LONG-TERM HYDROLOGIC DATABASE: GOODWATER CREEK, MISSOURI

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Abstract-- One of the more valuable ARS assets is the long-term record from their permanent watershed network. However, these data have not always been adequately documented, nor made easily available to the public. This report describes ongoing research at the 72-km^2 Goodwater Creek (GWC) watershed in north-central Missouri with objectives to 1) fully document; 2) provide quality assurance, and 3) make available in web-compatible form historical GWC data. This watershed, instrumented for hydrology in 1971 and water quality in 1993, is dominated by surface runoff. The original installation included three stream weirs, a rain gauge network, piezometers, and climate instruments. The later period included three field-sized watersheds and an automated weather station, plus autosamplers at all weirs. The GWC database will be made available through the ARS STEWARDS (Sustaining the Earth's Watersheds, Agricultural Research Data System) when it is released.

INTRODUCTION

USDA research, in cooperation with University of Missouri Agricultural Engineering Department, dates at least to 1929, with erosion research tied to the Bureau of Chemistry and Soils and then to the Soil Erosion Service. By 1935, this cooperation was identified with the recently established Soil Conservation Service, and in 1939, plans were made to establish forty 88-m^2 runoff plots for research into soil and water management at the Midwest Claypan Experiment Farm near Kingdom City MO. These plots were continuously monitored from 1941-1998, during which time the research arm of the Soil Conservation Service was transferred into the new Agricultural Research Service in 1953. Larger-scale watershed research by USDA-ARS at the Columbia location dates to the formation of the North Central Watershed Hydrology Research Unit in the fall of 1961, as the fourth watershed unit authorized by Senate Bill 59 (after Boise ID, Chickasha OK, and Tucson AZ). Related research in the region was conducted by scientists in this unit, including field-sized watersheds at Treynor IA and Kingdom City MO, the erosion research mentioned above, and sedimentation and hydrologic balance research on several regional reservoirs.

In 1969, plans were made to install a series of weirs on Goodwater Creek, north of Centralia MO. These weirs drained areas from 13 to 72 km^2, and represented nearly half of the drained area of Young's Creek, which had a long-term USGS gauging station draining 172 km^2. A dense precipitation gauging network was installed concurrent with the weir installation. Collateral data included groundwater elevations, intermittent sediment and nutrient transport, temperature and humidity, and pan evaporation. This configuration of instruments remained in place until approximately 1990, when the scope of monitoring was significantly increased.

At that time, additional funds were provided to add water quality measurements to the instrumentation. Automated samplers at the three stream weirs obtained samples during storm events, and periodic grab samples were taken under baseflow conditions. These samples were analyzed for sediment, nutrients, pesticides, and common pesticide metabolites. Three field-scale watersheds ranging from 7 to 35 ha were instrumented with weirs and automated samplers during 1992. These fields were farmed with contrasting practices, including mulch tillage and no tillage. Groundwater well nests were installed in these fields and elsewhere in the watershed to sample for nutrients and pesticides. A set of 30 plots, 0.37 ha each, was installed in 1991 as 10 plots in each of three replicates, on which several common farming practices were established. Fourteen of these plots were instrumented with flumes and walls and autosamplers to channel and sample runoff during the period 1996-2002. A modern weather station was installed in 1991. Strip chart recorders were augmented with electronic measurements for stream stage heights and rain gauges.

During this period of extensive watershed research, documentation of the instruments and data was done when research using them was published. For instance, a subset of flow data from the smallest of the three nested watersheds (W-11 in Table 1) was extracted by Hjelmfelt and Kramer (1988) and used repeatedly for unit hydrograph analysis (Hjelmfelt and Wang, 1994) and also for evaluating a DEM-based overland flow routing model (Wang and Hjelmfelt, 1998). Ward and others (1994) presented limited field groundwater and stream water quality data in an overview of the multi-state project. Alberts and others (1995a) described herbicide transport in surface

runoff from the field sites (F1-F3 in Table 1), and in Alberts and others (1995b) they included data from the weir locations as well. Lerch and others (1995) reported hydroxyatrazine loads and concentrations of atrazine and several of its metabolites at W-1 from 1992 to 1994. Kitchen and others (1997) described preliminary effects of farming systems on groundwater nitrate using sampling wells at the three field sites. Blanchard and Donald (1997) reported herbicide contamination of ground water in the fields and the watershed. Hjelmfelt and Wang (1999) used observations of runoff, sediment, and atrazine loss for 7 events on F1 to predict possible environmental effects of placing a grassed waterway in the drainage channel of the field. Wang and others (1999) calibrated the HSPF sediment model on 2 years of F1 data and tested it on data from W-1. Fraisse and others (2001) reported a simulation study for corn at 7 sites in F1 during 1997. Drummond and others (2003) described statistical and neural methods to predict site-specific yield on F1 and two additional fields just outside the watershed boundary. Alberts and others (2003) compared nutrient and herbicide concentrations in Goodwater Creek to those in Walnut Creek, IA. Wang and others (2003) used 3 years of weather data and field observations from F1 to evaluate the capability of the CROPGRO-soybean model to simulate within-field variability. Ghidey and others (2005) presented event-total runoff and pesticide concentrations and losses for a total of 36 site-years on 14 of the 0.37-ha plots. Lerch and others (2005) described the development of a conservation-oriented precision agriculture farming system on F1, and Kitchen and others (2005) explained the crop production assessments and the development of the system. These last two citations also present the history of F1, which includes several other research articles that describe soil- and crop-based data collected in F1.

However, little documentation of the watershed as a whole has been published, and only limited site descriptions have been collected into internal documents. One abstract described background information prior to the activity in the early 1990's (Hjelmfelt and others, 1990), and Ward and others (1993) listed the suite of water quality data collected during 1991-1992. Consequently, information is contained in locations specific to research topics and in forms prevalent at the time of the research. While quality assurance procedures were usually performed by the staff collecting the data, anomalies were often corrected without sufficient documentation to determine the problem or the solution. Consequently, in 2003, the Cropping Systems and Water Quality Research Unit initiated a comprehensive project to consolidate and document data obtained in the Goodwater Creek Watershed. Nearly coincident with this launch was that of the USDA-ARS database system STEWARDS (Sustaining The Earth's Watersheds Agricultural Research Database System; Steiner and others, 2005). The purposes of both the local and national projects are the same – providing publicly-funded research data to the public.

The objectives of the current paper are to fully document the extent of Goodwater Creek hydrology and water quality data, to describe the ongoing quality assurance project, and to establish a basis for submitting the Goodwater Creek data to the STEWARDS database system.

PHYSICAL DESCRIPTIONS

The Goodwater Creek watershed is located NE of Columbia MO, in a predominantly agricultural area (Figure 1). The area drained at the outlet (W-1) is 72 km^2, with two smaller watersheds (W-9, W-11) nested along the main channel. Topography is characterized by broad gently sloping divides, with roughly 37 m elevation from divide to outlet, which is at 235m MSL. From the outlet, Goodwater Creek drains into Young's Creek (172 km^2), which then drains into Long Branch Creek of the Salt River (466 km^2), which drains directly into Mark Twain Lake, which drains an area of approximately 6,000 km^2. The lake drains into the lower Salt River, which flows into the Mississippi River between Hannibal and St. Louis MO.

Soils in the watershed belong to Major Land Resource Area (MLRA) 113. Soil families include Vertic Epiaqualfs (Mexico Series), Vertic Albaqualfs (Adco series), and Vertic Epiaqualfs (Leonard series). (http://soils.usda.gov/technical/classification/, accessed 2/22/2006). In general, the soils are considered poorly drained because of an argillic horizon at depths from 15 to 45 cm, with clay contents >50 percent and of smectitic mineralogy. As a result of this argillic horizon, soils in the watershed are predominantly classified as hydrologic soil groups C and D, the two highest soil runoff categories. Preliminary analyses of storm vs baseflow indicate that storm flow represents an average of 85-95 percent runoff (Alberts and others 1993).

The watershed is dominated by agricultural land uses, but does include approximately half of the town (~170 ha) of Centralia MO on the southern divide. Stream channels generally have narrow, forested riparian corridors. Crops include corn, soybean, grain sorghum, wheat, and pasture/hay. Moderate amounts of livestock, mostly beef

operations, are in the watershed. During the period of record (1971-present), agricultural practices have changed from moldboard plowing to no-till or other conservation tillage practices.

Instrumentation

Locations of all installations, sensors, and recording instruments are shown in the watershed map in Figure 1. Period of record for each is shown in Table 1. For simplicity, the figure and table will not be cited at each mention.

Runoff

At the watershed outlet and those of the two nested subwatersheds, precalibrated, broad-crested 10:1 V-notch weirs were installed during 1971. Rating curves were developed between 1971 and 1986. Stage recorders in stilling wells provided the primary measurements of water level from 1971 to 1995. The stage recorders were installed in tandem, with daily and weekly clocks on separate recorders for backup in case of failure, and to aid in reading when dynamics caused the ink trace to be complicated. Data from these charts were reduced to breakpoint flow. Electronic head measurements and dataloggers (5-min interval) were installed with autosamplers in 1993, and were considered the primary measurement starting in 1995. The weekly chart-based recorders have been maintained as a backup. Baseflow and storm flow at these weirs have been sampled for sediment, nutrients, and pesticides with grab samples and autosamplers since 1993.

At the outlet of the field watersheds (F-1, F2, and F3), precalibrated broad-crested 3:1 V-notch weirs were installed in 1992. Flashiness of events on these small watersheds prevented developing a rating curve, thus theoretical calibrations were taken from tables in the hydrology field manual (Brakensiek and others, 1979, pg 84-85), adjusted for area above the weirs at several heights above the notch. Water levels above these weirs have been measured using electronic equipment since installation.

Precipitation

Weighing, recording rain gauges were installed in 1971 in a network of up to 39 gauges across the entire Young's Creek watershed, as the USGS station at Young's Creek was originally considered part of the nested watershed design. However, after the USGS decommissioned Young's Creek in 1970, the rain gauge network was reduced to include only the area in and near Goodwater Creek. These rain gauges were standard 20-cm weighing gauges with daily and weekly charts. Data from these charts were reduced to breakpoint values. A subset of the network was winterized by removing the funnel and placing ethylene glycol in the bucket to measure rainfall equivalent of snow; the remainder were removed during the winters. In 1997, load cells were installed under the buckets of all rain gauges to automate the measurement on 2-minute intervals. Charts were continued as a backup until confidence was developed in the automated system.

Groundwater Level and Sampling

During 1971, a 2.5-km^2 area was instrumented with piezometers to measure the elevation of the water table. In 1977, additional piezometers were installed around the periphery of the watershed. In the early 1990's, groundwater sampling well nests were installed at several points in the watershed, including several in each of fields F1, F2, and F3. These were formally established as water quality sampling sites, at depths ranging from 2.9 to 15.7 m, with a screened interval of 1.2 m. Each well consisted of 5-cm PVC pipe with concrete collar and locking cap. Dedicated hand pumps were installed in each. See Kitchen and others (1997) for a more-detailed description of sampling procedures. While the primary purpose of these wells was for sampling groundwater, elevations of the water table were recorded before obtaining samples.

Temperature/Humidity and Evaporation

A hygrothermograph was installed in 1971. Maximum and minimum air temperature and average relative humidity were recorded daily. A Class A evaporation pan was maintained at that site, with daily wind run recorded at the elevation of the pan. This pan was read with a standard hook gauge on work days. These instruments were decommissioned in 2004, with air temperature, humidity, and wind speed being measured at an automated weather station, and evaporation calculable from weather station data.

Weather

An automated weather station was installed in 1991, with confirmed data starting in 1993. Daily maximums and minimums for air temperature and soil temperature, and precipitation were recorded by the datalogger. In addition,

hourly average solar radiation, air temperature, saturated and actual vapor pressure, wind speed, wind direction, soil temperature, soil moisture, and precipitation were recorded and downloaded on a nominal weekly basis.

Sediment

Suspended sediment was determined on runoff and grab samples collected from the creek at various times from 1972 to present. There were sporadic measurements in 1972-73 and continuous data sets from 1979-82 and from 1991-present. The evaporation method (Brakensiek and others 1979) was used over the entire period of record. The method calls for adding a flocculant for removing clay-sized particles from suspension, but instead, samples were allowed to settle over a period of days to weeks, depending upon the clay content of the samples, before gravimetric analysis was performed.

Nutrients

All surface and ground water samples were analyzed for dissolved N and P forms [$(NO_3 + NO_2)$-N, NH_4-N, and PO_4-P]. Dissolved nutrient analyses were determined on runoff and grab samples collected from GWC at various times from 1979 to present. There were sporadic measurements from 1979-82 and continuous data sets from 1986-89 and 1991-present. From 1991-2004, groundwater samples were collected in spring and fall from approximately 90 wells. From 2005-present, groundwater sampling continued only for the 25 wells located at F1. Samples were filtered through 0.45-μm nylon filters within 48-72 hours of collection. Dissolved N and P species were determined colorimetrically using a Lachat flow injection system (Lachat Instruments, Loveland, CO) or an Aquakem 200 discrete colorimetric analyzer (Environmental Science Technology, Fairfield, OH).

Herbicides

Since fall 1991, all GWC samples have been analyzed for the following corn and soybean herbicides and selected triazine metabolites: acetochlor, alachlor, atrazine, deethylatrazine, deisopropylatrazine, metolachlor, and metribuzin. From 1991-1997, groundwater samples were collected in spring and fall from approximately 90 wells and analyzed for the same suite of herbicides and metabolites as surface water samples (Blanchard and Donald 1997). From 1997-2004, these same wells were sampled in spring only. Beginning in 2005, only the 25 wells in F1 continue to be sampled in the spring. Herbicides were isolated from water samples by solid-phase extraction (SPE), and terbutylazine was added as a surrogate for quality assurance. Herbicide concentrations were then determined by gas chromatography with either an N-P or mass selective detector (Donald and others 1998; Lerch and Blanchard 2003). Other compounds and triazine metabolites have also been included for selected time periods (Lerch and others 1995; Lerch and Blanchard 2003).

Data Documentation and Quality Assurance Procedures

The initial step in the data documentation procedure was to develop a detailed flow chart describing each data stream for each general instrumental method used during the history of the watershed. Each flow chart will include links to calibrations, example files, data processing programs, or more-detailed flow charts. These flow charts are a first step both toward documentation and toward formal total quality management of the data streams and are a crucial part of the metadata. After preliminary flow charts were developed for each data stream, quality assurance was initiated. This process is not yet completed.

Each data element was compared to its closest analog. For example, from 1993 until the end of the record (continuing for W-1), redundant measurements, electronic and chart-based, were made of stages at the 3 stream weirs. The time series of electronic data was plotted, and suspect points were identified visually. These points were compared to the charts, and the points were either confirmed or a decision was made to replace the automatic measurements with chart-based measurements. This process is complete for W-1. The same process will be used for W-9 and W-11. On the other hand, the chart data from 1971 to 1993 have no electronic counterpart. For that period, the closest analogs for each weir are the other two weirs, with precipitation records adding a more-distant analog. Therefore, plots of flow through the 3 weirs on a per-unit-area basis, overlaid with representative rainfall rates, will be examined visually to add confidence in the evaluation. If possible, this first-level screen will be automated .

The second data stream for which the quality assurance process is complete is that from the automated weather station. For it, the closest analog has been either the University of Missouri South Farm weather station or the Audrain County weather station. For instance, statistical comparisons of daily solar radiation indicated degradation in the calibration of the pyranometer at F1. However, these same comparisons indicated that the calibration change was consistent, which suggested that a ratiometric calibration change could be applied to the F1 data for the period.

Where the sensor completely failed, the South Farm data were used to replace the F1 solar radiation data. This process was developed to fully document the database, and is described in more detail below.

In general, for every time series of data, there now exists, or will exist, a table of raw data. In addition, where equipment failures or obviously erroneous raw data are detected, there will be a replacement data table containing the best known parameter estimates to be used as substitutes for the raw data. The intersection of these two tables creates our best data series. Each record with a replaced datum has a flag placed in the data tables and is keyed to a table of exceptions to document the action. Thus, an audit trail back to the raw data is always maintained. These tables of exceptions augment the usual station notes, which describe the data when the system is working properly.

Database descriptions

The data streams are periodically loaded into an Oracle database intended for use by CSWQRU scientists, cooperators, and eventually, the general public. The details of the raw and replacement data will not be stored for public use; however, the station notes and exceptions tables will be included and the details will be provided upon request. This database pre-existed the STEWARDS project, and the steps needed to transform the tables from the Goodwater Creek format to the STEWARDS format will be developed by the time of this conference.

CSWQRU's data store is hosted on the University of Missouri's Oracle database server. The host server runs Red Hat (Linux) Advanced Server 3.0 and Oracle 9i Release 9.2.0.7.0. Our main tablespace currently occupies 200 MB, to which users have read-only access. Currently, the ARS data store consists of 1,151,246 records in 32 tables built using a normalized relational database structure. In addition, 14 data views provide depictions of the contents in formats commonly expected by users.

Future plans

The STEWARDS system is being prototyped in spring 2006, with the intent that part of the Goodwater Creek database will be available for a demonstration in early May. An udate is scheduled for October 2006, with phased-in uploads of other ARS Conservation Effects Assessment Project watershed databases following as resources allow.

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Figure 1--Goodwater Creek Watershed map with locations of primary installations and instruments.

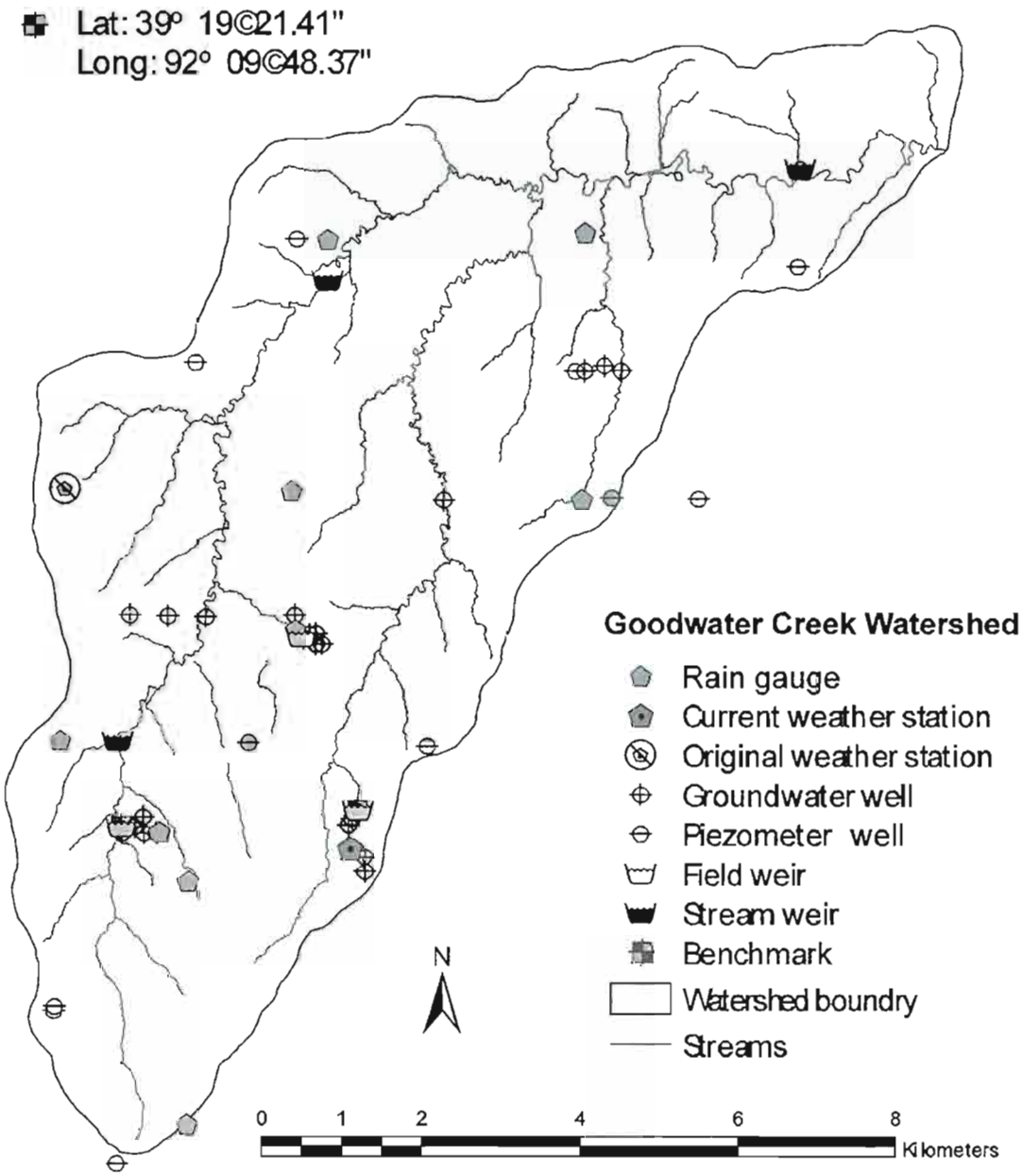

Table 1--Period of record for main instruments in Goodwater Creek watershed

Description	Year																																			# sites
	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
Precipitation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	10-39
Runoff																																					
W-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	1
W-9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										1
W-11	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					1
F 1																							X	X	X	X	X	X	X	X	X	X	X	X	X	X	1
F-2																							X	X	X	X	X	X	X	X	X						1
F-3																							X	X	X	X	X	X	X	X	X						1
Plots (6 per year)																											X	X	X	X	X	X					14
Groundwater elevations																																					
Piezometers	X	X	X	X	X	X	X	X	X	X	X											X	X	X	X	X	X	X	X	X	X	X	X	X	X		30-206
Sample wells																						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	111
Temperature/humidity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				1
Pan evaporation		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				1
Water quality (all)																					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	55
Plot yields																					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	30
Field yields																					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	3
Weather station																							X	X	X	X	X	X	X	X	X	X	X	X	X	X	1