RESERVOIR SEDIMENTATION ALONG THE UPPER WASHITA RIVER IN WESTERN OKLAHOMA AND NORTHERN TEXAS.

By

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PREFACE/ACKNOWLEDGMENTS

This study is intended as part of a larger project to understand the changes that have taken place along the Washita River, and investigate the feasibility of restoring the Washita Battlefield National Historic Site to its original state at the time of the 1869 historic battle. One of the most drastic changes has been numerous flood control structures, built in response to Dustbowl flooding episodes. These structures have altered the flow characteristics of the Washita River in ways which need to be investigated and understood.

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1. Introduction

1.1 Problem

The Dust Bowl of the 1930s caused massive episodes of drought and flooding, in response to which numerous flood control dams were built in Oklahoma to slow the discharge of tributaries into the main channels, thereby reducing peak flows and downstream flooding. Since 1948, 1944 flood control dams were built in 144 watersheds in Texas (USDA-NRCS 1999b), and 2097 flood control dams were built in 126 watersheds in Oklahoma (USDA-NRCS 1999a) by the NRCS under the authorization of the Flood Control Act of 1944 (PL78-534) and the Watershed Protection and Flood Control Act of 1953 (PL83-566). Data from the Washita River gauging station near Cheyenne, OK, has shown the effectiveness of flood control structures along the Washita River (OCC, 2001). Prior to 1961, the mean annual flow along the Washita was 41.7 ft^3/sec. From 1961-1999, the mean annual flow decreased to 19.9 ft^3/sec, with peak flows reduced significantly (Tortorelli, 2002).

All of the dams in this study were built under PL83-534 and have a projected sediment storage lifetime of 50 years (OCC, 2001). In Oklahoma, 80 dams built to protect agricultural lands now have homes or other structures downstream, and 110 dams are in serious need of rehabilitation (USDA-NRCS 1999a). In Texas, 25 flood control dams reached their life expectancy span in 2002. 158 dams in Texas must be upgraded due to downstream development (USDA-NRCS, 1999b). Assessments of these dams have not been undertaken for most of the watershed. Some sediment surveys have been preformed by the Oklahoma State NRCS office, however; the records pertaining to them are missing from their archives.

1.2 Purpose and Objectives

The focus of this research is to understand reservoir sedimentation in a sample of small watersheds in Western Oklahoma and Northern Texas in the Upper Washita River watershed. The following objectives were accomplished:

1) Measured the volume of impounded sediment in a sample of flood control reservoirs.
2) Utilized GIS to create delineate watershed boundaries and calculate watershed characteristics.
3) Determined the effectiveness of WEPP (Water Erosion Prediction Project) in predicting sedimentation within these watersheds.

1.3. Study Area

The study area is the Upper Washita watershed (HUC 11130301) and contains the headwaters of the Washita River (Figure 1). This watershed covers part of Roger Mills, Custer, Dewey, and Beckham Counties in Oklahoma and Hemphill, Gray, Roberts, and Wheeler Counties in Texas (Figure 1). Flood Control structures are located primarily in Roger Mills County, Oklahoma; and in Hemphill and Wheeler Counties, Texas. USGS gauging station 07316500, near Cheyenne, Oklahoma, is located at Lat 35°37’35”N and Long 99°40’05”W. The area drained upstream of the gauging station is 794 mi^2 (Tortorelli, 2002). The topography of this area varies from level to steep hills, with elevation varying from ~596’ to ~917’ above sea level. Soils are generally fine sandy loams and clays, underlain by red bed sandstone or brownish subsoils (USDA-NRCS 1963), and are within the Western Redbed Plains and High Plains geomorphic province contributing to the Red-Washita River basin. 43.1% of surface water drawn in this basin is used for water supply, 22.3% for industrial and mining, and 22.2% for livestock (Lurry and Tortorelli, 1996). The physical nature of this region is well described by Johnson et al. (1979) in a collection of generalized geomorphic, quaternary, and topographic maps of Oklahoma, as well as cross-sections of bedrock along select planes.

Lurry and Tortorelli (1995) compiled a map of data from various sources to symbolize the water withdrawals and usage statistics across Oklahoma. The study area is underlain by Permian sandstone and shales and includes gypsum outcrops (Johnson et al., 1979).

1.4. Justification for the Study

In the 1950s and early 1960s, numerous flood control dams were constructed to reduce flooding occurrences along the Upper Washita River in western Oklahoma and the Texas panhandle. Drastic flooding during the 1930s to the 1950s prompted these flood control measures to be taken, partly at the request of the local people who are in part responsible for the operation and maintenance of flood control dams on their property (SCS, 1958). Flood control in this area produced numerous impoundments, used for irrigation, cattle ponds, recreation, and in one case as the

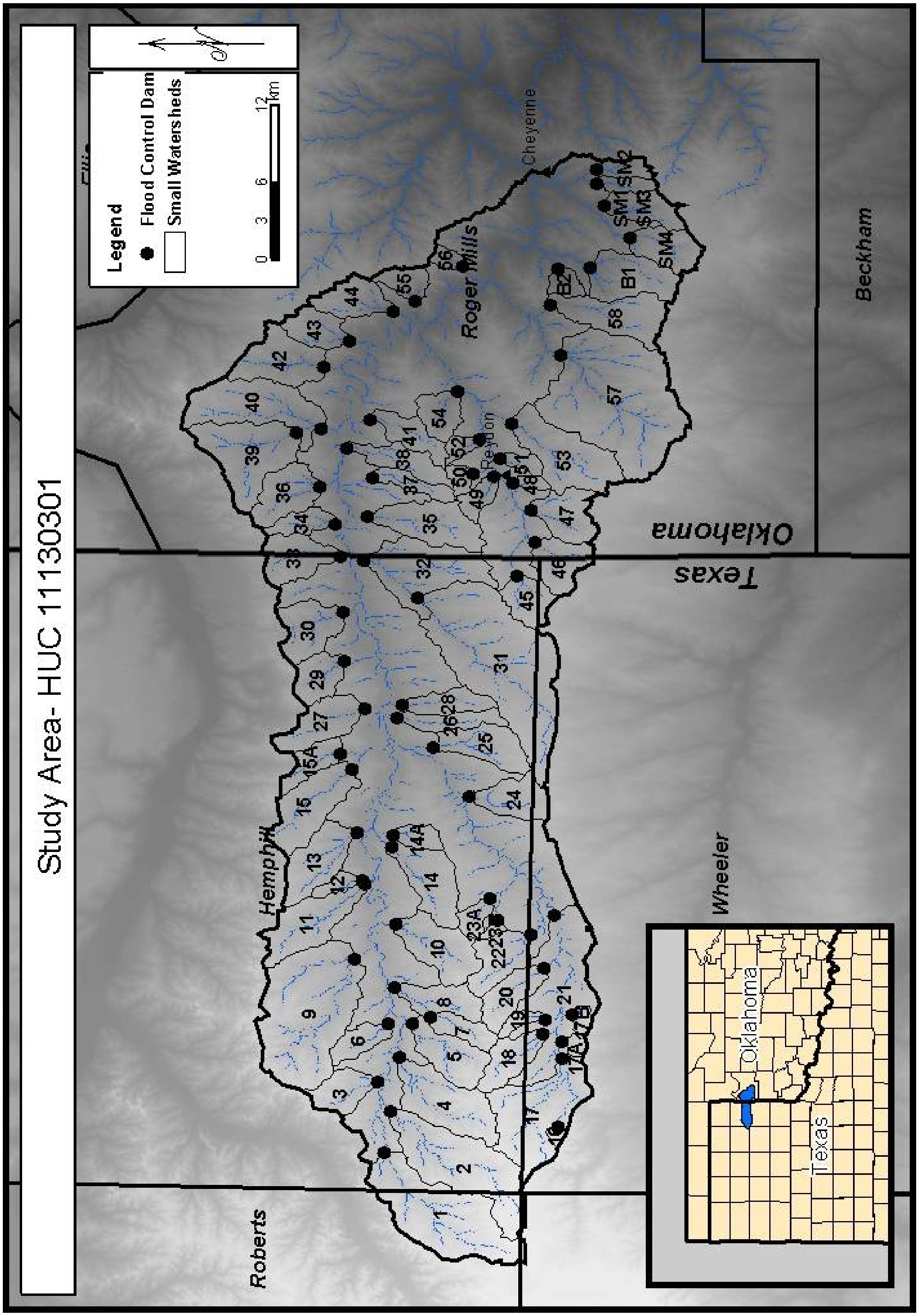


Figure 1. Study area divided into small watersheds

primary municipal water supply for Cheyenne, Oklahoma. A team of specialists representing both Oklahoma and Texas State Soil Conservation Service offices were involved in the site selection and design of each flood control dam. In this area, the runoff from a 6-hour, 25-year storm is approximately 1.3 inches. However, the design engineers decided to provide between 2 and 2.5 inches of detention storage in each floodwater retarding structure (SCS, 1958).

Aerial photographs from 1959, 1974, and 1995 show the effect of these structures on the channel profile and riparian vegetation along the Upper Washita River. The formerly broad, braided channel has become entrenched, with consequences to water quality that have not been thoroughly studied. Bergman and Sullivan (1963) studied altered stream characteristics along Sandstone Creek, which empties into the Washita River near Cheyenne, Oklahoma, and show that as early as 1963 the gradual release of flood waters has caused the once ephemeral creek to become perennial, with channel cross-section transformed from rectangular to V-shaped. The constant flow and reduced flooding has also allowed permanent vegetation to encroach and stabilize the banks of the channel. The larger scope of this project investigates changes in the channel as a result of flood control structures, and although Sandstone Creek is not in the study watershed, this study provides an example of the morphological changes expected as a result of flood control dams and what can be expected along the Upper Washita River. Channel entrenchment has lowered groundwater levels adjacent to the banks of the Washita River, which can no longer sustain cottonwood trees that characterized the channel in historic times. Temporal shifts in land use have caused additional changes in runoff and erosivity in the watershed.

Just upstream from Cheyenne is the Washita Battlefield National Historic Site, a 315-acre site acquired by the National Park Service to commemorate the location of the historic battle between Chief Black Kettle and Lt. Col. George A. Custer on November 27, 1868. Changes in the watershed upstream of this historic site have caused considerable variation in the main channel of the Washita River. This study is intended as part of a larger study to assess the anthropogenic impacts on the watershed, understand their effects on the Washita River, and determine the feasibility of restoring this site and maintaining it in the condition that prevailed at the time of the historic battle in 1868.

The USDA-NRCS (1999) has released a collection of publications to raise public awareness surrounding flood control structures and necessary attention. The publications regarding Oklahoma and Texas provide information about the problems being faced by the aging flood control dams in Oklahoma and Texas. Some dams originally built to protect farmland are now protecting populated areas, and much harm could result if dams go unattended and eventually fail. According to the USDA-NRCS (2002), in Oklahoma 110 flood control dams are in serious need of repair, and in Texas 25 flood control dams had reached their projected life expectancy by 2002. Many dams originally built to protect farmlands now protect urban development located downstream on the floodplain.

2. Previous Research

2.1 Flood Control Along the Washita River

Reber et al. (1999) assessed the possible effects of flood control structures on creeks and the Upper Washita River. Some changes in channel morphology and riparian vegetation can be inferred from accounts of the 1868 battle, which occurred near present-day Cheyenne, Oklahoma, and current conditions. They take into account other pre-record sources such as aerial photography and testimony by longtime residents of the area. Presented is an overview of aquatic ecology, surface water quality, and water quality at USGS station 07316500 (Washita River near Cheyenne, Oklahoma).

To further public awareness, the Oklahoma Conservation Commission (2001) published a short article on how small flood control dams are constructed and operated, how they reduce flooding downstream, plus a brief history of the flood control projects in Oklahoma. This was useful in gaining insight on the structural nature of flood control dams and planning field measurements and calculations.

Tortonelli (2002) summarized data collected at stream gauging stations in Oklahoma. Probability for flooding events and mean annual flow are calculated for time spans of 1938-1960 and 1961-1999. The variations between these periods illustrate the changes in average and peak flows after the inception of flood control structures in the Upper Washita River, proves that the flood control dams have greatly altered the flow characteristics of the Washita River upstream from gauging station 07316500 near Cheyenne, Oklahoma.

2.2 Hydrologic Modeling

Bhuyan et al. (2002) compared the accuracy of three popular hydrologic models: EPIC, ANSWERS, and WEPP. Each model was applied to three different tillage systems and compared with measured values from an erosion experiment field of Kansas State University at Ottowa, Kansas. Sensitivity of model inputs were tested, and model efficiency was determined by comparing measured and predicted values. General overprediction and underprediction were calculated for each model for all three tillage systems. This study was useful in reinforcing the choice to select the WEPP model for this research. Overall, the WEPP model produced the best results for the three common tillage systems during individual events, as well as long-term simulations.

Baffaut et al. (1997) performed validation of WEPP on several small watersheds (approximately 1 hectare in size). Objectives of the study are to investigate the importance of watershed discretization effects on model response and perform sensitivity analysis for different channel parameters. Their results help us understand the effect that varying levels of detail have on WEPP output, although all watersheds in this study are substantially larger than 1 hectare.

Liu et al. (1999) evaluated the WEPP model under different climate, topography, soil, and management regimes on a sample of small watersheds (.34 – 5.14 hectare). Similar to this study, no calibration of the WEPP model was performed to obtain results, and climate input was generated using the WEPP weather generator CLIGEN. WEPP was found to predict sediment yield and runoff amounts reasonably well when compared to measured data. The default soil erodibility and infiltration parameters were found to be effective and were used exclusively in this study.

Renschler and Harbor (2002) argue that the majority of research using hydrological models will involve data that is in the public domain, rather than expensive proprietary data or field measurements. WEPP is chosen as the soil erosion model and was selected because it is being considered by the USDA as the primary tool to support regulatory requirements. Input data includes NRCS soil survey maps, climate data generated by the CLIGEN weather generator, and USGS DEM topographic data. These data are identical to the data incorporated into this study, with the addition of USGS 1:24000 topographic maps and aerial photographs.

Yu and Rosewell (2001) attempt to validate the WEPP model on a study wheat field in Gunnedah, New South Wales, Australia. Predicted and observed values were recorded and plotted, and then the efficiency of the model was calculated. In this scenario, the WEPP model and CLIGEN climate generator were found to produce strong predicted results. This article was useful to understand how the coefficient of efficiency can be used to determine the strength of WEPP predictions to field measurements.

Savabi et al. (1995) performed similar tests on a small watershed in Indiana, using default parameter values and performing no calibration of the WEPP model. Results of modeling the same watershed using three degrees of detail indicate that greater detailed input produces progressively better results. Similar to this study, data of great detail for their study area was not always available.

2.3 Sediment Measurement and Production

Sediment impounded behind select flood control dams in Oklahoma has been characterized using experimental methods such as seismic surveying, vibracoring, and sedimentalogical analysis of those cores for color, particle size, magnetism, and chemical characteristics. The seismic surveys were taken in several transects across each reservoir, with paths recorded by GPS, and presented in UTM coordinates. The vertical profile and composition of the sediment can then be determined. Bennet and Cooper (2001) performed seismic surveys and extracted and analyzed cores at several reservoirs along the Upper Washita River. Dunbar et al. (2001) performed a seismic survey of Sugar Creek #12 reservoir in May 2001 to pilot a cost-effective and accurate method of acoustic profiling of sediment. This report expounds on Bennet and Cooper (2001) who previously obtained cores at this site. Dunbar et al. (2001) correlated these cores to their results.

Harden (1992) research has indicated that basin-scale erosion models often overlook two very important sources of sediment production: “abandoned land” and dirt roads and trails. Her rainfall simulation research in the Paute watershed in highland Ecuador indicates that although roads cover a very small percentage of the land area (< 1%) they contribute disproportionate amounts of sediment to the watershed. The scale at which WEPP was applied in this study forced road features to be omitted from the model and was found to have similar impact on results.

Verstraeten et al. (2000) investigated methods of determining trapping efficiency of flood control dams in different parts of the world. Trapping efficiency is one calculation that can be easily made for each impoundment modeled in WEPP. Previous trapping efficiency studies for flood control dams included in this study do not exist. However, as this article states, the intended purpose of these dams is to retard floodwater, suggesting that their trapping efficiency as modeled by WEPP should be relatively low.

Ziegler et al. (2000) simulated rainfall on dirt roads, footpaths, and agricultural lands in the Pang Khum Experimental Watershed, northern Thailand. Road surfaces consisted primarily of sandy-clay-loam texture covering (< 1%) of the watershed and were found to produce runoff coefficients >80% in the first minute of high-intensity precipitation events.

3. Methods

The original goal of this study was to measure volume of impounded sediment within a sample of the 63 flood control dams in the Upper Washita watershed. This sample size was restricted to 48 flood control dams on the basis of access and further because many dams contained negligible amounts of sediment. At each structure containing sediment, measurements were taken to be used in calculating volume of sediment currently impounded in the reservoir. Volume of sediment is calculated by determining thickness of sediment at the dam, estimating area of sediment pool, and then using these dimensions to calculate volume of sediment as a wedge shape that is thickest at the dam and tapers to zero at an arbitrary point upstream. This estimation is then compared to the output of the WEPP model, to determine the predictive capability of the WEPP hydrologic model in this watershed.

In order to secure a large and distributed sample of study sites within the watershed, basic measurements were taken at each site to allow more sites to be sampled in the time allotted. Since 61 of 63 potential sites are on private land, landowner/management permission was mandatory before visiting the site for legal and logistical reasons. Many of these structures exist considerable distances from any recorded road. Landowners/managers were imperative to direct us through private roads and often unlock gates.

3.1. Data Collection

Information regarding land ownership was gathered from several sources. In Roger Mills County, Oklahoma, public records archived at the Roger Mills County Courthouse were collected, and personnel were helpful in supplying contact information or directing us to the correct party to be contacted. Additionally, the Roger Mills County NRCS office publishes a land ownership map for the entire county (circa 1998). Information regarding land ownership for Hemphill County, Texas was acquired from the Hemphill County NRCS office. Contact information was gathered from the local phone book, as well as the Hemphill County Courthouse. Landowner and contact information for Wheeler County, Texas was acquired from county tax assessor's office.

Primarily, the limiting factors when contacting landowners were outdated public records, hospitalization, and in some cases the land was owned or managed out of area, and the appropriate party was unreachable. In all, 48 flood control dams were made available, and 48 flood control dams were visited. Prior to visiting these sites, original as-built blueprints were inspected for each flood control dam to determine:

1) spillway level of riser structure
2) date of dam construction
3) presence or absence of berm extending from base of dam beyond riser
4) length of berm extending from dam if berm is present

As-built blueprints are archived the office designated to manage the flood control structures in a particular county. As-built blueprints for flood control dams 34 - 44, and 46 - 58 (Roger Mills County, Oklahoma) were found at the Roger Mills County NRCS office, Cheyenne, Oklahoma. As-built blueprints for flood control dams 11 - 16, 23 - 33, and 45 (Hemphill County, Texas) were found at the Hemphill County Courthouse, Canadian, Texas. As-built blueprints for flood control dams 17-22 (Wheeler County, Texas) are stored at the Wheeler County NRCS office; however, this information was not made available to us for inspection, seemingly due to suspicion of ill intent. If necessary, these data could be retrieved from the Texas NRCS state office, in Temple, Texas, who had previously informed me that these data were openly available, free of charge under the Freedom of Information Act.

3.2 Method of Measuring Sediment Thickness:

Thickness of sediment was estimated by measurements relative to the spillway level of the riser. The riser of each flood control dam is typically built in the lowest part of the channel, where sediment can be assumed to accumulate the thickest. Thickness of sediment relative to spillway level of the riser was calculated as:

$$T_{sed} = H_{riser} - H_{rb} \tag{1}$$

Where T_{sed} is thickness of sediment; H_{riser} is height of riser, and H_{rb} is vertical distance from spillway height of the riser to bottom of reservoir. If the reservoir is filled to spillway level, H_{rb} is simply water depth, measured at the riser or the toe of berm, if a berm is present in dam construction. If the reservoir is filled below spillway level, H_{rb} is the vertical distance from waterline to spillway level added to water depth, measured at the riser or the toe of berm, if berm is present. Therefore, $H_{riser} - H_{rb}$ will yield sediment thickness in the center of the channel where it is assumed to be of maximum thickness.

The distance from the riser to the toe of the berm, if berm is present in dam construction, was measured from as-built blueprints. This insured that measurements of water depth reflected water depth to bottom of reservoir rather than water depth to berm.

To measure water depth at the appropriate location, a field assistant wearing a life vest floated out to the riser, or if berm is present in dam construction, the specified distance past the riser to reach the toe of the berm. The field assistant carried a 30m vinyl tape measure with a simple metal weight fastened to the end. The life jacket was to promote safety and also allowed both hands to be used when taking measurements. Measurements were taken by simply lowering the weighted end of the tape into the water until it came into contact with the bottom, after which the measurement of water depth was reported and recorded.

In many instances, reservoirs were found to be so severely devoid of both water and sediment that the aforementioned technique could be employed to determine a thickness of sediment. Measurements of H_{rb} would yield a thickness of zero. Often the concrete foundation of the riser structure was clearly exposed, completely devoid of sediment. In other cases, thin layers of sediment were visible; however, the source determined to be the dam itself.

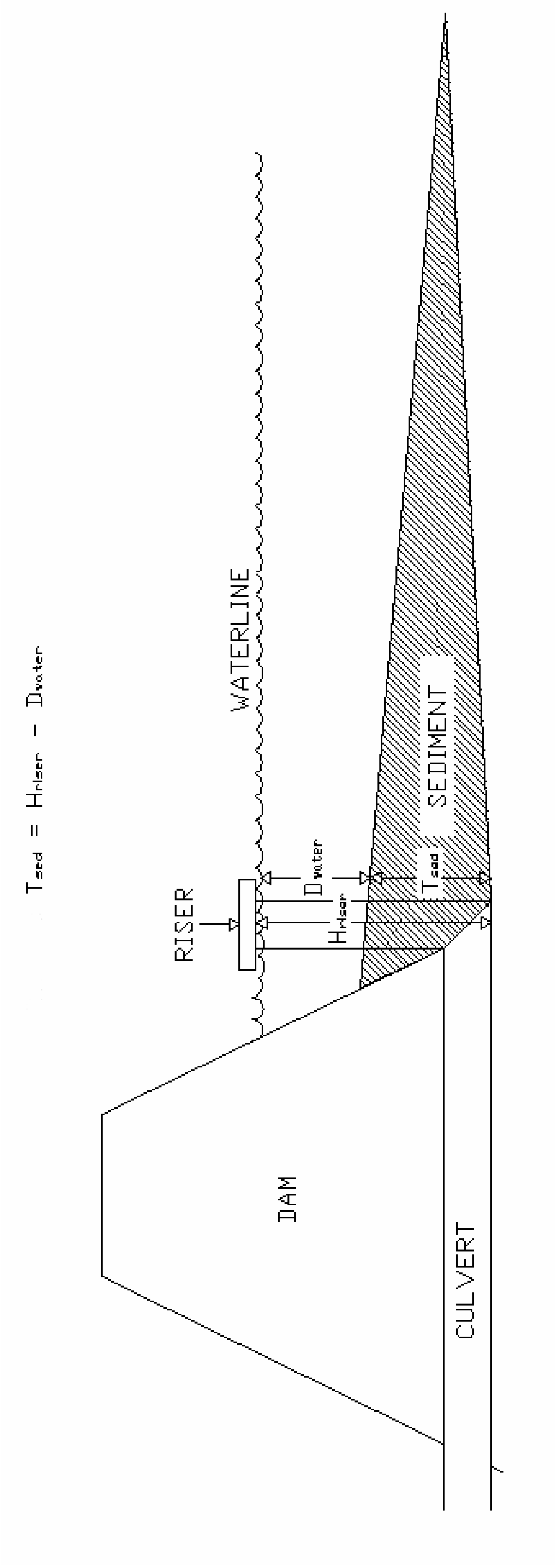


Figure 2. Method of measuring thickness of sediment at each dam

Livestock typically seek shade beneath the riser structure, trampling the grass and causing minor rill and gully erosion near the riser structure (Figure 3). Lack of measurable sediment is the scenario encountered at several flood control dams in Oklahoma and at every flood control dam in Texas.

Reservoirs containing negligible amounts of sediment were excluded from the dataset and not incorporated into any further analysis. In all, 29 flood control dams were recorded as “negligible” and removed from the dataset, leaving a total of 19 flood control dams for further analysis (Figure 4). Each flood control structure visited

Figure 3. Chris Ennen investigates sediment at riser as a result of livestock trampling

in Wheeler County was determined to contain “negligible” amounts of sediment, rendering missing as-built blueprints unneeded.

Two flood control dams posed exceptions to these measurement methods. Dam number 57 was observed to be a substantially larger construction, constructed in a slightly different manner, with its riser high on the former bank of the channel rather than the lowest point. For this occurrence, water depth was measured at the presumed center of the channel, and the riser height was added to the vertical distance from the bottom of the riser to the bottom of the channel, as measured from as-built blueprints. This calculation yielded a total height from riser height to bottom of channel. The water line was observed to be equal to the riser spillway height, therefore the thickness of sediment is simply:

$$T_{sed} = H_{tot} - D_{water} \tag{2}$$

Where H_{tot} is the total height from top of the riser to bottom of channel in feet. This was the only observation of this construction type in the watershed.

In the case of dam number 46, the riser height of 13 feet is believed to be in error as recorded on the as-built blueprints. At the base of each riser is a culvert into which the riser drains. The culvert then travels through the dam and discharges downstream. The culvert is 17-inch I.D. concrete pipe (approximately 22” O.D.) and is partially visible above the sediment as recorded in photographs taken at the sight. At this dam, initial calculations yielded $T_{sed} = H_{riser} - H_{rb} = 3.125$ feet. This was deemed incorrect since culvert is still partially visible T_{sed} must be less than 22”. H_{riser} was modified to 11 feet to correct this. This is a valid correction because all the riser heights in the watershed are in whole foot increments, there was no “standard” height, and the correction resulted in a

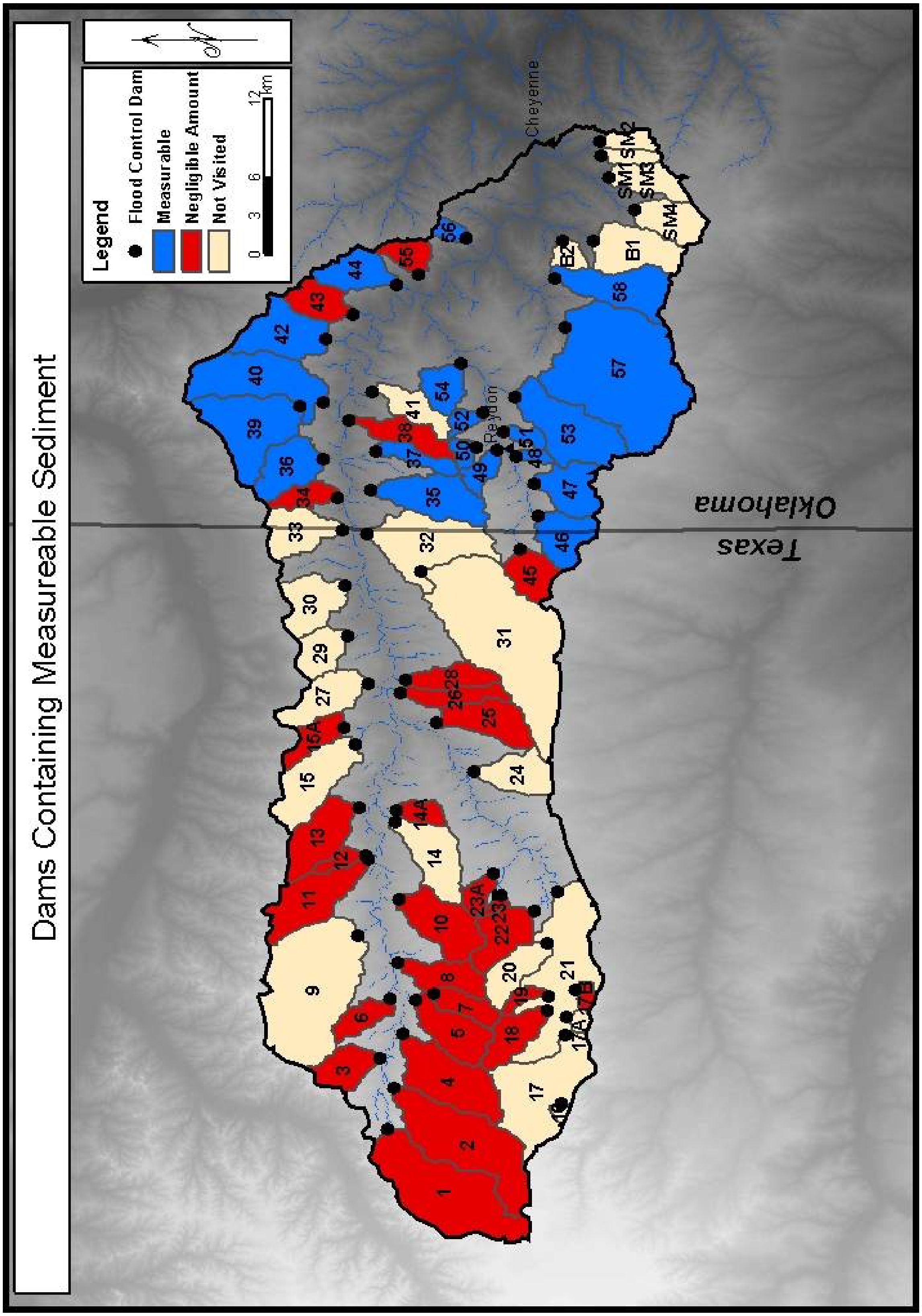


Figure 4. Measured, negligible, and sites not visited

T_{sed} of 1.125 feet, which is less than 22 inches, and is in agreement with the culvert being partially exposed as photographs taken at the site suggest. No more discrepancies were found in any measurements or constructions for any of the remaining flood control dams included in the sample. At each site visited, a GPS point was acquired to be used as the "pour point" of the watershed in further GIS analysis. This point was collected in UTM Zone 14N NAD-83 coordinates using a Trimble GPS receiver. The point was recorded from the top of each dam, approximately in line with the riser structure of the dam. The exact location of this point was arbitrary, as most would require micro-adjustment to integrate harmoniously with other data in the GIS analysis.

Field measurements of maximum sediment thickness at each flood control dam were then used to estimate the volume of sediment impounded at each site. Original USDA-NRCS construction plans provided important information for flood control dams in this watershed regarding:

1) maximum sediment storage capacity; and
2) maximum area of sediment pool.

It was originally planned to use maximum area of sediment pool to calculate volume. However, after field observations concluded that these reservoirs contained considerably less sediment than anticipated, initial calculations of sediment volume were observed to be severe overestimates. A correction became necessary to account for the area of the sediment pool diminishing with sediment thickness to avoid gross overestimations of volume. The corrected area of sediment pool was calculated by solving for equal ratios:

$$\frac{A_{curr}}{A_{\max}} = \frac{T_{sed}}{T_{\max}} \quad \text{therefore: } A_{curr} = \frac{(A_{\max})(T_{sed})}{T_{\max}} \tag{3}$$

Where A_{curr} is the current area of sediment pool in acres, A_{max} is the maximum area of the sediment pool, T_{sed} is the calculated thickness of sediment at the dam in feet, T_{max} is the maximum thickness of sediment possible for the particular structure in feet. This calculation assumes the sediment pool area will vary directly with sediment thickness, resulting in diminished area with decreasing thickness, and uses the measured thickness (T_{sed}) to estimate the appropriate diminishment of area. Applying this formula to reservoirs of negligible sediment (where $T_{sed} = 0$) would yield zero acres.

The volume of impounded sediment was then calculated based on current area of sediment pool (A_{curr}) and thickness of sediment at the dam (T_{sed}):

$$V_{meas} = \frac{(A_{curr})(T_{sed})}{2} \tag{4}$$

Where V_{meas} is the measured volume of sediment. Product of A_{curr} and T_{sed} yields the area of a rectangular prism, and when divided by 2 represents sediment as a wedge shape thickest at the dam, and tapering to 0 at an arbitrary point upstream.

Percentage of sediment capacity contained by each reservoir was then determined by calculating:

$$P_{cap} = \frac{V_{meas}}{V_{\max}} * 100 \tag{5}$$

Where P_{cap} is percentage of maximum sediment storage capacity reached.

Up to this point, measurements of sediment thickness have been in feet, measurements of sediment pool area have been in acres, and calculations of volume have been in acre/feet in agreement with units represented in as-built blueprints and USDA-NRCS construction plans. Calculated volume of sediment was then converted from acre/feet to tonnes to be comparable with the WEPP model output. Correctly calculating weight per volume of sediment is largely contingent on the composition of the sediment. Sediment in this watershed is characterized almost exclusively by fine-sandy-loam textured soils, weighing 71 pounds per ft^3 (Vanoni, 1975). First volume was converted from acre/feet to ft^3:

$$ft^3 = acre/feet * 43560.25 \tag{6}$$

Then converting ft^3 to pounds of fine-sandy-loam material:

$$FSL(lbs) = ft^3 * 71 \text{ lbs/ft}^3 \tag{7}$$

Then converting pound of fine-sandy-loam material to tonnes for comparison with the WEPP model:

$$FSL(tonnes) = FSL(lbs)/2204.6 \tag{8}$$

3.3. GIS Analysis

Digital Elevation Data (DEM), Digital Orthorectified Quarter Quadrangles (DOQQ), and vector road data for GIS analysis was gathered from several sources (Table 1).

Table 1. Sources of GIS data

DEM Elevation Data	http://seamless.usgs.gov/
DOQQ (Oklahoma)	http://www.geo.ou.edu/
DOQQ (Texas)	http://www.tnris.state.tx.us/DigitalData/doqs.htm
Section Line Roads	http://www.geo.ou.edu/

Modeling each watershed included in the sample was carried out in two phases. First, ArcGIS 8.x was used to mosaic aerial photographs and DEM data for the entire watershed, incorporate field-collected GPS points to create watershed boundaries and approximate drainage networks from DEM (Digital Elevation Model) data, and export jpg images of each watershed boundary overlaid onto aerial photographs for further use in WEPP modeling. Second, the WEPP model was used to create the channels, hillslopes, and impoundments within each watershed, run simulations, and output simulation results.

USGS DOQQ aerial photographs covering the entire watershed were used for several portions of the analysis. These photographs were specified as NAD83 UTM 14N METER using ArcCatalog. Each photograph was added to a map document in ArcGIS 8.x and incorporated in several stages of further analysis. These photographs overlain with other datasets provide a good representation of land use and drainage patterns within each watershed.

First, watershed boundaries were delineated for each small watershed in the study watershed. To accomplish this, DEM from the USGS NED (National Elevation Data) dataset was acquired for the entire watershed. Using Spatial Analyst, the DEM was processed using the following steps:

1) DEM rasters were combined to create one continuous raster for the entire watershed using Spatial Analyst:

continuousGrid = Mosaic([grid1], [grid2], …[gridn])

2) Sinks were filled in the DEM to eliminate pits in the landscape resulting from errors inherent to the data, the dams themselves, or anything else that would likely interfere with the discontinuity of drainage in the watershed using a Fill Sinks tool downloaded from the ESRI website (http://www.esri.com). Removing the topographic profile of the dam structures is acceptable in this

case, as their presence in the topography is nonessential to further GIS analysis or WEPP modeling.

3) A flow direction grid was created using Spatial Analyst:

flowDirGrid = flowdirection([continuousGrid])

To create this grid, Spatial Analyst calculates the direction each cell drains toward, and assigns a value based on the eight cardinal and intercardinal directions. This grid is the first step to modeling the hydrology of a landscape.

4) A flow accumulation grid was created using Spatial Analyst:

flowAccumGrid = flowaccumulation([flowDirGrid])

To create this grid, Spatial Analyst counts the number of cells that drain into each cell (theoretically "upstream" from it), based on the flow direction grid, and assigns the cell an integer to represent the number of cells upstream from it.

5) A drainage network was created using Spatial Analyst:

drainageNetworkGrid = con(flowAccumGrid > 500, 1)

To create this grid, Spatial Analyst simply selects cells from the flow accumulation grid that display flow convergence of greater than a threshold number (in this case 500) cells, and assign each cell fulfilling that criteria a value of 1. Every other cell not fulfilling these criteria is given a value of 0. A lower threshold will result in a denser drainage network; a higher threshold will result in a less dense drainage network. A threshold of 500 was selected based on qualitative evaluation of several thresholds, and used strictly to aid in locating channels on DOQQ aerial photographs and not for further analysis. The drainage network grid as delineated by Spatial Analyst was visually compared to visible channels on the DOQQ aerial photographs, and found to be exceptionally accurate.

6) Using GPS points collected from each site along with the flow direction grid, the drainage area of each watershed was created. This was done in three steps:

   a) GPS vector data points from each site were confirmed to exist along drainage network grid. Points were adjusted slightly if necessary to prevent inaccuracies in further raster analysis. Points became "pour points," or terminal point of watershed drainage.

   b) Vector data pour points were then converted to raster format of identical spatial extent and cell size as flow direction grid.

   c) A watershed boundaries grid representing the perimeter of each small watershed was created using Spatial Analyst:

smallWatershedsGrid = watershed ([flowDirGrid], [pourPts])

This grid incorporates the flow direction and pour points grids to create a new grid delineating each cell upstream from each pour point as being contained within a separate watershed. These generated watershed boundaries were compared with hand-sketched boundaries as recorded in the USDA-NRCS Upper Washita River Watershed (1957) work plan and found to be in agreement.

The resulting map of aerial photographs overlain with watershed boundaries and drainage network was used in subsequent analysis in the WEPP hydrologic model. A layout was created in ArcGIS 8.x with dimensions 18" wide and 22" high. Each watershed was zoomed in Layout View to a scale of 1:24000, and exported as a .jpg image file. This combination of dimensions and scale was chosen to match those of 1:24000 USGS quadrangles, and allow on-screen measurements to coincide with map measurements. Resulting images included aerial photographs, watershed boundaries, and approximate drainage networks, and were used as a backdrop to model channels, hillslopes, and impoundments in the WEPP hydrologic model.

3.4. The WEPP Model

The WEPP model (Water Erosion Prediction Project) is a physically based process model, intended to provide continuous spatially distributed watershed simulations with minimum calibration (Renschler, 2004). By using the WEPP model, individual hillslopes can be modeled based on their slopes, soil characteristics, and land management practices. As many as three hillslopes may contribute to a single channel, and as many as three channels can feed an impoundment. This allows the flexibility to model both simple and complex watersheds upstream from selected flood control dams.

Development of the WEPP model began in 1985 by the USDA-NRCS, and extensive development of the WEPP model is ongoing at Purdue University. The model incorporates the fundamentals of hydrology, including plant sciences, soil physics, and erosion mechanics. Considerations are also included for climate generation, snowmelt, irrigation, crop growth, residue decomposition, rill hydraulics, and transport and deposition of sediment (Risse et al., 1995).

There were several reasons to utilize WEPP over other hydrologic models, both processes based and empirical.   WEPP has several advantages over earlier empirical models such as USLE (Universal Soil Loss Equation) and RUSLE (Revised Universal

Soil Loss Equation) including considerations for sediment deposition, sediment transport, and temporal changes in land management. The SWAT (Soil Water Assessment Tool) model is also process based, but does not facilitate the finer hillslope-level resolution provided by WEPP. In addition, WEPP has been selected by the USDA-NRCS and EPA for designation as the primary soil erosion assessment tool that will be used in the future to support regulatory requirements (Renschler and Harbor, 2002). The National Forest Service has begun incorporating WEPP into “watershed assessment” to determine impacts of timber, livestock forage, and hydroelectric power production on National Forest System lands. These assessments are intended to go beyond previous qualitative methods and balance commodity production with ecosystem integrity (Gallegos, 1999). Other soil loss models such as EPIC and ANSWERS are based on revisions of the USLE and the RUSLE and were evaluated in controlled experiments along with WEPP by Bhuyan, S.J. et al. (2002) and found to produce less accurate results.

WEPP is currently being tested and validated in varying conditions and in different countries. Yu and Rosewell (2001) attempted to validate the WEPP model on a study wheat field in Gunnedah, New South Wales, Australia. The sensitivity of different independent variables was tested regarding their effect on the dependent variables, and model efficiency was calculated by correlating predicted and observed results. In this scenario, the WEPP model and CLIGEN climate generator, used to generate climate files for input, were found to produce good results.

Further testing of the WEPP model was performed by Bhuyan et al. (2002) by comparing the accuracy of three popular hydrologic models: EPIC, ANSWERS, and WEPP. Each model was applied to three different tillage systems, and compared with measured values from an erosion experiment field of Kansas State University at Ottowa, Kansas. Sensitivity of model inputs were tested, and model efficiency by comparing measured and predicted values. General overprediction and underprediction were calculated for each model for all three tillage systems, with WEPP selected as most accurate. Overall, the WEPP model produced the best results for the three common tillage systems during individual events, as well as long-term simulations. Renschler and Harbor (2002) tested WEPP using different inputs of readily available data. The authors argue that majority of research using hydrological models will involve data that is in the public domain, rather than expensive proprietary data or field measurements. This is considered important for the future of the WEPP model in public decision-making. Their research is similar to the goal of this project.

3.5. WEPP Modeling

For each watershed simulation, WEPP requires channels, hillslopes, and optionally impoundments. First, channels were needed for input into the WEPP model. Several problems were encountered in this step, and several changes were made to adapt to observed field conditions and data limitations. Rather than blue lines on topographic maps or drainage networks generated using spatial analyst, aerial photographs were used in discretization of the drainage network in each watershed. There are two reasons for proceeding in this manner:

1) In several cases, channels represented by blue lines on topographic maps were observed to be absent in the field and/or indiscernible on aerial photographs.
2) In many cases, channels drawn by Spatial Analyst were not consistent with aerial photographs. Spatial Analyst simply calculates flow convergence

between cells due to topography, ignoring other factors that may influence channel formation. The proper threshold of flow convergence was likewise an issue, with similar thresholds producing dense drainage networks in larger watersheds and zero density in smaller watersheds.

To aid modeling in WEPP, jpg images created for each watershed in ArcGIS 8.x, and displaying aerial photographs, watershed boundary, and approximate drainage network as drawn by Spatial Analyst were used as background images in the WEPP watershed simulation.

Channels were entered into WEPP adhering to the following criteria:

1) Length was discernable on the aerial photograph for greater than 400m. Discernable channels showed presence of water, dense riparian vegetation, gully formation, or discoloration due to moisture.
2) Length of channel segment does not exceed 1600m for any single segment.
3) Channel valley deflected at an angle of > 30 degrees. In these instances, center line of channel was drawn on topographic map and measured with a protractor.
4) If channel length exceeds 1600m before becoming indiscernible or bifurcating, a second channel was appended to its end, and created consistent with the above criteria.

Gradient of each channel was measured from topographic maps by simply measuring linear length of the feature with an engineering scale and change in elevation from beginning to end of feature, as determined from contour lines on the map:

$$s = \frac{\Delta_{elev}}{S_{length}} * 100 \tag{9}$$

Where Δ_{elev} is the change in elevation from beginning to end of the channel segment and S_{length} is the linear length from beginning to end of the channel segment.

Soil properties for each channel were determined from SCS soil maps. Dominant soil types found along channels include Zavala Series, fine sandy loam found on floodplains and small drainageways, and Lincoln Series, a reddish-brown, calcareous, sandy soil found on floodplains (USDA-NRCS, 1963). Detailed attributes for these soils were acquired from Purdue University and incorporated into the WEPP model without modification to the default settings. Channel type was left as default (waterway), width as default (1 meter), and land use as fallow.

For each channel, a hillslope is required to exist at the “downstream left” and “downstream right” locations of the channel. In the case of first order channels, a “top” hillslope is also required. The hillslope consists of slope, soil type, and land management. The slope parameters include the length and profile of the hillslope.

Hillslopes were created by similar techniques as channels. WEPP allows each channel to have up to three adjacent hillslopes. For higher order streams, downstream-right and downstream-left hillslope were modeled. For first order channels, a downstream-right, downstream-left, and top hillslopes were modeled. Each hillslope requires information regarding slope, soil, and land use.

Slope for each hillslope was determined from USGS 1:24000 quadrangle measurements, using the same method implemented to determine channel slope:

$$s = \frac{\Delta_{elev}}{S_{length}} * 100 \tag{10}$$

By measuring S_{length} at a right angle to the midpoint of its respective channel segment, from channel to drainage divide. Δ_{elev} was measured as the difference in elevation at either end of transects used to measure S_{length}.

Soil properties for each hillslope were determined from SCS soil maps. Dominant soil types on hillslopes include Pratt Series, characterized by brownish loamy fine sand or fine sandy loam; Nobscott, characterized by grayish-brown fine sand underlain by yellowish-red find sandy loam; Miles, characterized by reddish brown fine-sandy loams and loamy sands; Eroded Sandy Land, consisting of severely eroded Nobscott and Miles soils; Rough Broken Land, characterized by deep channel incisions and exposed bedrocks, having sparse vegetation and very little measurable soil (USDA-NRCS, 1963). Input files for these soils were acquired from Purdue University at http://topsoil.nserl.purdue.edu/nserlweb/weppmain/data/soildownloads.htm and incorporated into the WEPP model without any modifications to the default parameter settings.

Land uses primarily consisted of cattle pasture and wheat fields in this watershed. Cattle range has always been an important land use in this area. As of 1963, a little more than two-thirds of the land area is rangelands (USDA-NRCS, 1963). According to NRCS-Roger Mills County personnel, many areas shifted from wheat cultivation to cattle pasture as erosion control measures in the late 1960s. Again in the mid-1980s additional areas converted from wheat cultivation to native grasses used for grazing. Determining changes in land use since time of dam construction was done by comparing DOQQ aerial photographs of the area from 1958, 1974, and 1995. Land displaying wheat cultivation in 1959 that was converted to cattle pasture by 1974 was assumed to have shifted in 1969.

Land displaying wheat cultivation in 1974 but converted to pasture by 1995 was assumed to have shifted in 1985. When areas formerly covered with wheat were converted to pasture, they were re-vegetated with native grasses, mainly bluestem prairie grass. WEPP is packaged with many land use files for rangeland and cultivation. Three of these presets were incorporated into this study, with all default settings intact. Cattle pasture on privately owned land is assumed to be "bluestem prairie with grazing." Cattle pasture on publicly owned land is assumed to be "bluestem prairie without grazing." Areas displaying wheat cultivation are "wheat conventional till." For slopes undergoing changes in land use during the simulation period, the hillslope was created twice, each time with the appropriate changes in land use, identical soil types, and identical slope profile.

After each hillslope for a particular watershed was modeled, each was added to the watershed simulation as either downstream-right, downstream-left, or top slopes. WEPP inputs them as rectangular, the width of the hillslope contingent on the length of the channel, and the length of the hillslope contingent on the value S_{length} in the slope profile. These rectangular representations where then modified to conform to the contours of the watershed boundary as generated by Spatial Analyst and overlain on DOQQ aerial photographs used for a modeling backdrop.

WEPP supports many different impoundments, including ponds with drop spillways, rock fill dams, straw bales, emergency spillways, and silt fences. Each flood control structure in the dataset most closely resembles the "drop spillway with rect riser and circ barrel" impoundment included in WEPP. For each flood control dam, this structure was saved as a new impoundment file and modified slightly to more closely represent the flood control dam as it exists in the field. Measurements gathered from as-built blueprints were primarily used for this. The following drop spillway parameters were modified: stage of riser inlet, length of riser box, and width of riser box. In particular, riser height is the main contributing factor to spillway overflow during elevated water levels and on which sediment trapping efficiency is contingent. All other settings were left as defaults and are of less importance in modeling overflow and the sediment trap efficiency of the flood control dam. Each impoundment was added to the outlet of the appropriate watershed, where the location of the dam could be observed from the aerial photograph backdrop.

Each watershed was modeled using CLIGEN generated input climate file for Reydon, Oklahoma. Reydon, Oklahoma (population 165), is the most centrally located weather station relative to watersheds included in the sample. The number of years the watershed simulation was run was based on the number of years since the dam was built, until 2003, when field measurements of impounded sediment were collected. In all, 188 hillslopes, 56 channels, and 19 impoundments were modeled for 19 watersheds.

The model was run for the prescribed number of years, and sediment yield is calculated and presented for each hillslope, channel and outflow from each impoundment. In the situations where land use was determined to shift from wheat cultivation to rangeland, the model was run for different intervals of time with the appropriate hillslopes bearing the correct land use for each interval. WEPP output is given in tons per year on average for the simulation; therefore the total was simply calculated by:

$$Sed_{total} = (AvgerageAnnual * years) - ImpoundmentOutflow \tag{11}$$

Meaning that total sediment impounded in the reservoir is the annual average production multiplied by years of simulation, less the amount of sediment passing through the riser structure during overflow events. In the case of a watershed requiring multiple simulations on behalf of shifting land use, total sediment yield (Sed_{total}) was calculated as above for each simulation interval and totaled after all necessary simulations were run.

4. Results and Discussion

In most cases, WEPP severely underestimated sediment impounded in the reservoir (Table 2). These discrepancies were drastic enough to prompt a reevaluation of the methods and calculations that had been performed. No errors or discrepancies were found, and the methods and calculations were not modified. Sediment trapping efficiencies (TE) of the dams were calculated for each flood control dam as suggested by Verstraeten and Poesen (2000):

$$TE = \frac{SedInflow - SedOutflow}{SedInflow} = \frac{SedSettled}{SedInflow} \tag{12}$$

Where 1 would indicate a perfectly trapping structure, and 0 a perfectly non-trapping structure. WEPP suggested TE for flood control dams in the sample set ranged from .014 to .70. These values can be explained by the fact that flood control structures are

Table 2. Results of analysis for each flood control dam

Dam #	Year Const	Measured Sediment Thickness (ft)	Measured Sediment Weight (tonnes)	WEPP Total Impounded (tonnes)	Percent Full	Trapping Efficiency	Residual (tonnes)	Water shed Area (km^2)	Basin Elonga-tion	Length of Sec. Ln Rds (km)	Sediment yield (tonnes/ km^2)
35	1961	3.0	10272	1764	3.5%	40.7%	-8508	22.2	0.57	24.6	462.3
36	1961	2.4	16058	4685	3.2%	17.5%	-11373	17.2	0.78	16.6	931.4
37	1961	2.4	5833	1885	4.0%	47.1%	-3948	7.5	0.46	10.9	777.4
39	1961	6.0	87142	1418	9.3%	1.4%	-85724	33.8	0.77	39.7	2578.0
40	1960	2.2	17999	8824	2.1%	8.7%	-9175	33.5	0.60	30.7	537.3
42	1961	3.4	16375	4308	3.5%	41.5%	-12067	22.5	0.67	23.5	727.9
44	1960	3.0	10377	4972	4.1%	34.5%	-5406	13.8	0.62	8.8	751.5
46	1961	1.1	2320	574	0.8%	70.7%	-1747	14.7	0.90	4.9	158.0
47	1961	5.3	37747	4954	13.8%	36.0%	-32793	15.7	0.82	18.6	2409.8
48	1961	2.2	2543	2583	2.8%	53.0%	40	2.3	0.57	0.9	1127.4
49	1960	3.9	11103	2544	9.1%	42.9%	-8558	6.1	0.72	5.9	1814.1
50	1960	1.2	1145	530	1.4%	65.3%	-615	3.7	0.96	5.8	313.0
51	1961	1.3	835	2134	1.0%	56.6%	1299	3.6	0.62	6.0	232.7
52	1960	3.0	5328	1151	5.2%	56.6%	-4178	3.8	0.65	5.1	1393.7
53	1960	1.5	3821	7358	0.6%	26.2%	3537	30.7	0.62	30.4	124.3
54	1960	3.8	11025	3903	5.6%	25.1%	-7122	10.3	0.85	10.6	1067.2
56	1960	1.1	710	1868	0.8%	36.9%	1158	3.5	0.79	0.0	200.5
57	1960	9.2	231809	1302	15.3%	4.5%	-230507	85.7	0.90	78.6	2703.8
58	1961	12.0	50190	4257	54.2%	18.1%	-45933	23.0	0.60	21.6	2185.9

designed to primarily hold water, and should remain at their highest level for as long a period as possible. This means that TE should be low. Sediment basins should be designed with high TE (Verstraeten and Poesen, 2000). Dams were also observed to be filled to only a fraction of their maximum sediment capacity (Figure 5).

Output from the WEPP model converted from English tons to metric tonnes:

$$Tonnes = \frac{tons}{1.102} \tag{13}$$

The coefficient of efficiency was calculated for the data. This helps to determine the predictive ability of the model, and is calculated using the formula:

$$E = 1 - \frac{\sum (Y - O)^2}{\sum (O - \overline{O})^2} \tag{14}$$

Where *O* represents field observations and *Y* represents model output. The equation will yield a number between $-\infty$ and 1, with 1 being a perfectly efficient model, and less than zero indicating more favorable results can be obtained by calculating the mean of observed values (Yu nd Rosewell 2001). The coefficient of efficiency between observed data versus predictions by the WEPP model is -.227. This indicates very poor prediction from the WEPP model.

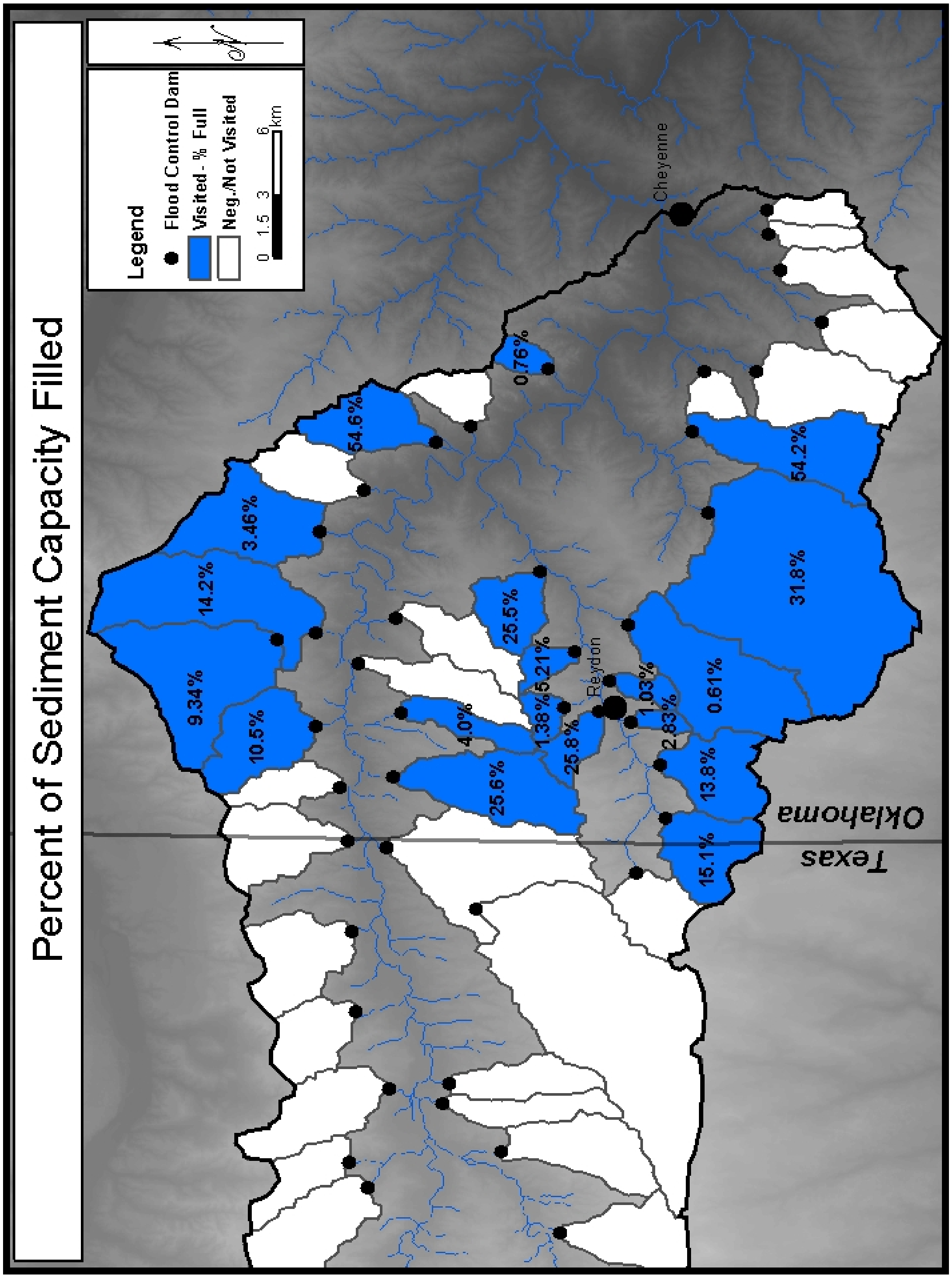


Figure 5. Percent of sediment capacity reached by each measured dam

When observed values are plotted against values predicted by WEPP, the data has shown WEPP to produce very inconsistent results when compared to amounts of sediment measured in the field (Figure 6). The WEPP model has mainly underestimated output, with a few overestimations. Using SPSS 12.0 for Windows, the data was tested for statistically significant relationships. Correlation between observed (dependent) and predicted values (independent) shows no significant relationship with $R^2 = .025$.

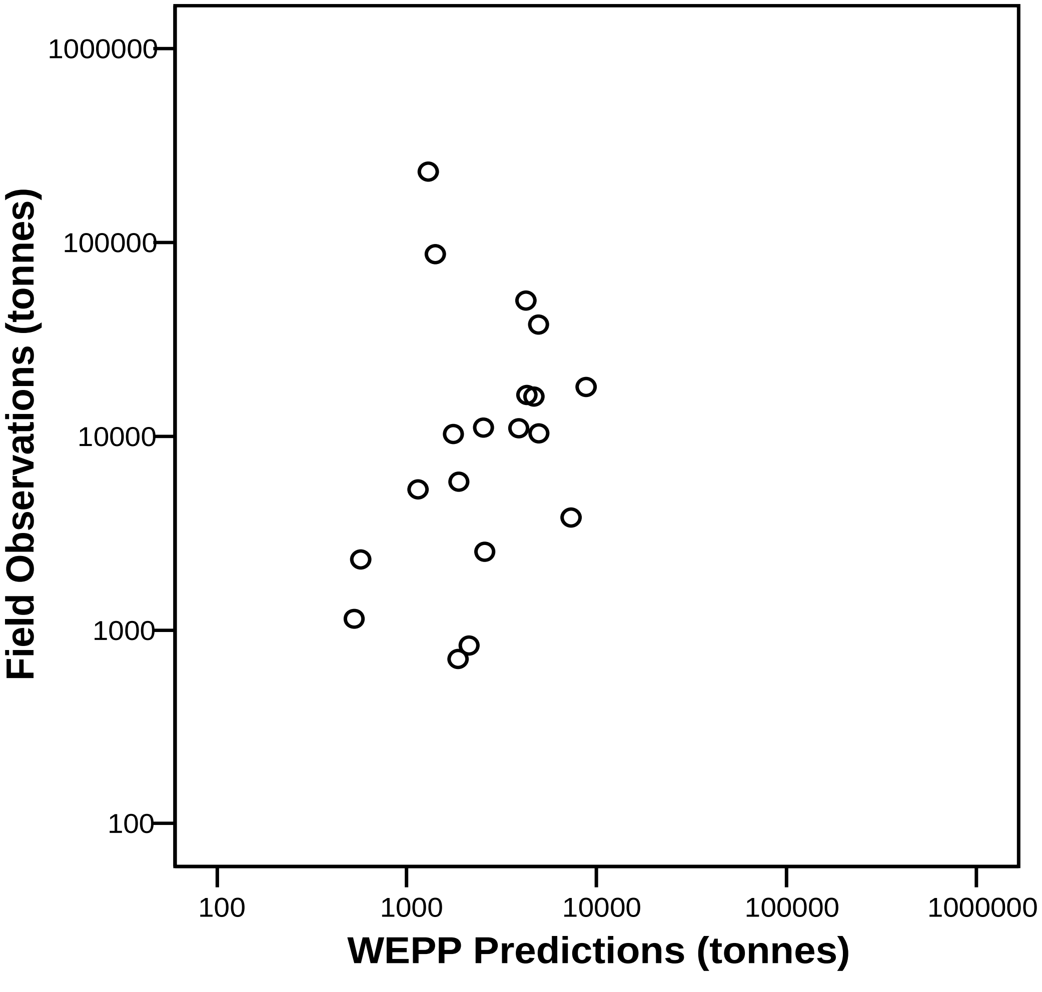


Figure 6: Field observations when compared to WEPP predictions yields R^2 = .025

4.1 Residual Analysis

With statistically insignificant relationships apparent between observed and predicted values, the next step was attempting to correlate residuals against other quantifiable variables that may not have taken into account by the WEPP model. First, residuals for each reservoir in the sample were calculated:

$$\text{Residuals} = \text{WEPP Predictions} - \text{Field Observations} \quad (15)$$

These values simply reflect the variation between values as predicted by WEPP and field measurements.

Three variables logically related to sediment production and delivery were chosen to be measured: length of dirt roads within each watershed, elongation ratio of each watershed, and area of each watershed. The scale at which WEPP modeling took place forced individual dirt road features to be omitted from the watershed simulations. These roads were observed in the field to be constructed along section lines, often crossing ephemeral channels. In these occurrences, culverts were rarely implemented, and field observations along with personal contact with the grader operator for Roger Mills County confirmed sections of these roads typically wash out with each heavy rain, producing large amounts of sediment in the watersheds. Evidence of this is also visible on aerial photographs in this instance where a section line road crosses Turkey Creek just downstream from dam number 39 (Figure 7). Impounded water is clearly visible, as well as downstream previously washed-out sediment from the section line road. Watershed elongation and watershed size are important morphometric characteristics of watersheds that can increase peak flows and affect sediment delivery to the reservoir. There are several ways to measure watershed elongation, and the objective "elongation ratio" was chosen for this study as proposed by Schumm (1959). To calculate elongation ratio, measurements are required of length and area of each watershed. The elongation ratio takes into account the maximum length of a watershed from outlet to farthest point along the drainage divide and the diameter of a circle with area equal to that of the watershed. Therefore, a perfectly round watershed would yield an elongation ratio of 1.0, while progressively more elongated basins will yield ratios approaching 0. Watershed size is simply the area of the watershed and can affect sediment delivery to reservoirs by

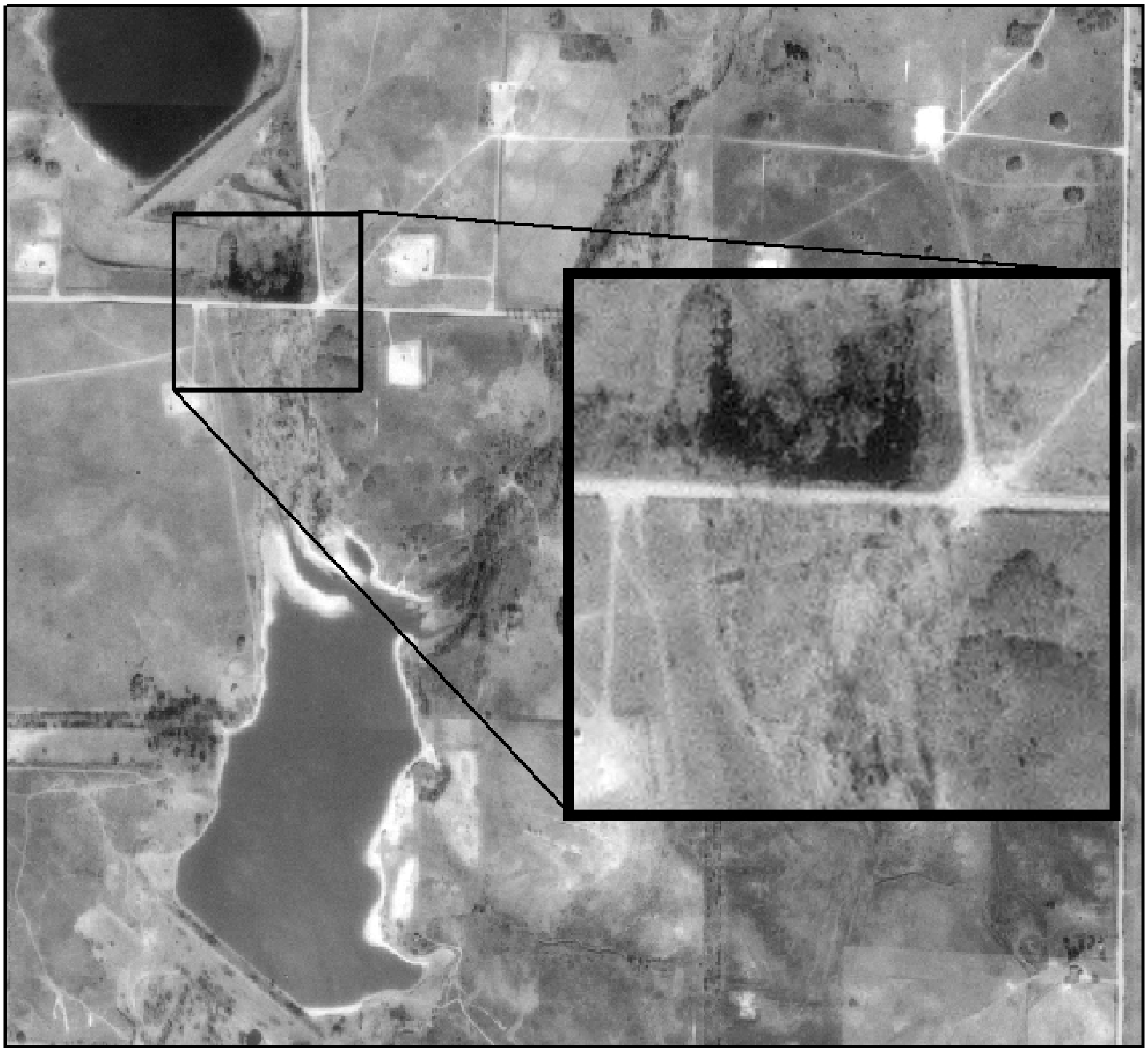


Figure 7. Section-line road crossing Turkey Creek downstream from dam #39

creating more locations for produced sediment to be stored en route to the reservoir, such as point bars and floodplains.

Measurements of watershed size were greatly accelerated by performing analysis in ArcGIS using polygon boundaries as created by Spatial Analyst. Watershed size was likewise important in calculating the elongation ratio for each watershed in the sample.

To measure length of dirt roads in watershed, a combined technique was implemented to measure section line roads separately from field roads. Roger Mills County section line road data was acquired from http://www.geo.ou.edu/ and imported into an ArcGIS map, along with watershed boundaries created by Spatial Analyst. The map was visually inspected to be certain this data was complete, and contained only section line roads. First, the section line road data was intersected with the watershed boundaries data using the ArcGIS Geoprocessing tool, incorporating the section line road data as its input file, and watershed boundaries as an overlay file. This operation yielded a dataset of line features representing section line roads and sharing attributes of both the watershed boundary it is contained in and the section line roads. The length of each of these road features was calculated and added to the dataset by first adding a new numeric field to the attribute table, and then calculating field values using the following VBScript code:

```
Dim dblLength as Double
Dim pCurve as ICurve
Set pCurve = [shape]
dblLength = pCurve.Length
```

Where *dblLength* is the length of each road feature, and is used to assign a value to each record in the field. The attributes of the data are then queried in Microsoft Access using the following Structured Query Language (SQL) statement, where underlines have been included as part of the original expression:

```
SELECT wtrshd_Rds.Dam_Num,
   Sum(wtrshd_Rds.Shape_Length) AS
   SumOfShape_Length
FROM wtrshd_Rds
GROUP BY wtrshd_Rds.Dam_Num;
```

Which groups the section line roads features by their watershed boundary attribute, and displays the sum of length of section line roads per watershed.

To calculate length of field roads per watershed, a map wheel and USGS 1:24000 quadrangles were used. Boundaries had previously been traced on these maps for each watershed when measuring and inputting hillslopes and channels into the WEPP model. Using the map wheel, length was measured and then multiplied to correct scale. No section line roads were measured using this technique. Roads symbolized by either double solid lines not residing on section lines, double dashed lines, and single dashed lines were measured. These roads represent field roads, ranch roads, lease roads, and private driveways. In the field, the construction of these roads was observed to vary tremendously. Paved lanes, gravel roads, caleche roads, dirt roads, tire ruts, and impressions in pasture grasses were all common observations. Length of field roads was totaled for watersheds included in the analysis and added to length of section line roads, yielding total length of dirt roads in each watershed.

Next was to measure area and length of each watershed for calculating the elongation ratio for each watershed. Measurement of length from outlet to furthest point along drainage divide was made using an ArcGIS measurement tool. Watershed boundaries as created by Spatial Analyst were determined to be more consistently accurate than those traced by hand. Each watershed boundary was measured from its "pour point" GPS point at each dam to the farthest location along drainage divide.

To calculate area of each watershed, first, a numeric field was added to the attribute table of the watershed shapefile. Next, the area of each watershed polygon was calculated by using the following VBScript code:

```
Dim dblArea as Double
Dim pArea as IArea
Set pArea = [shape]
dblArea = pArea.Area
```

Where *dblArea* is the area of the polygon feature, and is used to assign a value to each record in the field.

The elongation ratio then required we calculate the diameter of a circle with area equal to that of the watershed:

$$D_c = \frac{(4A)}{\pi} \tag{16}$$

Where A is the area of the watershed in square meters, and D_c is the diameter of a circle with like area in meters. Once measurements of length and diameter of a circle with like area were calculated, the elongation ration was calculated:

$$R_e = \frac{D_c}{L_b} \tag{17}$$

Where R_e is a unitless elongation ratio, D_c is the diameter of a circle with equal area to the watershed, and L_b is the length of the basin from outlet to farthest point along the drainage divide.

Using SPSS 12.0 for Windows, variables representing Watershed Size, Watershed Elongation, Length of Section Line Roads, Length of All Roads, and Residuals were analyzed for normality and collinear relationships, and regression analysis was performed.

Normality of the data was tested using Shapiro-Wilk Test (W). The Shapiro-Wilk test is favorable when sample sizes are small (n < 30) (Rogerson, 2001). To determine assumptions of normality with 95% certainty ($W_{.05}$), critical value of the test when n = 19 is .901 (Table 3).

Table 3: Shapiro-Wilk Test of Normality

	Statistic	df
Wastershed_Size	.735	
Watershed_Elongation	.954	
Length_Section_Line_Roads	.793	
Residuals	.503	
Length_Of_All_Roads	.766	

$W_{.05}$ = .901

In the case of Watershed Elongation (W = .954), we accept the null hypothesis and conclude that there is not enough evidence to reject the assumption of normality. Watershed Size (W = .735), Length Section Line Roads (W = .793), Residuals (W = .503), and Length All Roads (W = .766) all provide sufficient evidence to reject the null hypothesis and conclude the data is non-normally distributed. This is likely due to heteroskedasticity in the data and small sample size. Because of the small sample size and asymmetric distribution, it is necessary to use Spearman's rank correlation coefficient (r_s) in situations where only ranked data are available or where assumptions of normality are not satisfied (Rogerson, 2001). Watershed Elongation was included in Spearman's correlation analysis due to the fact that although normally distributed, it remains a small (n < 30) dataset. To explore the possibility of using multiple regression to explain residuals, independent variables were analyzed for collinearity. Spearman's nonparametric correlations indicate that Watershed Size (r_s = -.688 with p = .001), Length of Section Line Roads ($r_s = -.646$ with $p = .003$), and Length of All Roads (-.668 with p = .002) all display strong correlation to the residual values for each watershed (Table 4).

Table 4: Spearman's Nonparametric Correlations

		Wastershed Size	Watershed Elongation	Length Sec. Ln Rd km	Residual	Length_Of _All Rd km
Wastershed_Size	Correlation Coefficient	1.000	.017	.921	-.688	.974
	Significance:	.	.946	.000	.001	.000
	N	19	19	19	19	19
Watershed_ Elongation	Correlation Coefficient	.017	1.000	-.135	-.158	-.026
	Significance:	.946	.	.583	.517	.917
	N	19	19	19	19	19
Length_Section_ Line_Roads	Correlation Coefficient	.921	-.135	1.000	-.646	.963
	Significance:	.000	.583	.	.003	.000
	N	19	19	19	19	19
Residuals	Correlation Coefficient	-.688	-.158	-.646	1.000	-.668
	Significance:	.001	.517	.003	.	.002
	N	19	19	19	19	19
Length_All_Roads	Correlation Coefficient	.974	-.026	.963	-.668	1.000
	Significance:	.000	.917	.000	.002	.
	N	19	19	19	19	19

Negative correlations are due to residuals being negative; therefore as watersheds increase in area or contain progressively greater length of section line roads or progressively greater length of total roads; WEPP further underestimates sediment in reservoir. Spearman's correlations also indicated that each of these variables is strongly correlated with the other two. To avoid problems of multicolinearity in further regression analysis, these variables cannot be used in the same model. The collinear relation between these variables is logical, as larger area watersheds will contain progressively more sections, therefore progressively more section line roads, with proportionately more field roads in addition to those section line roads. Length of Section Line Roads and Length of All Roads were chosen for further regression analysis. This was due to the fact that presence of section line roads were completely omitted from the model. Differences in sediment transport between watersheds of different sizes are considered in the WEPP model, which calculates production from hillslopes and transport down their corresponding channels. Watershed Size is strongly correlated due its tendency to contain more section line roads, which were omitted from the model. Watershed Size itself is probably not a causal factor of underestimation in the WEPP model.

To perform linear regression analysis, Length of Section Line Roads and Length of All Roads, and Watershed Elongation were used as the independent variable, and residual values were used as dependent variable in a regression model using the stepwise algorithm. Watershed Elongation was included due to the possibility that a variable exhibiting poor linear correlation can often exhibit significance in strengthening a regression model. The resulting model included Length of Section Line Roads, and omitted Length of All Roads and Watershed Elongation in its first iteration, and ended. Although Length of All Roads displayed a stronger linear relationship when correlated to the dependant variable Residuals, it exhibits a weaker non-linear relationship than Length of Section Line Roads, and was determined by the stepwise model to be collinear and omitted from the model. Watershed Elongation continued to display a statistically insignificant relationship to Residuals. The resulting model strength $R^2 = .775$, with an adjusted $R^2 = .762$, and significance of $p < .001$ (Figure 9). The final equation to explain 77.5% of variation between field measurements and WEPP predictions is:

$$\textit{Residuals} = -2590.67(\textit{Length of Section Line Roads}) + 22499.88 \tag{18}$$

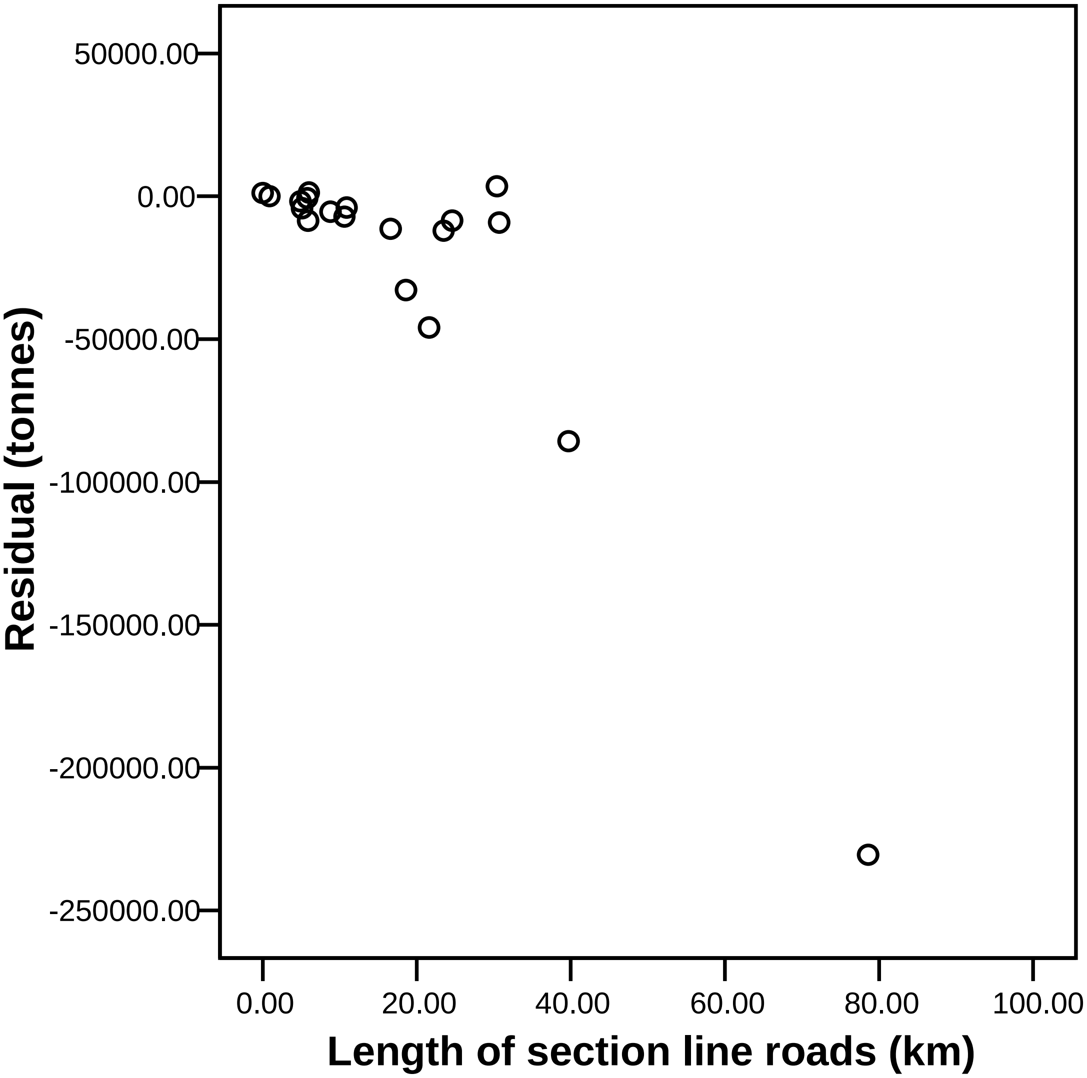


Figure 8- Length of section line roads when compared to Residuals yields R^2 = .775

Liu et al. (1999) evaluated WEPP for 15 small watersheds (.34 to 5.14 ha) with no calibrations and found the model gave reasonable predictions for both total and event runoff and sediment yield. Watersheds sampled were considerably smaller than those in this study. This is based on the recommendation of Nearing and Nicks (1997), who suggest that WEPP tends to overpredict erosion on hillslopes longer than 100m. No problems in this study were encountered with overprediction of sediment with all hillslopes in excess of 100m, possibly due to omission of dirt roads from the model.

Baffaut et al. (1997) observed a decrease of the sediment load as the descretization level increased, possibly due to decrease of shorter hillslope contribution because of a decrease in rill erosion in watersheds about 1ha in size.

Selection of the WEPP model in this application was influenced by comparative studies performed by Bhuyan et al. (1997) who found WEPP to be a better solution than the EPIC and ANSWERS model. This supposition is not supported nor refuted by the results of this project. Although initially the results produced by WEPP were negative, no other models were applied. Renschler and Harbor (2002) also influenced the choice to use WEPP based on its acceptance by the USDA as a standard model. Their results incorporate commonly available data analyzed at different levels of discretization, however without field measurements for comparison. Coarser resolution data was found to produce substantially higher erosion rates than more detailed data, in agreement with Nearing and Nicks (1997). The coarse resolution data incorporated in this study showed no signs of overestimating soil loss. It is possible that WEPP is in fact overpredicting soil loss from hillslopes, and the omission of dirt roads is more significant than this study has indicated.

Calibration of the WEPP model is an important issue to this study. The goal was to determine the effectiveness of WEPP in modeling small agricultural watersheds with no calibration. Savabi et al. (1995) experimented with non-calibrated simulations using different levels of detail. Greater levels of detail produced more accurate results, but much like this study, information was not always available. Yu and Roswell (2001) found that a set of equations for estimating effective saturated hydraulic conductivity and soil erodibility improved results within the study area. This is in contrast to Liu et al.

(1997), who performed no calibration on soil parameters. No adjustments were made to soil parameters in this study.

Rainfall simulations in Ecuador, Costa Rica, and the United States by Carol Harden (1992) have shown dirt roads to be extremely active components for runoff production in tropical and temperate watersheds. Harden argues that their significance makes it necessary to include them in hydrologic models, where they are often overlooked, confirming the findings of this study. Ziegler et al. (2000) also found dirt roads to produce disproportionate amounts of sediment in watershed. Their research in Pang Khum Experimantal Watershed in northern Thailand indicates less than one percent of surface area produced over 80 percent of sediment. This phenomenon and its likeliness to be omitted from basin-level studies clearly exists all over the world.

The sediment characterization studies by Bennet and Cooper (2001) and Dunbar et al. (2001) in select reservoirs in Oklahoma indicated the correct way to estimate impounded sediment. Seismic survey transects of these reservoirs yield wedge-shaped profiles of sediment, thickest at the dam and tapering upstream. None of these reservoirs are included in the sample analyzed in this study; however, the similarities in size and construction, as well as geographic location make them comparable and usable for understanding sediment deposition within reservoirs.

The goal of this study was not to measure trapping efficiency of each flood control dam. However, this calculation was simple to achieve, and WEPP impoundment simulations were found to produce reasonably low trapping efficiencies, concurrent with the flood control purpose of the structures as suggested by Verstraeten et al. (2000). This result boosts confidence in the WEPP model and suggests the model may produce better results with greater detailed data. No trapping efficiency field measurements were acquired for comparison, nor do any currently exist.

Tortonelli (2002) has shown in statistical summaries that flood control dams in the Upper Washita Watershed have slowed the discharge of the Washita River and drastically reduced peak flows since 1961. Drastic reductions can be accounted for by the numerous dams observed to be dry. Most dams in Texas and a few in Oklahoma are not known to have ever discharged water. Large portions of the watershed have effectively been isolated, lessening the drainage area and morphometric characteristics to a degree that is yet undetermined. Changes in the channel cross-section including narrowing and entrenchment have become apparent since Bergman and Sullivan (1963) investigated changes along Sandstone Creek. This creek was not in the study area, but is in close geographic proximity and exhibits changes that can be expected in other creeks and tributaries in the area, as well as the Washita River itself.

4.2 Investigation of Dam Placement

The multitude of dams devoid of water and sediment in this watershed raises questions regarding the necessities of dam size and number. Dams included in the sample set were investigated for statistically significant relationships between sediment yield of watershed, dam capacity, and percent filled to capacity (Table 5).

Table 5. Spearmans Nonparametric Correlations

		Percent Full	Sediment Yield (tonnes/km^2)	Max Dam Capacity (m^3)
Percent Full	Correlation Coefficient	1.000	.918	.152
	Significance	.	.000	.535
	N	19	19	19
Sediment Yield (tones/km^2)	Correlation Coefficient	.918	1.000	.154
	Significance	.000	.	.530
	N	19	19	19
Max Dam Capacity (m^3)	Correlation Coefficient	.152	.154	1.000
	Significance	.535	.530	.
	N	19	19	19

The correlation coefficient between Percent Full and Max Dam Capacity is .918, which is an expected relationship, meaning that more rapidly filling dams impound more erosive watersheds. However, on the average these dams are 6% full, with even the best placed being only 54% full. The end of their projected 50-year sediment storage lifetime is approaching; however, of those with measurable sediment, no dams are in danger of being filled.

The correlation between Max Dam Capacity and Sediment Yield is .154, which means the larger capacity dams are not always placed in the most erosive watersheds. Figure 9 shows that the dams with the greatest capacity are not built in the most erosive watersheds. The horizontal trend shows dams of similar capacity being built in watersheds which greatly vary in sediment yield. Figure 10 likewise shows that larger dams are not always placed in more erosive watersheds. Sediment yield and dam size are aggregated by quantile to show variance of dam construction in similarly erosive watersheds.

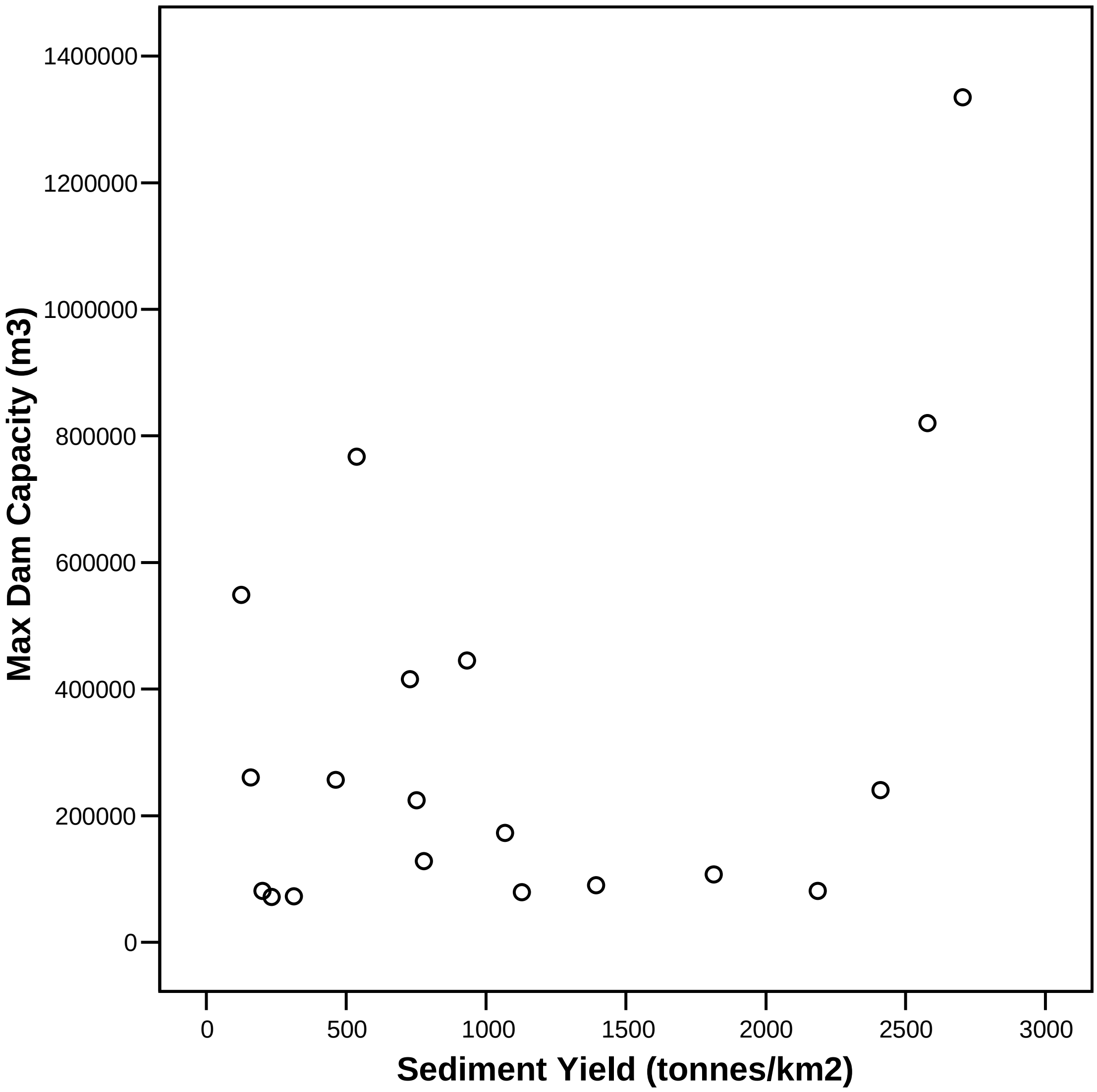


Figure 9. Sediment Yield and Max Dam Capacity

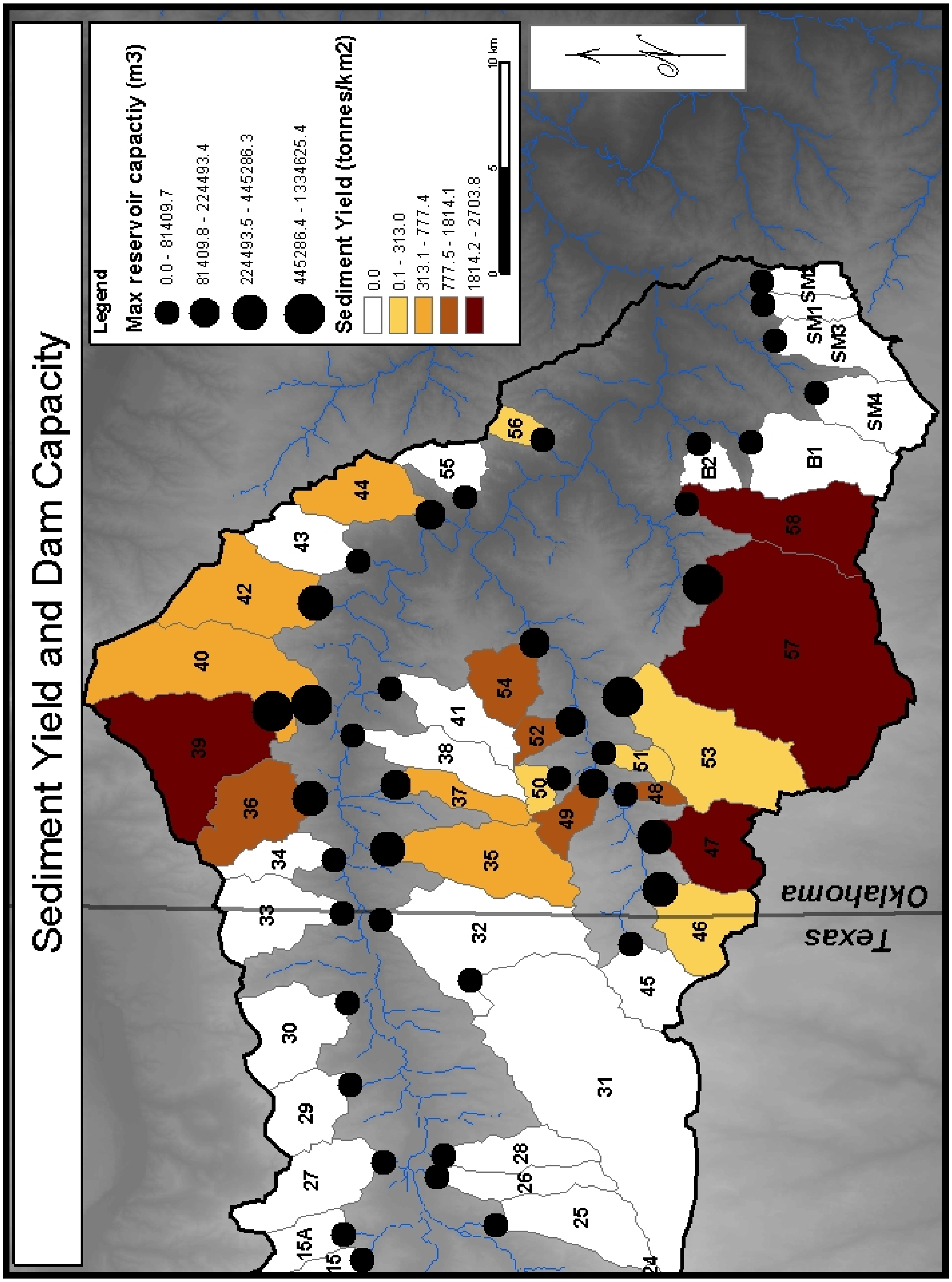


Figure 10. Dam capacity and sediment yield aggregated by quantile

5. Conclusions

In this study, field data were collected, watersheds were delineated from DEM data, and the WEPP model was applied to a watershed-level problem, with data generalized from several sources. Flood control dams in Texas were observed to be more devoid of water and sediment than flood control dams in Oklahoma. Ranching is the primary land use in Hemphill County, Texas (USDA-NRCS, 1974). Additionally, most of Wheeler County, Texas, is rangeland (USDA-NRCS, 1974). Ranch management personnel indicated that wheat is rarely a profitable crop in this area, due to out-production by Kansas, and range has been predominant since flood control dam construction. In Roger Mills County, wheat, corn, sorghum, and other crops have been principal cash crops in the past, but the trend in agriculture has progressed toward livestock farming. In 1959, the sale of livestock and livestock products amounted to 62% or the total agricultural sales (USDA-NRCS, 1963). Field observations indicated that range is by far the predominant land use in this watershed. Differences in land use may account for varying amounts of soil loss on opposite side of a political boundary, within the same watershed. It does not however, account for the current presence of water in most reservoirs in Oklahoma, and lack thereof in most reservoirs in Texas, since both states are display homogenous land use at the present. Other factors may include relief, soil texture, and slope gradient. No small watersheds in Texas were modeled, making comparison difficult. Too many dams were constructed downstream from areas that do not require flood control measures. Dams built downstream from erosive watersheds average only 6% full and are either extremely oversized or have severely underestimated projected lifetimes.

Using ArcGIS 8.x with Spatial Analyst to delineate watershed boundaries upstream from each flood control dam proved to be an effective approach for this application and was used for both analysis and display purposes. However, the correct threshold for drainage network delineations was uncertain. A threshold of 500 was accurate enough to use for display purposes and aiding in locating channels on aerial photographs.

The WEPP model severely underestimates reservoir sedimentation in most cases. Further investigation revealed that the omission of section line roads from hillslopes explains 77.5% of residuals between predicted and observed sediment production. This was determined by quickly measuring the length of section line roads per watershed, rather than adding each one to the model with a high degree of detail.

Although the goal of this study was not derivation or sensitivity analysis of the WEPP model, it is clear that WEPP is sensitive to certain generalizations. Ideally, data used for WEPP input should quite detailed, utilizing complex input parameters to their fullest extent. However, this was not feasible for the geographically distributed sample that was desired. Past validation and sensitivity analysis studies on the WEPP model suggest that highly detailed data is imperative for accurate results. Generalizations on hillslopes included land use, soil type, and slope, any of which may possibly account for discrepancies in the data. Generalizations in channel inputs, including channel cross-sections and channel roughness, as well as soil parameters, impoundment inputs including fluid dynamics at the riser were beyond the scope of this study, and typically left as default parameters in the WEPP model. Any of these may alleviate portions of the remaining discrepancies in predicted results.

Overall, WEPP was shown to produce good results in these watersheds when accounting for road features omitted during generalization. Rather than representing roads as hillslope elements at a detailed level, the features themselves were generalized and statistically incorporated into the model. The model was improved to a satisfactory level using this very feasible and efficient approach. Further research in this topic may involve the application of the WEPP model to select hillslopes within the watershed, modeled in great detail to determine if additional effort on defining the specifics of each hillslope will yield an appreciably better model than the generalized approach taken in this study.

Literature Cited:

Baffaut, C. Nearing, M. A., Ascough, J. C. II, Liu, B.1997. “The WEPP watershed model: II. Sensitivity analysis and discretization on small watersheds” *Transactions of the ASAE* 40(4) 935 - 942.

Bennet, S.J. and Cooper, C.M. 2001. “Characterizing the Sediment Impounded by USDA-NRCS Flood Control Dams, Oklahoma” *NRCS Research Report No. 20*, 135 pp.

Bergman, D.L. and Sullivan, C.W. 1963. “Channel Change on Sandstone Creek Near Cheyenne, Oklahoma” USGS *Professional Paper* 478-C, C145-C148.

Bhuyan, S.J., Kalita, P.K., Janssen, K.A., Barnes, P.L. 2002. “Soil loss predictions with three erosion simulation models” *Environmental Modelling and & Software* 17, 137 - 146.

Dunbar, J.A., Allen, P.M., Bennett, S.J. 2001. “Acoustic Imaging of Sediment Impounded by a USDA-NRCS Flood Control Dam, Oklahoma” *NRCS Research Report* No. 22. 54 pages.

Gallegos, A. J. 1999. “Using the Watershed Erosion Predication Project (WEPP) model as a tool to making decisions on public lands” *Abstracts with Programs-Geological Society of America.* 31(7) 435.

Harden, C. P. 1992. “Incorporating roads and footpaths in watershed-scale hydrologic and soil erosion models” *Physical Geography* 13(4) 368 - 385.

Johnson, K. S. et al. 1979. “Geology and Earth Resources of Oklahoma: An Atlas of Maps and Cross Sections” Oklahoma Geological Survey, Norman, OK.

Liu, B. Y., Nearing, M. A., Baffaut, C., Ascough, J. C. II. 1999. “The WEPP watershed model: III. Comparisons to measured data from small watersheds.” *Transactions of the ASAE* 40(4) 945-952.

Lurry, D.L. and Tortorelli, R.L. 1995. “Estimated freshwater withdrawals in Oklahoma, 1990.” *Water Resources Investigations Report* 95-4276. USGS, Oklahoma City, OK. 2 sheets.

Nearing, M. A. and Nicks, A. D. 1997. “Evaluation of WEPP: Hillslopes and small watersheds.” In *Global Change: Modeling Soil Erosion by Water*. Oxford, England.

Oklahoma Conservation Commission (OCC) 2001. “How a Small Flood Control Dam Works” http://www.okcc.state.ok.us/Newsletter/how_a_small_flood_control_dam_works.pdf.

Reber, J., Flora, M., Harte, J. 1999. "Washita Battlefield National Historical Site, Oklahoma: Water Resources Scoping Report" Technical Report NPS/NRWRS/NRTR-99/235. 26 pages.

Renschler J.H. and Harbor, J. 2002. "Soil erosion assessment tools from point to regional scales - the role of geomorphologists in land management research and implementation" *Geomorphology* 47, 189 - 209.

Renschler, C.S. 2004. "Modeling climate change impact on geomorphological process." Paper presented at the 100th annual meeting of the Association of American Geographers.

Risse, L. M., Nearing, M. A., Lui, B. Y. Zhang, X. C., Baffaut, C. and Laflen, J. M. 1995. "WEPP: Validation and Applications" International Erosion Control Association. Conference. Atlanta, Georgia. 471 - 478.

Rogerson, Peter A. 2001. "Statistical Methods for Geography" Sage Publications Ltd. London, England.

Savabi, M. R., Hebel, B., Flanagan, D. C., Engel, B. A. 1995. "Application of WEPP and GIS-GRASS to a small watershed in Indiana" *Journal of Soil and Water Conservation* 50(5), 477 - 483.

Schumm, S. A. 1956. "The evolution of drainage systems and slopes in badlands at Perth Amoby, New Jersey. *Geological Society of America Bulleting* (67) 597 - 646.

Soil Conservation Service. 1958. "Work Plan: Upper Washita River Watershed of the Washita River Watershed Roger Mills County, OK, and Hemphill, Wheeler, and Roberts County, TX" Soil Conservation Service, USDA-NRCS Stillwater, OK, Temple, TX.

Tortonelli, Robert L. 2002. "Statistical Summaries of Streamflow in Oklahoma through 1999" *USGS Water Resources Investigations Report* 02-4025: 390 - 393.

United States Department of Agriculture. (USDA-NRCS) 1963. Soil Survey: Rodger Mills County, Oklahoma. Series 1959 no. 9.

United States Department of Agriculture (USDA-NRCS). 1999. "Dams in Danger, People at Risk?" (Oklahoma) Reinvesting in America's Watersheds: A Special Report. 2 pages.

United States Department of Agriculture. (USDA-NRCS) 1999. "Dams in Danger, People at Risk?" (Texas) Reinvesting in America's Watersheds: A Special Report. 2 pages.

United States Department of Agriculture. (USDA-NRCS) 1974. Soil Survey: Hemphill County, Texas. Series 1974.

United States Department of Agriculture. (USDA-NRCS) 1974. Soil Survey: Wheeler County, Texas. Series 1974.

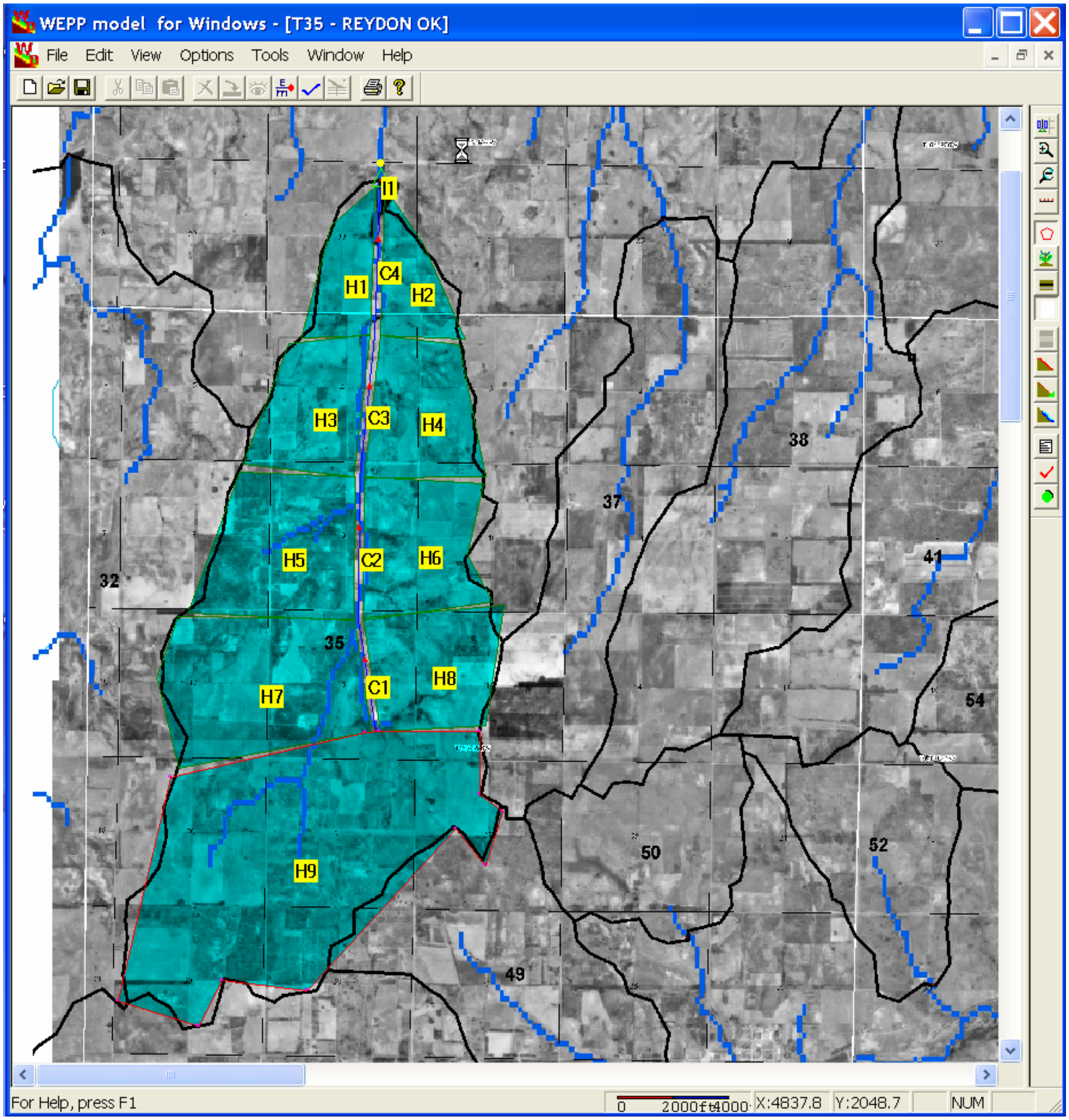
Vanoni, Vito, A. ed. 1975. “Sedimentation Engineering” The American Society of Engineers. 745 pages.

Verstraeten, Gert, and Poesen, Jean. 2000. “Estimating trap efficiency of small reservoirs and ponds: methods and implications for the assessment of sediment yield” *Progress in Physical Geography* 24(2) 219 - 251.

Yu, B. and Rosewell, C.J. 2001. “Evaluation of WEPP and soil loss prediction at Gunnedah, NSW, Australia” *Australian Journal of Remote Sensing.*

Ziegler, A. D., Sutherland, R. A., Giambelluca, T. W. (2000) “Runoff generation and sediment production on unpaved roads, footpaths, and agricultural land surfaces in northern Thailand” Earth Surface Processes and Landforms 29, 519 - 534.

6. Appendix A- WEPP watershed simulations



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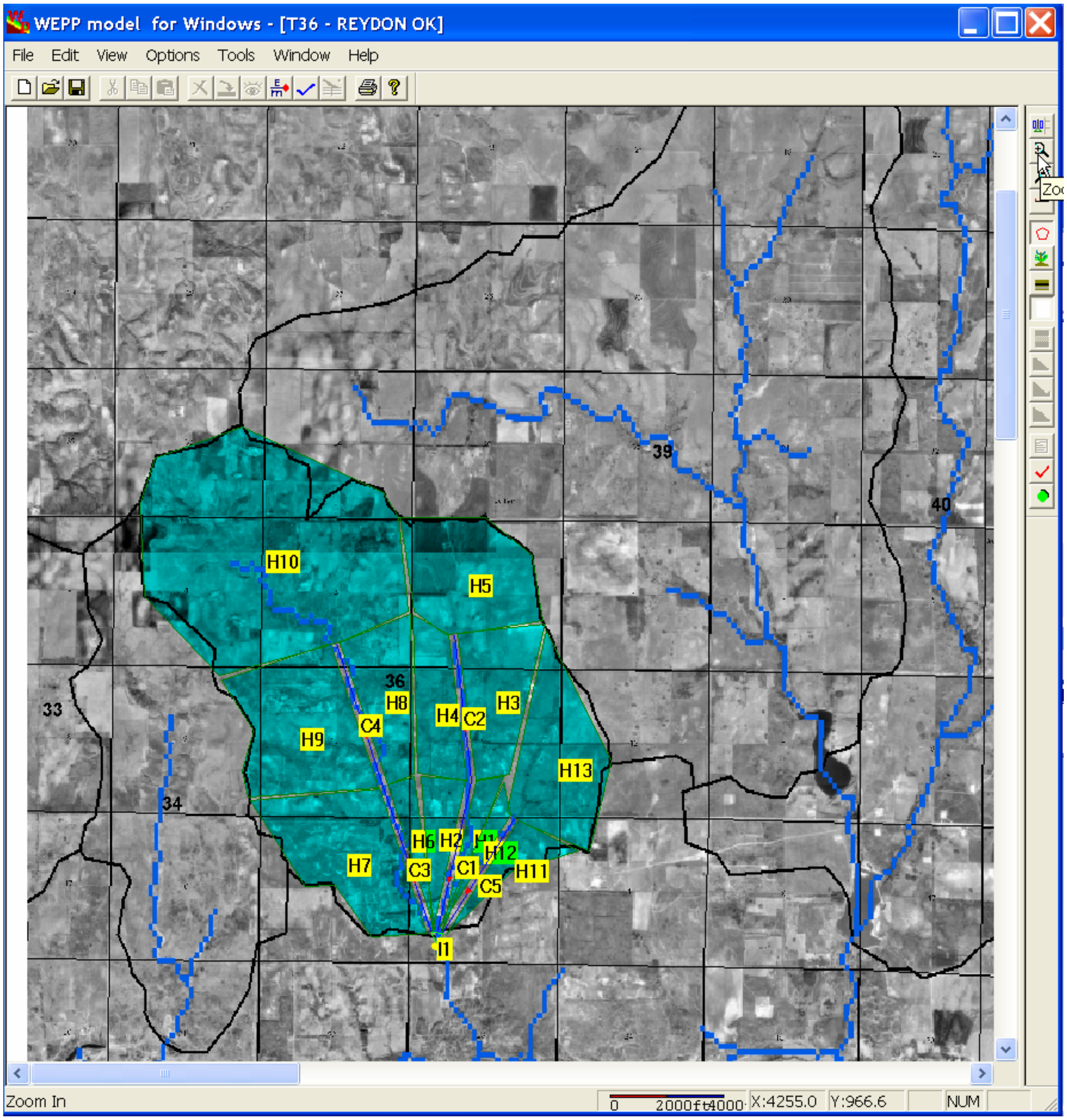

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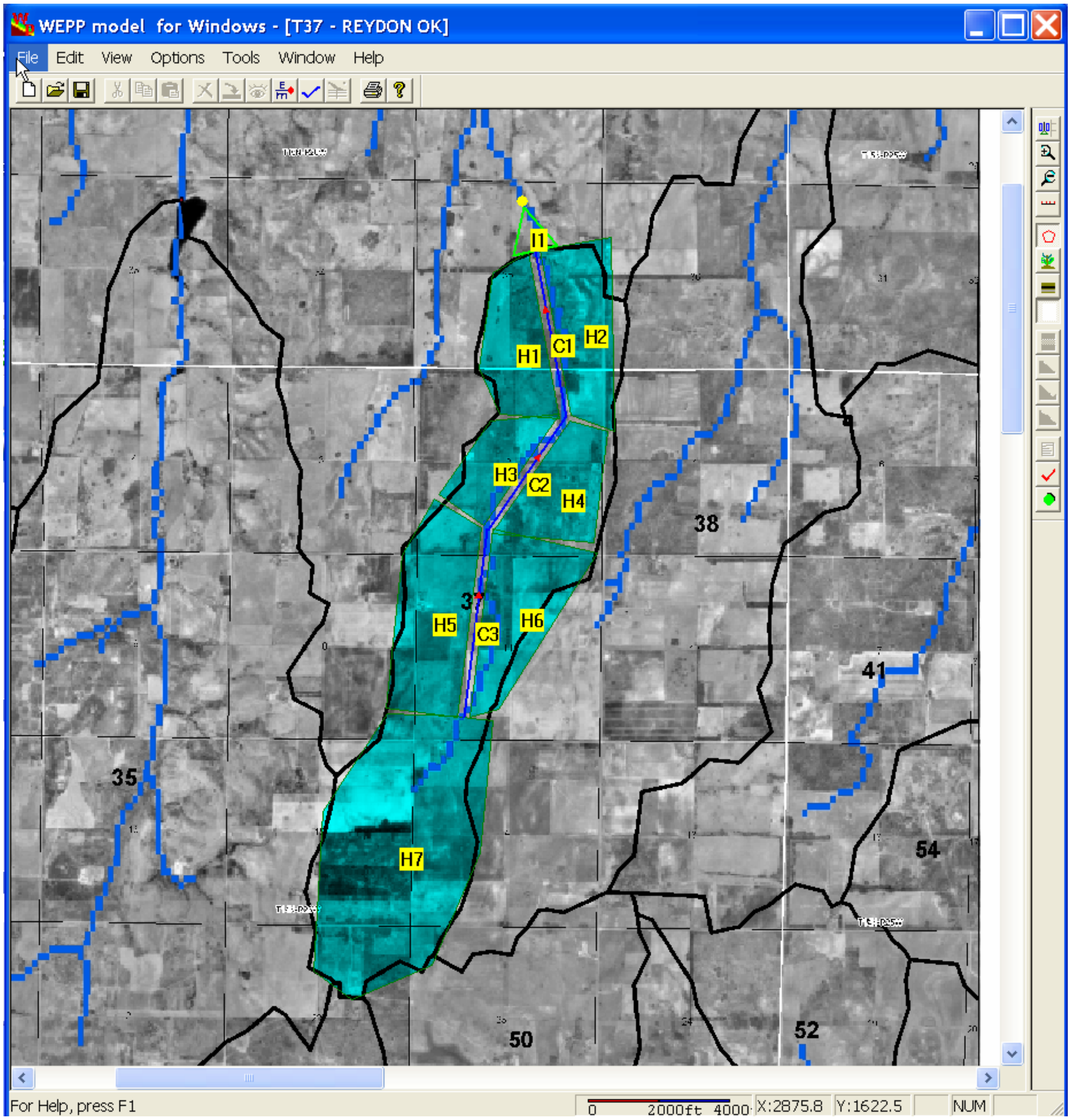

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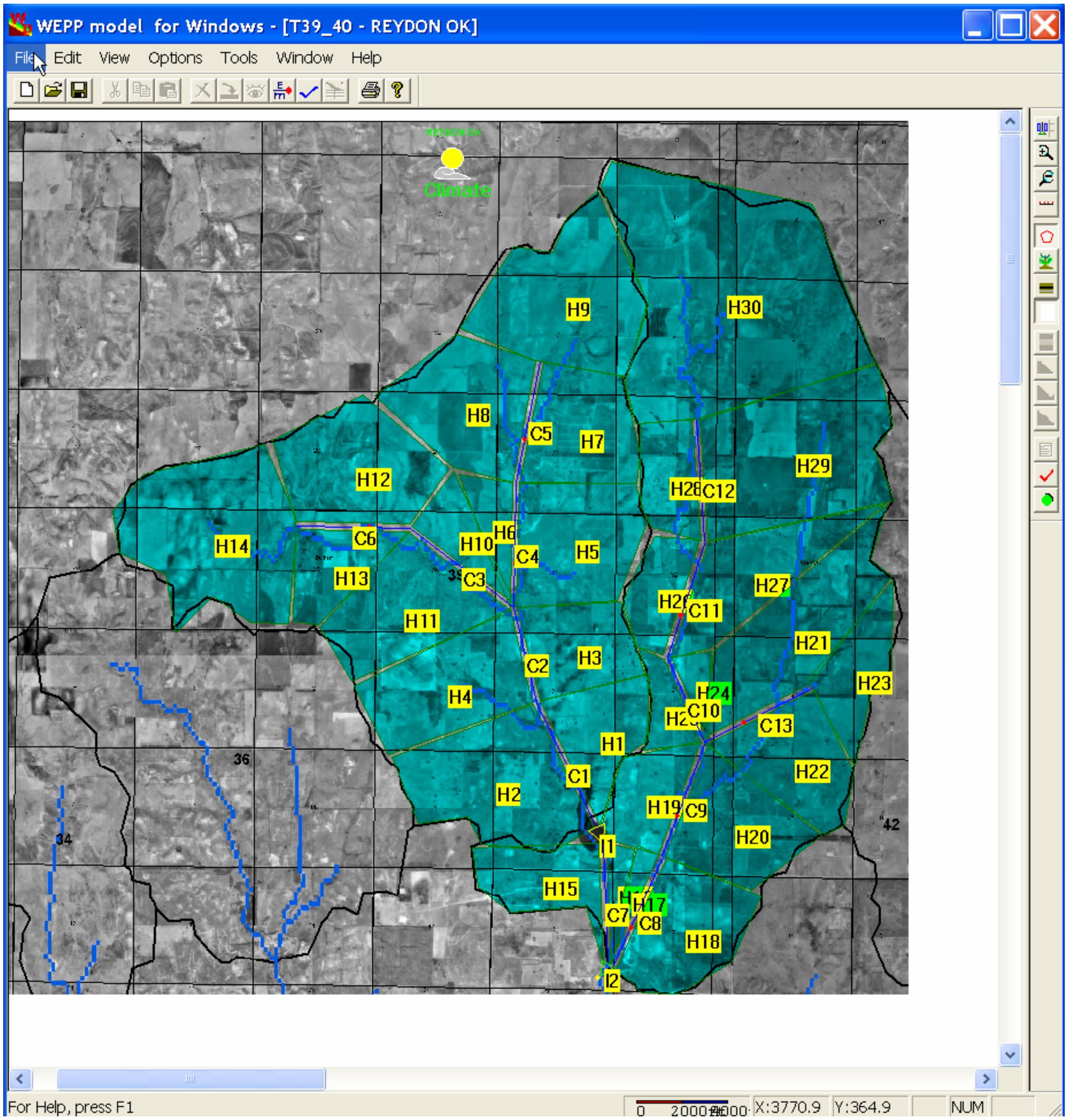

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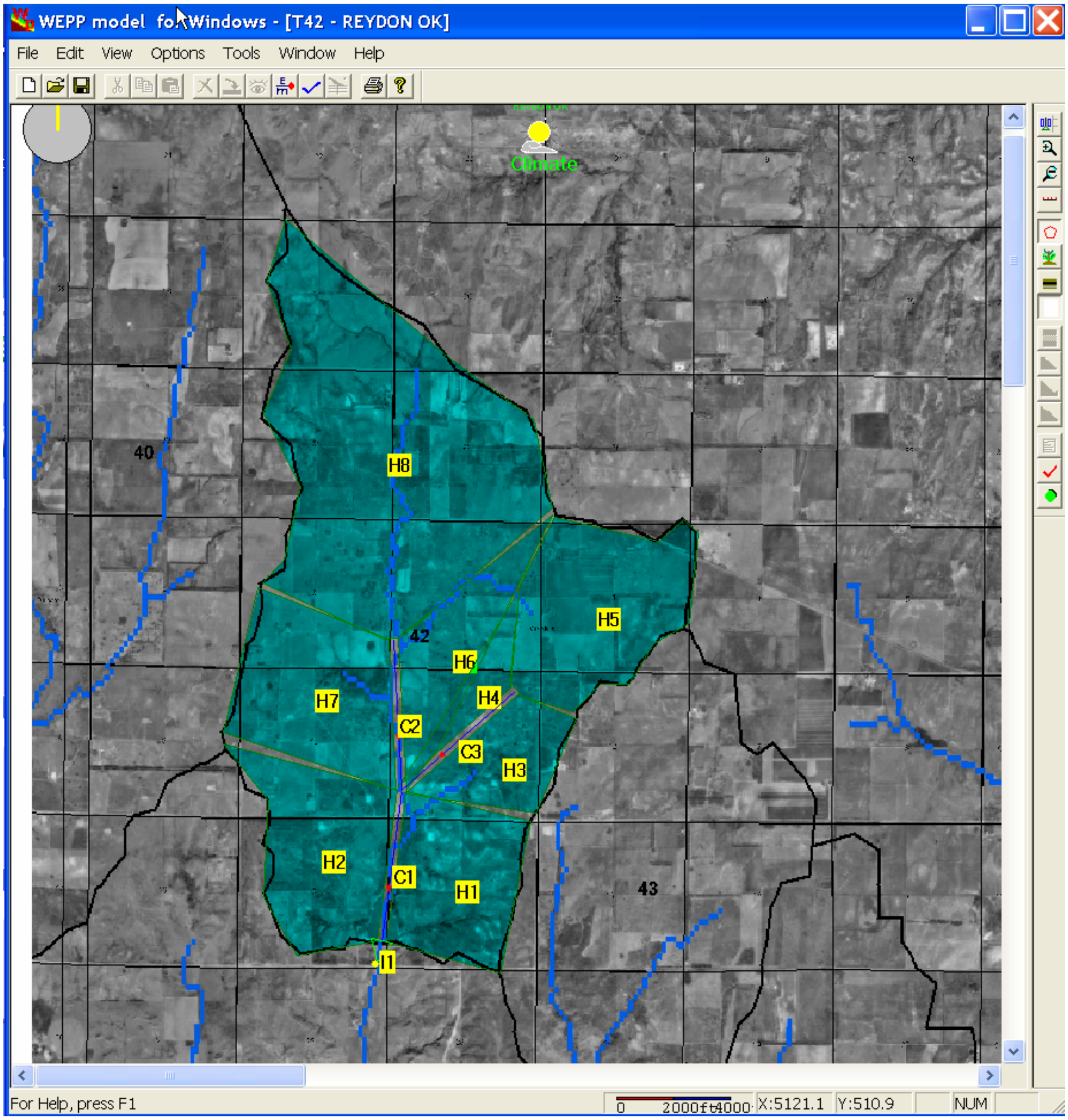

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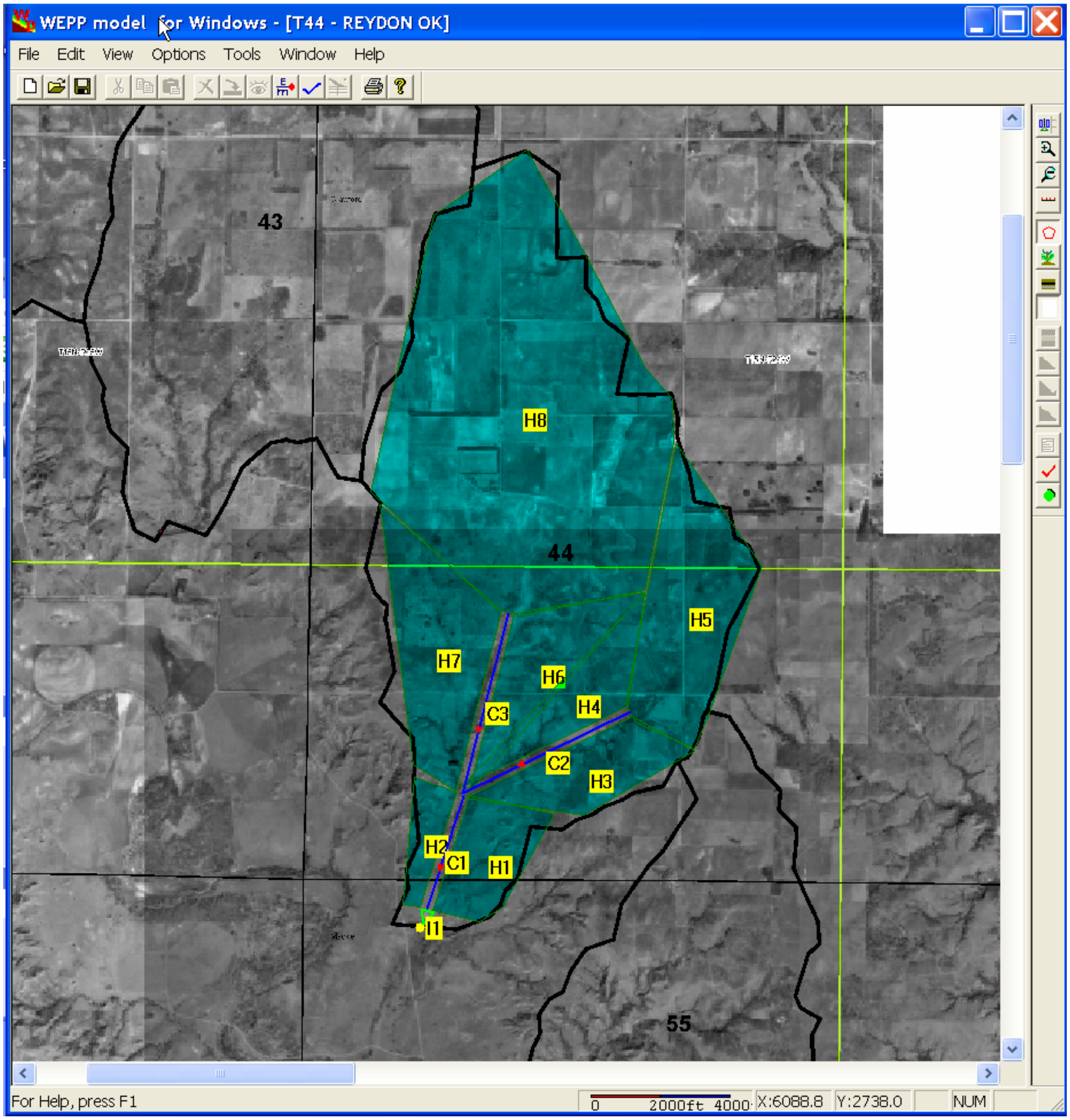

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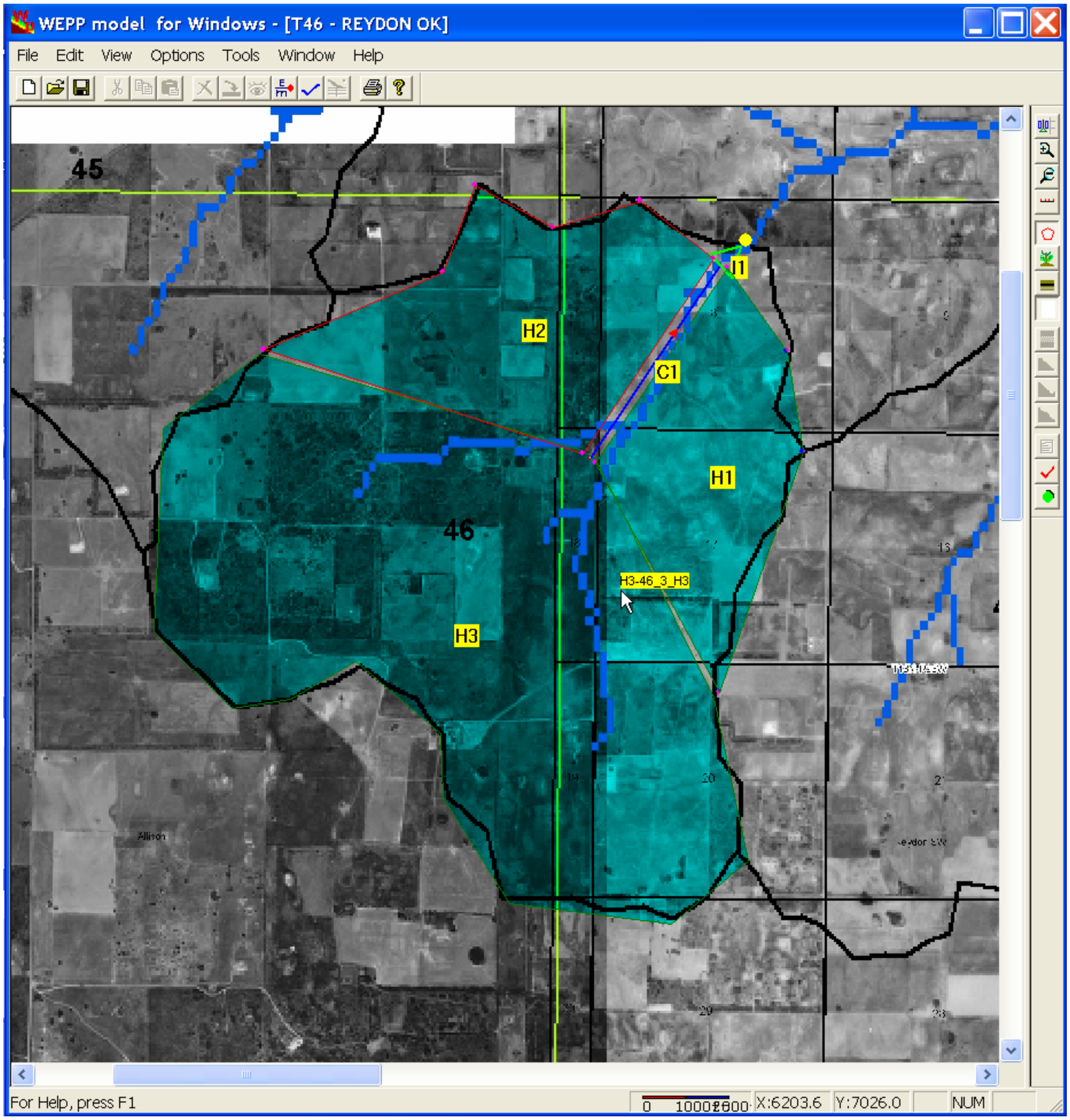

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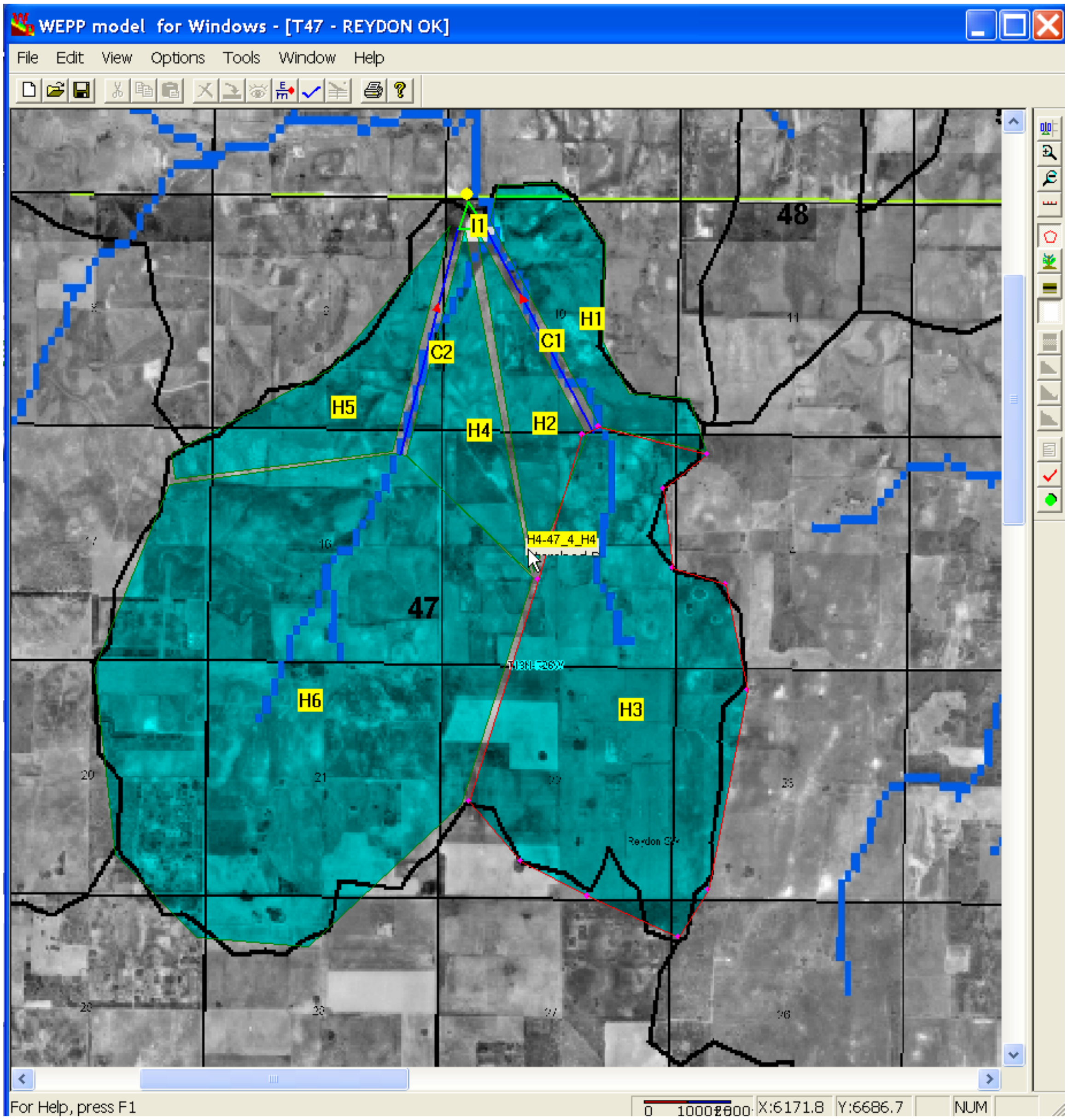

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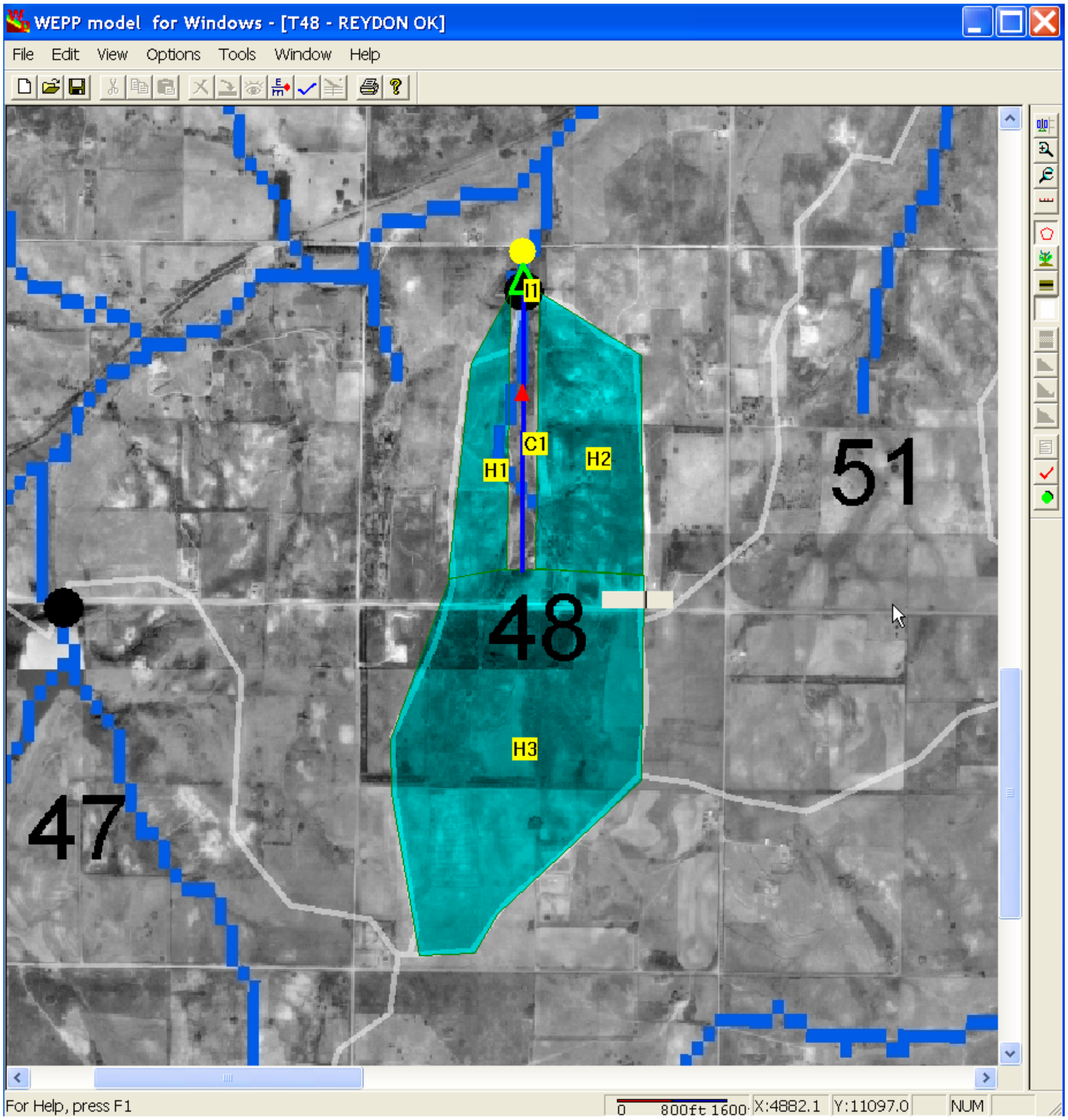

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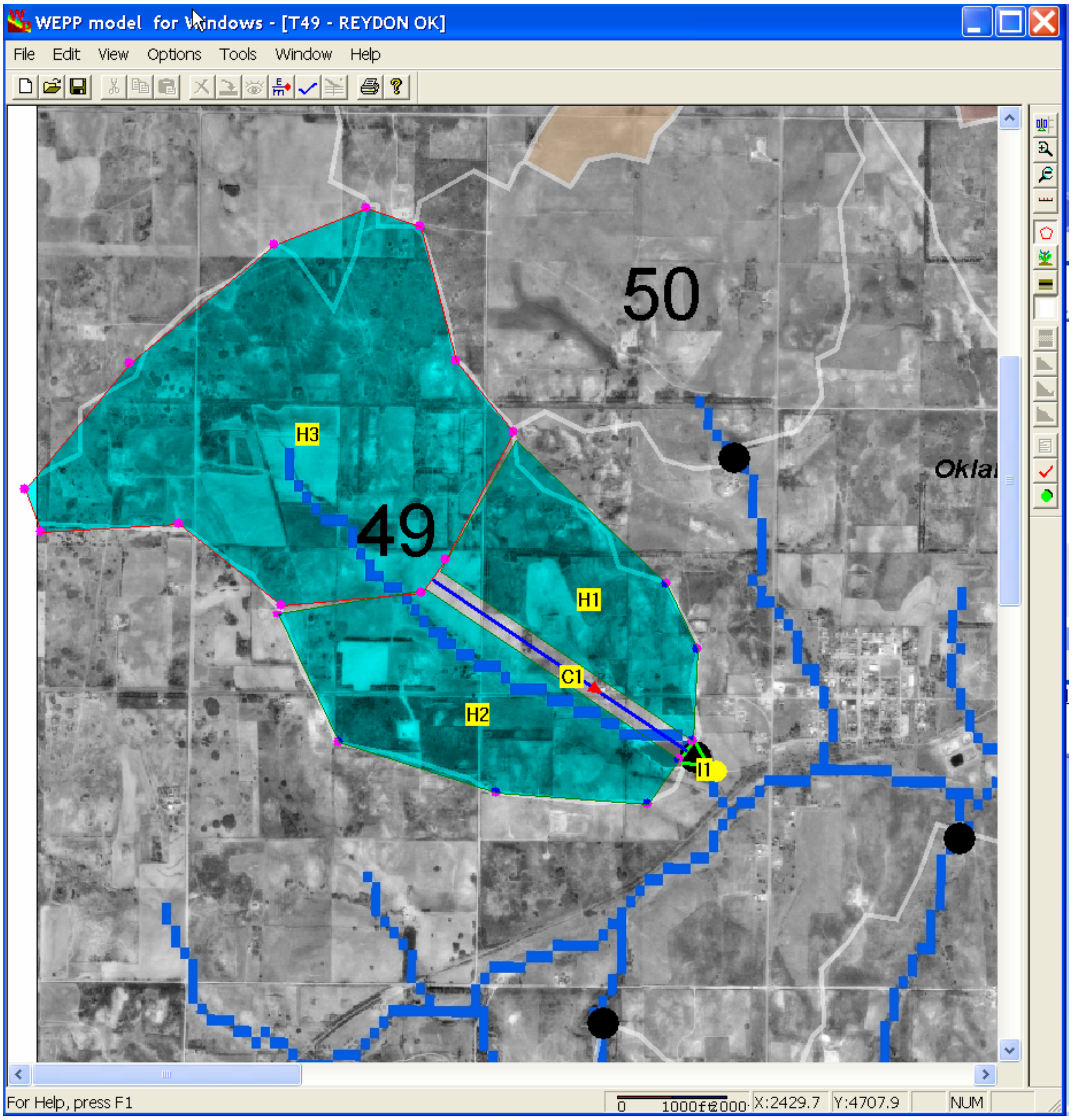

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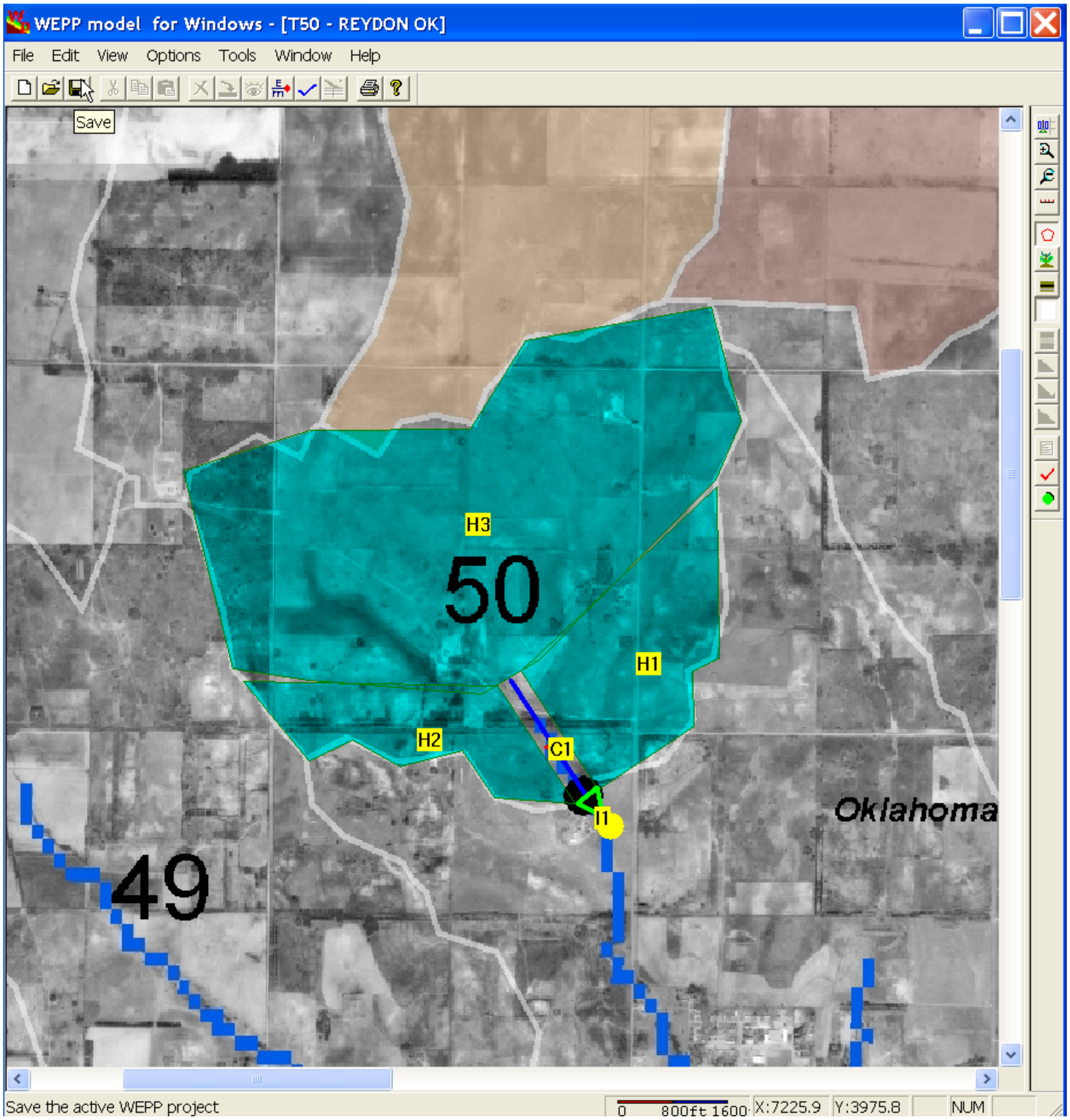

Save the active WEPP project

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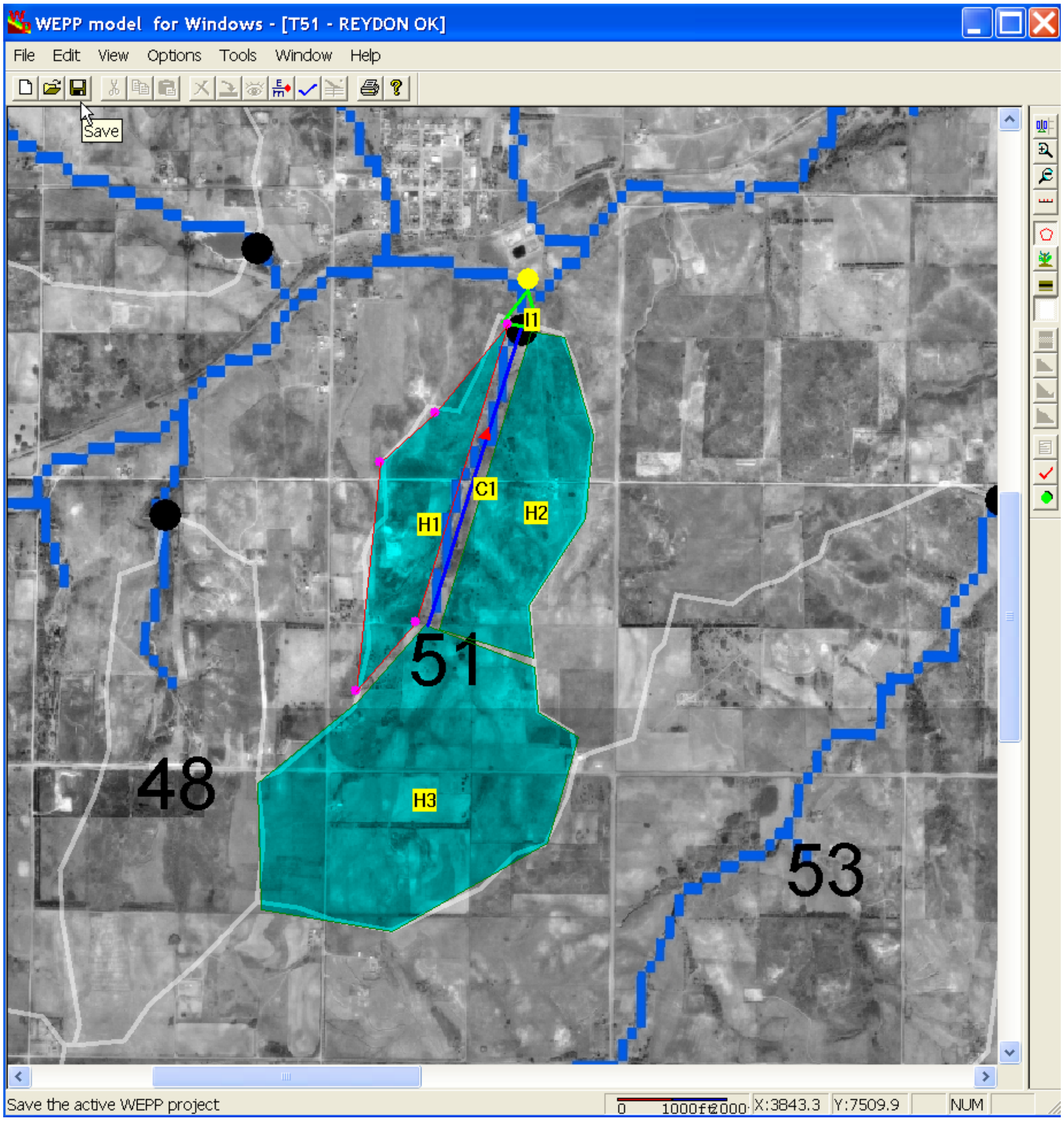

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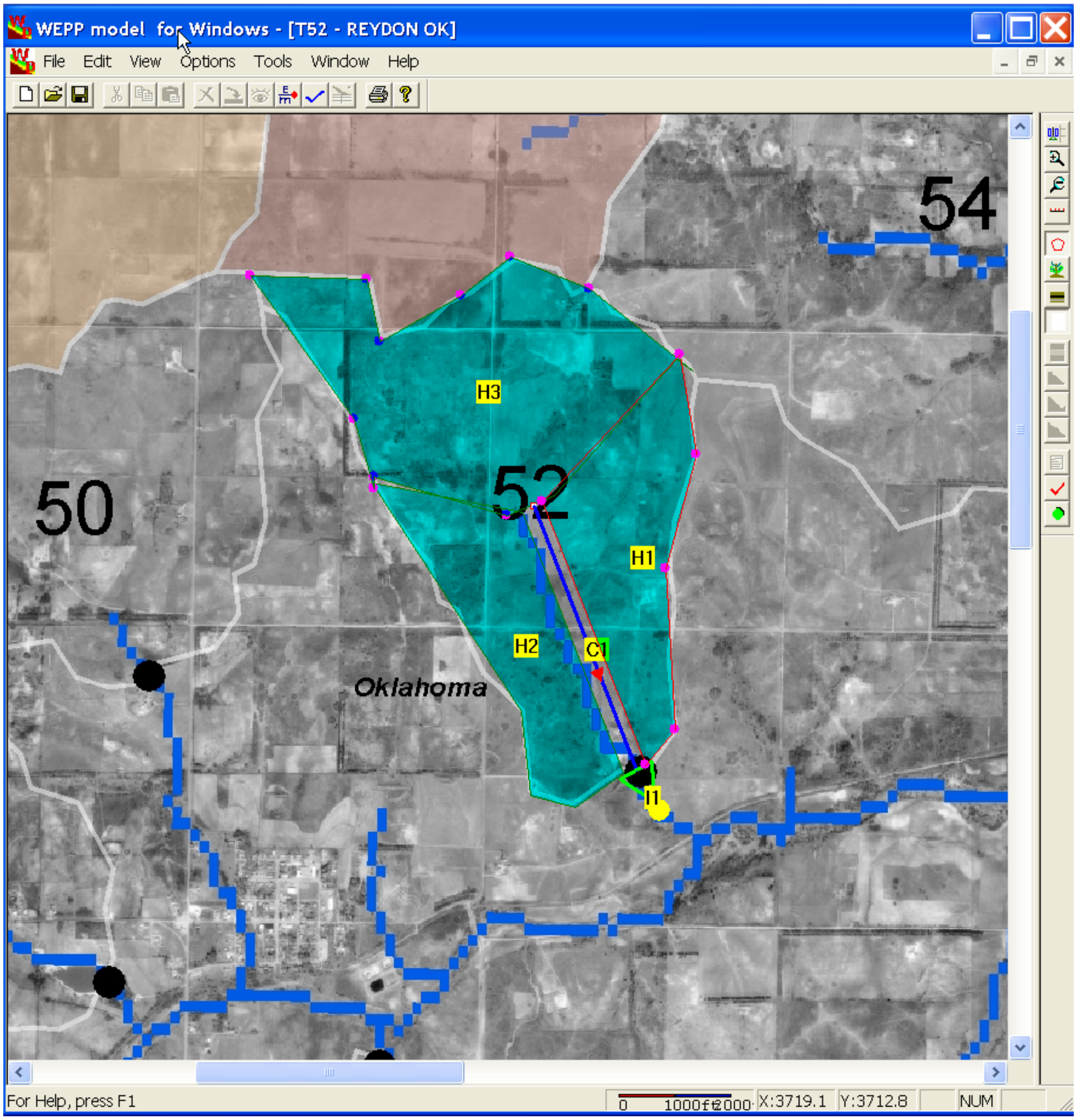

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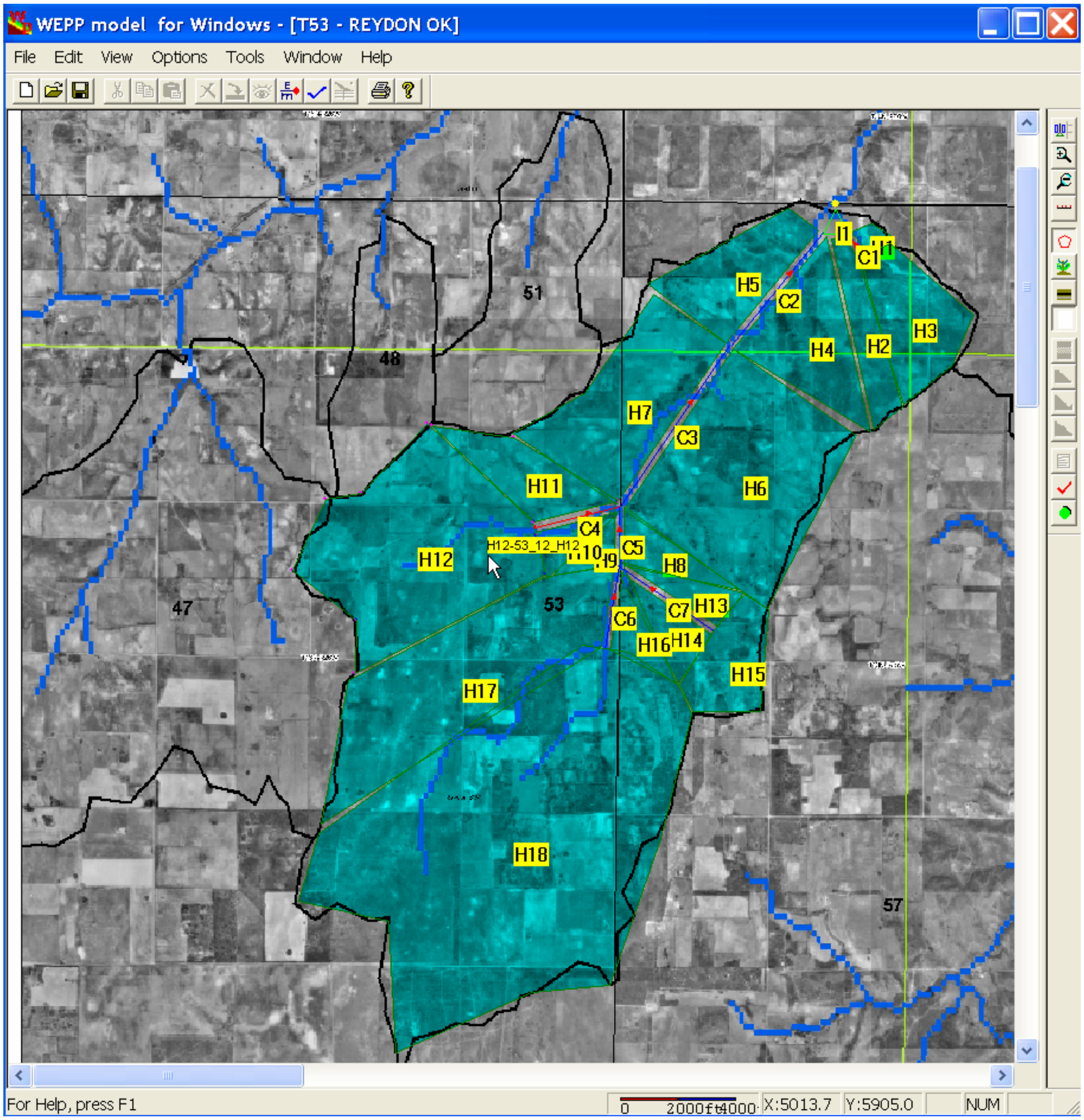

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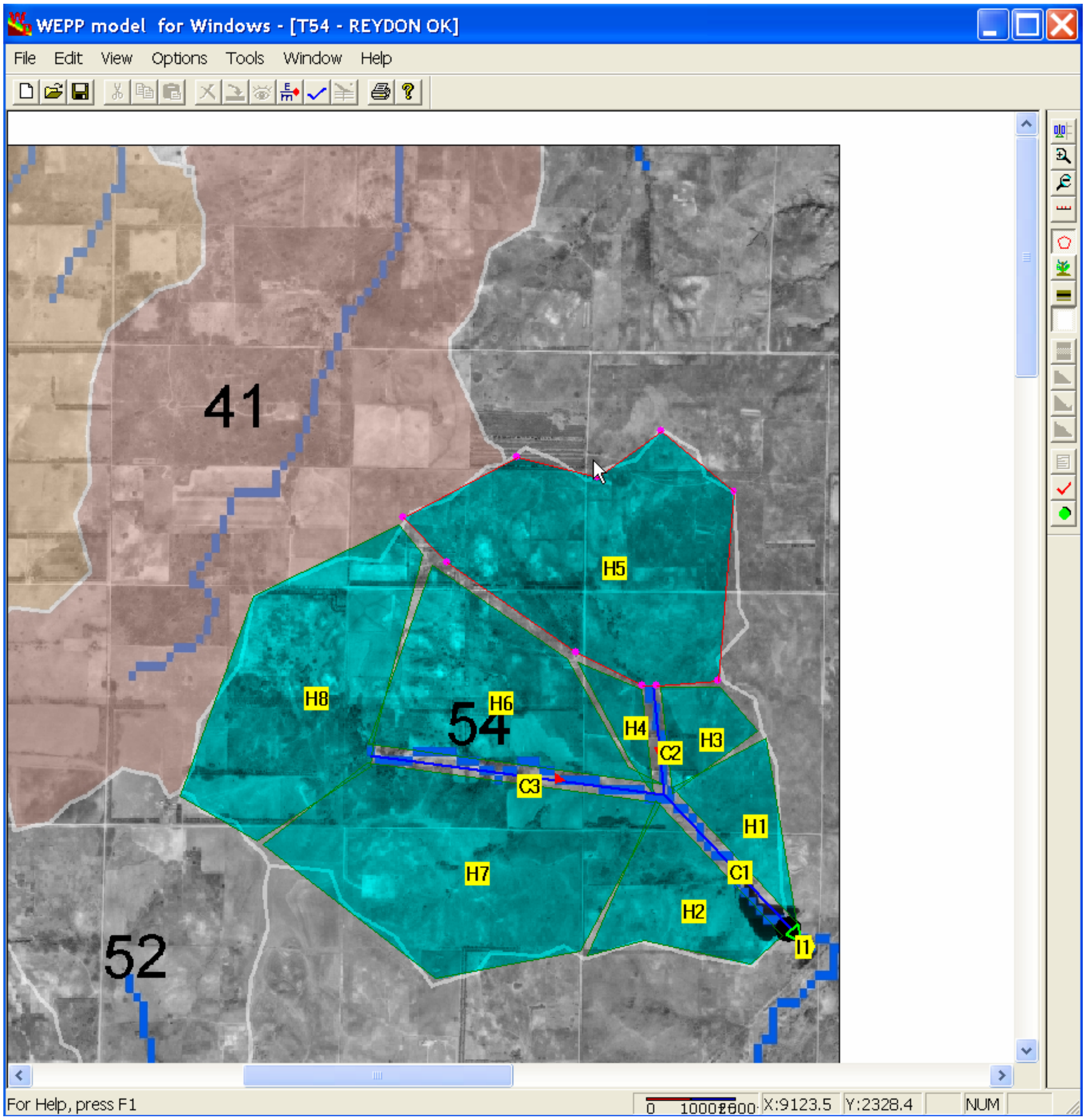

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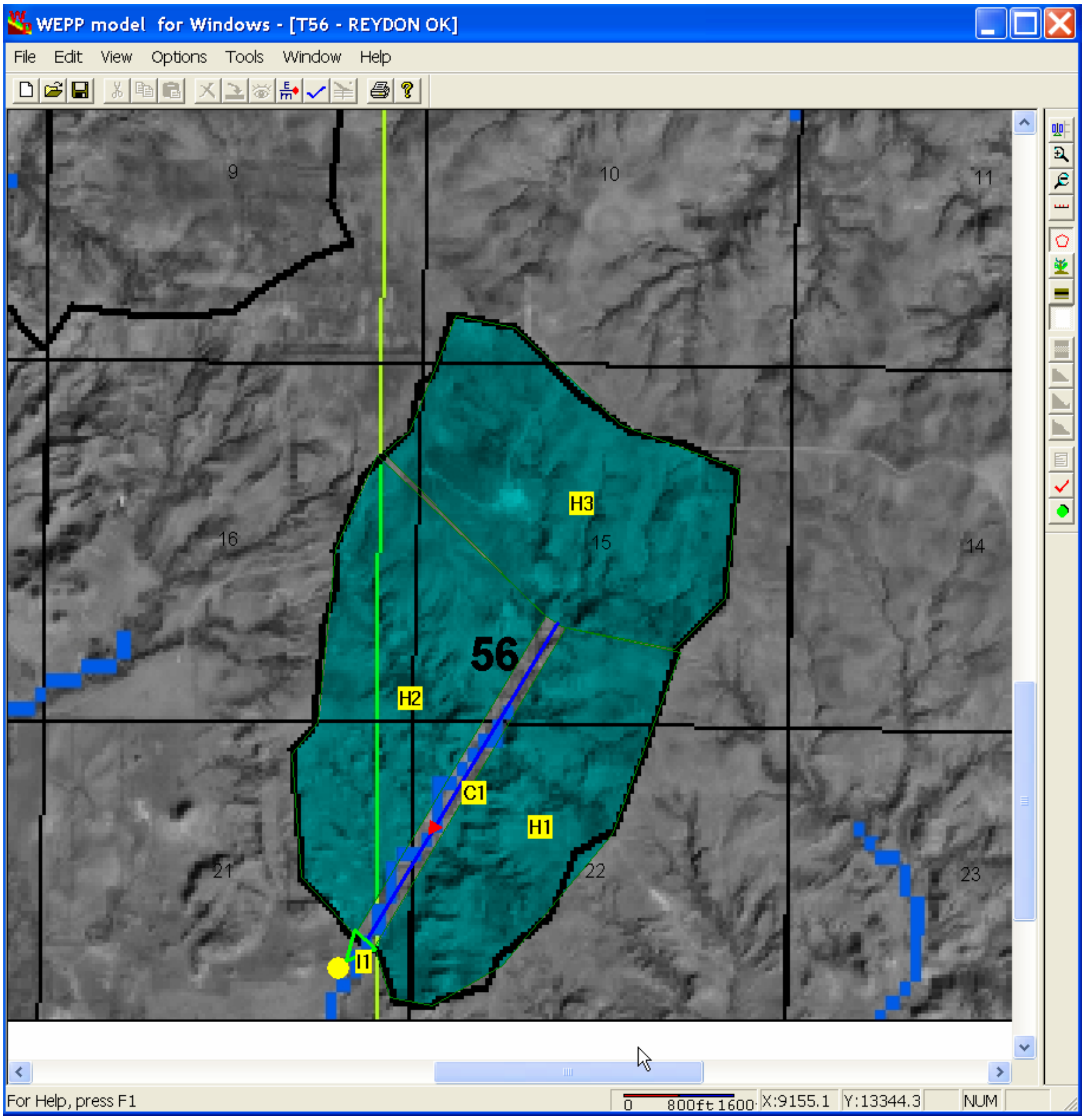

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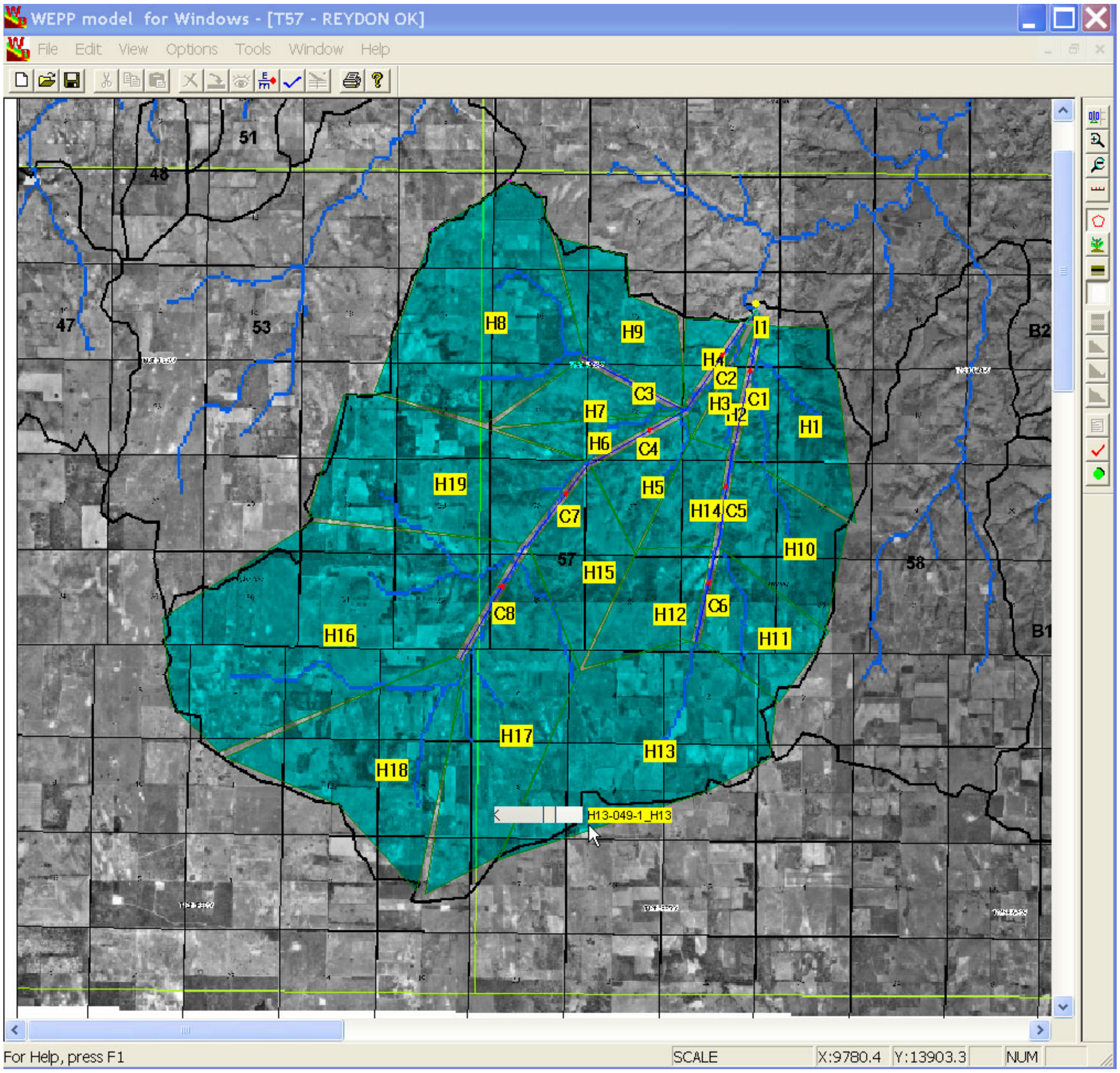

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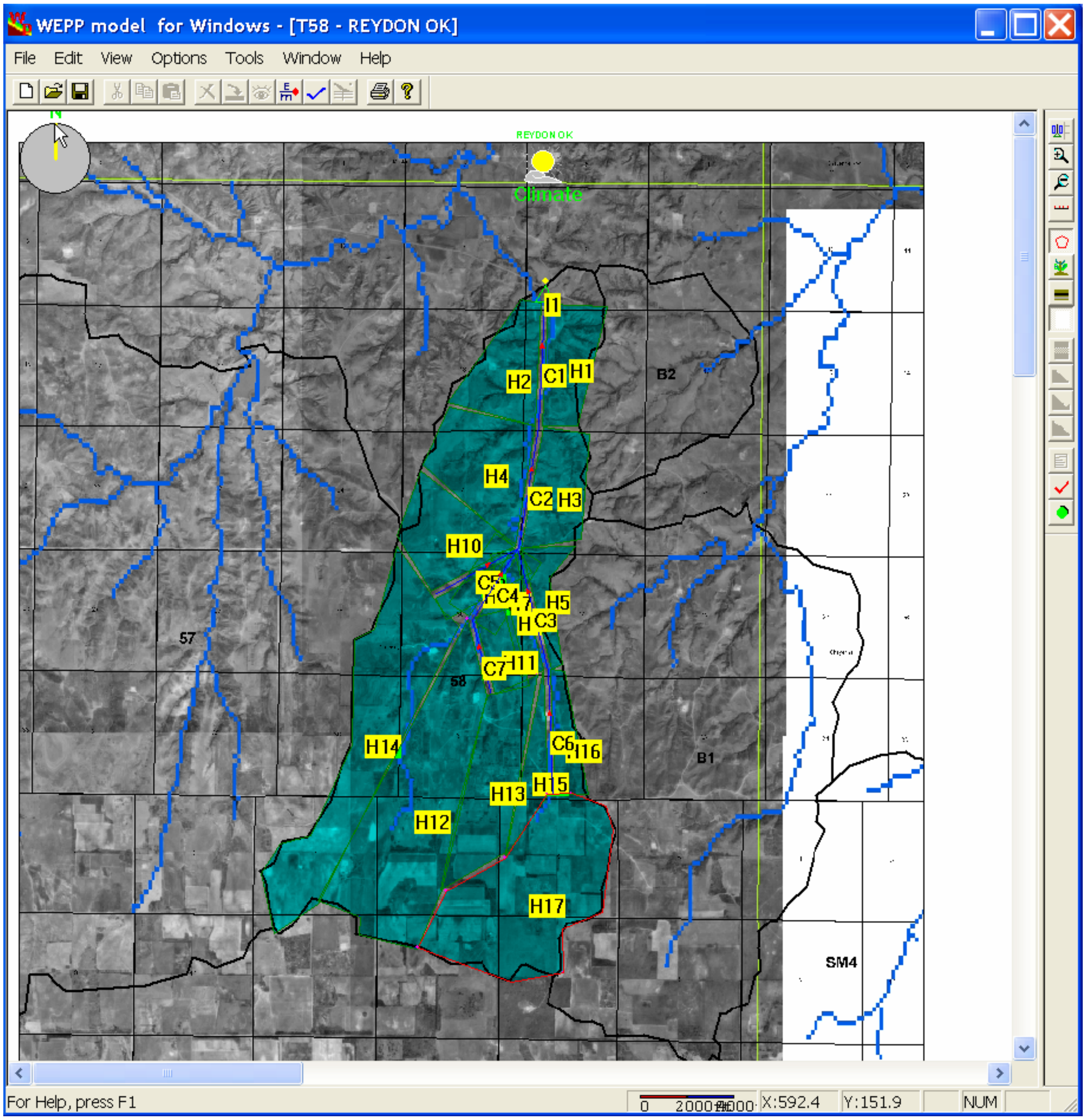

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