPTER 5 -Model Sensitivity Analysis

The influence of different inputs on the outputs from the model was tested on the reservoir DPL-Hogan. Sensitivity analyses establish the relative importance of different input parameters to the model outputs. I will use the standard practice of changing each of the input parameters one at a time in a step-wise manner to test the sensitivity and performance of the model.

Methods and Materials

The simulations were run for the historical weather data from 1971 to 2007. The details of the reservoir characteristics are presented in the Table 5.1. The inputs I selected to examine are inflow from the watershed area, seepage rate, water storage depth, soil depth of the lower zone at each level section of the reservoir, and evapotranspiration rate that was applied to both the water surface area and the 14 levels of the reservoir when they were not inundated. For all tests individual input parameters tested, the value for all other input parameters were held constant at their original value. Since overflow and net seepage are the most important outputs of interest, I will report all results by showing how those outputs change relative to the original values for the 37-year long-term simulation results. To show the relative effect of the different values of the input values for the parameters, I will graph the percentage change of the outputs versus the change in the inputs. The procedure for testing each above-mentioned input parameter is discussed below.

The main source of water to the reservoir is the runoff (inflow) from the watershed area. To assess the effect of inflow on outflows of net seepage and overflow, the amount of inflow was changed to test the performance of the model. The original daily inflows for the long run were changed by 25-percent steps from +100% to -75%.

In the same way the seepage rate was changed for all levels of the reservoir. The seepage rate was changed in increments of 25% between 75% less up to 200% more.

The depth of the reservoir was altered in 25-percent increment steps so that surface area changed but the volume remained the same for the new depth.

Lower zone soil depth is one of the crucial assumptions made to estimate effect of the amount of water removed from the rooting zone in the reservoir on net seepage. It has no effect on overflow. To examine its effect, the original lower zone soil depth of 1.2 m was changed. During the development of the model, lower zone depth was decided on by looking into the root zone depth. The inspections in the reservoir location indicated that, there were perennial grass and weed growth. It was assumed that, to facilitate these plants to extract water, a 1.2-m lower zone depth was selected. Here, lower zone soil depths were changed to 0.2-m increments from 0.2 m to 2.4 m.

Table 5.1. Reservoir characteristics and base case output original values for DPL-Hogan

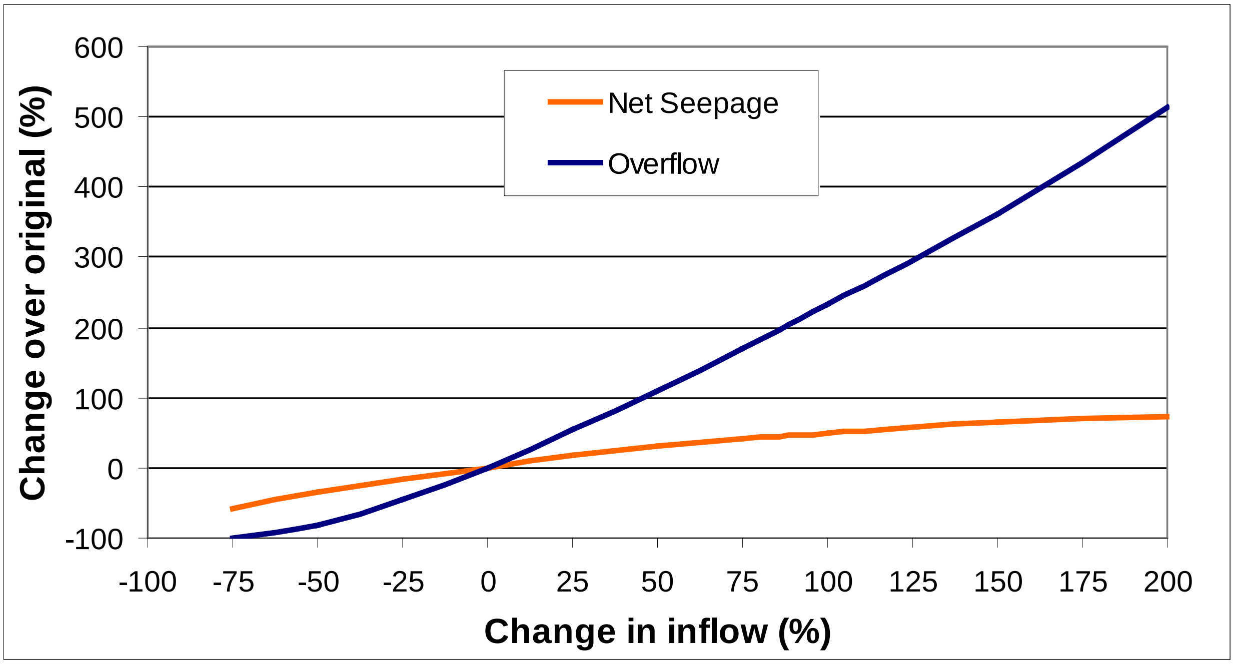
Characteristics	
Volume at spillway (m^3)	5,378
Area at spillway (ha)	0.44
Depth at spillway (m)	2.8
Weighted average standard seepage rate on 0.3 m head (cm/day)	8.3
Average annual volume of inflow from watershed (m^3/year)	4,320
Average depth of inflow from watershed (cm/year)	1.35
Average annual inflow volume/Reservoir volume (I/V)	0.8
Ratio of watershed area to reservoir surface area at spillway level	78.3
Average annual precipitation (cm/year)	64.0
Average annual reference evapotranspiration, ET_0 (cm/year)	130.1
Average net seepage (m^3/year) [original value]	2,892
Average overflow (m^3/year)) [original value]	1,243

Finally, while developing the modules, evaporation from the water surface area, and evapotranspiration demand on the plants was assumed to be equal to $ET_{0.}$ To test the effect of this assumption, the original daily ET_0 values were changed in increments of 25% between 75% below to 200% above the original values.

Results and Discussion

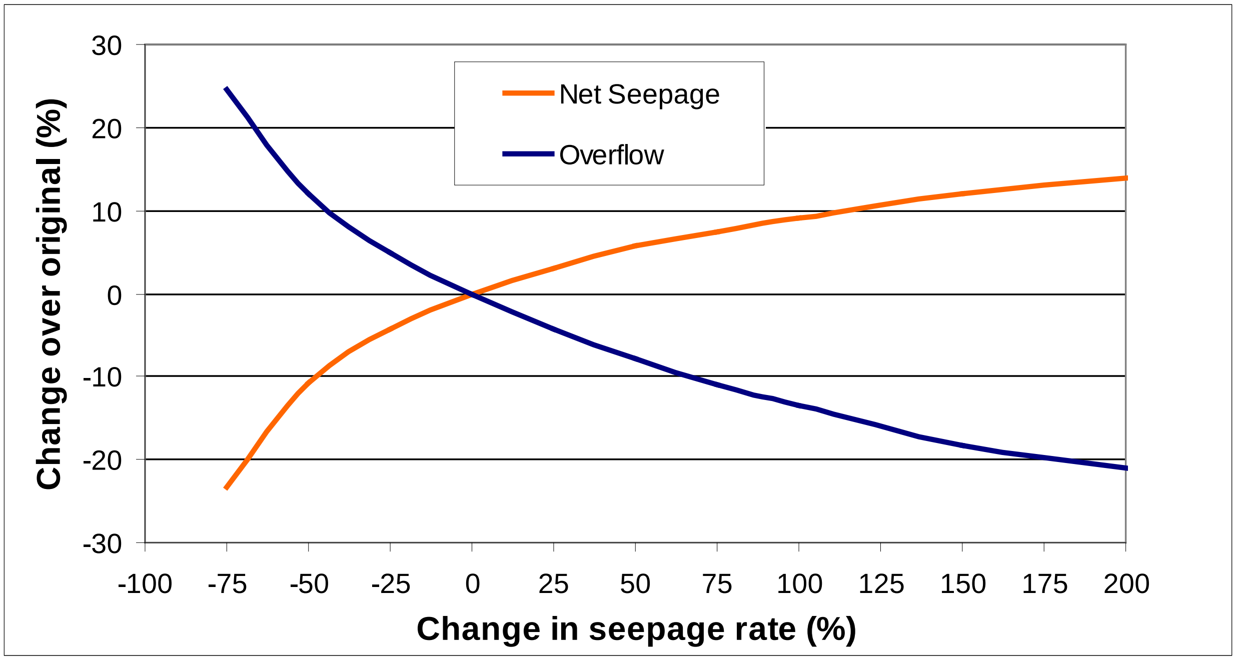
The results of effect of inflow on net seepage and overflow are shown in the Figure 5.1. It was observed that, by reducing inflow by 50%, net seepage and overflow were reduced by 30% and 83%, respectively. More of the smaller amounts of inflow remained in the reservoir and were subsequently lost as net seepage. When inflow was increased by 100%, net seepage was increased by 47% and overflow increased by 234% above the original amounts. This indicated that both of the outputs are affected substantially, but net seepage was less sensitive compared to overflow. More inflow results in more water retained in the reservoir more of the time to increase seepage, but it also resulted in less storage volume for subsequent inflows. Increasing the inflow compared to the reservoir volume also resulted in more large inflows that were greater than the reservoir storage volume even when the reservoir was empty. So more of the inflow went directly out as overflow.

Figure 5.1. Relative change in net seepage and overflow as affected by change in the inflow to the reservoir DPL-Hogan, 1971-2007



The effect of altered seepage rate is shown in the Figure 5.2. Net seepage amount was increased by increasing the seepage rate whereas overflow showed the opposite trend. This is because the higher seepage rate increased the storage volume that was available for subsequent inflows so more inflow was retained. The increased seepage resulted in greater amounts percolation that led to greater net seepage. Note, however, relative effects for changes in seepage on overflow and net seepage are much less than for changes inflow amounts.

Figure 5.2. Relative change in net seepage and overflow as affected by change in seepage rate for the reservoir DPL-Hogan, 1971-2007



The influence of change in depth of the reservoir and the resulting increase in surface area on net seepage and overflow is shown in the Figure 5.3. The results showed that, there was limited impact on both net seepage and overflow. As the depth was reduced, the surface area increased to accommodate the storage volume, which increased evaporation from the water surface. Therefore, this resulted in a reduction of both net seepage and overflow. When the depth was increased this led to more water stored with a smaller surface area for evaporation and seepage. This created more overflow and a very slight decrease in net seepage. Again, relative changes are rather small compared to the changes caused by change in inflow.

In the sensitivity test to examine the effect of the lower zone soil depth only net seepage is affected. These results are presented in the Figure 5.4. The net seepage was decreased as the depth of the lower zone increased. This is because the increased depth increases the water storage capacity of the lower zone. More water is required to fill the soil storage before percolation out of the lower soil zone occurs. More storage, in turn, provides more water for plants to remove from the soil during the dry periods between inundations. Subsequently, more of the gross seepage is required to refill the greater storage volume in the lower zone before percolation out of the lower zone occurs. Conversely, a smaller depth of the lower zone is easily

Figure 5.3. Relative change in net seepage and overflow as affected by change in the depth for the reservoir DPL-Hogan, 1971-2007

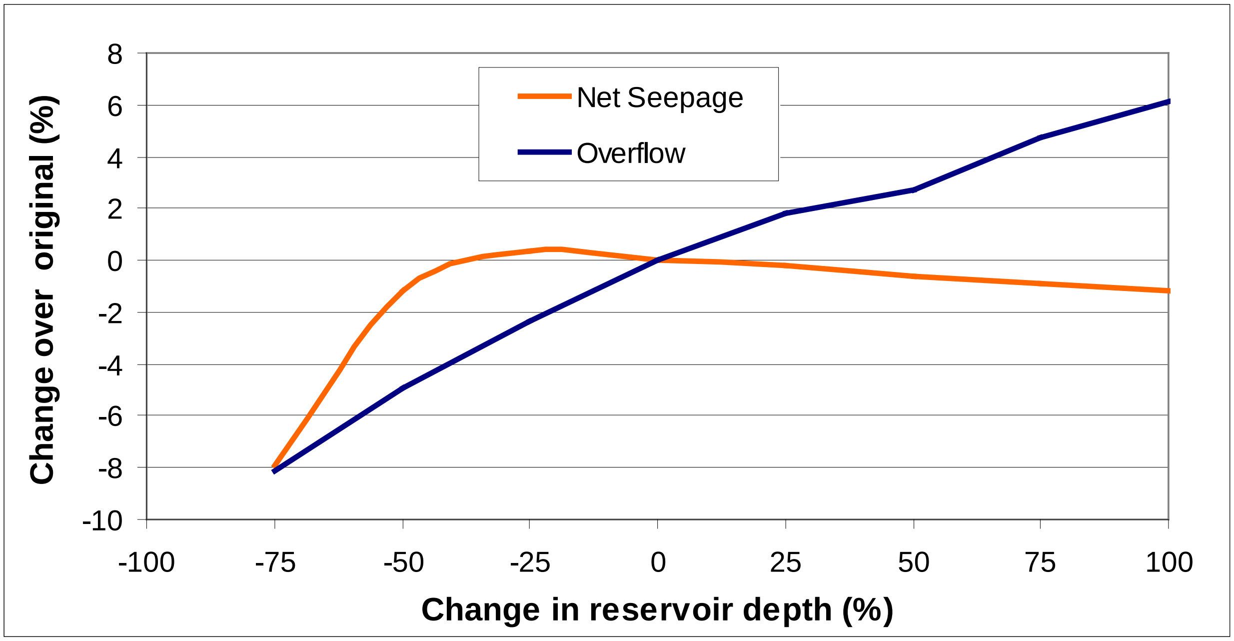
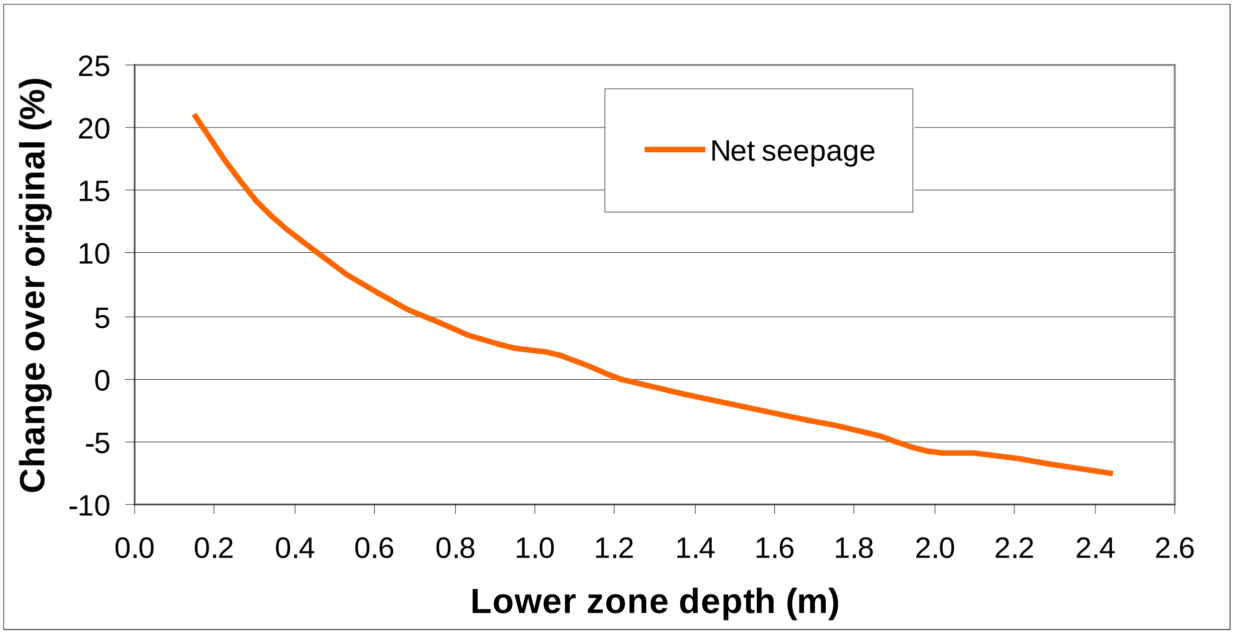


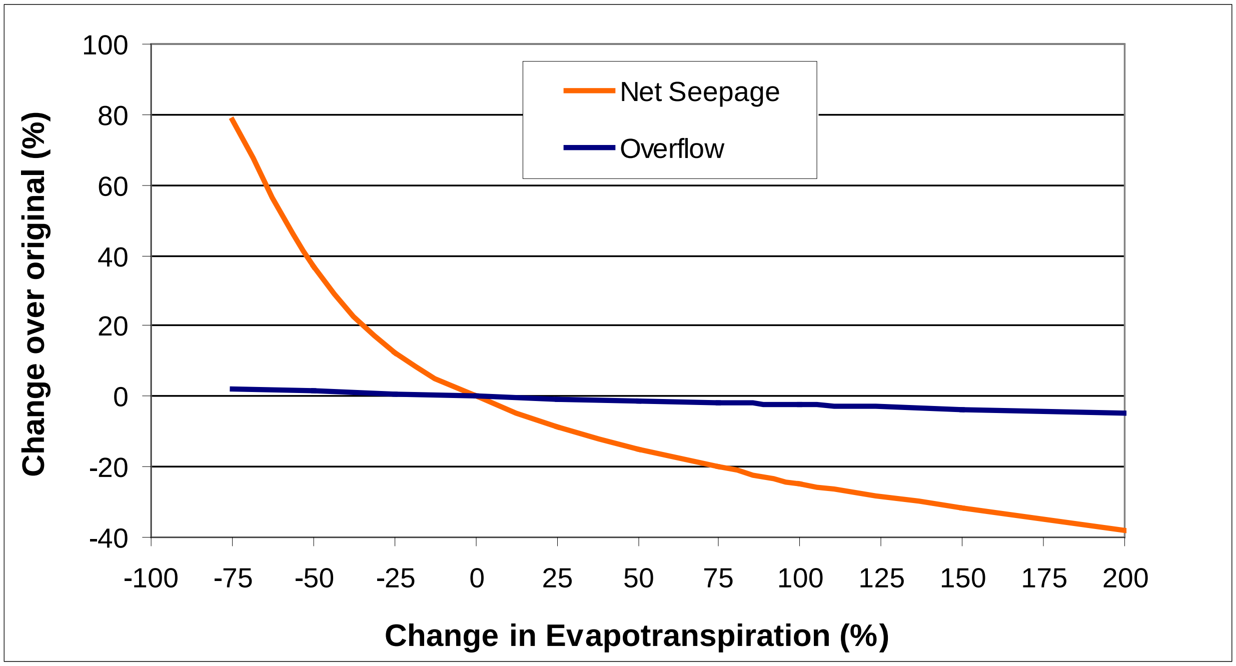
Figure 5.4. Relative change in net seepage as affected by the lower zone soil depth for the reservoir DPL-Hogan, 1971-2007



refilled and can and does result in percolation occurring with minor inundation events during wetter periods. Of course, plant grown is limited by having less available water stored for subsequent use. In the extreme with a very shallow lower zone, the percolation under areas that were seldom inundated occurred during the wet periods that do occur sometimes in the region because soil storage is limited. This is like having a porous soil such as sand that has little soil-water storage capacity.

When ET_0 was increased to test its effect on the outputs, both overflow and net seepage showed a decreasing in trend (Figure 5.5). Overflow is affected only slightly because it is influenced only by how much evaporation changes the amount of water stored in the reservoir which is usually only small amounts. Net seepage was more sensitive to the changes in ET_0 because the changes affect the terrestrial processes of bare soil evaporation and plant transpiration the sum to actual evaporation. These terrestrial processes affect net seepage considerably by changing the amount of water moving through the soil system and subsequently to net seepage.

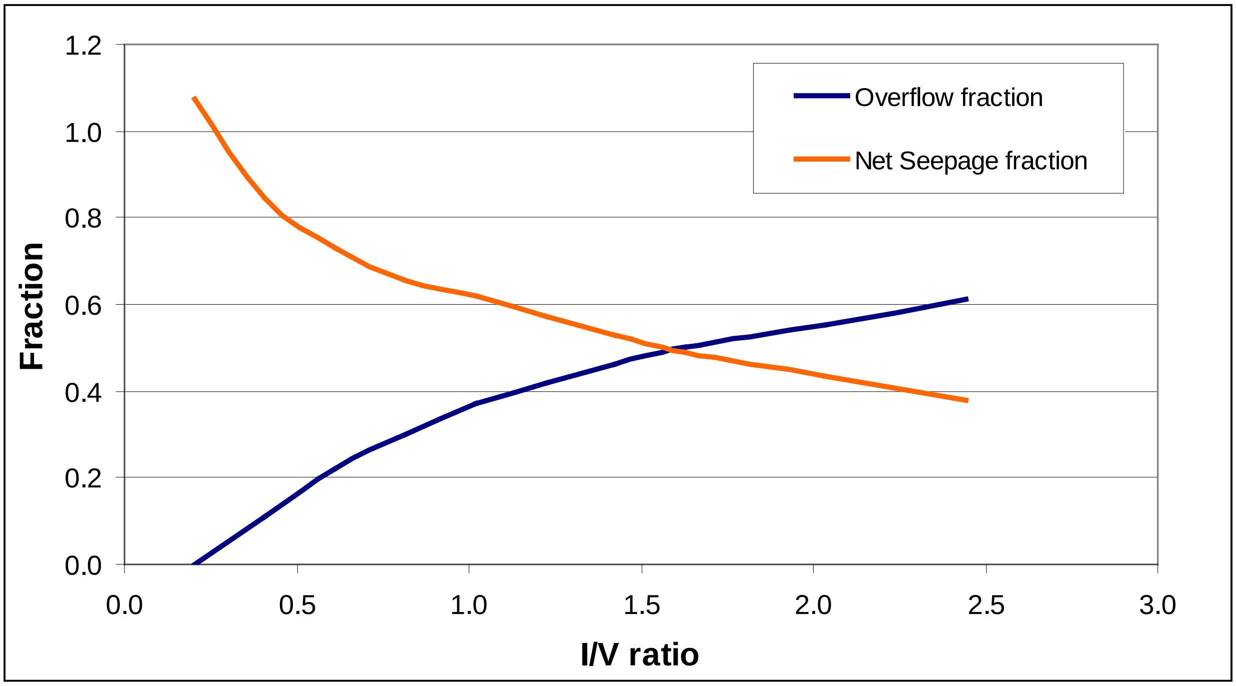
Figure 5.5. Relative change in net seepage and overflow as affected by change in the reference evapotranspiration rate at the reservoir DPL-Hogan, 1971-2007



Results in tabular form for all of the sensitivity tests can be found in the Appendix B.

Since average annual inflow volume compared to reservoir volume (I/V) was found to be very important by these analyses, I have prepared a graph that illustrates the effect of I/V on the fractions of the inflow that becomes overflow and net seepage (see Figure 5.6). As shown in Table 5.1, the I/V value for DPL-Hogan was 0.8. That results in the fraction of inflow that becomes overflow to be 0.29 and the fraction of inflow that became net seepage to be 0.67. This relationship between I/V and fraction of overflow and fraction of net seepage should provide a basis to estimate the fraction of overflow and net seepage for other reservoirs in the region. Note on the graph in Figure 5.6 that the sum of the fractions is close to 1.0 which indicates that nearly all of the inflow is lost as overflow and net seepage. Evaporation losses are the only other important route of loss, but evaporation from the reservoir is partially offset by the precipitation that falls on the water surface. Evaporation less precipitation is a very small part of the total water budget for these small reservoirs. They are often empty or nearly empty, so the surface area is small. Finally, when the I/V ratio is small, no overflow is likely to occur and the net seepage fraction shown is greater than 1.0! This occurs because net seepage includes the small amount of percolation that occurs within the reservoir area from precipitation on those parts of the reservoir area that are seldom inundated. The long-term simulation results estimated percolation for Level 14 that was never inundated at DPL-Hogan to be 1.5 cm/year.

Figure 5.6. Effect of average annual inflow volume/reservoir volume (I/V) on overflow and net seepage for the reservoir DPL-Hogan



CHAPTER 6 - Conclusions and Recommendations

Conclusions

This work showed that for reservoirs that have inflow only from surface runoff it is possible to estimate daily seepage from daily water depth measurements provided reasonable estimates of precipitation and ET_o are available to use when inspecting the water depth record. Over a 4-year study period, between 82 and 91% of inflow to three reservoirs was retained. More than 90% of the retained water in the reservoirs was calculated to be lost as gross seepage out of the reservoir.

The gross seepage module method approach used to simulate the operation of a typical reservoirs located in the Republican River Basin gave a satisfactory result for gross seepage amounts. Representing the reservoir stage-storage and stage-surface area relationship by 14 level sections helped account for the different seepage rates within the reservoir area. Hydraulic head effect on the seepage rate for the various levels was found to be best represented by applying a power of 0.25 to the head above each level when the total head on a level was greater than 0.3 m. The gross seepage module predicted good agreement between measured and simulated water depths in three reservoirs.

A net seepage module was developed and applied to estimate how much of the gross seepage might be expected to move through the rooting depth of plants in the reservoir storage area and become potential ground-water recharge using a water budget method on each of the 14 level sections assuming only vertical water movement. With a 1.5-m rooting depth, 94% of the gross seepage was estimated to be net seepage below the rooting depth and potential ground-water recharge.

At the reservoir site, DPL-Hogan, streamflow was reduced by 16,500 m^3, but net seepage or potential for ground-water recharge was increased by 14,860 m^3**.** This results in about a 10% reduction in the sum of streamflow and potential ground-water recharge at the reservoir site.

The sensitivity analyses showed that the ratio of average annual inflow to reservoir storage volume (I/V) was the most important variable affecting the amount inflow that was lost by overflow as well as the amount that became net seepage for a reservoir. Increasing I/V by 25% increased overflow by 55% and increased net seepage by 19%. Reducing I/V by 25%

decreased overflow by 45% and decreased net seepage by 16%. The relative seepage rate from the reservoir had a about the same relative effect on net seepage and overflow, but the size of both effects were considerably less than I/V. Either a 25% increase or decrease in seepage rate changed overflow and net seepage by 5% or less. The depth of the reservoir had little effect either overflow or net seepage. Either a 25% increase or decrease in reservoir depth changed overflow and net seepage by less than 3%. Increasing the depth of the lower zone from 1.2 m to 2.0 m showed only about a 5% decrease in net seepage. Conversely, decreasing the depth of the lower zone to 0.6 m increased the net seepage by 5%. Finally, by increasing the reference evapotranspiration, ET_0, by 25%; overflow was essentially unchanged and net seepage was reduced by 8%. When ET_0 was decreased by 25%, again overflow was essentially unchanged and net seepage was increased 12%.

The effect of a reservoir on downstream surface water supply and ground-water recharge that might have occurred in the alluvial stream system depends upon several factors that are beyond the scope of this work and these factors complicate considerably the aggregated effect of all of the 716 reservoirs in the entire study area.

Recommendations

To improve the reservoir model there is a need for improvement in the field data. These include

1. Good measured daily inflow from the watershed area data at reservoir site
2. Grass evapotranspiration(ET_0) data at reservoir site
3. Precipitation data at reservoir site
4. Soil-water content measurements at various levels of the reservoir
5. Seepage rates by level of the reservoir
6. Good measure of Water Use Coefficient and Residue Factor

Further work could develop relationships that are able to be used to estimate the operations of other reservoirs. Results from the sensitivity analyses estimate the fraction of inflow that become net seepage fraction and overflow fraction that includes ratio of inflow and storage volume of the reservoir (I/V), selection of seepage rate, reservoir depth, and evapotranspiration for other reservoirs. This could provide a basis for estimating the results for all similar reservoirs

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Appendix A - Reservoir data

32 reservoirs equipped with water-level monitoring equipment			
RESERVOIR ID	RESERVOIR NAME	LOCATION	NORMAL STORAGE (m^3)
COLORADO			
Flagler	Flagler Reservoir	NW1/4SW1/4 Sec. 3, T9S, R50W	3,807,758
KANSAS			
DDC-0057	Shirley Rd. Fill Dam	SE1/4SE1/4 Sec 2 T3S R30W	39,829
DRA-0001	Atwood Lake	SW1/4SE1/4 Sec 5 T3S R33W	86,344
DRA-0083	Holste Dam	NE1/4NW1/4 Sec 9 T3S R32W	32,477
DNT-1AA	Archer Dam	SE1/4SW1/4 Sec 35 T2S R32W	82,470
DRA-0056	Olson Dam	NW1/4NE1/4 Sec 2 T3S R32W	100,898
DPL-Hogan	Hogan Dam	SW1/4SW1/4 Sec 25 T1S R20W	5,378
DPL-Knape	Knape Dam	NW1/4SW1/4 Sec 7 T1S R18W	12,334
DCN-Zimb	Zimbelman Dam	SW1/4NW1/4 Sec 24 T3S R41W	6,562
DCN-Otto	Calvin Raile Dam	SW1/4NW1/4 Sec 12 T4S R40W	88,810
DDC-Moore	L. Moore Dam	SE1/4SW1/4 Sec 3 T3S R29W	45,392
DNT-Arford	Arford Dam	SW1/4 SW1/4 Sec 6 T2S R22W	84,567
NEBRASKA			
NE00244	Schiermeyer Reservoir	SE1/4NE1/4 Sec. 21, T2N, R7W	84,246
NE00376	Arehart Dam	NE1/4SW1/4 Sec. 36, T6N, R20W	29,603
NE00406	Sindt Dam	NW1/4NW1/4 Sec. 14 T1N R14W	143,083
NE00478	Paine Dam	SW1/4SW1/4 Sec. 21 T4N R22W	74,008
NE00482	Johnson DET Dam 3	E1/2W1/2 Sec. 12 T3N R25W	33,304
NE00496	Stamford Dam 3-A	S1/2SE1/4 Sec. 8, T2N, R20W	53,040
NE00557	Dry Creek 3-A	W1/2NE1/4 Sec. 9 T4N R27W	13,568
NE00559	Dry Creek South 2-A	SW1/4SE1/4 Sec. 18 T2N R29W	75,242
NE00617	Fredrichs Dam-1	NE1/4NW1/4 Sec. 19, T3N, 15W	61,674
NE01139	Kilpatrick Dam	NE1/4SE1/4 Sec. 20, T6N, R40W	160,352
NE01152	Anderson Reservoir	NE1/4SE1/4 Sec. 12, T2N, R37W	10,855
NE01171	Kugler Dam/Miller Reservoir	S1/2NW1/4 Sec. 32 T3N R31W	88,811
NE01290	Meents Dam	SE1/4Ne1/4 Sec. 28, T3N, R9W	14,308
NE01311	Cole Dam	S1/2SE1/4 Sec. 30, T8N, R28W	198,591
NE01316	Hueftle Reservoir	SE1/4SW1/4 Sec. 19, T8N, R24W	42,678
NE01337	Ford Reservoir	SW1/4Sw1/4 Sec. 25, T7N, R23W	43,172
NE01357	Bantam-Coe Reservoir	SE1/4SW1/4 Sec. 23, T1N, R19W	9,868
NE01468	Felker Dam	SW1/4SW1/4 Sec. 32, T7N, R32W	617
NE01485	Harms Reservoir	NE1/4SW1/4 Sec. 9, T10N, R35W	1,233
NE01492	Matheny Reservoir	NW1/4SE1/4 Sec. 26, T1N, R27W	0

Appendix B – Sensitivity Test Data

Table B.1. Relative change in net seepage and overflow caused by changing inflow from the watershed area of the reservoir DPL-Hogan

Change in inflow from the watershed area (%)	Net seepage from the reservoir (m^3)	Overflow from the reservoir (m^3)	Change in net seepage over original inflow (%)	Change in overflow over the original (%)
-75	43,700	35	-58.8	-100.0
-50	68,400	8,900	-35.4	-81.7
-25	88,800	26,800	-16.2	-44.76
0*	106,000	48,500	0.00	0.00
25	125,800	75,000	18.7	54.7
50	138,900	101,700	31.1	109.8
75	150,000	130,400	41.6	169.2
100	158,500	161,900	49.6	234.2
150	175,300	224,100	65.5	362.5
200	183,800	297,400	73.5	513.7

* Original inflow from the watershed area used for simulation

Table B.2. Relative changes in net seepage and overflow by changing seepage rate of the reservoir DPL-Hogan, 1971-2007

Change in seepage rate (%)	Net seepage from the reservoir (m^3)	Overflow from the reservoir (m^3)	Change in net seepage over original (%)	Change in overflow over the original (%)
-75	82,700	58,100	-23.0	25.6
-50	96,500	52,000	-10.2	12.6
-25	103,400	48,600	-3.8	5.2
0*	107,400	46,200	0.0	0.0
25	110,600	44,100	3.0	-4.5
50	112,700	42,700	5.0	-7.5
75	114,500	41,400	6.7	-10.4
100	116,300	40,300	8.3	-12.9
150	118,800	38,500	10.6	-16.8
200	120,700	36,900	12.4	-20.2

* Original seepage rate at level sections of the reservoir used for simulation

Table B.3. Relative change in net seepage and overflow by changing depth of the reservoir DPL-Hogan, 1971-2007

Change in reservoir depth (%)	Net seepage from the reservoir (m^3)	Overflow from the reservoir (m^3)	Change in net seepage over original depth (%)	Change in overflow over the original depth (%)
-75	98,900	42,500	-7.9	-8.2
-50	106,200	44,000	-1.2	-4.9
-25	107,800	45,100	0.3	-2.4
0*	107,400	46,200	0.0	0.0
25	107,200	47,100	-0.2	1.8
50	106,700	47,500	-0.6	2.7
75	106,400	48,400	-0.9	4.8
100	106,200	49,100	-1.2	6.1

* Original reservoir depth used for simulation

Table B.4. Relative change in net seepage with change in lower zone depth of the reservoir DPL-Hogan, 1971-2007

Change in lower zone depth (m)	Accumulated net seepage (m^3)	Change in accumulated net seepage over original (%)
0.2	129,900	20.9
0.3	122,600	14.1
0.5	118,200	10.1
0.6	114,800	6.8
0.8	112,200	4.5
0.9	110,400	2.7
1.1	109,400	1.8
1.2*	107,400	0.0
1.4	106,200	-1.2
1.5	105,000	-2.3
1.7	103,800	-3.3
1.8	102,800	-4.3
2.0	101,300	-5.7
2.1	100,900	-6.0
2.3	100,100	-6.8
2.4	99,300	-7.5

* Original lower zone depth used for simulation

Table B.5. Relative change in net seepage and overflow by changing reference evapotranspiration rate for the reservoir DPL-Hogan

Change in ET_0 (%)	Net seepage from the reservoir (m^3)	Overflow from the reservoir (m^3)	Change in net seepage over original inflow (%)	Change in overflow over the original (%)
-75	189,300	49,600	78.6	2.27
-50	145,000	49,200	36.9	1.55
-25	118,800	48,800	12.2	0.64
0*	107,400	46,200	0.0	0.00
25	97,000	48,100	-8.4	-0.63
50	90,200	47,900	-14.8	-1.24
75	84,600	47,500	-20.2	-1.90
100	79,900	47,300	-24.6	-2.48
150	72,100	46,600	-31.9	-3.77
200	65,800	46,300	-37.9	-4.54

* Original ET_0 from the water surface area of the reservoir used for simulation

Appendix C – Mathematical Reservoir Model Coding

FORTRAN 95

Gross Seepage Module

```
PROGRAM GROSSEEP
        IMPLICIT NONE
        INTEGER:: DAY, MONTH, YEAR, i, j, Overflowcount, m, k, L, mm, jj, n, II, KK, &
        nn, Seep1, Seep2, YEART, MONTHT, DAYT, DCount, RUN
        REAL:: RUNOFF, RAINFALL, PDEPTH, ET, INFLOW, Evapvolume, Seepagevol, &
                Rainvolume, Depthspillway, Overflow, PVolume, stage, Sumevapvol,&
                Sumrainvol, Sumoverflowvol, Sumseepvol, Inflowvol, Suminflowvol,&
                Deltavolume, Balance, Years, Incarea, Seepdepth, Depth, areaaccum, Volume, &
                Seeprate, Headexponent, Volumefull, WSarea,Yvolume, Sumraindepth,&
                SumETdepth, Averagerainvol, Averagevapvol, Averageseepvol, &
                Averageinflowvol, Averageoverflowvol, Averageraindepth, AverageETdepth, &
                Overflowduration, Overflowpotential, Overflowestimate,Excess, DepthUZ, &
                ETT, RAINFALLT, INFLOWT, STAGET, umMETD, SumMPrecD, FCS, &
                SumMInfD, SumMETV, SumMRainV, SumMInfV, umMOvrV, umMSeepV, &
                DeltaStorage, Perc,PercT, Percvol,& SumPercvol, SumMPercV, Startvolume, &
                Averagepercvol, Volumeyesterday,
        Dimension Incarea (14)
        Dimension Seepdepth (14)
        Character (100) :: filename, output, Filein, Fileout
        Dimension Depth (15), Areaaccum (15), Volume(15), Seeprate(14)
                        !  THE FOLLOWING SECTION IS FOR THE USER TO INPUT THEIR
                        ! PARTICULAR VALUES FOR THEIR POND
                        !  Enter depths that are the water depth from the bottom for each flat area
                        ! location in feet
```

```
                    !  Depth (13) must be the depth at the spillway, feet
DATA Depth /0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.03, 9.33, 10.3, 11.3/
                    !  Enter the water depth at spillway, feet
                    !  Enter the surface area in the pond in acres at each water depth
                    !  Areaaccum (13) must be the area at the spillway depth, Depth (13)
DATA Areaaccum / 0.0, 0.07, 0.11, 0.14, 0.18, 0.21, 0.27, 0.36, 0.47, 0.58, 0.70, 0.83, &
1.11, 1.20, 1.42/
                    !   Enter the accumulated storage volume in ac-ft at each water depth
                    !   Volume (13) must be the accumulated storage volume in ac-ft at the
                    ! spillway depth, Depth (13)
DATA Volume /0.0, 0.02, 0.07, 0.13, 0.21, 0.30, 0.43, 0.73, & 1.14, 1.66, 2.29, 3.03, &
4.36, 5.48, 6.79/
                    !  Enter the seepage rate at 1 foot of head at each depth from the bottom in
                    ! inches per day
DATA Seeprate / 0.15, 0.25, 0.35, 0.5, 0.75, 0.875, & 1.0, 1.0, 1.5, 3.0, 4.00, 5.00, 6.0, &
6.0/
                    !  Enter the exponent to apply to the hydraulic head to account for greater
                    ! seepage rate when the head is greater than 1 foot, default is 0.25

Headexponent = 0.25
                    !  Enter the volume of the pond at the spillway depth in acre -feet
Volumefull = 4.36
                    !  Enter the total watershed area for the pond in acres that is above Depth
                    ! (15) of the pond,
WSarea = 80.3
                    ! Enter the starting pond volume in  ac-ft, default is 0.0
Volumeyesterday = 0.0
Startvolume = 0.0
                    !   Filename for the daily input numerical data in the form, “yourname”,
                    ! that contains a line for each day
```

```
                    !  Year, Month, Day, ET in inches, Precipitation in inches, Watershed
                    ! runoff in inches
Filein = 'Hoganseep4years.txt'
                    ! NOTE:  Last record must look like this 999 0 0 0 0 0 0 0 0
                    !  Enter the number of years of input data or number of years to run if less
                    ! than the total length of your data set
Years = 4
                    !   Enter the filename for your input in the form, 'yourname'
Fileout = 'Hoganseep4years.out'
                    !  Now, save this file, then compile it with FORTRAN 95, check for any
                    ! errors during compilation and revise as needed.
                    !  Finally, run the file, Seep.exe and then open the output file in Notepad
                    !or other text editor and examine the results.
                    !  END OF USER INPUT AREA

Rainvolume = 0.0
Overflow = 0.0
Overflowcount = 0
Overflowpotential = 0.0
Inflow = 0.0
Volumeyesterday = 0.0
Sumevapvol = 0.0
Sumrainvol = 0.0
Sumoverflowvol = 0.0
Sumseepvol = 0.0
SumPercvol = 0.0
Sumraindepth = 0.0
SumETdepth = 0.0
Averagerainvol = 0.0
Averagevapvol=0.0
Averageseepvol = 0.0
```

```
          Averageinflowvol = 0.0
          Averagepercvol = 0.0
          Averageoverflowvol = 0.0
          Averageraindepth = 0.0
          AverageETdepth = 0.0
          Seepagevol = 0.0
          SumMETD = 0.0
          SumMPrecD = 0.0
          SumMInfD = 0.0
          SumMETV = 0.0
          SumMRainV = 0.0
          SumMInfV = 0.0
          SumMPercV = 0.0
          SumMOvrV = 0.0
          SumMSeepV = 0.0
          RUN = 365.25*(Years)
          DCount = 0
          I=0
          II = 0
          Mm = 0
          Do jj =1, 14
          Incarea (jj) = areaaccum (jj+1) - areaaccum (jj)
          End Do
          Open (UNIT = 1, file = Filein, status = "unknown", IOSTAT = i)
          Open (UNIT = 2, file = Fileout, status = "unknown", blank = 'zero')
          Open (UNIT = 3, file = 'monthlyHoganseep4years.out', status = "unknown", blank =
          'zero')
                              ! Opens output file for water balance calculation results.
          READ (unit=1,*) YEAR, MONTH, DAY, ET, RAINFALL, INFLOW, PERC, STAGE
DO j=1,Years*366+3
          Do nn=1,14
```

```
Seepdepth (nn) = 0.0
End Do
READ (unit=1,*) YEART, MONTHT, DAYT, ETT, INFLOWT, PERCT, STAGET, &
RAINFALLT
        ! Pdepth in feet is the actual field data (inventory), ET, Rainfall and
        ! Runoff are in inches
DCount = Dcount+1
Inflowvol = Inflow * ( WSarea + (areaaccum (14) - areaaccum (II+1)))/12 .
        ! Inflowvol is  in acre-ft
Percvol = perc/12.
        ! Percvol is in acre-ft
Rainvolume = Rainfall * areaaccum (II+2)/12.
PVolume = Volumeyesterday + Inflowvol + Percvol + Rainvolume
        !Pvolume is in acre-ft

IF (PVolume > Volumefull) THEN
    Overflowpotential = PVolume - Volumefull      ! Overflowpotential is in acre feet
IF ((0.333*Overflowpotential) > &
    (Depth (14)-Depth (13))*areaaccum(13)) THEN
    Excess = (Depth (14)-Depth (13))
    Overflowestimate = Overflowpotential-((Depth (14)-Depth (13))*areaaccum(13))
    PVolume = Volume (14)
ELSE
    Overflowestimate=0.667*Overflowpotential
    Excess = 0.333*Overflowpotential / areaaccum(13)
    Pvolume = Volume (13) + 0.333*Overflowpotential
END IF
    PDepth = Depth (13) + Excess        !  Depth (13) is the spillway depth at stage 13
    Overflowcount = Overflowcount+1
ELSE
    PVolume = PVolume
```

```
    END IF
Do k = 1,15
    IF (PVolume < Volume (K)) exit
    I=I + 1
END DO
    IF (Pvolume < Volume (13)) THEN
            PDepth = Depth (I) + (( Pvolume - Volume (I))/ (Volume (I+1) - Volume (I)))* &
             (Depth (I+1)-Depth (I))
    ELSE
            PDepth = PDepth
    END IF
    L = 1
DO WHILE (Pdepth > Depth (L))
    IF (PDepth > (Depth (L) + 1.0)) THEN
            Seepdepth (L) = Seeprate (L)* (PDepth – Depth (L)) ** Headexponent
    ELSE IF (PDepth > (Depth (L) + Seeprate (L)/12.)) THEN
            Seepdepth (L) = Seeprate (L)
    ELSE
            Seepdepth (L) = (Pdepth – Depth (L))*12.
            Pdepth = Depth (L)
    END IF

    L=L+1
END DO

Do n=1,14
    Seepagevol = Seepagevol + Seepdepth(n)*incarea (n)/12.
END DO
            EvapVolume = ET*areaaccum (L) /12.
            Yvolume = PVolume – Evapvolume - Seepagevol
    IF (Yvolume<0.0) THEN                ! Included to avoid negativity in Evapvolume
```

```
            Evapvolume = 0.0
            Yvolume = PVolume - Seepagevol
    END IF

    IF (Yvolume<0.0) THEN
            Seepagevol = Pvolume
            YVolume = 0.0
            Pvolume = 0.0
            Seepdepth(1)=(Seepagevol/areaaccum(2))*12.
    END IF

    II=0
    KK=1
DO WHILE (Volume (KK) <= Yvolume)
    KK=KK+1
    II=KK-1
END DO
            PDepth = Depth (II) + (Yvolume - Volume (II))/ (Volume (II+1)-Volume (II))* &
            (Depth (II+1) – Depth (II))
    IF (Overflowestimate > 0.) THEN
    IF (Yvolume > Volumefull) THEN
            Yvolume = Volumefull
    ELSE
            Yvolume = Yvolume
    END IF
            Overflow = Inflowvol + Rainvolume + Percvol - (Yvolume -Volumeyesterday)
            Overflowestimate = 0.0                          ! Overflow is in ac-ft
    ELSE
            Overflow=0.0
    END IF
```

```
WRITE (2, 10) Year, Month, Day, ET, Rainfall, (Seepdepth (i), I = 1, 14), &
                    Inflow, Percvol, PVolume, PDepth, Inflowvol, Overflow, Stage
  10 FORMAT (I4, 1x, I2, 1x, I2, 23 (F7.3))
           Volumeyesterday = YVolume
          Sumrainvol = Sumrainvol + Rainvolume
          Sumevapvol = Sumevapvol + Evapvolume
          Sumoverflowvol = Sumoverflowvol + Overflow
          Sumseepvol = Sumseepvol + Seepagevol
          Suminflowvol = Suminflowvol + Inflowvol
          Sumpercvol = Sumpercvol + percvol
          Sumraindepth = sumraindepth + rainfall
          SumETdepth = SumETdepth + ET
          SumMPrecD = SumMPrecD + Rainfall
          SumMETD = SumMETD + ET
          SumMInfD = SumMInfD + Inflow
          SumMETV = SumMETV + Evapvolume
          SumMRainV = SumMRainV + Rainvolume
          SumMInfV = SumMInfV + Inflowvol
          SumMPercV = SumMPercV + Percvol
          SumMOvrV = SumMOvrV + Overflow
          SumMSeepV = SumMSeepV + Seepagevol
          Seepagevol = 0.
          Overflow = 0.
          Overflowpotential = 0.0
           I=0
IF (MONTH/=MONTHT) THEN
          DeltaStorage = Yvolume-StartVolume
WRITE (3, 2) YEAR, MONTH, DCount, SumMETD, SumMPrecD, SumMInfD, &
          SumMETV, SumMRainV, SumMInfV, SumMOvrV, SumMPercV, Yvolume, &
          DeltaStorage, SumMSeepV, PDepth
2 Format (I4, x, I2, x, I2, 12 (F8.3))
```

```
        IF (YEART < 1900) THEN
        WRITE (2,*) '999 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0'
        EXIT
        END IF
                SumMETD = 0.0
                SumMPrecD = 0.0
                SumMInfD = 0.0
                SumMETV = 0.0
                SumMRainV = 0.0
                SumMInfV = 0.0
                SumMPercV = 0.0
                SumMOvrV = 0.0
                SumMSeepV = 0.0
                StartVolume=Yvolume
                DCount=0
        END IF
                Year =YearT
                Month = MonthT
                Day = DayT
                ET = ETT
                Rainfall = RainfallT
                Inflow = InflowT
                Perc = PercT
                Stage = StageT
END DO
                Deltavolume =Yvolume-Startvolume
                Balance = Sumrainvol + Suminflowvol – Sumevapvol – Sumseepvol - &
                      Sumoverflowvol – Deltavolume + Sumpercvol
```

```
WRITE (3, 20) Sumrainvol, Sumevapvol, Sumseepvol, Suminflowvol, Sumpercvol, &
        Sumoverflowvol, Deltavolume, Balance, Sumraindepth, &  SumETdepth,  &
        overflowcount
20 FORMAT (10 (F9.3), 2x, I4)
        Averagerainvol = Sumrainvol / Years
        Averagevapvol = Sumevapvol / Years
        Averageseepvol = Sumseepvol / Years
        Averageinflowvol = Suminflowvol / Years
        Averagepercvol = Averagepercvol / Years
        Averageoverflowvol = Sumoverflowvol / Years
        Averageraindepth = Sumraindepth / Years
        AverageETdepth = SumETdepth / Years
WRITE (3, 30) Averagerainvol, Averagevapvol, Averageseepvol, Averageinflowvol, &
        Averageoverflowvol,  Averagepercvol, Averageraindepth, AverageETdepth
30 FORMAT (8 (F7.3))
Close (Unit=1)
Close (Unit=2)
Close (Unit=3)
STOP
END PROGRAM GROSSEEP
```

Net Seepage Module

```
PROGRAM NETSEEP
          IMPLICIT NONE
          INTEGER:: DAY,MONTH,YEAR, i, j, k, m, n, Years, JJ, DAYT, MONTHT, &
                      ii, YEART, Dcount, L
          REAL:: RAINFALL, ET, INFLOW, ETc, SMC, YETc, Area1, RCN, S, KR, Kb, &
                    SUMVOLSEEP, PondMNetSeep, AETLZ, SUMVOLPERCLZ, DEPTHLZ, &
                    AETBUZ, DepthUZ, ETREM, DepthBUZ, OVERALLNETSEEP, Evapbare, &
                    FACTOR, Kc, PERCENTNETSEEP, ETin,ETinT, RAINFALLT, WSArea, &
                    INFLOWT, Rain,WSMNetPerc, WSMRunoff, SumMNetSeep, AETTOT
          CHARACTER (100):: filename, output
          DIMENSION AETBUZ (1:14), Kc (1:12, 1:14), AETLZ (1:14), DepthUZ (1:14), &
                    DepthBUZ (1:14), DEPTHLZ (1:14), ETREM (1:14), Evapbare (1:14), &
                    FACTOR (1:14), PERCENTNETSEEP (1:14), Rain (1:14), ET (1:14)
                              ! Kc is the crop coefficient assigned for each month of the year for each
                              ! Area.
          DATA Kc / 0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                              ! Area 1 monthly Kc values
                    0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                              ! Area 2 monthly Kc values
                    0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                              ! Area 3 monthly Kc values
                    0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                               ! Area 4 monthly Kc values
                    0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                              ! Area 5 monthly Kc value
                    0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                              ! Area 6 monthly Kc value
                    0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
```

```
                ! Area 7 monthly Kc values
        0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                ! Area 8 monthly Kc values
        0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                ! Area 9 monthly Kc values
        0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                ! Area 10 monthly Kc values
        0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                ! Area 11 monthly Kc values
        0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                ! Area 12 monthly Kc values
        0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1, &
                 ! Area 13monthly Kc values
        0.05, 0.05, 0.1, 0.4, 0.6, 0.75, 0.85, 0.8, 0.65, 0.5, 0.3, 0.1/
                ! Area 14 monthly Kc values
Real, Dimension (1:15):: AREAAccum = (/0.0, 0.07, 0.11, 0.14, 0.18, 0.21, 0.27, 0.36, &
        0.47, 0.58, 0.70, 0.83, 1.11, 1.20, 1.42/)
Real, Dimension (1:15):: Depth = (/0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, &
        8.03, 9.33, 10.3, 11.3/)
Real, Dimension (1:14)::AETFrBUZ = (/0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2,0.2, &
        0.2, 0.2, 0.2, 0.2/)
Real, Dimension(1:14)::FCS = (/1.4, 1.4, 1.4, 1.4, 1.4, 1.4, 1.4, .4, 1.4, 1.4,  1.4, 1.4, &
        1.4, 1.4/)
Real, Dimension(1:14)::FCBUZ = (/2.8, 2.8, 2.8, 2.8, 2.8, 2.8, 2.8, 2.8, 2.8, 2.8, 2.8, &
        2.8, 2.8, 2.8/)
Real, Dimension (1:14)::FCLZ = (/16.8, 16.8, 16.8, 16.8, 16.8, 16.8, 16.8, 16.8, 16.8, &
        16.8, 16.8, 16.8, 16.8, 16.8/)
Real, Dimension (1:14):: FLOOD = (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, &
        0.0, 0.0, 0.0/)
Real, Dimension (1:14):: HALFPWP = (/0.4, 0.4, 0.4, 0.4, 0.4, 0.4, 0.4, 0.4, 0.4,0.4, &
        0.4, 0.4, 0.4, 0.4/)
```

```
Real, Dimension (1:14)::MINASMBUZ = (/1.96, 1.96, 1.96, 1.96, 1.96, 1.96, 1.96,&
          1.96, 1.96, 1.96, 1.96, 1.96, 1.96, 1.96/)
Real, Dimension (1:14)::MINASMLZ = (/11.7, 11.7, 1.7, 11.7, 11.7, 11.7, 11.7, &
          11.7, 11.7, 11.7, 11.7,1 1.7, 11.7, 11.7/)
Real, Dimension (1:14)::PERCBUZ = (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, &
          0.0, 0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14)::PERCUZ = (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real,Dimension (1:14)::PercLZ = (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14)::PWPBUZ = (/1.6, 1.6, 1.6, 1.6, 1.6, 1.6, 1.6, 1.6, 1.6,1.6, &
          1.6, 1.6, 1.6, 1.6/)
Real, Dimension (1:14)::PWPLZ = (/9.6, 9.6, 9.6, 9.6, 9.6, 9.6, 9.6, 9.6, 9.6, 9.6, &
          9.6, 9.6, 9.6, 9.6/)
Real, Dimension (1:14):: AREA
Real, Dimension (1:12, 1:14):: Residue
DATA Residue / 0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &
          !   Area 1    Residue is the residue coefficient assigned for 12 months
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 2
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 3
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 4
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 5
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 6
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 7
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 8
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 9
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 10
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 11
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 12
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45, &          !   Area 13
          0.4, 0.35, 0.2, 0.15, 0.1, 0.1, 0.1, 0.2, 0.4, 0.5, 0.5, 0.45/            !   Area 14
```

```
Real, Dimension (1:14):: REW = (/1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, &
          1.0, 1.0, 1.0/)
Real, Dimension (1:14):: RFACTOR = (/1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, &
          1.0, 1.0, 1.0, 1.0/)
Real, Dimension (1:14):: RUNOFF = (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14):: Seep
Real, Dimension (1:14):: SeepT
Real, Dimension (1:14):: SUMAETBUZ (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14):: SUMAETLZ (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14):: SUMPERCUZ (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14):: SUMPERCBUZ(/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14):: SUMPERCLZ (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14):: SUMRAINFALL(/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14):: SUMSUMRUNOFF = (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, &
          0.0,0.0, 0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14):: SUMRUNOFF (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14):: SUMEVAPBARE (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, &
           0.0, 0.0, 0.0, 0.0, 0.0/)
Real, Dimension (1:14)::SUMET= (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0,  0.0, &
          0.0, 0.0, 0.0/)
Real, Dimension (1:14):: SUMSEEP = (/0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, &
           0.0, 0.0, 0.0, 0.0/)
```

```
    Real, Dimension (1:14):: VOLSEEP
    Real,Dimension(1:14)::VOLPERCLZ
    Real, Dimension (1:14):: YDEPTHUZ = (/0.7, 0.7, 0.7, 0.7, 0.7, 0.7, 0.7, 0.7, 0.7, 0.7, &
            0.7, 0.7, 0.7, 0.7/)
            ! Depth of SMC 2.0-----1.4(FC) ------1.0(REW) ----0.8(PWP) -----0.4(0.5PWP)
            !units are in inches
            ! Upper zone bare soil ET calculation: At 100% ASM, Kr=1
            ! Kr = (DepthUZ-0.5pWP/REW-0.5PWP)
    Real, Dimension (1:14):: YDEPTHBUZ = (/2., 2., 2., 2., 2., 2., 2., 2., 2., 2., 2., 2., 2., 2./)
            ! Depth of SMC 4.0--2.8(FC)--2.0Start value------1.6(PWP) units are in inches
            ! Below Upper zone AET calculation1: MINASMBUZ = (FCBUZ-PWP)*0.3
            ! + PWPBUZ = (2.8-1.6)*0.3 + 1.6 = 1.96, Calculations are made for
            ! BUZ at 8inches ie, 8 inches from soil surface
    Real, Dimension (1:14):: YDEPTHLZ = (/10.0, 10.0, 10.0, 10.0, 10.0, 10.0,10.0, 10.0, &
            10.0, 10.0, 10.0, 10.0, 10.0, 10.0/)
            ! Depth of SMC 32.0--16.8(FC)--16.08(90%FC) ---10.0 start value--9.6(PWP)
            ! units are in inches
            ! Below Upper zone AET calculation
            ! MINASMBUZ = (FCBUZ-PWP)*0.3 + PWPBUZ = (16.8-9.6)*0.3 + 9.6=
            !11.7, Calculations are made for LZ at 36 inches deep from soil surface
    WSArea = 80.3
            ! Area above Depth (15) in acres, pond accumulated area at Depth (15) = 1.42
    Years = 37.0
    Dcount = 0
    SumMNetSeep = 0.0
    WSMNetPerc = 0.0
    WSMRunoff = 0.0
    AETTOT = 0.0
Do L=1, 14
    Area (L) = AreaAccum(L+1) - AreaAccum(L)
END DO
```

```
    OPEN (UNIT=1, file = 'Hoganseeplong.out', status = "unknown", IOSTAT = i)
            !Daily Input    File
    OPEN (UNIT = 2, file = 'Netseep.out', status = "unknown", blank = 'zero')
             ! Daily Output File
    OPEN (UNIT=3, file = 'MonthlyNetseep.out', status = "unknown", blank = 'zero')
            ! Monthly Output File
    OPEN (UNIT=4, file = 'NetseepL.out', status = "unknown", blank = 'zero')
             ! Daily Output File for different level sections
    WRITE (unit=2,*)'Year Mo Day      ET    R.fall DepthUZ    Kr     PercUZ&
            & Evapbare DEPTHBUZ PERCBUZ AETBUZ DEPTHLZ PercLZ&
            & AETLZ  Runoff  Flood   Factor   Seepage'
    READ (unit=1,*) YEAR, MONTH, DAY, ETin, RAINFALL, &
             (Seep(i),I = 1,14), Inflow                          ! All inputs are in inches
            JJ=Years*365+20
DO j=1,JJ
    READ (unit = 1,*) YEART, MONTHT, DAYT, ETinT, RAINFALLT, &
            (SeepT(i), I = 1,14), InflowT                        ! All inputs are in inches
            DCount = Dcount+1
    IF (Year < 1900) Exit
    Do k = 1,14
    IF (Seep (k) <= 0.0) THEN
                    !  Calculations for those areas that are NOT covered with water as
                    ! indicated  by seep(K) = 0.0 for the day
            Runoff (k) = Inflow
                    ! Inflow is in inches from the watershed and is assumed to be the same for
                    ! each Incremental area of the pond above the water depth at the
                    ! beginning of the day.
            Rain (k) = Rainfall
            ET (k) = ETin
    IF (Flood (k) < 7.0) THEN
```

```
                ! It is a flood scenario where flooding for fewer than 7 days does not affect
                ! plant growth and other land-based  water budget calculations
        Factor (k) = 1.0                    .
ELSE IF (Flood (k) > 30.0) THEN
        Factor (k) = 0.0
ELSE
        Factor (k) = ((30-7) - (Flood (k) - 7)) / (30 - 7)
                 ! Factor in the range from 7-30 days gradually reduces
END If
        Flood (k) = Flood (k) - 1
IF (Flood (k) < 0.0) THEN
        Flood (k) = 0.0
ELSE
        Flood (k) = flood (k)
END If
        DepthUZ(k) = YDepthUZ(k) + (Rain(k) - Runoff(k))
        Kb = (1.0 - Factor (k)*Kc (MONTH, k))
IF (DepthUZ(k) > FCS(k)) THEN
        PercUZ(k) = (DepthUZ(k)-FCS(k))                              !PercUZ is in inches
        Evapbare(k) = ET(k)*Kb*(1.0 - residue(month, k))
        DepthUZ(k) = DepthUZ(k) - PercUZ(k) - Evapbare(k)    ! DepthUZ is in inches
        Kr = 1.0
        ETrem(k) = ET(k) - Evapbare(k)
ELSE IF (DepthUZ(k) > REW(k)) THEN
        PercUZ(k) = 0.0
        Evapbare(k) = ET(k)*Kb*(1.0 - residue(month,k))
        DepthUZ(k) = DepthUZ(k) - Evapbare(k)
        Kr = 1.0
        ETrem(k) = ET(k) - Evapbare(k)
ELSE IF (DepthUZ(k) > halfPWP(k)) THEN
        Kr = (DepthUZ(k) - HalfPWP(k))/(REW(k) - HalfPWP(k))
```

```
            !Kr starts decreasing when depthUZ < REW till it reaches 0.5PWP
    Evapbare(k) = ET(k)*Kr*Kb*(1.0 - residue(month, k))
    DepthUZ(k) = DepthUZ(k) - Evapbare(k)
    ETrem(k) = ET(k) - Evapbare(k)
ELSE IF (DepthUZ(k) < HalfPWP(k)) THEN
    Evapbare(k) = 0.0
    ETrem(k) = ET(k) - Evapbare(k)
    Kr=0.0
END If
    YDepthUZ(K) = DepthUZ(k)

        ! Below Upper zone AET calculations.

    DepthBUZ(k)=YDepthBUZ(k)+PercUZ(k)
IF (DepthBUZ(k) > FCBUZ(k)) THEN
    SMC = 1.0
    PercBUZ(k) = (DepthBUZ(k) - FCBUZ(k))
    AETBUZ(k) = Kc(MONTH,k)*AETFrBUZ(k)*SMC*ETRem(k)*Factor(k)
    DepthBUZ(k) = DepthBUZ(k) - AETBUZ(k) - PERCBUZ(k)
ELSE IF (DepthBUZ(k) > MINASMBUZ(k)) THEN
    SMC = 1.0
    PercBUZ(k) = 0.0
    AETBUZ(k) = Kc(MONTH,k)*AETFrBUZ(k)*SMC*ETrem(k)*Factor(k)
    DepthBUZ(k) = DepthBUZ(k) - AETBUZ(k) - PercBUZ(k)

ELSE IF (DepthBUZ(k) > PWPBUZ(k)) THEN
    SMC = (DepthBUZ(k) - PWPBUZ(k))/(MINASMBUZ(k) - PWPBUZ(k))
    AETBUZ(k) = Kc(MONTH,k)*AETFrBUZ(k)*SMC*ETrem(k)*Factor(k)
        DepthBUZ(k) = DepthBUZ(k) - AETBUZ(k)
    PERCBUZ(k) = 0.0
    ETrem(k) = ETrem(k) - AETBUZ(k)
```

```
    ELSE
        PercBUZ(k) = 0.0
    END IF
        YDEPTHBUZ (k) =DEPTHBUZ (k)
        DepthLZ(k) = YDepthLZ(k) + PercBUZ(k)
                ! Below upper zone AET calculations
    IF (DepthLZ(k) > (FCLZ(k) - 0.1*(FCLZ(k) - PWPLZ(k)))) THEN
            ! To decide the FCLZ, it is assumed that 10%less than FCLZ ie (1-.9)as
the         ! 100%ASM& PWPLZ as 0%ASM
        SMC = 1.0
        PercLZ(k) = DepthLZ(k) - (FCLZ(k) - 0.1*(FCLZ(k) - PWPLZ(k)))
        AETLZ(k) = Kc(MONTH,k)*(1-AETFrBUZ(k))*SMC*ETrem(k)*Factor(k)
                !Assumed to be 60% SMC for AET calculation
        DepthLZ(k) = DepthLZ(k) - AETLZ(k) - PERCLZ(k)
    ELSE IF (DepthLZ(k) > MINASMLZ(k)) THEN
        SMC = 1.0
        PercLZ(k) = 0.0
        AETLZ(k) = Kc(MONTH,k)*(1 - AETFrBUZ(k))*SMC*ETrem(k)*Factor(k)
        DepthLZ(k) = DepthLZ(k) - AETLZ(k) - PERCLZ(k)
    ELSE IF (DepthLZ(k) > PWPLZ(k))THEN
        PERCLZ (k) = 0.0
        SMC = (DepthLZ(k) - PWPLZ(k))/(MINASMLZ(k) - PWPLZ(k))
        AETLZ(k) = Kc(MONTH,k)*(1 - ETFrBUZ(k))*SMC*ETrem(k)*Factor(k)
            DepthLZ(k) = DepthLZ(k) - AETLZ(k) - PERCLZ(k)
    ELSE
        PercLZ(k) = 0.0
    END IF
        YDEPTHLZ (k) = DEPTHLZ (k)

    ELSE
        Rain (k) = 0.0
```

```
          ET (k) = 0.0
          Kr = 0.0
          Evapbare (k) = 0.0
          AETBUZ (k) = 0.0
          AETLZ (k) = 0.0
          DepthUZ (k) = YDepthUZ(k) + Seep(k)
          Flood (k) = Flood (k) + 1
IF (Flood (k) > 0.0) THEN              ! Sets Flood factor 0.0 since area is inundated.
                    Factor (k) = 0.0
END IF
IF (Flood (k) > 60.0) THEN
          Flood (k) = 60.0
END IF
If (DepthUZ(k) > FCS(k))THEN                ! Seepage>0.0 starts executing from here
          PercUZ(k) = (DepthUZ(k) - FCS(k))
          DepthUZ(k) = FCS(k)
          YDepthUZ(k) = DepthUZ(k)
ELSE
          PercUZ(k) = 0.
          YDepthUZ(k) = DepthUZ(k)
END IF
          DepthBUZ(k) = YDepthBUZ(k) + PercUZ(k)
IF (DepthBUZ(k) > FCBUZ(k)) THEN
          PercBUZ(k) = (DepthBUZ(k) - FCBUZ(k))
          DepthBUZ(k) = FCBUZ(k)
          YDepthBUZ(k) = DepthBUZ(k)
ELSE
          PercBUZ(k) = 0.0
          YDepthBUZ(k) = DepthBUZ(k)
END IF
          DepthLZ(k) = YDepthLZ(k) + PercBUZ(k)
```

```
IF (DepthLZ(k) > (FCLZ(k) - 0.1*(FCLZ(k) - PWPLZ(k)))) THEN
        PercLZ(k) = DepthLZ(k) - (FCLZ(k) - 0.1*(FCLZ(k) - PWPLZ(k)))
        DepthLZ(k) = FCLZ(k) - 0.1*(FCLZ(k) - PWPLZ(k))
        YDepthLZ(k) = DepthLZ(k)
ELSE
        PercLZ(k) = 0.0
        YDepthLZ(k) = DepthLZ(k)
END IF
END IF

WRITE (2, 10) Year,Month,Day, ET(k),Rain(k), DepthUZ(k), Kr, PercUZ(k), &
        Evapbare(k), DEPTHBUZ(k), PercBUZ(k), AETBUZ(k), DEPTHLZ(k), &
        PercLZ(k), AETLZ(k), Runoff(k), flood(k), Factor(k), seep(k)
10 FORMAT (I4, 2x, I2, 2x, I2, 2x, 16(F8.3))
IF (k= =12) THEN
        AETTOT = AETBUZ (k) + AETLZ (k)
WRITE (4, 40) Year, Month, Day, ET(k), Evapbare(k), AETBUZ(k), AETLZ(k),&
        AETTOT
40 FORMAT (I4, 2x, I2, 2x, I2, 2x, 5(F8.3))
END IF

        SumEvapbare(k) = Evapbare(k) + SumEvapbare(k)
        SumpercUZ(k) = PercUZ(k) + SumPercUZ(k)
        SumET(k) = ET(k) + SumET(k)
        Sumrainfall(k) = Rain(k) + Sumrainfall(k)
        SumAETBUZ(k) = AETBUZ(k) + SUMAETBUZ(k)
        SUMPERCBUZ(k) = PERCBUZ(k) + SUMPERCBUZ(k)
        SUMPERCLZ(k) = PERCLZ(k) + SUMPERCLZ(k)
        SUMAETLZ(k) = AETLZ(k) + SUMAETLZ(k)
        Sumrunoff(k) = Runoff(k) + sumrunoff(k)
        Sumseep(k) = Seep(k) + Sumseep(k)
```

```
        PondMNetSeep = PondMNetSeep + perclz(k)*Area(k)/12.
END DO          ! End of loop k for
        WSMNetPerc = WSMNetPerc + PerclZ(14)*(WSArea+AreaAccum(14))/12.
                ! Assumes percolation from Area(14) represents the percolation
                ! from the  entire watershed.
        WSMRunoff = WSMRunoff+Inflow*(WSArea+AreaAccum(14))/12.
    IF (MONTH/ = MONTHT) THEN
    WRITE (3,100) Year, Month, Dcount, PondMNetSeep, WSMNetPerc, WSMRunoff
                ! Writes out monthly net seepage from the pond, net percolation from the
                ! entire  area without pond, and runoff from the entire without pond, in
                ! acre-feet
    100 FORMAT (I4, x, I2, x, I2, 3(F8.3))
    IF (YEART < 1900) THEN
    WRITE (2,*) '999 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0'
    EXIT
    END IF
        PondMNetSeep = 0.0
        SumMNetSeep = 0.0
        WSMNetPerc = 0.0
        WSMRunoff = 0.0
        DCount=0
    END IF
        Year = YearT
        Month = MonthT
        Day = DayT
        ETin = ETinT
        Rainfall =RainfallT
        Inflow = InflowT

    DO ii = 1,14
        Seep(ii) = SeepT(ii)
```

```
END DO
END DO
      WRITE (unit=2,*)’Stage SumET     SumRain  SumSeep  sumPercuz SumEvapuz &
                 SUMAETBUZ SUMPERCBUZ SUMAETLZ SUMPERCLZ   &
                 Sumrunoff Vol. Seep in  Vol.percLZ out % Net seep'
DO m = 1, 14
          VOLSEEP (m) = SUMSEEP (m)*AREA (m)
          VOLPERCLZ (m) = SUMPERCLZ (m)*AREA (m)
          PERCENTNETSEEP (m) = VOLPERCLZ (m)/VOLSEEP (m)*100
          SUMVOLSEEP = VOLSEEP (m)/12. + SUMVOLSEEP
          SUMVOLPERCLZ = VOLPERCLZ (m)/12. + SUMVOLPERCLZ

      WRITE (2,20) Depth(m), SumET(m), SumRainfall(m), SumSeep(m),
          SumpercUZ(m), Sumevapbare(m), SUMAETBUZ(m), SUMPERCBUZ(m),
          SUMAETLZ(m),SUMPERCLZ(m), umrunoff(m), volseep(m), volperclz(m), &
          percentnetseep(m)
END DO
          OVERALLNETSEEP = (SUMVOLPERCLZ/SUMVOLSEEP)*100
      WRITE (unit = 2, *) 'Overall Net Seepage,  Volume of Percolation, ac-feet &
          & Volume of Seepage, ac-feet'
      WRITE (2, 30) OVERALLNETSEEP, SUMVOLPERCLZ, SUMVOLSEEP
      20 FORMAT (F5.1, 10(F10.3), 3(F12.2))
      30 FORMAT (10x, F6.1, 2(F25.2))
      Close (Unit = 1)
      Close (Unit = 2)
      Close (Unit = 3)
      Close (Unit = 4)
      STOP
      END PROGRAM NETSEEP
```