Appendix G

APPENDIX G

DETAILED PROGRESS REPORT
OF
UNIVERSITY OF NEBRASKA-LINCOLN

Progress Report

Modeling and Field Experimentation to Determine the Effects of Land Terracing and Non-Federal Reservoirs on Water Supplies in the Republican River Basin Above Hardy, Nebraska

Cooperative Agreement No. 05EC601962

Reporting Period: May, 2005 – May 2006

Principal Investigator: Derrel Martin
Department of Biological Systems Engineering
University of Nebraska-Lincoln
Lincoln, NE
dlmartin@unlnotes.unl.edu 402-472-1586

Project Objectives

This a joint project between the University of Nebraska-Lincoln, Kansas State University and the Bureau of Reclamation. The project involves the following responsibilities:

1. Field experimentation to quantify the water balance for representative terraced land sites and small non-federal reservoirs. Subprojects include:
    a. Installation, calibration and maintenance of monitoring equipment.
    b. Identification of suitable monitoring sites.
    c. Collection of water balance data from representative sites.
    d. Processing and summarizing research results.
    e. Limited studies will be conducted to estimate the transmission losses in ephemeral streams and other waterways.

2. Modification, calibration and verification of simulation models used to predict the effects of reservoirs and terraces on subwatersheds that provide water to the riparian area adjacent to the Republican River.

3. Development of databases required to simulate the water balance of subwatersheds.

4. Development of a Geographic Information System to aggregate and process input data for simulation models and to process simulation results to enhance understanding of depletive effects of terraces and reservoirs.

5. Conduct simulations to develop comparisons between conditions with and without terraces and small reservoirs.

6. Integration of model results and supporting data and programs to develop an overall project report.

FIELD MEASUREMENT

Terrace Research Sites

Five sites were selected for the field research on the impact of terraces. The sites include two conservation bench terrace systems located near Culbertson, Nebraska and Colby, Kansas; two level terrace systems with closed ends located near Curtis, Nebraska and Norton, Kansas; and one level terrace system with open end(s) located near Stamford, Nebraska (Figure 1).

Rectrified digital imagery photographs from the USDA-FSA for each site are shown in Figures 2-4. The soil mapping units from the SSURGO databases are included for each site on the field maps. The mapping units and the mapping unit names are listed in Appendix 1. The soils at the sites are predominately silt loam with Keith Silt Loam being more prominent at the Western Sites (*i.e.*, Culbertson and Colby) and Holdrege Silt Loam most prominent at the three eastern sites (*i.e.*, Curtis, Norton and Stamford).

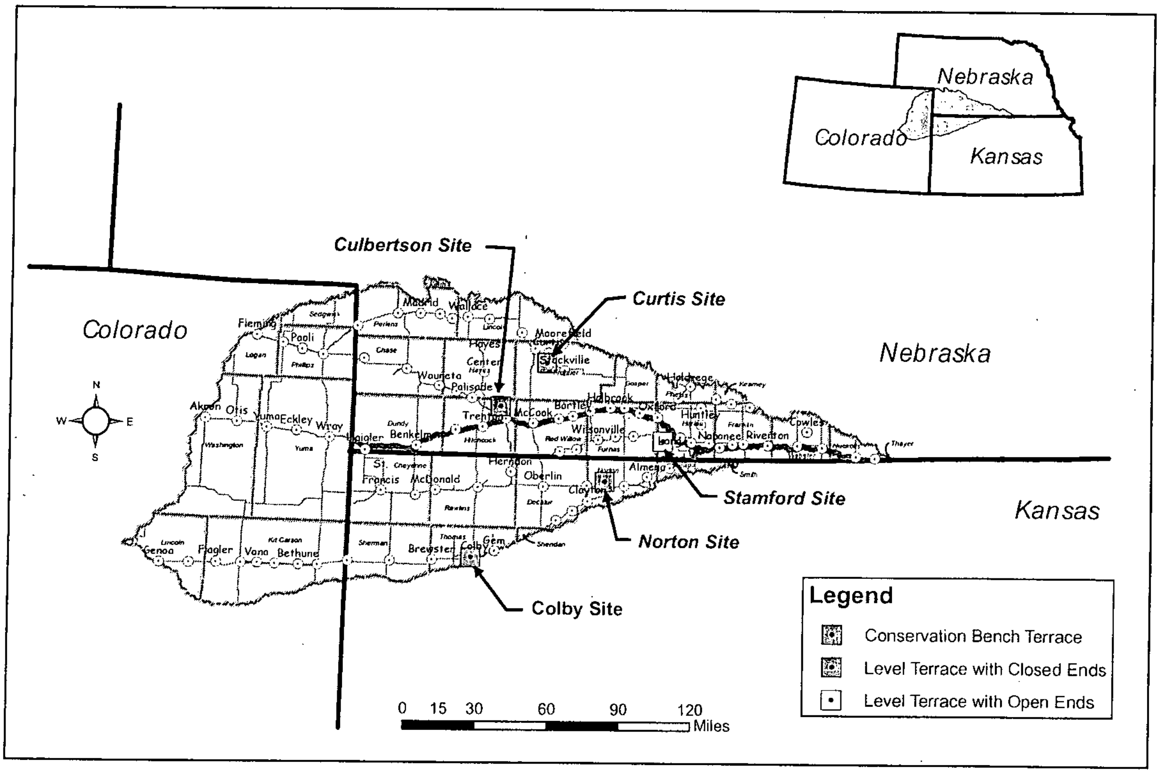
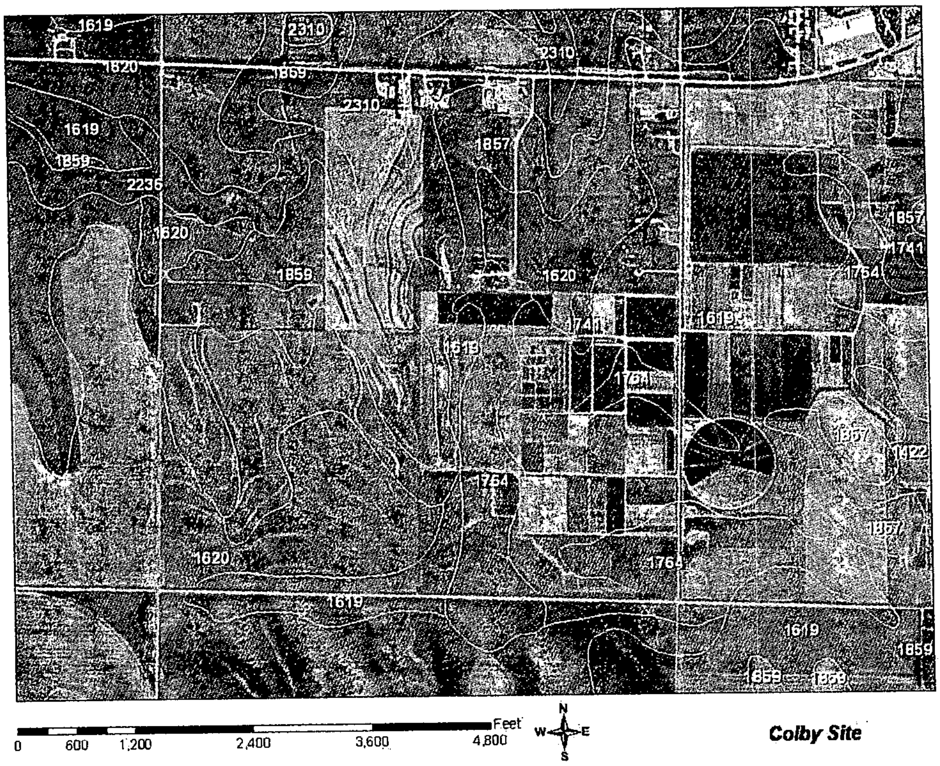
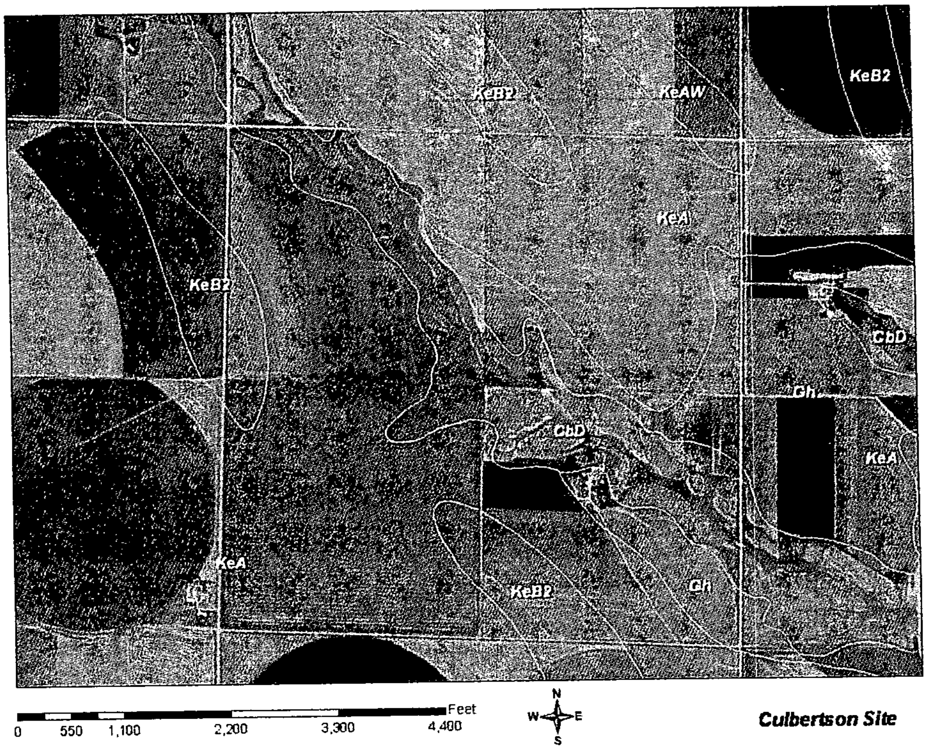


Figure 1. Location of conservation terrace research sites in the Republican River Basin.

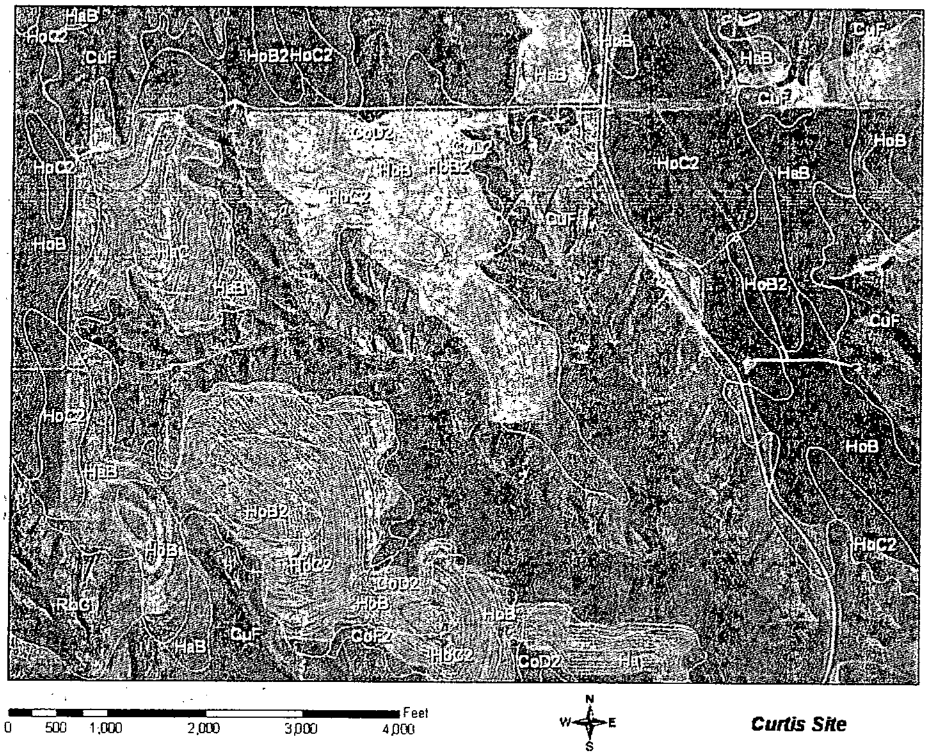


Colby Site

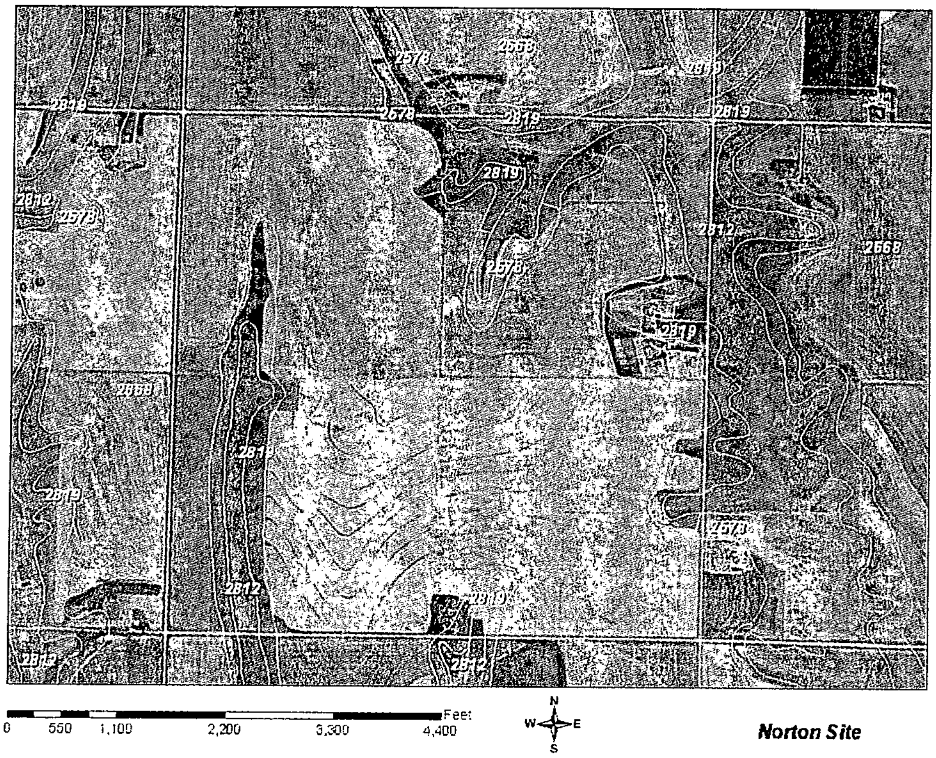


Culbertson Site

Figure 2. Maps of the Colby and Culbertson research sites. Soil mapping units from the SSURGO database are described in Table 1 for each County



Curtis Site



Norton Site

Figure 3. Maps of the Curtis and Norton research sites. Soil mapping units from the SSURGO database are described in Table 1 for each County

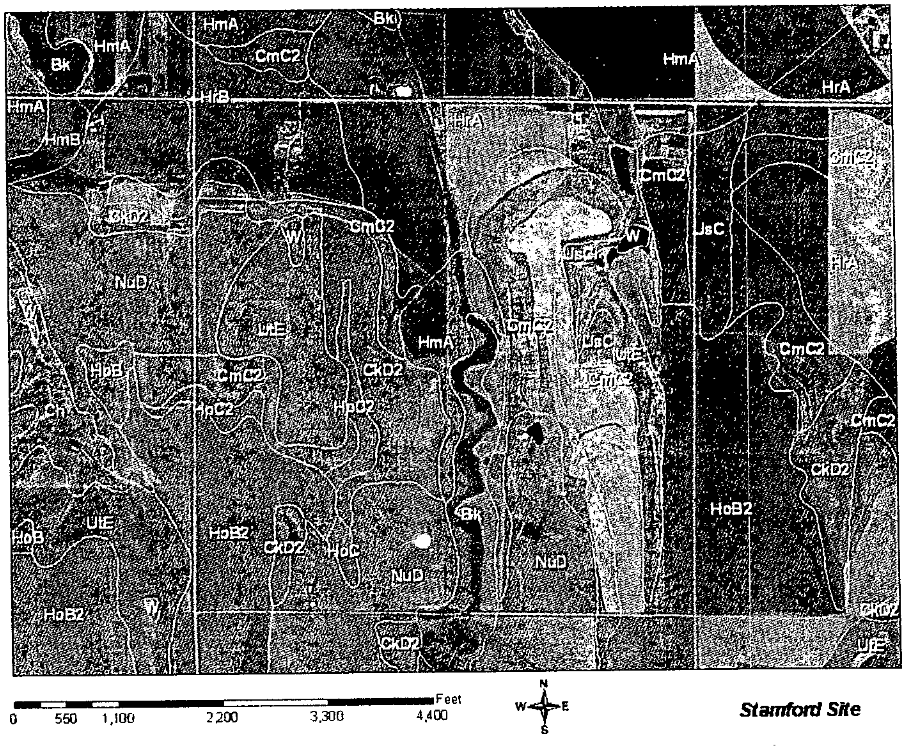


Figure 4. Maps of the Stamford research sites. Soil mapping units from the SSURGO database are described in Table 1 for Harlan County

Terrace Measurements

Terraces are positioned in the field to generally store the amount of runoff that would be expected from a 10-year storm. The distance between the ridges of two successive terraces, when measured perpendicular to the terrace, is called the terrace interval. The size of the interval depends on the amount of runoff expected, the type of soil and the prevailing slope in this region. Earth is moved from the terrace channel to form the ridge on the downside of the terrace. A portion of the land between the terraces is not affected by terrace construction. This area is called the contributing area. Water runs off of the contributing area and accumulates in the terrace channel. The rough sketch in Figure 5 illustrated the terrace channel and the contributing area.

Conservation terraces are designed with little or no slope along the terrace channel. The flat channels are made to store water in the field to provide for opportunity time to infiltrate the water into the soil profile. The terrace ridge must be tall enough to store the design storm. Frequently the terraces can store 12 inches of water in the channel. The terrace channel can be either open-ended or close-ended. Open-ended terraces allow water to slowly flow from the terrace channel. Close-ended terraces are constructed to store most of the water that can be retained in the channel.

Finally, the cross-section of the terrace channel can vary. Conservation bench terraces are constructed to have a wide bottom to allow for uniform distribution of water within the channel and to enhance water use by plants. We are referring to level terraces as terraces that have a flat channel; however the bottom width is much less than for conservation bench terraces. Level terraces pond water to a greater depth than conservation bench terraces. Conservation-bench terraces usually have closed ends. Level terraces may have open or closed ends.

The sites that we have selected contain two conservation bench terraces with closed ends, two level terraces with closed ends and one level bench system with on open end. Based on the design and the way that water is distributed and retained in the terrace channel it is clear that substantial differences can be expected for the performance of these terrace types. Thus it is important to measure the water balance of the contributing areas and the terrace channels for each type of terrace. The layout of measurement equipment in the terrace channel and the contributing areas are diagrammed in Figure 6. The types of measurements being made and the type of equipment we are using is described below.

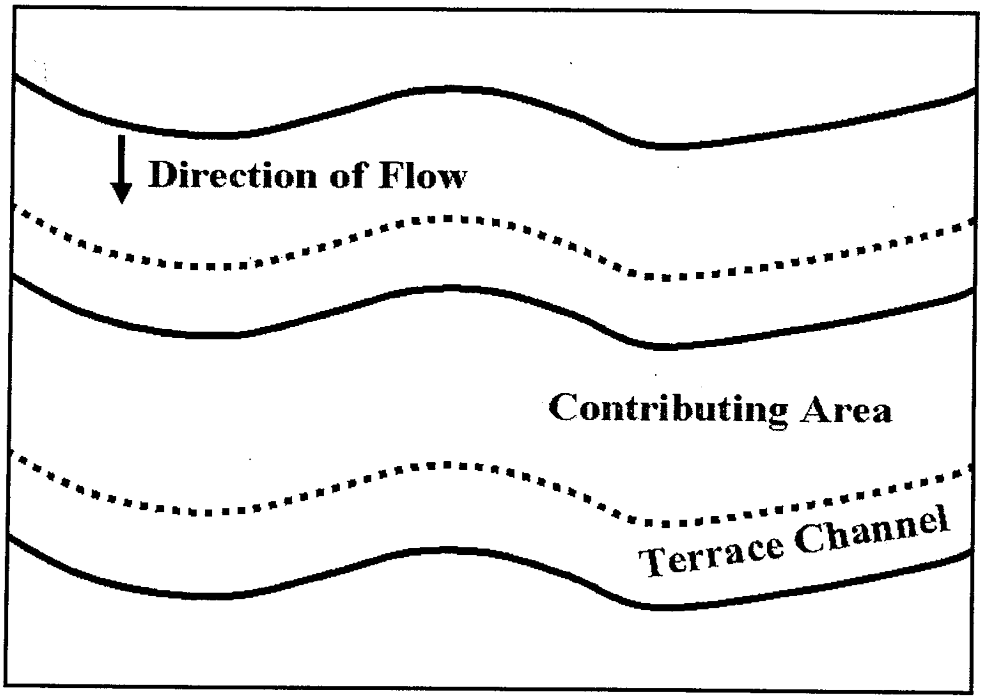


Figure 5. Plan view of a pair of conservation terraces.

Ham et al. (1999) represent the water balance as:

$$Q_{in} + P = Q_{out} + E + ET + S \qquad (1)$$

where; Q_{in} = inflow $[L^3/T]$
P = precipitation $[L/T]$
Q_{out} = outflow $[L^3/T]$
E = evaporation from free water surface $[L/T]$
ET = evapotranspiration from soil and vegetated surfaces $[L/T]$
S = seepage $[L/T]$

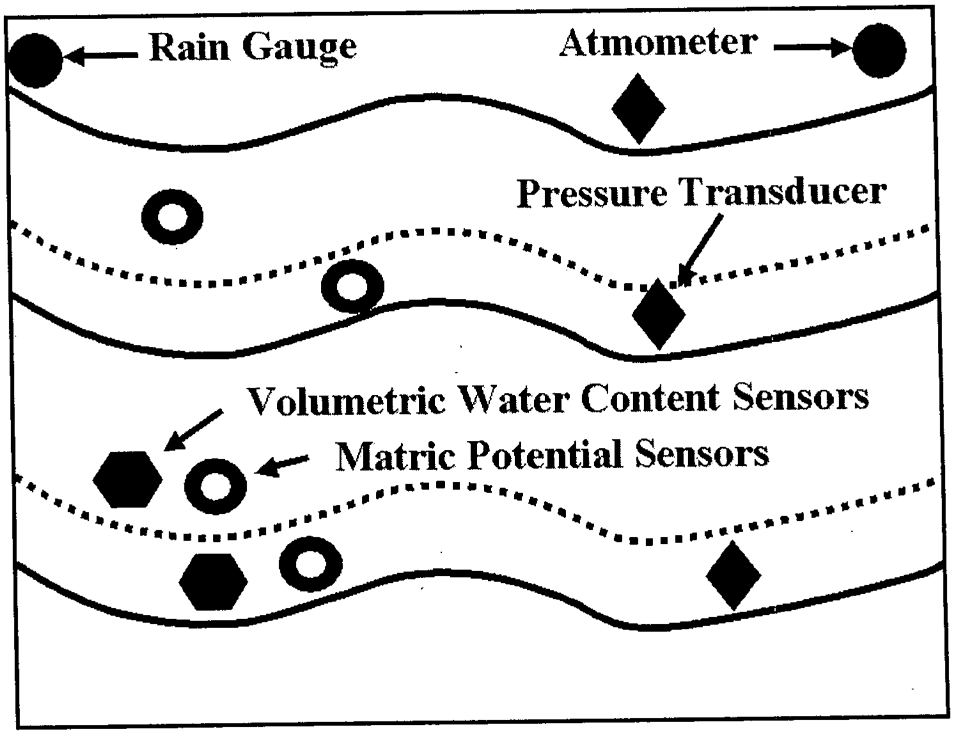


Figure 6. Layout of equipment for monitoring a level terrace system.

Precipitation is measured with a 20 cm (8 in.) diameter Hydrological Services TB4-L tipping bucket rain gauge. Reference evapotranspiration (ET) data is collected using a Model E atmometer. The rain gauge and atmometer were installed along a fence line, at a height of 0.9 m (3 ft), to avoid interference with farming practices. The rain gauges are connected to a HOBO datalogger (Figure 7). Figure 8 shows the installation of the tipping bucket rain gauge.

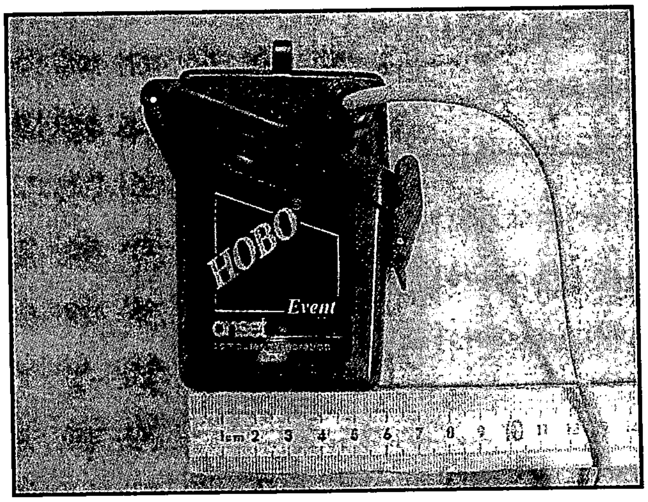


Figure 7: HOBO datalogger used for collection of precipitation and evapotranspiration (ET) data.

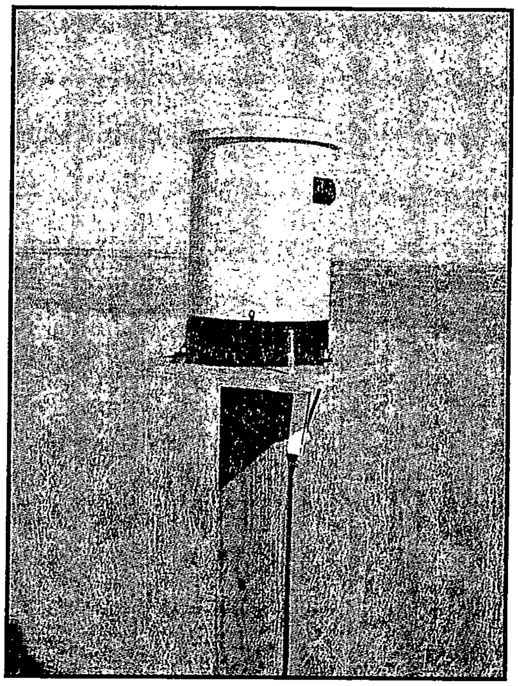


Figure 8. Tipping bucket rain gauge.

Mini LT Leveloggers made by Solinst (Figure 9) are being used to measure inflows into terrace channels. The Leveloggers were installed along the bottom of two terrace channels to give pressure readings at pre-set time increments during precipitation events. The Leveloggers were installed vertically inside a 5.1 cm (2 in.) diameter schedule 40 PVC pipe. The pipe has a total length of 0.91 m (3 ft), with 0.3 m (1 ft) buried underground. A barologger (same appearance as the Levelogger) was installed inside of one pipe. The barologger compensates for barometric pressure, and is used in conjunction with the Leveloggers. Figures 9 and 10 show a cross-section of the Levelogger installation and the finished installation.

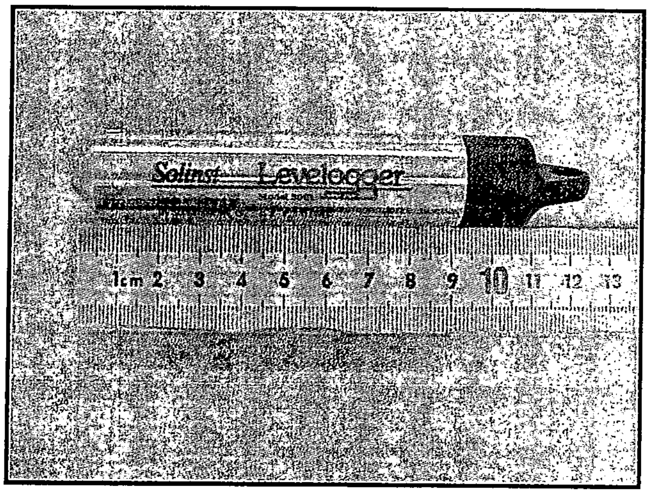


Figure 9. Solinst Levelogger used to measure the height of water in the terrace channels.

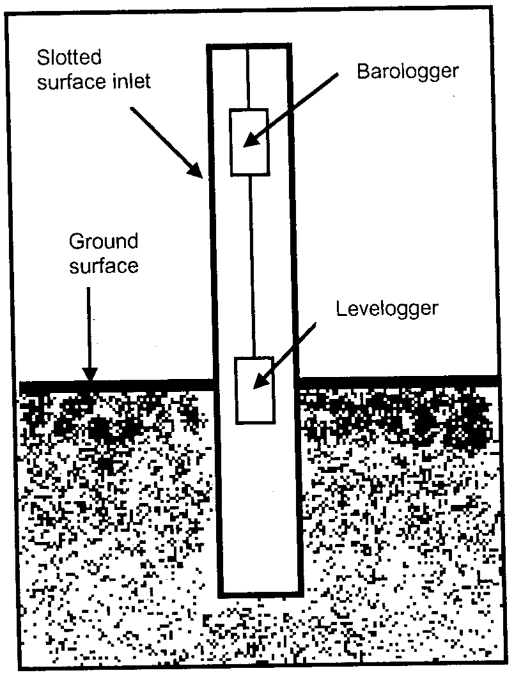


Figure 10. Cross-section of Levelogger installation. PVC pipe 0.91 m long (3 ft) buried 0.3 m (1 ft) underground.

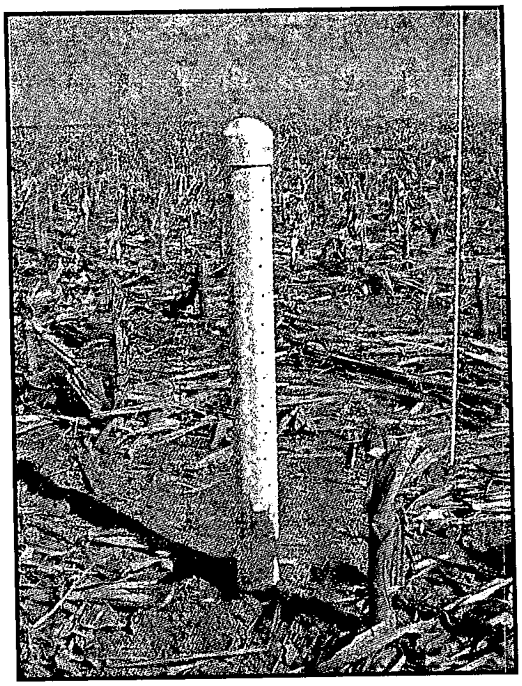


Figure 11. Completed Levelogger installation.

By knowing the Levelogger pressure readings (cm) and the correction due to barometric pressure (cm), the ponded water depth can be calculated. These values do include precipitation depths, so subtracting the precipitation depth from the ponded water depth will give the depth of runoff into each respective terrace channel. The installation of the Leveloggers will provide minor inconveniences to farming practices.

Outflows in the conservation bench terrace systems and level terrace systems with closed ends, if present, will be measured in two terraces per location using the Leveloggers. A topographic survey was conducted to determine the elevations along the top of the monitored terrace ridges. Subtracting these elevations from the elevation of water in the terrace channels will yield the height of water flowing over each terrace ridge. The flow rate over the ridges can then be calculated by (Munson et al., 1998):

$$Q = CLH^{3/2} \qquad (2)$$

where;
Q = flow rate over weir $[L^3/T]$
C = weir coefficient $[L^{.5}/T]$
L = weir length $[L]$
H = height of water above terrace berm crest $[L]$

Outflows for the level terrace system with open end(s) will be measured using two ISCO area/velocity meters. The area/velocity meters measure both water column height and water velocity. Inputting an area allows the meter to calculate flow rate:

$$Q = VA \qquad (3)$$

where;
Q = flow rate $[L^3/T]$
V = water velocity $[L/T]$
A = Area $[L^2]$

A channel section could be constructed in the terrace channel to allow for the installation of the area/velocity meter. Recommended specifications for the channel include using 1.27 cm (0.5 in) treated plywood. Furthermore, an underground cutoff will need to be added to prevent water from flowing under the channel. Lastly, the channel should be staked into the ground to prevent it from being washed away. Figure 24 shows a cross-section of the constructed channel, along with approximate dimensions (each terrace location will have it's own unique set of dimensions). This set-up will provide some minor inconveniences to the farmer. Care will need to be taken to not drive over any equipment during farm practices.

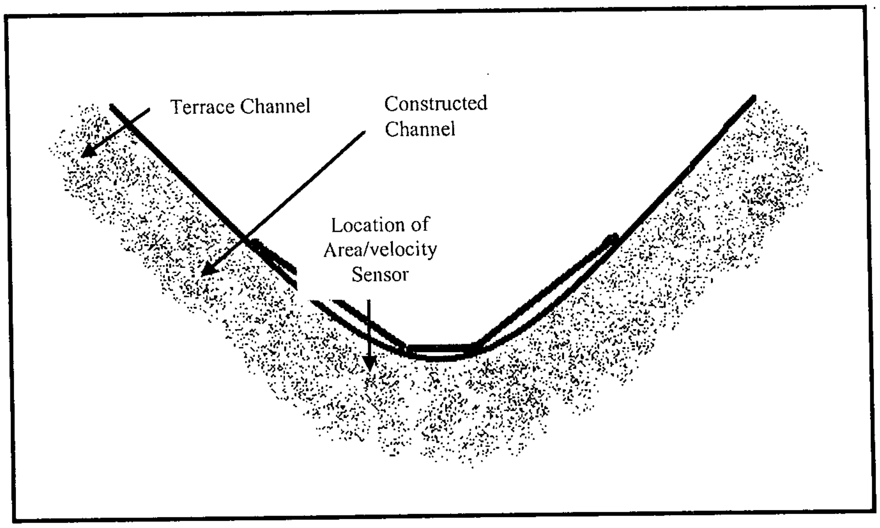


Figure 12. Cross-section of constructed channel used for outflow measurements. The constructed channel will have approximate bottom and top widths of 0.61 m (2 ft) and 7.3 m (24 ft), respectively. The area/velocity meter is placed in the center of the constructed channel. The channel will have a length of 2.4 m (8 ft).

Deep percolation (flux) at specific depths below the root zone in the contributing areas and terrace channels for all conservation terrace systems will be calculated using two methods. The first method, the unit gradient approach, will use field measurements of soil volumetric water content (θ_v), along with an estimated unsaturated hydraulic conductivity function ($K(\theta_v)$), to estimate flux (Stephens, 1996):

$$q = -[K(\theta_v)]\ i \qquad (4)$$

where; q = flux [L/T]
$K(\theta_v)$ = unsaturated hydraulic conductivity function [L/T]
i = hydraulic gradient

When applying equation 4 for unsaturated flow, the hydraulic gradient is usually assumed to be equal to one. This assumes that only gravity has the primary influence of flow in the vadose zone and that capillarity is negligible. This can be a source of error ; however, it is typically accepted to be a reasonable (Stephens, 1996).

ThetaProbe sensors made by Delta-T Devices are being used to continuously measure volumetric water content below the root zone. The ThetaProbe sensor measures the soil's dielectric constant and converts it into a DC voltage for storage in a datalogger. The stored DC voltage is proportional to the soil's volumetric water content (Delta-T Devices, 1999). Installed ThetaProbe sensors were placed at a depth of 2.29 m (7.5 ft) in both the contributing areas and terrace channels. A piece of 1.91 cm (0.75 in.) schedule 80 PVC pipe was connected to the sensor to aid in its installation. The hole around the pipe was filled with bentonite to eliminate preferential flow down the pipe. Data from the ThetaProbe sensors is being collected using Campbell CR-200 dataloggers. Figures 13 and 14 show the ThetaProbe sensor and installation of the sensor using a Giddings probe, respectively.

Calibration of the ThetaProbe sensors can be done two different ways. A soil-specific calibration of the ThetaProbe sensors can be accomplished by determining the two coefficients, a_o and a_l, (Delta-T Devices, 1999):

$$\theta_v = \varepsilon^{0.5} - a_o - a_l \tag{5}$$

where; ε = dielectric constant
a_o and a_l = coefficients
θ_v = volumetric water content $[L^3/L^3]$

If a soil-specific calibration is not needed, a generalized calibration can be used. In this case, a_o and a_l have values of 1.6 and 8.4 for mineral soils, respectively (Delta-T Devices, 1999). When using either calibration process, values for the dielectric constant can be obtained using a relationship comparing ThetaProbe output voltage to dielectric constant (Delta-T Devices, 1999).

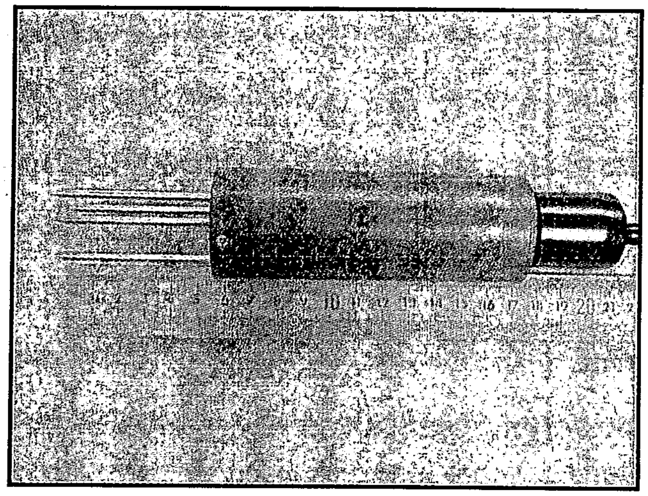


Figure 13. ThetaProbe sensor used for measuring volumetric water content.

Figure 14. ThetaProbe installation using a Giddings probe.

The second soil moisture monitoring method will use field measurements of soil matric potential (h_c), along with an estimated relative conductivity function ($k(h_c)$), to estimate flux using the Buckingham-Darcy equation (Jury and Horton, 2004):

$$Z_2 - Z_1 = -\int_{h1}^{h2} \frac{dh}{1 + \frac{q}{k(hc)}} \tag{6}$$

where: Z_2 = elevation at sensor 2 [L]
Z_1 = elevation at sensor 1 [L]
h_2 = matric potential at sensor 2 [L]
h_1 = matric potential at sensor 1 [L]
q = flux [L/T]
$k(h_c)$ = relative conductivity function [L/T]

This equation was developed for use with steady flow problems. While this flux calculation will not be steady, dividing the analysis into small time steps will allow this error to be minimized (Jury and Horton, 2004).

Watermark sensors made by Irrometer Company are being used to continuously measure matric potential (h_c) at two depths, 2.13 m (7 ft) and 2.44 m (8 ft), below the soil surface in both the contributing areas and terrace channels. A piece of 1.91 cm (0.75 in.) diameter CTS CPVC pipe was connected to the Watermark sensors and used as an extension to aid in installation. A soil probe was used to make a 1.91 cm (.75 in.) diameter hole to the desired depth. Slurry was poured down the hole during installation to ensure good contact between the Watermark sensor and the surrounding soil. To stop any preferential flow along the CPVC pipe, a hole 15 cm (6 in.) in diameter and 30 cm (12 in.) in depth was centered on the CPVC pipe. This hole was then back-filled with bentonite.

Temperature sensors were installed in a 1.91 cm (.75 in.) diameter hole to a depth of 1.68 m (5.5 ft). These sensors allow automatic corrections of the measured matric potential due to fluctuations in soil temperature. The sensor was installed at 1.68 m because one temperature sensor was used to compensate all Watermark sensors (including the Watermark sensors used for root zone soil moisture measurement described later). Data from the sensors is being collected using a datalogger from Irrometer Company. Figures 15, 16, and 17 show the Watermark sensor, the soil probe installation, and the installed sensors/datalogger, respectively.

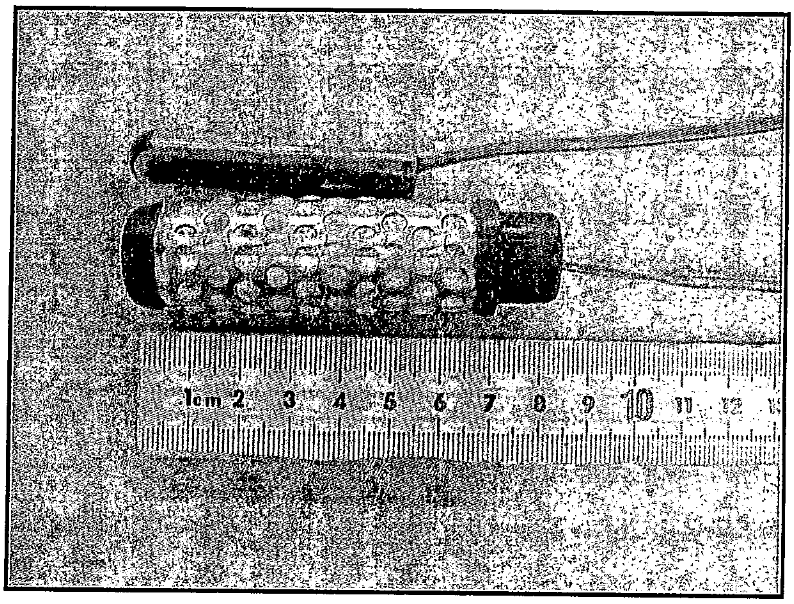


Figure 15. Watermark sensor used for measuring soil matric potential and a soil temperature sensor (smaller device in picture).

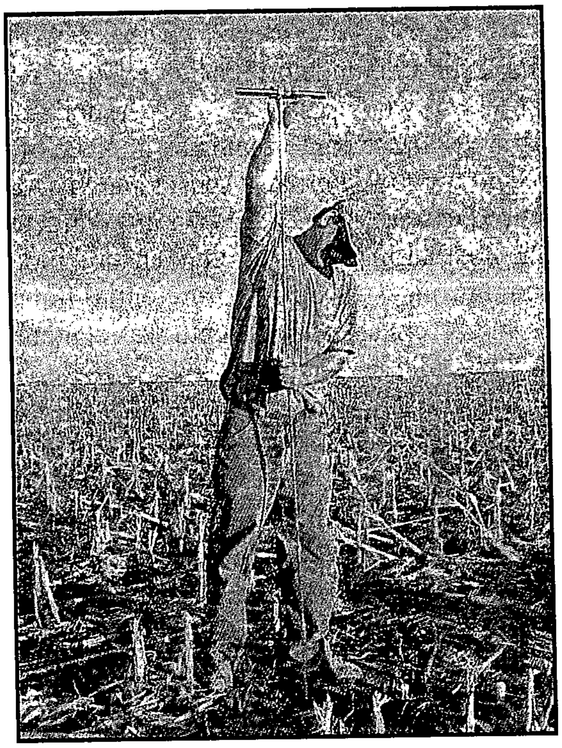


Figure 16: Picture showing soil probe installation of Watermark sensors.

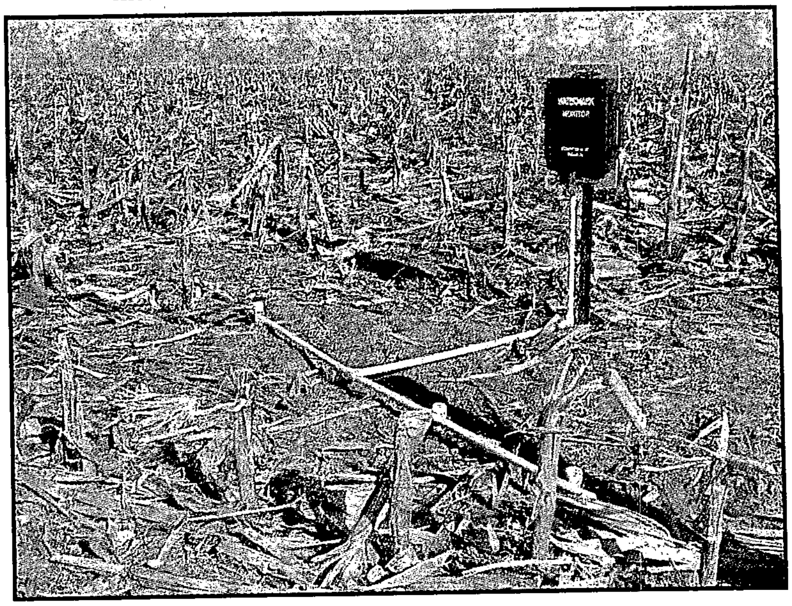


Figure 17. Picture showing completed Watermark sensors/datalogger installation. Extra PVC pipe was used to protect sensor wires..

Applying two different methods to the flux calculation will allow a comparison between methods. Furthermore, a comparison between the flux from the contributing area and the flux from the bench area will also be possible. This could help determine what impacts the different terrace systems are having on deep percolation.

Monitoring of soil moisture within the root zone is also a part of this project. This will allow a comparison between crop water usage of plants within the bench area and on the contributing slope. Root zone soil moisture monitoring will be accomplished by continuously measuring both matric potential and volumetric water content in the root zone on one terrace.

Watermark sensors (installed as previously described) are measuring matric potential at two depths, 0.91 and 1.22 m (3 and 4 ft). Volumetric water content is measured at six depths using a 2 m (6 ft) frequency domain reflectometry (FDR) Sentek EnviroSMART probe. The six depths are: 20.32, 30.48, 60.96, 91.44, 142.2, and 182.9 cm (8, 12, 24, 36, 56, and 72 in.). Data from the EnviroSMART probe is collected using the same Campbell CR-200 dataloggers as the ThetaProbe sensors use (see Appendix C for copy of CR200 program). Figures 18 and 19 show the EnviroSMART installation process and the installed probe.

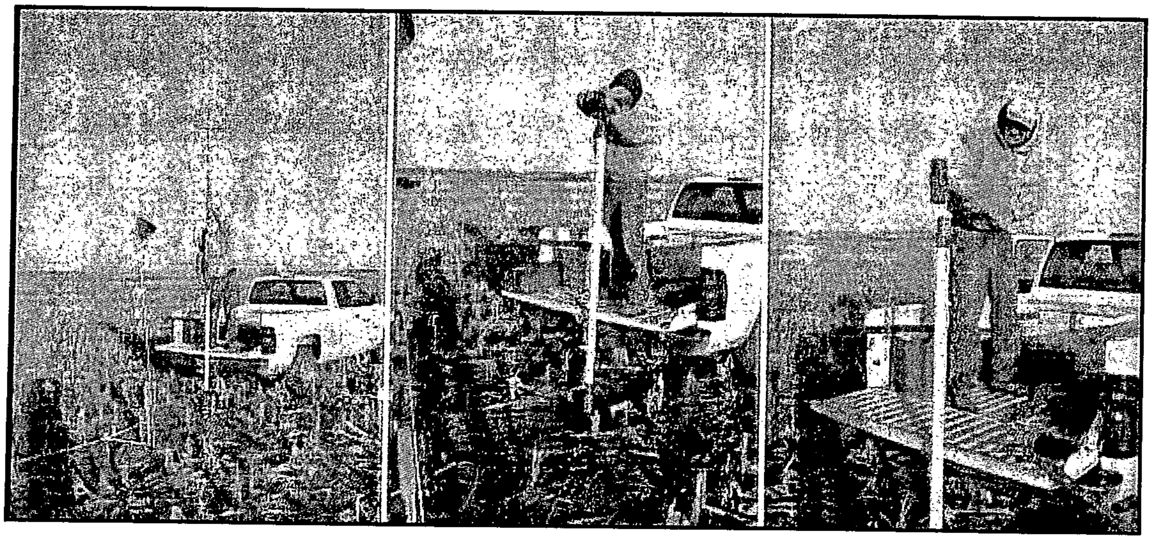


Figure 18. EnviroSMART probe installation. Photo on left shows auger being placed inside of the access tube. Center photo shows auguring of the pilot hole and the photo on the far right shows the access tube being pounded into the ground after auguring. This process was repeated several times to complete the access tube installation.

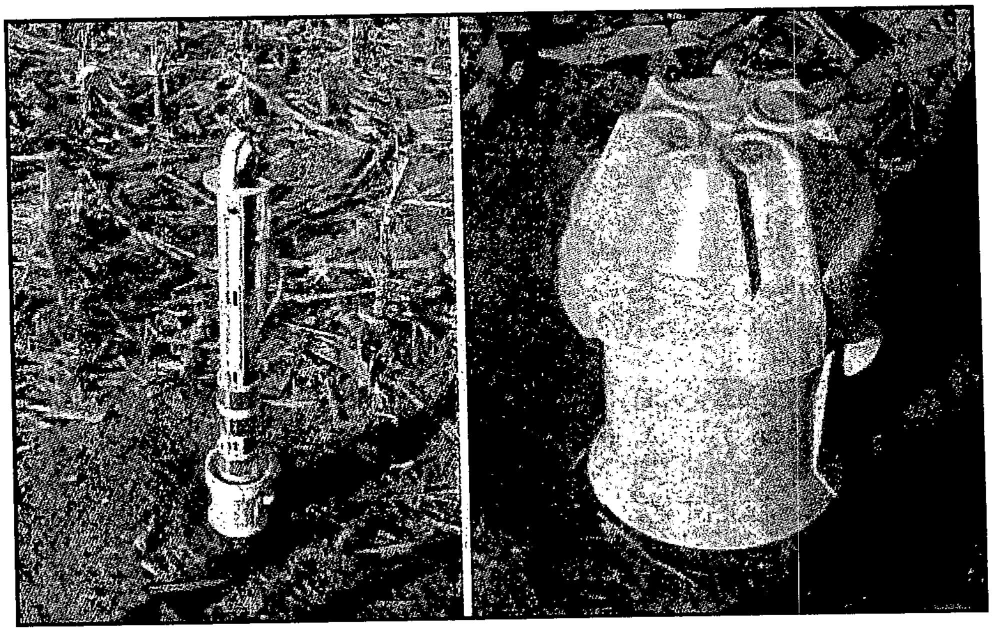


Figure 19. Pictures showing the EnviroSMART probe installation into the access tube (left), and the completed access tube/ EnviroSMART probe installation (right).

The field site instrumentation has all been completed with the exception of the runoff station at the open-ended terrace system near Stamford, NE. Field work planned in the near future includes ring infiltrometer tests for the determination of parameters for the Green-Ampt infiltration equation.

Some preliminary data are illustrated in Figures 20 and 21 for the Culbertson Site where winter wheat is raised on a field that has conservation bench terraces. The water content shows that the terrace channel experiences more water input following the precipitation on March 26 and 27. The soils in the terrace channel increased about 7% while the soils in the contributing area only increased by about 2 to 3%. The water content patterns show the water use from the profile as the crop began to grow and transpire in the spring.

Data are shown in Figure 22 for soil matric potential and rainfall at the Curtis Site. The data shows that little rain fell during this period but the soil matric potential dropped during this time in response to the rain. Surprisingly the soil at the seven and eight foot depths are much drier than anticipated. The Watermark Logger only records matric potential to a maximum potential of 200 centibars. We will need to investigate using a different logging technique for such dry soils. It is unlikely that any significant downward flow of water is occurring at these water contents thus recharge estimates are probably not materially affected by the limitations on the datalogger.

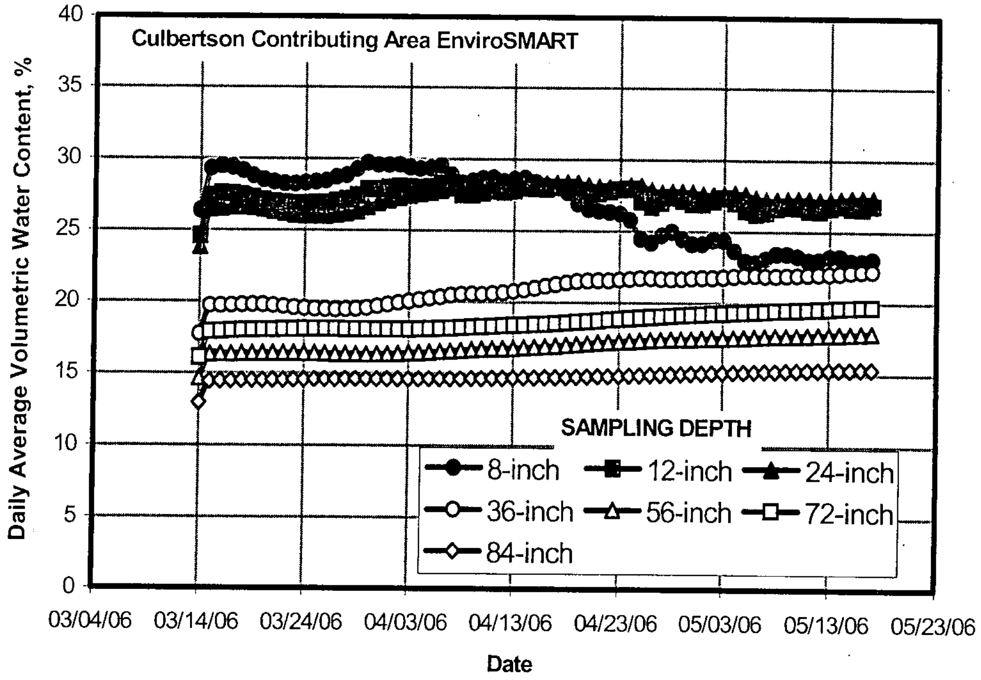


Figure 20. Pattern of volumetric water content for two months for the contributing area at the Culbertson site. Site is planted to winter wheat.

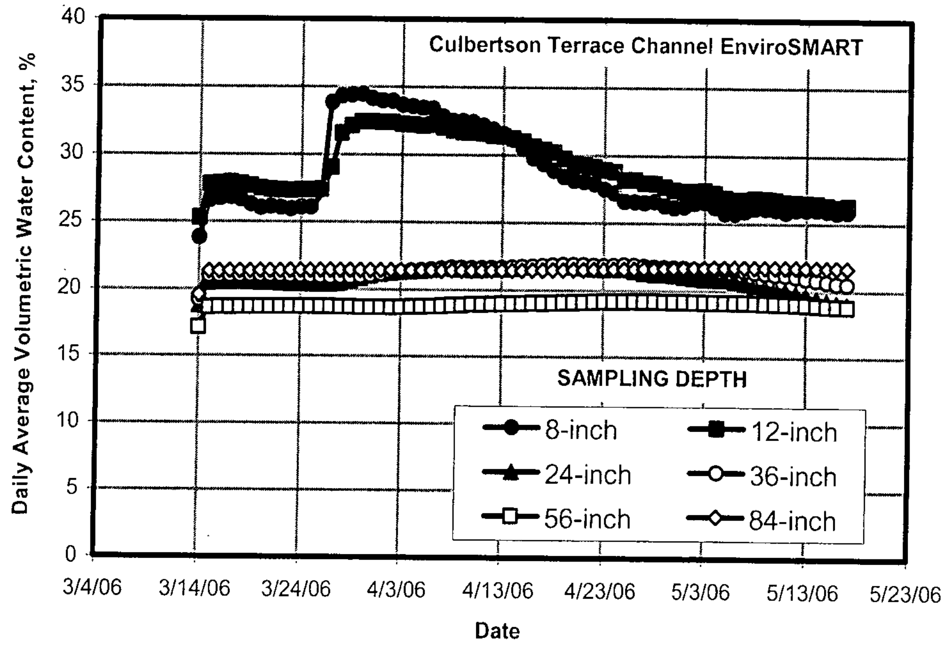


Figure 21. Pattern of volumetric water content for two months for the terrace channel at the Culbertson Site where the terraces are conservation bench terraces.

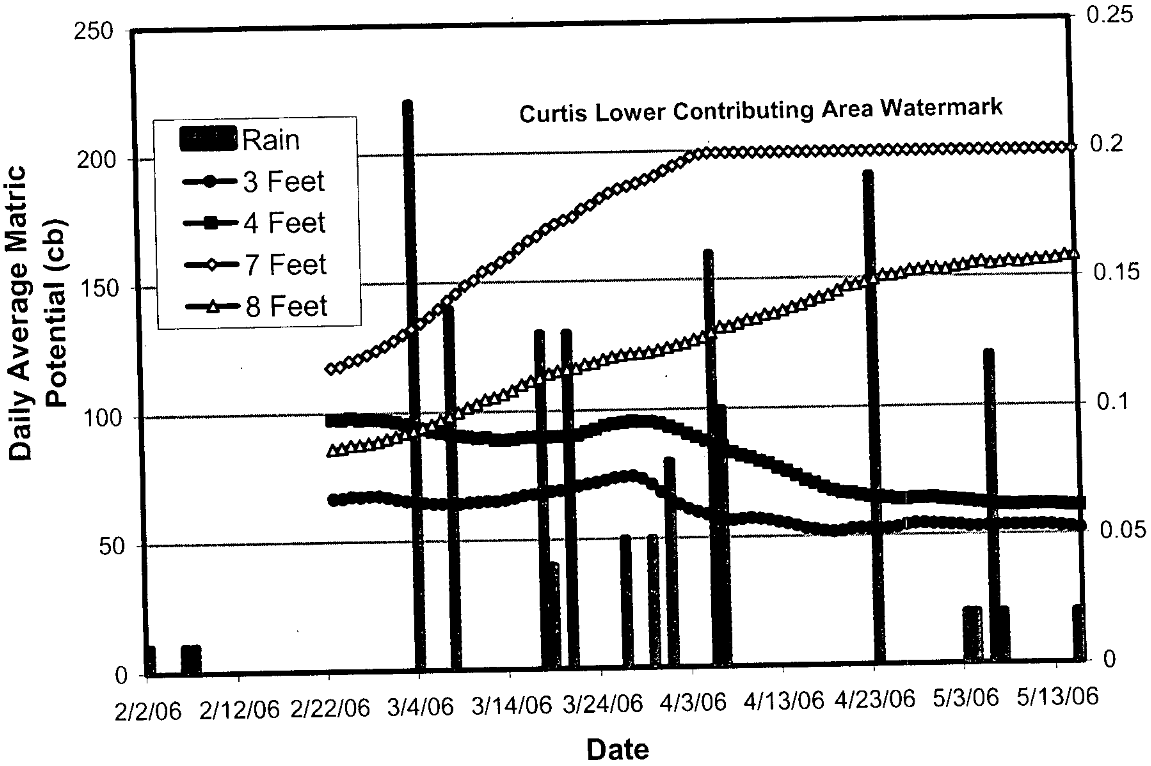


Figure 22. Example of data from Watermark Sensors to monitor soil matric potential and rainfall at the Curtis Site.

The final aspect of the field investigations for the impact of terraces involves deep drilling of soil cores to a depth of 25 feet. A continuous soil sample was obtained for this depth in the terrace channels and in the contributing area. We have analyzed these cores in the laboratory to determine the difference in water throughout the 25-foot profile. Results of these comparisons at the Culbertson Site are shown in Figure 23. These results show that considerably more water is stored beneath the terrace channels that below the contributing area. Higher water contents contribute to higher hydraulic conductivities and more rapid flow of water through the vadose zone. Based on this preliminary data it appears that more recharge has occurred from the terrace channel than for the contributing area. Further work is needed to analyze all sites and to relate water patterns to climatological records and cropping patterns.

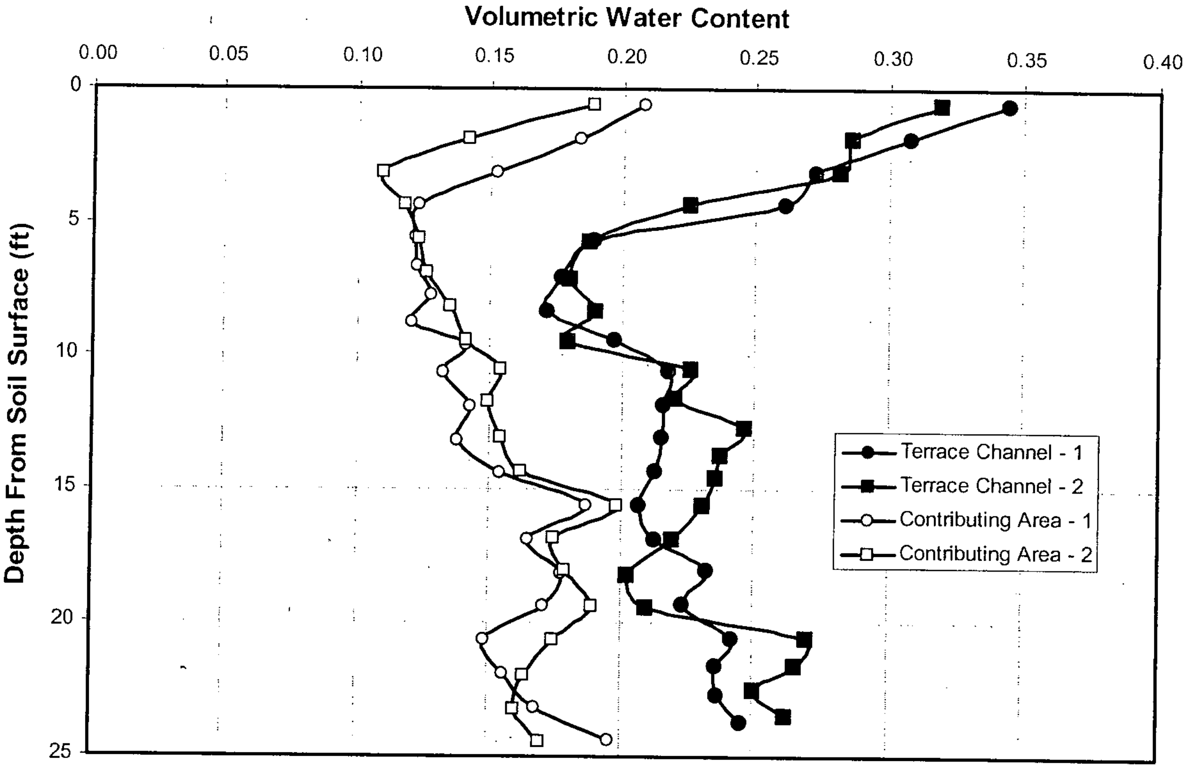


Figure 23. Comparison of volumetric water content throughout the 25-foot profile for terrace channels and contributing areas for conservation bench terraces at the Culbertson Site.

Reservoir Monitoring

Monitoring of reservoir evaporation rates is lagging behind schedule. The Bowen Ratio equipment that we will use to measure evaporation from a small pond was late in arriving. In addition many of the reservoirs currently monitored have had very little water. The Bowen Ratio system needs float on a lake and cannot set on a dry riverbed without damaging some sensors. Thus, additional reservoirs have been explored for locating the measuring equipment. The system should be ready to install by mid to late summer.

HYDROLOGIC MODELING

The majority of the material presented in this portion of the report was part of the M.S. thesis written by Travis Yonts titled <u>*Modeling and Monitoring the Hydrology of Conservation Terrace Systems*</u>, UNL, May, 2006. This portion of the modeling study focused on simulating the flow of water into and through the terrace channel. The HEC-HMS model was used as to simulate terrace systems. HEC-HMS (USCE, 2001) is a computer program used to model rainfall/runoff processes for various types of watersheds. To accomplish this, the model first determines rainfall excess from the watershed through a method chosen by the user such as the

NRCS curve number method. Second, HEC-HMS transforms the rainfall excess into a runoff hydrograph through a transform method chosen by the user such as the kinematic wave. Third, it necessary, the model performs reservoir routing using the level pool method, and provides a reservoir outflow hydrograph based on reservoir routing information provided by the user.

While the model was applied on both gradient terraces with outlets and level terraces with and without outlets, this report is limited to the application to conservation bench terraces. HEC-HMS input parameters for the conservation bench terrace models were derived from a publication by Sharda and Samra (2002).

Two models were created for modeling conservation bench terrace systems. The first model is a "traditional" approach to modeling the conservation bench terrace system, while the second model is a "simplified" approach. One of the objectives of this project is to develop modeling techniques that can be used to predict the basin-wide hydrologic impacts of overland flow from the conservation bench terrace systems thus the need for the simplified approach.

Two sub-basins and one reservoir were used to represent each terrace in the HEC-HMS traditional conservation bench terrace model (CBT 1). The sub-basins represent the terrace contributing area and the reservoir represents the terrace channel. Two sub-basins were used to remain consistent with the underground outlet and grassed waterway terrace system models. However, it is possible one sub-basin could have been used to represent the entire terrace contributing area.

Upon over-topping, outflow from the reservoirs was simulated using a broad-crested weir with the crest length being equal to the terrace berm length. The equation for a broad-crested weir (Munson et al., 1998) with a value of three for the weir coefficient, (C) is given by:

$$Q = CLH^{3/2} \tag{7}$$

where; Q = weir discharge $[L^3/T]$
C = weir coefficient $[L^{0.5}/T]$
L = weir length $[L]$
H = height of water above terrace berm crest $[L]$

Reaches were used to route this over-topping water from the upper reservoirs (terrace channels) to the lower reservoirs (terrace channels). HEC-HMS model input parameters, such as slope, length, and width, for these reaches were equal to the parameters of the sub-basins representing the contributing area.

HEC-HMS does not simulate rainfall onto a reservoir. The terrace channels of a conservation bench terrace system constitute a large percentage of the field surface area, so another sub-basin with a 100% impervious area was added to each terrace to account for rainfall directly onto the reservoir (terrace channel). The areas of these impervious sub-basins were equal to the surface area of the terrace channel at the terrace berm crest elevation. Figures 24 and 25 show the plan view and HEC-HMS schematic for the traditional conservation bench terrace model, respectively.

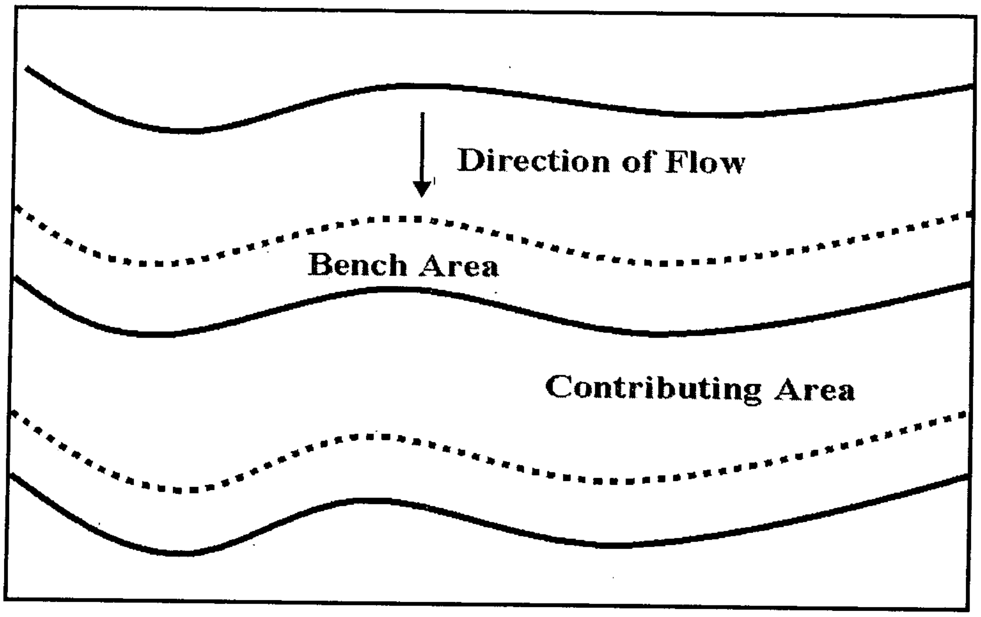


Figure 24. Plan view of a conservation bench terrace system showing two terraces.

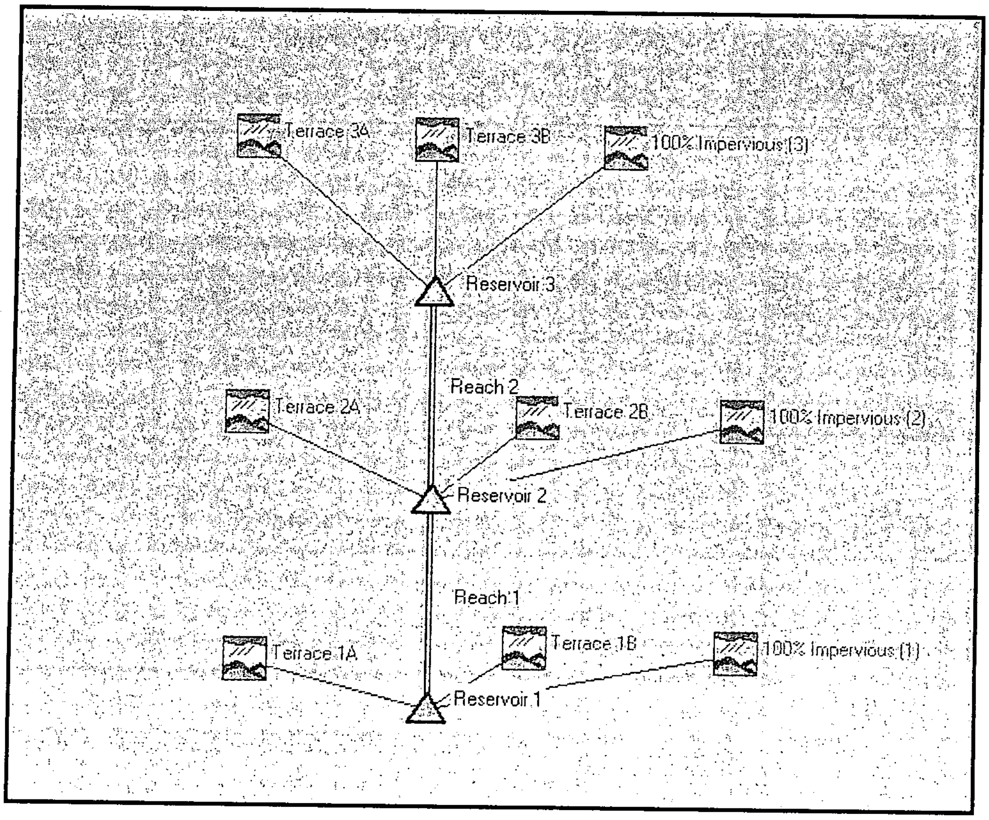


Figure 25. HEC-HMS schematic of the traditional conservation bench terrace model (CBT 1) for three terraces.

The simplified conservation bench terrace model (CBT 2) uses two sub-basins and one reservoir to model an entire conservation bench terrace system regardless of how many terraces there are in a field. One of the sub-basins represents the combination of all modeling parameters from the contributing areas while the other sub-basin accounts for rainfall onto all of the terrace channels. Furthermore, stage/storage/outflow relationships from all terrace channels are combined into one reservoir. Figure 26 shows the HEC-HMS schematic of the simplified conservation bench terrace model, and Table 1 provides the HEC-HMS input parameters for both the conservation bench terrace models. As illustrated in Figure 26, an entire three-terrace conservation bench terrace system can be represented with two sub-watersheds and one reservoir (CBT 2) instead of nine sub-watersheds and three reservoirs (CBT 1).

Rainfall for the HEC-HMS conservation bench terrace models was distributed in time using a NRCS type II storm with the rainfall depth being provided by Sharda and Samra (2002). The resulting hyetograph is shown in figure 27. Moreover, both HEC-HMS conservation bench terrace models were calibrated and validated using results from a finite element model developed by Sharda and Samra (2002). The model developed by Sharda and Samra (2002) used Richards' equation with a sink term for infiltration and soil/water dynamics under cropped conditions, St Venant equation with kinematic wave approximation for overland and channel flow, and the sediment continuity equation to describe the transport of upland soil erosion. For five simulations, Sharda and Samra (2002) found approximate relative errors of -22%, -16%, 13%, 67%, and 11% when comparing the predicted and observed runoff values. The authors note higher errors seemed to be present during smaller rainfall events, and argue soil antecedent moisture condition could be one reason for this.

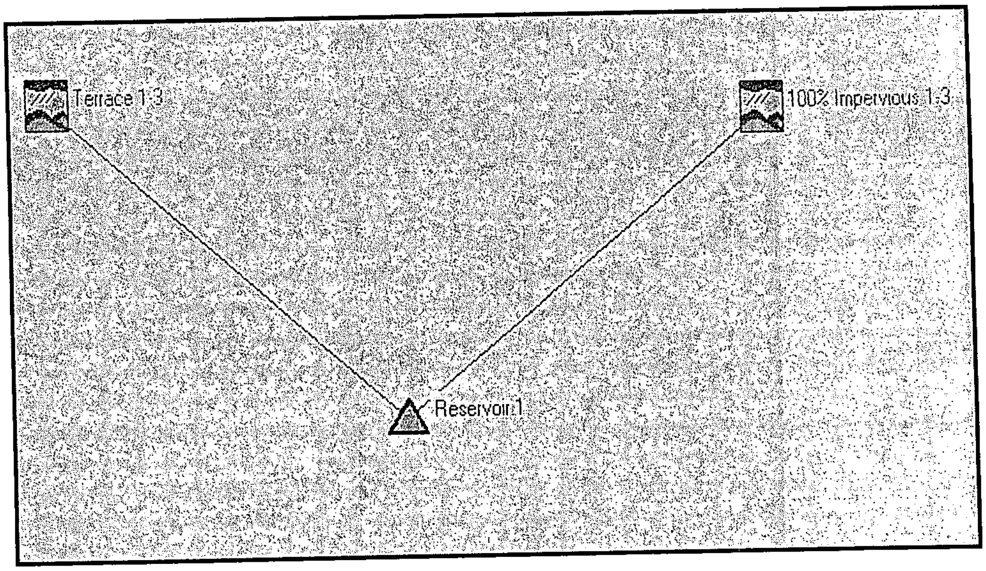


Figure 26. HEC-HMS schematic of the simplified conservation bench terrace model (CBT 2). In this case, three terraces were modeled.

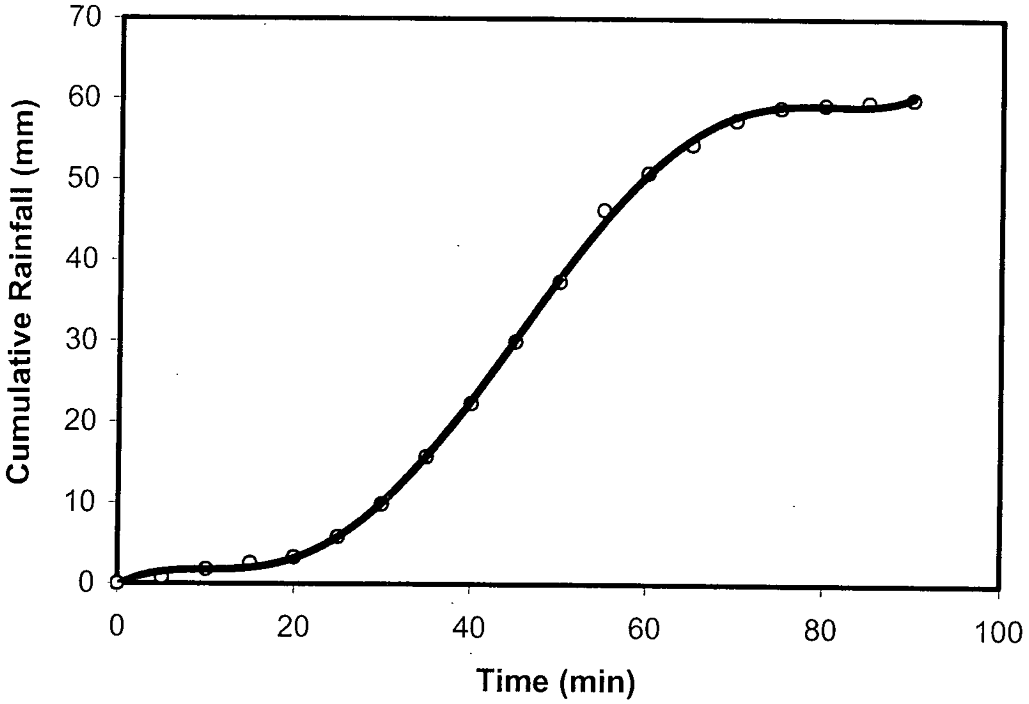


Figure 27. Rainfall hyetograph used for conservation bench terrace models (Sharda and Samra, 2002).

Table 1: Input parameters for conservation bench terrace model scenarios. Parameters (other than field area) are for one terrace from Sharda and Samra (2002).

Parameter	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
Field area	0.45 ha	0.45 ha	0.45 ha	0.45 ha
Number of terraces	3	3	3	3
Terrace spacing	100 m	100 m	100 m	100 m
Ratio of contributing to bench areas	3:1	3:1	3:1	3:1
Terrace crest length	15 m	15 m	10 m	5 m
Impoundment depth	0.05 m	0.1 m	0.05 m	0.05 m
Runoff curve number	91	85	86	83
Crop	Row crop	Row crop	Row crop	Row crop
Land slope	2%	2%	2%	2%
Saturated hydraulic conductivity	0.003 m h^{-1}	0.003 m h^{-1}	0.003 m h^{-1}	0.003 m h^{-1}
Plane length	75 m	75 m	75 m	75 m
Plane Manning's n	0.1	0.1	0.1	0.1
Plane transform method	Kinematic wave	Kinematic wave	Kinematic wave	Kinematic wave
*Plane routing channel slope**	6%	6%	6%	6%
*Plane routing channel Manning's n**	0.001	0.001	0.001	0.001
Channel impoundment depth	0.05 m	0.1 m	0.05 m	0.05 m
Channel retention volume	19 m^3	38 m^3	19 m^3	19 m^3

Since the kinematic wave transform method was used on the plane, a channel was needed to route water from the plane (contributing area) to the reservoir (terrace channel). This channel was given a steep slope and small roughness value to allow water to be routed from the contributing area to the terrace channel as quickly as possible.

Four different scenarios for the conservation bench terrace were modeled using HEC-HMS. These scenarios involved changing the terrace channel depth and/or the assumed crest length of the outflow weir (conservation bench terraces were assumed to behave as a broad-crested weir upon overtopping). The changes were made to match data provided by Sharda and Samra (2002). For the calibration of the model, a terrace channel depth of 0.05 m and a crest length of 15 m were used (scenario 1). Other combinations modeled included a channel depth of 0.1 m with a crest length of 15 m (scenario 2), a channel depth of 0.05 m with a crest length of 10 m (scenario 3), and a channel depth 0.05 m with a crest length of 5 m (scenario 4).

Figure 27 shows the calibration results for the HEC-HMS conventional conservation bench terrace model (CBT 1) and the simplified conservation bench terrace model (CBT 2). The NSE for the CBT 1 and CBT 2 models was 0.86 and 0.53, respectively. NSE values for the CBT 1 and CBT 2 models of scenarios 2 through 4 were 0.89 and 0.90, 0.74 and 0.56, and 0.63 and

0.67, respectively. The NSE values for CBT 2 lend support that the objective of developing a simplified approach for modeling the Hortonian hydrology of conservation bench terrace systems was satisfied.

Table 2 gives a summary of the HEC-HMS conservation bench terrace models, and compares HEC-HMS results to results from Sharda and Samra (2002). HEC-HMS calculations for runoff volume provided promising results. Calibration results for CBT 1 and CBT 2 (figure 27) showed HEC-HMS calculated higher runoff volumes by 5.8% and 4.3%, respectively. Validation results from the HEC-HMS conservation bench terrace models are shown in figures 28 through 31. CBT 1 and CBT 2 results show HEC-HMS simulated higher runoff volumes in the remaining six cases. Typically the error was within 5% to 8% of the runoff volume modeled by Sharda and Samra (2002). However, when compared to Sharda and Samra (2002), CBT 1 and CBT 2 of scenario 2 had runoff volume errors of 19% and 13% higher, respectively. Overall, both the CBT 1 and CBT 2 models simulated runoff volume with reasonable accuracy. Once again, this lends support that the objective of developing a simplified approach for modeling the Hortonian hydrology of conservation bench terrace systems was satisfied.

HEC-HMS did not predict runoff volume from the conservation bench terrace systems as accurately as it did from the underground outlet or grassed waterway terrace systems. Back-calculated NRCS curve numbers for each individual site and/or storm calibrated all HEC-HMS models. However, in the case of the conservation bench terrace model, an additional step was required because the permanent storage in the terrace channel had to be added to the runoff leaving the field when calculating a NRCS curve number for the contributing area. This permanent storage was considered to be the amount of surface water stored in the terrace channels.

One question to ask here is what effect is during event infiltration in the terrace channels having on the amount of water considered permanent storage? In reality, the amount of water stored in the terrace channels would be a larger volume than simply the amount of surface water stored in the terrace channels due to during event infiltration. HEC-HMS does not account for this infiltration since the terrace channels are being modeled using a reservoir as illustrated in figures 26 and 27 (HEC-HMS does not simulate infiltration in a reservoir). However, this lack of accounting for during event infiltration most likely does not explain the HEC-HMS runoff volume errors. Back-calculated NRCS curve numbers used in HEC-HMS are under-estimating the amount of runoff from the contributing areas into the terrace channels since they are also not accounting for during event infiltration. They are only accounting for the volume of runoff leaving the field as modeled by Sharda and Samra (2002). As a result, these NRCS curve numbers should still yield the same volume of runoff as Sharda and Samra (2002).

HEC-HMS modeled peak runoff rates for the conservation bench terrace models are shown in Table 2. The CBT 1 and CBT 2 models did a reasonable job of modeling peak runoff rates, and HEC-HMS did not routinely over or under-estimate peak runoff rates. As with the HEC-HMS underground outlet and grassed waterway terrace system models, the HEC-HMS conservation bench terrace model was not calibrated using peak runoff rates.

An analysis of how the two HEC-HMS conservation bench terrace models compared to each other was performed using the NSE test. The results showed the models compared favorably to one another. Comparing scenario 1 gave a NSE value of 0.84. Scenario 2 yielded a NSE value at 0.89. A NSE value of 0.81 was calculated for scenario 3. Lastly, a NSE value of 0.77 was calculated for scenario 4. Differences in peak runoff rates, as well as shifts between hydrographs (in some cases), provided the most source of error in the NSE calculations.

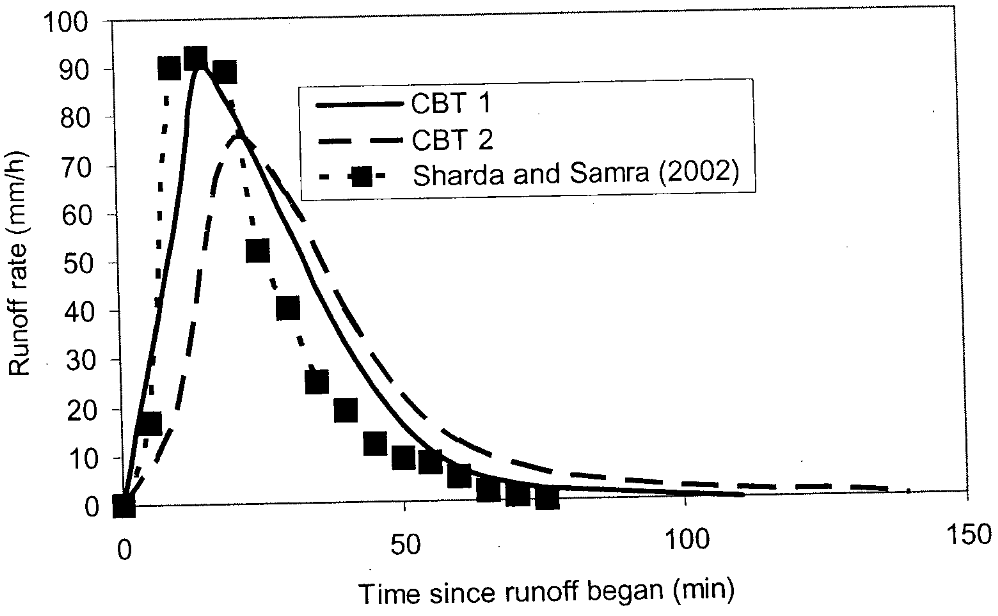


Figure 28. Hydrograph of data for the CBT 1 and CBT 2 models for scenario 1.

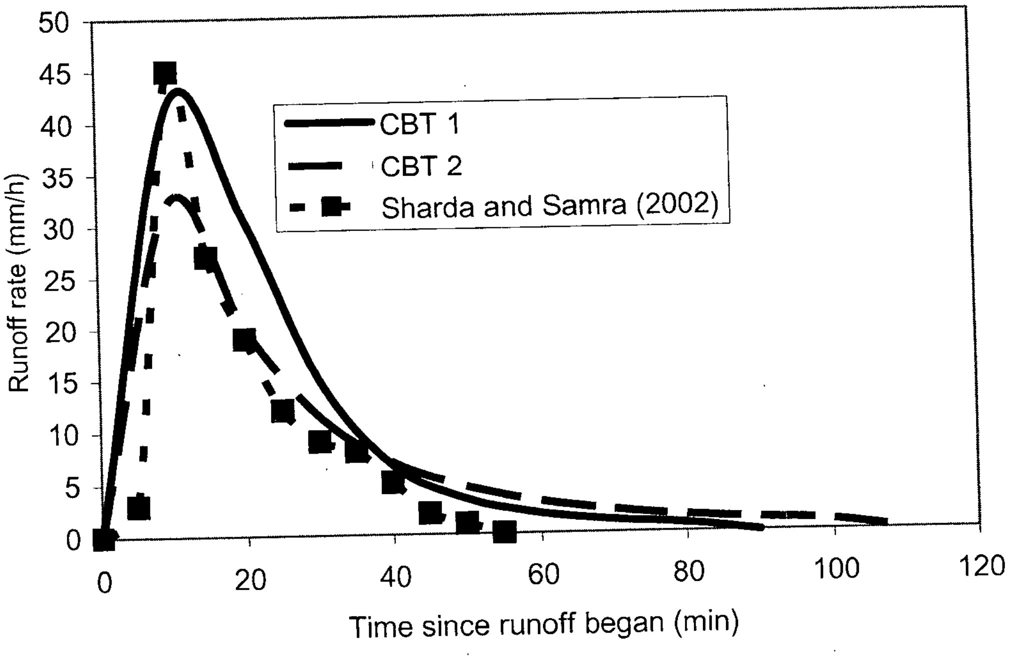


Figure 29. Hydrograph of HEC-HMS data for the CBT 1 and CBT 2 models for scenario 2.

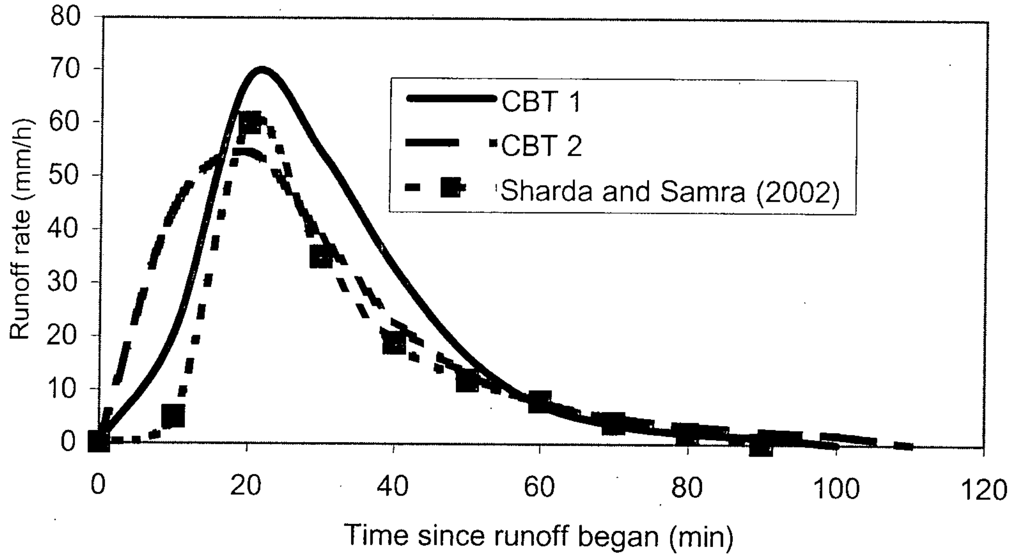


Figure 30. Hydrograph of HEC-HMS data for the CBT 1 and CBT 2 models for scenario 3

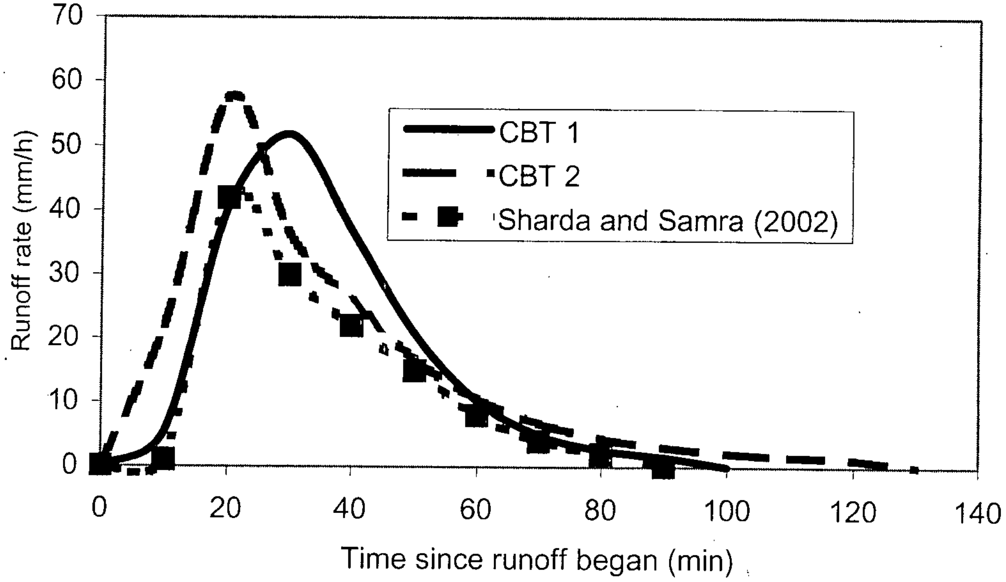


Figure 31. Hydrograph of HEC-HMS data for the CBT 1 and CBT 2 models for scenario 4.

Table 2: Summary of HEC-HMS model results for the conservation bench terrace systems.

Parameter	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
HEC-HMS model type	CBT 1	CBT 2	CBT 1	CBT 2	CBT 1	CBT 2	CBT 1	CBT 2
Impoundment depth (m)	0.05	0.05	0.1	0.1	0.05	0.05	0.05	0.05
Crest length (m)	15	15	15	15	10	10	5	5
Rainfall (mm)	60	60	60	60	60	60	60	60
Area (ha)	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Sharda and Samra (2002) modeled hydrograph duration (min)	75	75	55	55	90	90	90	90
HEC-HMS modeled hydrograph duration (min)	110	140	90	110	100	110	100	130
Ratio of Sharda and Samra (2002) hydrograph duration to HEC-HMS hydrograph duration	1.5	1.9	1.6	2.0	1.1	1.2	1.1	1.4
Sharda and Samra (2002) modeled runoff (m^3)	139	139	48	48	109	109	93	93
Sharda and Samra (2002) modeled runoff (mm)	31	31	11	11	24	24	21	21
HEC-HMS modeled runoff (m^3)	147	145	57	54	117	115	101	98
HEC-HMS modeled runoff (mm)	33	32	13	12	26	26	22	22
% difference between Sharda and Samra (2002) modeled runoff and HEC-HMS modeled runoff	-5.8	-4.3	-18.8	-12.5	-7.3	-5.5	-8.6	-5.4
Sharda and Samra (2002) modeled peak runoff (mm/h)	92	92	45	45	60	60	42	42
HEC-HMS modeled peak runoff (mm/h)	90	74	42	32	69	55	52	58
% difference*	2.2	19.6	6.7	28.9	-15.0	8.3	-23.8	-38.1
NRCS CN	91	91	85	85	86	86	83	83
NSE	0.86	0.53	0.89	0.90	0.74	0.56	0.63	0.67

* % difference = (Sharda and Samra (2002) modeled value – HEC-HMS modeled value) / Sharda and Samra (2002) modeled value

A sensitivity analysis was performed using the HEC-HMS modeling parameters from conservation bench terrace scenario 4. Three different roughness values were modeled. They included the original roughness value of 0.10, as well as two other values: 0.01 and 0.30. Figures 32 and 33 show the hydrographs from these HEC-HMS model runs for CBT 1 and CBT 2, respectively. The change in roughness did not have a large impact on time to peak values for the hydrographs. However, there was a noticeable change in peak flow between the hydrographs, particularly when using a roughness value of 0.30.

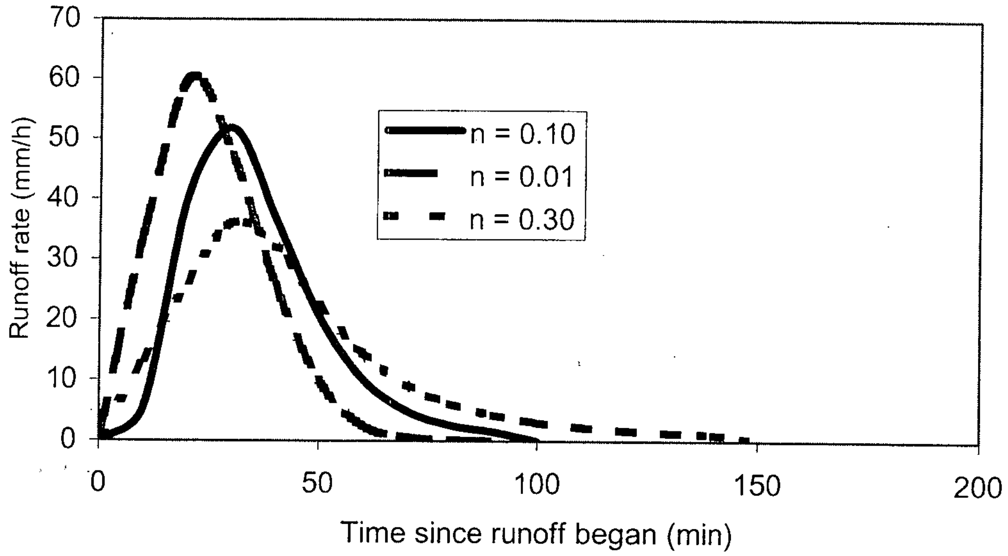


Figure 32. Sensitivity analysis for CBT 1 of scenario 4. Three different Manning's n roughness values were modeled in HEC-HMS.

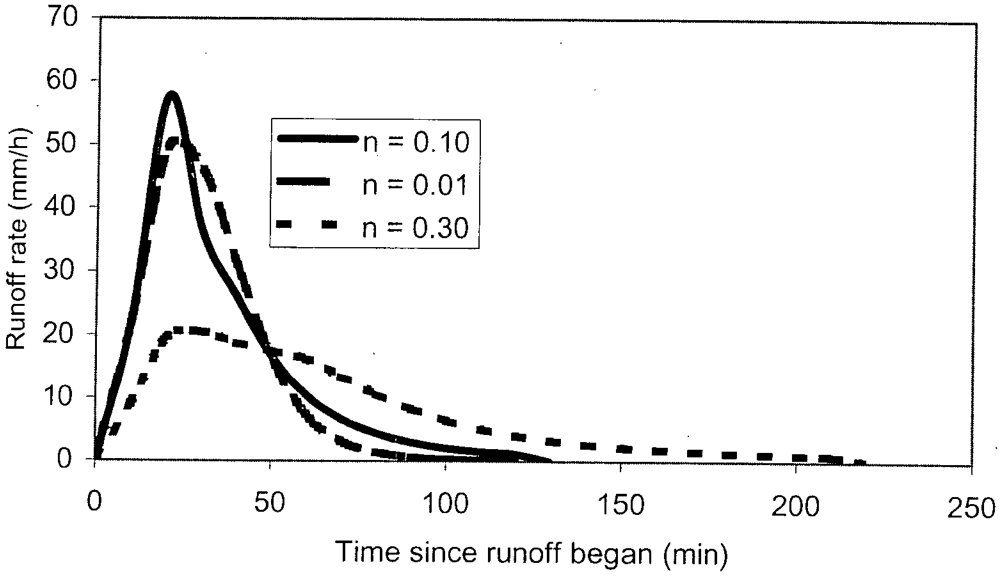


Figure 33. Sensitivity analysis for CBT 2 of scenario 4. Three different Manning's n roughness values were modeled in HEC-HMS.

The two HEC-HMS conservation bench terrace models (CBT 1 and CBT 2) were used to predict runoff from a "typical" conservation bench terrace site located in the basin (near Colby, Kansas). The rainfall hyetograph for the modeled storm is shown in figure 34. The hyetograph was developed using an intensity-duration-frequency curve from Colby, Kansas. The NRCS curve number used for the contributing areas in the Republican River Basin HEC-HMS conservation bench terrace models is the NRCS table value assuming antecedent moisture condition II, row crops, good hydrologic condition, and hydrologic soil group B (Haan et al., 1994). Additional HEC-HMS modeling parameters for the Republican River Basin conservation bench terrace models are shown in table 3. Figure 35 and table 4 show the resulting CBT 1 and CBT 2 HEC-HMS hydrographs and runoff data, respectively.

A visual comparison of the hydrographs produced by CBT 1 and CBT 2 show the hydrographs compare very well. Performing a NSE test on the hydrographs from CBT 1 and CBT 2 yielded a value of 0.92, giving further evidence the hydrographs correlate well with one another. This model was not compared to any measured rainfall/runoff data, so further analysis of the hydrographs is not included.

Table 3: HEC-HMS modeling parameters for Republican River Basin trial runs.

Field area	5.6 ha
Number of terraces	3
Terrace spacing	64 m
Ratio of contributing area to basin area	3:1
Terrace crest length	305 m
NRCS runoff curve number	72
Crop	Row crop
Land slope	2%
Topsoil texture	n/a
Plane length	49 m
Plane Manning's n	0.1
Plane transform method	Kinematic wave
Plane routing channel slope*	6%
Plane routing channel Manning's n*	0.001
Terrace channel impoundment depth	0.60 m
Terrace channel retention volume/terrace	751 m^3

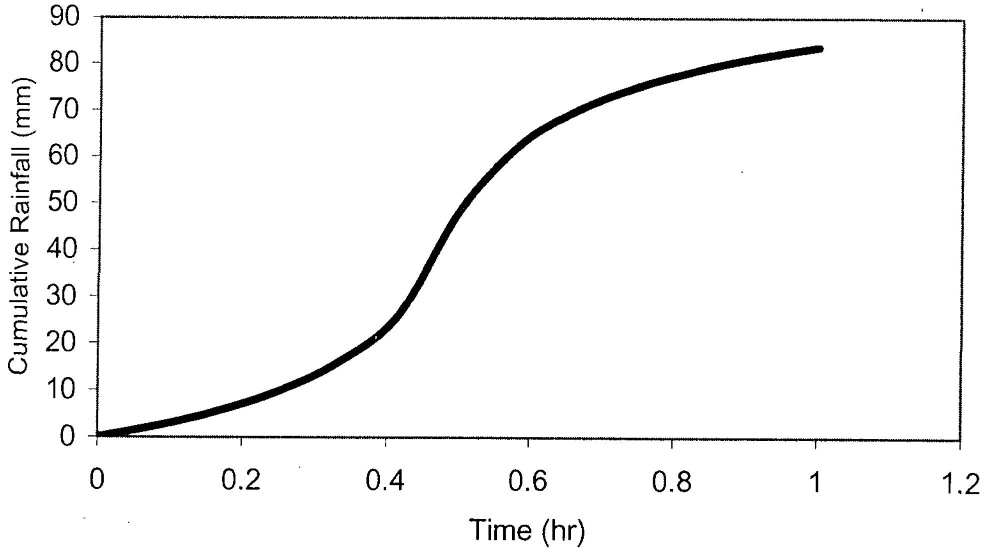


Figure 34. 100-yr, 1-hr rainfall hyetograph for Republican River Basin near Colby, Kansas.

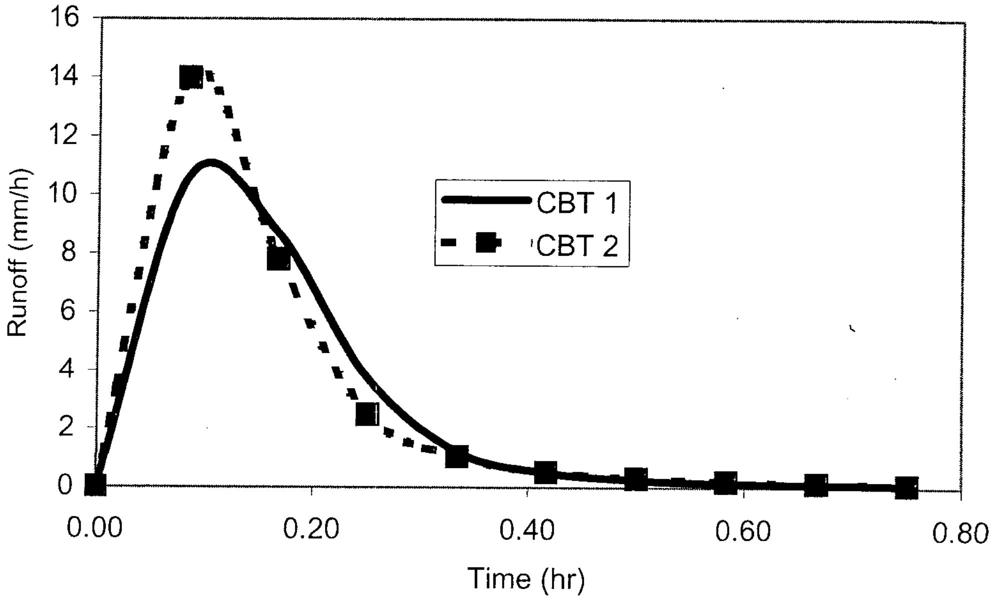


Figure 35. Hydrograph of HEC-HMS data for CBT 1 and CBT 2. HEC-HMS modeling parameters imitated the conditions existing in the Republican River Basin near Colby, Kansas.

Table 4: Summary of results for Republican River Basin CBT 1 and CBT 2 models.

HEC-HMS Model Type	CBT 1	CBT 2
Impoundment Depth (m)	0.18	0.18
Crest Width (m)	305	305
Rainfall (mm)	83.6	83.6
Area (ha)	5.81	5.81
HEC-HMS Runoff (m^3)	118	110
HEC-HMS Runoff (mm)	2.0	1.9
HEC-HMS Peak runoff (mm/h)	11	14
NRCS CN	72	72

The models presented above do not account for the "during event" infiltration in the terrace channel. Infiltration is only computed after the rainfall runoff event is complete. This could lead to overestimation of direct runoff from the terrace system. A modeling project is currently being developed to estimate the impact of "during event" infiltration on the direct runoff hydrograph. We will continue to improve modeling of water flow through terraces to develop relationships in POTYLD and other models to account for outflow from the terraces rather than infiltration in the channel.

Database Development

Databases have been developed fo ruse in simulating thehydrolic iimpact of small reservoirs and terraces. The databases include the following data.

Soils

The SSURGO database has been downloaded for all counties in the Republican River Basin. These data are illustrated in the soil maps that are included in Figures 2-4. We are currently processing the information included by the NRCS in the databases to develop characteristics and parameters needed for simulation. Soils are being grouped according to predominate soil texture, NRCS hydrologic group, slope and available soil water holding capacity. These attributes are used to reduce the large number of soil mapping units into a smaller set of classifications that will be used to define hydrologic response units in POTYLD and other models.

Weather Data

Two types of weather data have been assembled. Data from the automated weather data network (AWDN) operated by the high plains Regional Climate Center are being used to compute reference crop evapotranspiration using the hourly Penman-Monteith Method developed by the ASCE-EWRI (2005).The AWDN data are also used to calibrate the Hargreaves equation for the Great Plains. The Hargreaves method only requires the daily maximum and minimum air temperature to estimate reference crop ET. The calibrated Hargreaves method is then used with data from the Cooperative program operated by NOAA and the National Weather Service (NWS). These data re referred to as the NWS data. These records only include the daily maximum and minimum air temperature and the amount of precipitation received for the day. The Hargreaves method is used with these data to develop estimates of reference crop ET as used in the CROPSIM and POTYLD models. The location of the AWDN and NWS weather stations selected for simulation across the basin are presented in Figure 36.

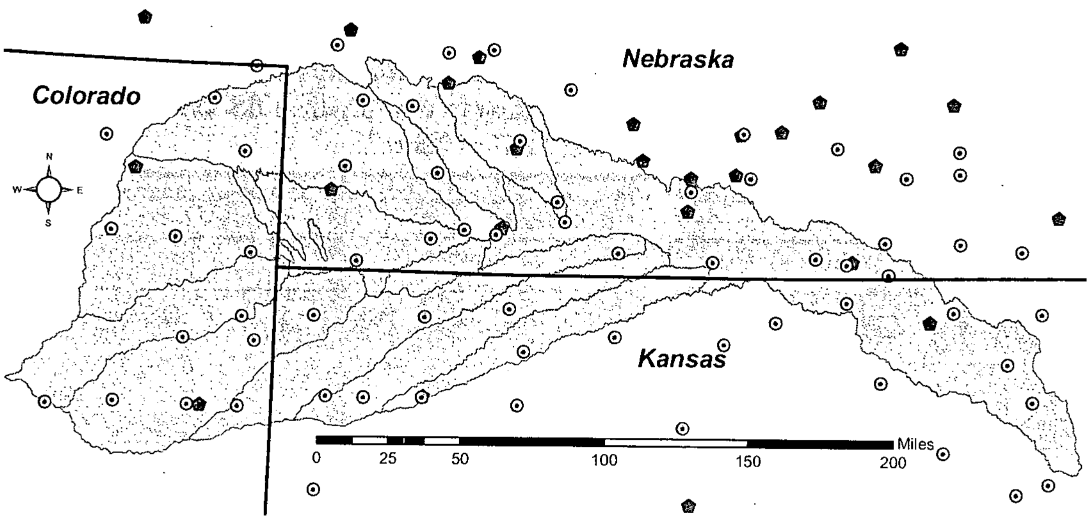


Figure 36. Location of AWDN stations (blue symbol) and NWS stations (green symbols).

Other Databases

Several other databases have been developed for the project as briefly described below.

- Datasets from the NHD have been downloaded and are being used to delineate watershed boundaries and to define contribution areas for specific reservoirs. The NHD data is being combined with digital elevation models to also define subwatershed for simulation.
- Landuse dataset has been downloaded from the USGS source. These data are rather crude and will mostly be used to define cropped areas from native range, urban and riparian ecosystems. We will combine these data with county NASS data to develop cropping patterns for hydrologic response units.
- Public land survey system data has been developed for the region.
- Highway and city locations have been incorporated.

- Tillage practices have been investigated for each county using the CTIC database. We plan to use these data to represent current practices in developing hydrologic response units.
- Irrigation well locations are available for Nebraska. Dataset for other states are being explored. We will also need to utilize pumpage records or estimates to simulate the hydrology of the region.
- Stream flow records, including baseflow separation, has been initiated but is not complete.

Remaining Objectives

The remaining objectives for the project are underway but depend on the form and development of the simulation models. We are working with the Jim Koelliker at Kansas State University to modify the simulation model and then to develop the GIS interface. This will be a high priority project for the summer and early fall of 2006.

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Appendix 1. Soil Mapping Units for Nebraska and Kansas Counties.

Mapping Units for Nebraska Counties

Mapping Unit	Mapping Unit Name
2Dc	DUROC SILT LOAM, TERRACE, 0 TO 1 PERCENT SLOPES
2DcA	DUROC SILT LOAM, TERRACE, 1 TO 3 PERCENT SLOPES
2Gd	GLENBERG FINE SANDY LOAM, SALINE-ALKALI
2HL	HAVERSON AND LAS LOAMS, SALINE-ALKALI
2Mb	MCCOOK LOAM, OVERFLOW
4Mb	MCCOOK LOAM, SAND SUBSTRATUM VARIANT
AED	ARENTS, EARTHEN DAM
An	ANSELMO FINE SANDY LOAM, 0 TO 1 PERCENT SLOPES
AnA	ANSELMO FINE SANDY LOAM, 1 TO 3 PERCENT SLOPES
AnB	ANSELMO FINE SANDY LOAM, 3 TO 5 PERCENT SLOPES
AnC	ANSELMO FINE SANDY LOAM, 5 TO 9 PERCENT SLOPES
AoAW	ANSELMO LOAMY FINE SAND, 0 TO 3 PERCENT SLOPES
AoBW	ANSELMO LOAMY FINE SAND, 3 TO 7 PERCENT SLOPES
Ba	BROKEN ALLUVIAL LAND
BCa	ROUGH BROKEN LAND, CALICHE
BcA	BANKARD LOAMY FINE SAND
Bf	BAYARD FINE SANDY LOAM, 0 TO 1 PERCENT SLOPES
BfA	BAYARD FINE SANDY LOAM, 1 TO 3 PERCENT SLOPES
BfA2	BAYARD LOAMY FINE SAND, HUMMOCKY
Bk	BROKEN ALLUVIAL LAND
BL	ROUGH BROKEN LAND, LOESS
BP	BORROW PITS
Br	BRIDGEPORT SILT LOAM, 0 TO 1 PERCENT SLOPES
BrA	BRIDGEPORT SILT LOAM, 1 TO 3 PERCENT SLOPES
BrB	BRIDGEPORT SILT LOAM, 3 TO 7 PERCENT SLOPES
Bu	BUTLER SILT LOAM
Bw	BAYARD LOAM, 0 TO 1 PERCENT SLOPES
CbCW	COLBY SILT LOAM, 7 TO 9 PERCENT SLOPES
CbD	COLBY SILT LOAM, 9 TO 30 PERCENT SLOPES
Ch	COLY AND HOBBS SILT LOAMS
CkD2	COLY AND NUCKOLLS SILT LOAMS, 9 TO 31 PERCENT SLOPES, ERODED
CmC2	COLY AND ULY SILT LOAMS, 3 TO 9 PERCENT SLOPES, ERODED
CoA	COZAD SILT LOAM, 0 TO 1 PERCENT SLOPES
CoB	COZAD SILT LOAM, 1 TO 3 PERCENT SLOPES
CoC	COZAD SILT LOAM, 3 TO 7 PERCENT SLOPES
CoD2	COLY SILT LOAM, 5 TO 9 PERCENT SLOPES, ERODED
CoF2	COLY SILT LOAM, 9 TO 20 PERCENT SLOPES, ERODED
CuF	COLY AND ULY SILT LOAMS, 9 TO 30 PERCENT SLOPES
DeA	DETROIT SILT LOAM, 0 TO 1 PERCENT SLOPES
DVC	DWYER-VALENTINE LOAMY FINE SANDS, 3 TO 17 PERCENT SLOPES
Fm	FILLMORE SILT LOAM, 0 TO 1 PERCENT SLOPES
Gd	GLENBERG FINE SANDY LOAM
Gh	GOSHEN SILT LOAM, 0 TO 1 PERCENT SLOPES
GP	GRAVEL PIT
Ha	HALL SILT LOAM, 0 TO 1 PERCENT SLOPES
HaB	HALL SILT LOAM, 1 TO 3 PERCENT SLOPES
HaC	HALL SILT LOAM, 3 TO 6 PERCENT SLOPES
Hb	HOBBS SILT LOAM, OCCASIONALLY FLOODED, 0 TO 2 PERCENT SLOPES
Hd	HORD SILT LOAM, 0 TO 1 PERCENT SLOPES
Hf	HAVERSON FINE SANDY LOAM
HmA	HOBBS AND MCCOOK SILT LOAMS, 0 TO 1 PERCENT SLOPES

HmB	HOBBS AND MCCOOK SILT LOAMS, 1 TO 3 PERCENT SLOPES
Ho	HOLDREGE SILT LOAM, 0 TO 1 PERCENT SLOPES
HoA	HOLDREGE SILT LOAM, 0 TO 1 PERCENT SLOPES
HoB	HOLDREGE SILT LOAM, 1 TO 3 PERCENT SLOPES
HoB2	HOLDREGE SILT LOAM, 1 TO 3 PERCENT SLOPES, ERODED
HoC	HOLDREGE SILT LOAM, 3 TO 7 PERCENT SLOPES
HoC2	HOLDREGE SILT LOAM, 3 TO 6 PERCENT SLOPES, ERODED
HpC	HORD SILT LOAM, 3 TO 6 PERCENT SLOPES
HpC2	HOLDREGE AND ULY SOILS, 3 TO 7 PERCENT SLOPES, ERODED
Hr	HORD SILT LOAM, TERRACE, 0 TO 1 PERCENT SLOPES
HrA	HORD AND HALL SILT LOAMS, TERRACE, 0 TO 1 PERCENT SLOPES
HrB	HORD AND HALL SILT LOAMS, TERRACE, 1 TO 3 PERCENT SLOPES
InB	INAVALE FINE SANDY LOAM, 0 TO 3 PERCENT SLOPES
INT	INTERMITTENT WATER
JmB	JAYEM LOAMY VERY FINE SAND, 1 TO 3 PERCENT SLOPES
KeA	KEITH SILT LOAM, 1 TO 3 PERCENT SLOPES
KeAW	KEITH SILT LOAM, 1 TO 3 PERCENT SLOPES, ERODED
KeB	KEITH SILT LOAM, 3 TO 7 PERCENT SLOPES
KeB2	KEITH SILT LOAM, 3 TO 7 PERCENT SLOPES, ERODED
KG	KEITH AND GOSHEN SILT LOAMS, 0 TO 1 PERCENT SLOPES
LD	SANITARY LANDFILL
Le	LESHARA SILT LOAM
Mb	MCCOOK SAND, OVERWASH
Mc	MCCOOK SILT LOAM, 0 TO 1 PERCENT SLOPES
McB	MCCOOK SILT LOAM, 1 TO 3 PERCENT SLOPES
Md	MCCOOK SILT LOAM, OCCASIONALLY FLOODED, 0 TO 2 PERCENT SLOPES
Me	MCCOOK SILT LOAM, WET, 0 TO 1 PERCENT SLOPES
MP	MINE OR QUARRY
MtB	MUNJOR LOAMY FINE SAND, 0 TO 3 PERCENT SLOPES
MuB	MUNJOR FINE SANDY LOAM, 0 TO 3 PERCENT SLOPES
M-W	MISCELLANEOUS WATER, SEWAGE LAGOON
NuD	NUCKOLLS AND ULY SILT LOAMS, 9 TO 15 PERCENT SLOPES
NuE2	NUCKOLLS AND ULY SILT LOAMS, 9 TO 31 PERCENT SLOPES, ERODED
NyE	NUCKOLLS, ULY, AND CANLON SOILS, 9 TO 31 PERCENT SLOPES
Pm	PLATTE AND MCCOOK SOILS
Pt	PLATTE LOAM
RaG	ROUGH BROKEN LAND, CALICHE, 30 TO 60 PERCENT SLOPES
RbG	COLY-ULY-HOBBS SILT LOAMS, 2 TO 60 PERCENT SLOPES
RcG	ROUGH BROKEN LAND, SANDY, 30 TO 60 PERCENT SLOPES
SaD	SARBEN LOAMY VERY FINE SAND, 3 TO 9 PERCENT SLOPES
Sc	SCOTT SILT LOAM
Ss	SLICKSPOTS
Sx	SANDY ALLUVIAL LAND
Sy	BROKEN ALLUVIAL LAND
UaC2	ULY SILT LOAM, 3 TO 6 PERCENT SLOPES, ERODED
UaD	ULY SILT LOAM, 6 TO 9 PERCENT SLOPES
UcD2	ULY AND COLY SILT LOAMS, 6 TO 9 PERCENT SLOPES, ERODED
UcF	ULY AND COLY SILT LOAMS, 9 TO 20 PERCENT SLOPES
UsB2	ULYSSES SILT LOAM, 3 TO 7 PERCENT SLOPES, ERODED
UsC	ULY SILT LOAM, 3 TO 9 PERCENT SLOPES
UsC	ULYSSES SILT LOAM, 7 TO 9 PERCENT SLOPES
UsC2	ULYSSES AND COLBY SILT LOAMS, 7 TO 9 PERCENT SLOPES, ERODED
UtE	ULY AND COLY SILT LOAMS, 9 TO 31 PERCENT SLOPES
VaC	VALENTINE FINE SAND, ROLLING
VeB	VETAL LOAMY VERY FINE SAND, 0 TO 3 PERCENT SLOPES
W	WATER

Wx WET ALLUVIAL LAND

Mapping Units for Kansas Counties.

Mapping Unit	Mapping Unit Name
1125	BRIDGEPORT SILT LOAM, OCCASIONALLY FLOODED
1422	GOSHEN SILT LOAM, RARELY FLOODED
1580	COLBY SILT LOAM, 5 TO 15 PERCENT SLOPES
1619	KEITH SILT LOAM, 0 TO 1 PERCENT SLOPES
1620	KEITH SILT LOAM, 1 TO 3 PERCENT SLOPES
1652	KUMA SILT LOAM, 0 TO 1 PERCENT SLOPES
1741	PLEASANT SILTY CLAY LOAM, PONDED
1764	RICHFIELD SILTY CLAY LOAM, 0 TO 1 PERCENT SLOPES
1820	SCHAMBER GRAVELLY SANDY LOAM, 5 TO 25 PERCENT SLOPES
1856	ULYSSES SILT LOAM, 0 TO 1 PERCENT SLOPES
1857	ULYSSES SILT LOAM, 1 TO 3 PERCENT SLOPES
1858	ULYSSES SILT LOAM, 1 TO 3 PERCENT SLOPES, ERODED
1859	ULYSSES SILT LOAM, 3 TO 6 PERCENT SLOPES
2177	MCCOOK SILT LOAM, OCCASIONALLY FLOODED
2202	MUNJOR SANDY LOAM, OCCASIONALLY FLOODED
2234	ROXBURY SILT LOAM, CHANNELED
2236	ROXBURY SILT LOAM, OCCASIONALLY FLOODED
2310	BRIDGEPORT SILT LOAM, RARELY FLOODED
2315	COZAD SILT LOAM, 0 TO 2 PERCENT SLOPES, RARELY FLOODED
2316	COZAD SILT LOAM, 2 TO 5 PERCENT SLOPES, RARELY FLOODED
2375	ROXBURY SILT LOAM, RARELY FLOODED
2562	CAMPUS-CANLON COMPLEX, 3 TO 30 PERCENT SLOPES
2578	COLY AND ULY SILT LOAMS, 6 TO 10 PERCENT SLOPES, ERODED
2579	COLY AND ULY SILT LOAMS, 10 TO 20 PERCENT SLOPES, ERODED
2667	HOLDREGE SILT LOAM, 0 TO 1 PERCENT SLOPES
2668	HOLDREGE SILT LOAM, 1 TO 3 PERCENT SLOPES
2669	HOLDREGE SILT LOAM, 1 TO 3 PERCENT SLOPES, ERODED
2670	HOLDREGE SILT LOAM, 3 TO 7 PERCENT SLOPES
2671	HOLDREGE SILT LOAM, 3 TO 7 PERCENT SLOPES, ERODED
2760	PENDEN-CANLON LOAMS, 7 TO 30 PERCENT SLOPES
2767	PENDEN-ULY COMPLEX, 7 TO 20 PERCENT SLOPES
2812	ULY COMPLEX, 10 TO 20 PERCENT SLOPES
2817	ULY SILT LOAM, 3 TO 6 PERCENT SLOPES
2819	ULY SILT LOAM, 6 TO 10 PERCENT SLOPES
2820	ULY SILT LOAM, 6 TO 10 PERCENT SLOPES, ERODED
2828	ULY-PENDEN COMPLEX, 6 TO 20 PERCENT SLOPES
2950	WAKEEN COMPLEX, 5 TO 20 PERCENT SLOPES
3561	HOBBS SILT LOAM, OCCASIONALLY FLOODED
3593	HUMBARGER LOAM, OCCASIONALLY FLOODED
3725	DETROIT SILTY CLAY LOAM, RARELY FLOODED
3750	HORD SILT LOAM, NONFLOODED
3755	HORD SILT LOAM, RARELY FLOODED
9971	ARENTS, EARTHEN DAM
9976	BORROW PITS
9983	GRAVEL PITS AND QUARRIES
9999	WATER