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Geographic information systems database, Walnut Gulch Experimental Watershed, Arizona, United States

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[1] The geographic information systems (GIS) database complementing the Walnut Gulch Experimental Watershed (WGEW) special section papers in this issue of *Water Resources Research* is described. Spatial data layers discussed here will be especially useful to modelers interested in simulating the spatial and temporal characteristics of rainfall, runoff, erosion, and sedimentation processes on the WGEW. All data are available as either images or individual GIS data layers (vector or raster format) via the U.S. Department of Agriculture Agricultural Research Service Southwest Watershed Research Center at http://www.tucson.ars.ag.gov/dap/. Standard metadata are provided with attending projection information and restrictions on use.

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1. Introduction

[2] The USDA Agricultural Research Service, Southwest Watershed Research Center, Walnut Gulch Experimental Watershed (WGEW) in southeastern Arizona is in the Basin and Range Province and a transition zone between the Sonoran and Chihuahua Deserts. WGEW is recognized as the most densely instrumented semiarid experimental watershed in the world, and a premier outdoor laboratory for semiarid watershed hydrology studies [*Renard et al.*, 2008]. Instrumentation on the watershed and the data repository for long-term research are operated and managed by the U.S. Department of Agriculture Agricultural Research Service, Southwest Watershed Research Center (SWRC) in Tucson, Arizona, United States.

[3] A robust and comprehensive geographic information systems (GIS) database has been developed for WGEW in which the spatial distributions of numerous characteristics have been digitized to produce vector and raster layers suitable for research. This manuscript offers a description of the GIS data sets with references to more detailed information and metadata. Links to a Web site from which the files and images can be downloaded or requested are provided. Finally, some applications in which these data sets have been used are given to illustrate the unique and valuable nature of this information for hydrologic research in semiarid regions.

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2. GIS Data

[4] Long-term data sets based on a nested watershed design within WGEW provide a significant resource for researchers interested in understanding and modeling semiarid hydrologic processes. Systematic efforts to study distributed processes on a watershed the size of Walnut Gulch (150 km^2) are feasible only if data can be manipulated digitally. To support such efforts numerous GIS data layers were created (Table 1) and are being made available to the research community. Data access policies are dependent on the map layer, with some restrictions on use accorded to data collected under specific contract agreements, but the WGEW data layers shown in Table 1 are not restricted.

[5] The scope and scale of the GIS database was designed to support hydrologic modeling and geomorphic exercises, and an emphasis has been accorded to the collection of highly accurate stream channels, topographic, and soil information. A significant body of research has been undertaken in recent years related to vegetation and soil moisture characterization through remote sensing. As such, the database has been expanded to include data layers relevant and appropriate for ecological applications, soil erosion studies, and similar large-scale applications. The database houses data sets at a range of scales, allowing for theoretical and applied research relating to modeling, uncertainty, and error propagation. Additional publicly available GIS layers of possible interest are provided as a convenience. All GIS layers have been projected in universal transverse Mercator (UTM) coordinates (zone 12) using the North American Datum of 1983 (NAD-83), GRS-83 spheroid and metric units (meters).

[6] Structured metadata in extensible markup language (xml) format were created for all of the GIS data layers following Federal Geographic Data Committee (FGDC) metadata standards. In addition, detailed narrative descriptions of the geology, geomorphology, soils, ecological sites, and vegetation layers are available. As per standard GIS use procedures, users are advised to read the individual map

Table 1. Primary GIS Data Layers for the Walnut Gulch Experimental Watershed

File Name	Contents	Comments	Original Source[a]	Last Revision
boundary	Watershed boundary	Also available with 100 m buffer	SWRC	2004
subws	Small watershed boundaries	Gauged subwatersheds, ponds, and unit area watersheds	SWRC	2004
streams	Stream network (polygons)	1237 polygons (channels > 1 m width)	SWRC	2004
streamlines	Stream network (lines)	8365 polylines (channels < 1 m width)	SWRC	2004
nhd_high	Stream network (lines)	National data set; 352 polylines	NHD	2004
nhd_med	Stream network (lines)	National data set; 45 polylines	NHD	2004
dem_10m	10 m DEM	National data set	USGS	2004
dem_30m	30 m DEM	National data set	USGS	2004
instrumentation	All instrumentation	Digital and analog rain gauges, flumes, stock ponds, metflux, soil moisture profiles (also available as individual layers)	SWRC	2006
geology	Geology polygons	13 geology mapping units	USGS	2006
geomorphology	Geomorphology polygons	7 geomorphology mapping units	USGS	2006
soils	Soil polygons from WGEW survey	25 soil map units	NRCS	2004
ssurgo	SSURGO soil polygons	National data set; 33 soil map units on watershed + 1 km buffer	NRCS	2004
statsgo	STATSGO soil polygons	National data set; 3 soil map units	NRCS	2004
ecosites	Ecological site polygons	14 ecological site map units (defined, but not mapped across west)	NRCS	2004
vegetation	Vegetation polygons	7 vegetation mapping units	SWRC	2006
roads	Road locations	National data set; U.S., state, county highways; streets; primitive roads; trails and alleys (not all are passable)	TIGER	2004
owner	Ownership	State data set; BLM, Arizona State Trust, and private	ASLD	2004
orthophoto07	aerial photo mosaic	National data set; 1 m ground sample distance from the Compressed County Mosaic flown in June, 2007; Large (∼450 MB)	NAIP	2007

[a]SWRC is Southwest Watershed Research Center; NHD is the National Hydrography Dataset; USGS is the U.S. Geological Survey; NRCS is Natural Resources Conservation Service; TIGER is the Census Bureau's Topologically Integrated Geographic Encoding and Referencing database; ASLD is the Arizona State Land Department; and NAIP is the National Agriculture Imagery Program.

layers' metadata as the standards under which the individual maps were created, including their provenance, vary widely.

2.1. Watersheds

[7] The watershed boundary and source areas contributing to each flume were mapped on the basis of field surveys, orthophotos and digital elevation models and are available as separate GIS layers. A GIS layer containing the watershed boundaries of 10 instrumented stock ponds is also available. The pond watersheds do not contribute to the runoff and sediment yield in the watersheds containing the ponds, except for the largest events. *Nichols* [2006] analyzed the historical records from 8 of the stock ponds for periods ranging from 30 to 47 years.

2.2. Topography and Stream Network

[8] Standard USGS 10 and 30 m digital elevation model (DEM) data sets cover the WGEW. In addition, a special mapping effort was undertaken with aerial photography (1:12,000 average photo scale) and corresponding ground control surveys in 1988. This effort resulted in orthorectified 1:5000 map sheets with 5 m contour intervals that, in conjunction with a high-resolution stream map (see below), formed the basis for the creation of a 10 m DEM and as the base maps for subsequent GIS data layer development. These maps meet or exceed national map accuracy standards. As part of the orthophoto map development, photogrammetrically derived elevations were manually read on a 40 m grid.

[9] Total station surveys on both steep and relatively flat, but dissected, portions of the watershed have been conducted to assess the accuracy of the photogrammetrically derived postpoint elevations and the USGS 30 m DEM data. Statistics from the comparison of the postpoint elevations and a field survey are shown in Table 2. In both areas the mean difference in elevations between the survey and the SWRC's 40 m DEM was much less than for the nationally available 30 m DEM from the USGS.

[10] A detailed depiction of the stream network was digitized directly from the 1:5000 map sheets. Channels greater than approximately 1 m width were digitized as

Table 2. Statistics of DEM Minus Total Station Ground Survey Differences[a]

Statistic	Highly Dissected Area of WG		Steep Hilly Area of WG	
	30 m Survey[b]	40 m Survey[c]	30 m Survey	40 m Survey
Minimum Difference, m	−4.0	−2.3	−2.8	−2.8
Maximum Difference, m	11.3	1.5	7.4	2.3
Mean Difference, m	3.5	−0.2	2.8	−0.5
Standard Deviation, m	2.8	0.8	2.4	1.4

[a]For highly dissected area, n = 90; for steep hilly area, n = 35.
[b]USGS 30 m DEM. Total station survey elevations, conservative estimate of vertical point accuracy = 0.2 m.
[c]ARS 40 m DEM postpoints.

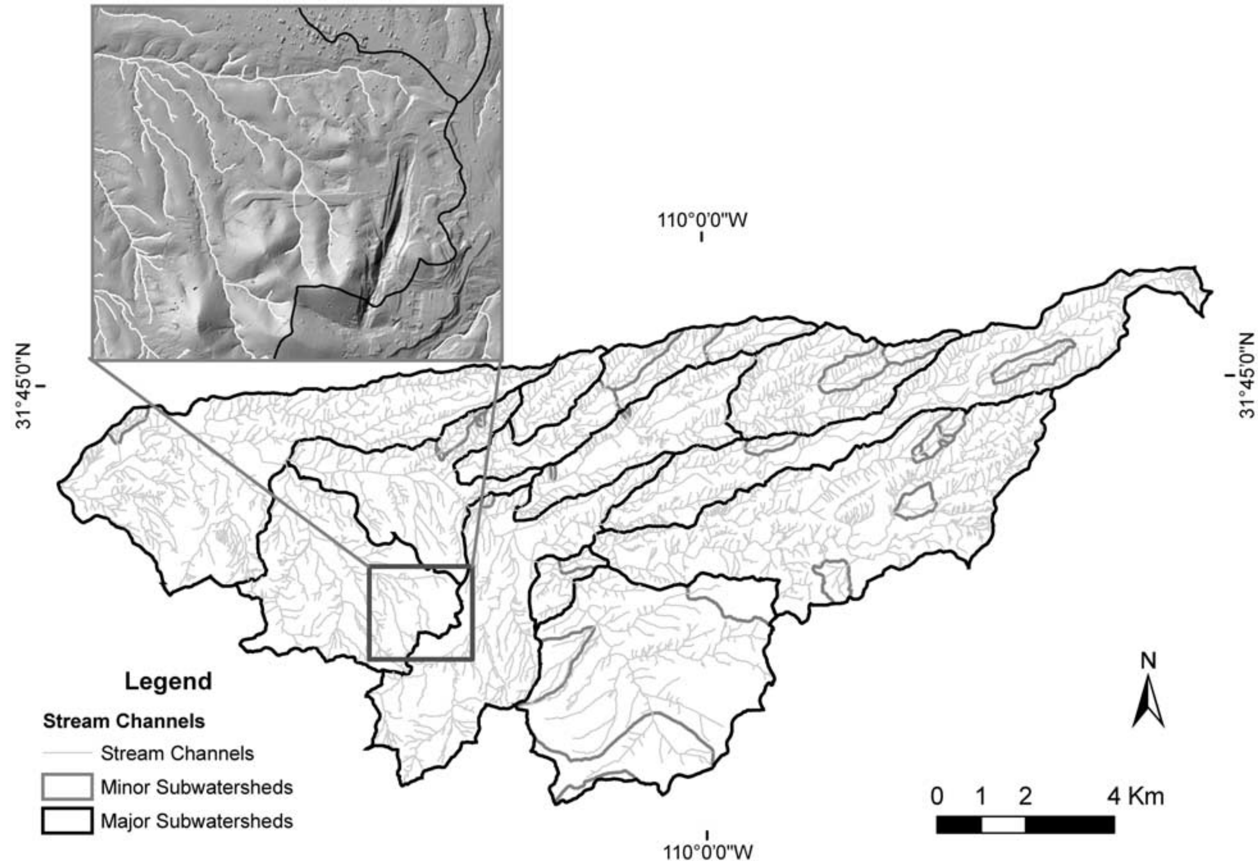

Figure 1. Walnut Gulch stream system with an inset example of the 1 m lidar DEM hill shade showing some of the buildings in Tombstone as well as the mine.

polygons, while smaller channels were digitized as linear features. The stream network was then digitized as a polygon from the planimetric channel projections on the 1:5000 orthophotomaps with corresponding field verification [see *Goodrich et al.*, 1997, Figure 1 inset; *Miller et al.*, 2001]. To allow for more seamless integration with hydrologic modeling efforts, polygonal streams were transformed into simple vectors through the use of a perpendicular bisector routine, resulting in a secondary channel data layer that is fully routed. The resulting stream layer, shown in Figure 1, is much more detailed than the medium or high-resolution stream networks in the National Hydrography Dataset. The digitized stream network was combined with the 40 m postpoint in an interpolator which maintains stream networks to produce a WGEW 10 m DEM.

[11] A 1 m resolution light detection and ranging (lidar) topographic surface was created from an overpass in 2003. The lidar data were collected with approximately 1 m postings, and a bald earth 1m DEM was produced from these data. Small gaps exist in this surface model, but it represents greater than 95% coverage of the watershed. Merging of multiflight lidar will use additional real-time kinematic GPS ground surveys. These surveys are in planning stages and once sufficient QA/QC work is completed the lidar-based DEM will be released. A preliminary view of the 1 m DEM can be seen in the inset of Figure 1, where the mine and buildings in the town of Tombstone are visible.

2.3. Instrumentation

[12] The WGEW was designed and instrumented to study the dominant processes determining watershed response in the southwest. Summer precipitation in the form of high-intensity, convective storms requires a dense network of rain gauges to capture the temporal and spatial variability. *Goodrich et al.* [2008] describe the instrumentation and long-term precipitation database. A map of the current 88 digital, and 91 historic analog weighing rain gauges on WGEW is shown in their Figure 2.

[13] The locations of 11 supercritical flow flumes and several instruments on 8 small watersheds to measure runoff constitute another GIS layer (Figure 2). Included in the layer are rain gauges, metflux stations, flumes, as well as gauged and ungauged ponds. *Stone et al.* [2008] describe the long-term runoff database associated with these point locations. A real-time kinematic GPS survey was completed in early 2007 to locate watershed instrumentation with measurements tied to a GPS base station established at the WG field office in Tombstone.

[14] Reliable methods have yet to be developed to measure sediment concentrations through the large flumes given the ephemeral flows and huge range in particle size classes. *Nichols et al.* [2008] present the long-term sediment database from smaller watersheds, and there is a corresponding point layer of the locations of current sediment samplers including both pump and the traversing slot sediment samplers.

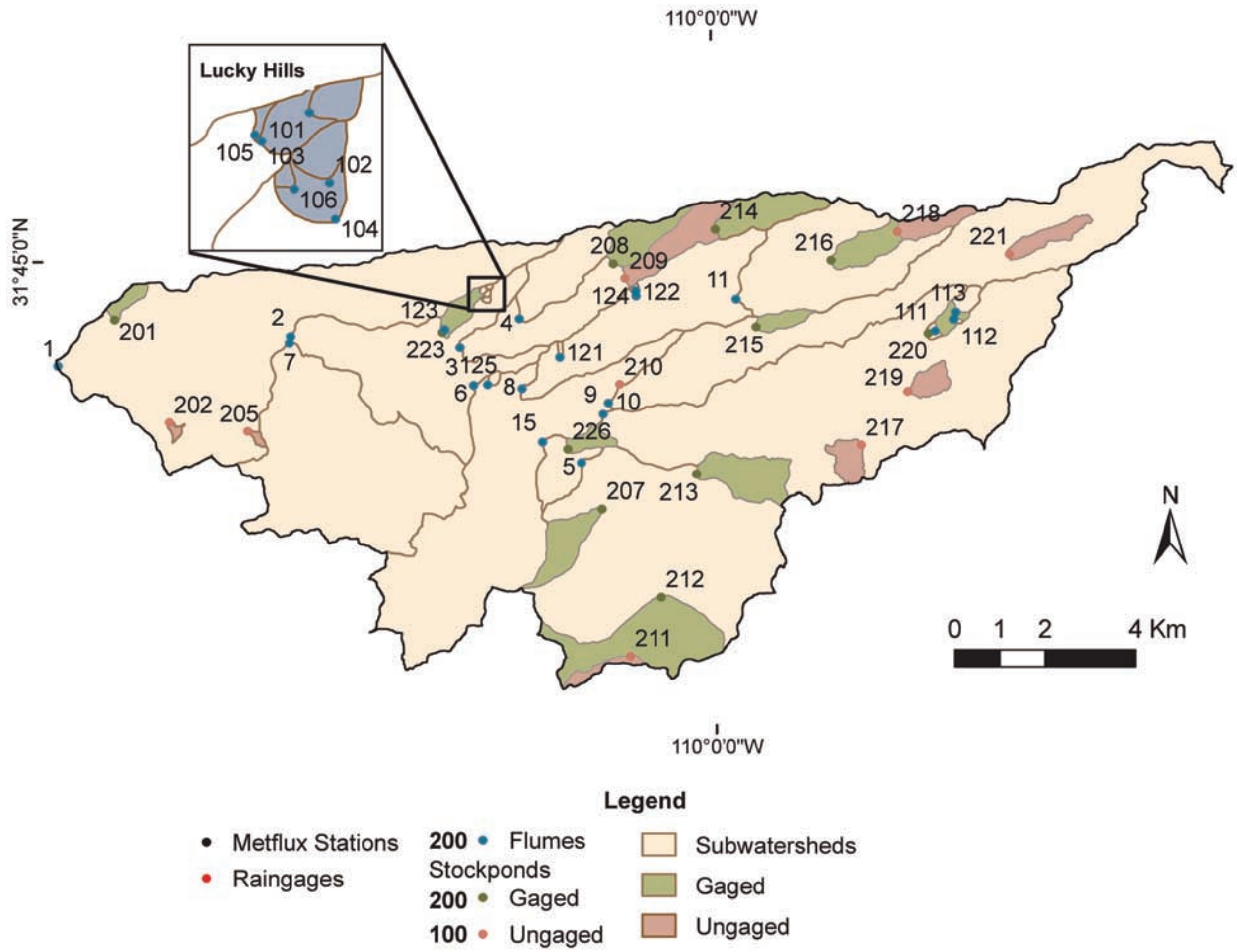

Figure 2. Instrumentation of the Walnut Gulch Experimental Watershed.

[15] Metflux stations at the Lucky Hills and Kendall intensive study sites provide detailed measurements of solar radiation, wind speed, and soil moisture as described by *Keefer et al.* [2008] and shown in their Figure 1. Sampling for the CO_2 and water flux stations is described by *Emmerich and Verdugo* [2008].

2.4. Categorical Data

[16] Five GIS data layers provide the geology, geomorphology, soils, potential and actual vegetation on Walnut Gulch. Most of the experimental watershed is a high foothill alluvial fan, primarily composed of Cenozoic alluvium, more than 400 m deep in places. Geologic influences on watershed hydrology include intrusive igneous dikes in the Tombstone hills that affect surface and subsurface flow, as well as faulting and highly compacted conglomerate beds that affect stream channel locations.

[17] *Breckenfield et al.* [1995] of the Natural Resources Conservation Service (NRCS) mapped 26 soil series in an order 3 soil survey of WGEW. Surface textures range from gravelly to cobbly loams. As a convenience, the nationally available SSURGO and STATSGO maps from the NRCS are also available.

[18] While there are implications for management that lead the NRCS to distinguish between soil mapping units, similar soils can be grouped together in terms of their potential to produce similar vegetation communities. Fourteen of these units, called ecological sites, were mapped by the NRCS across Walnut Gulch concurrently with the 1994 soil survey. Together, the geology, soils and ecological sites and management history determine the current vegetation. *Skirvin et al.* [2008] show the current vegetation classification of WGEW in Figure 3 and *King et al.* [2008] discuss WGEW vegetation monitoring in more detail.

2.5. Roads, Land Ownership, and Orthophoto

[19] Cultural features provide a very useful set of landmarks for field work on the watershed. We provide a road layer originally obtained from the Topologically Integrated Geographic Encoding and Referencing (TIGER) files of the U.S. Census. A layer originally developed by the Arizona Land Resource Information System contains land ownership in private, Arizona State Land Department, or BLM categories. Figure 3 shows both layers. As the USDA does not own the land comprising WGEW it is important to maintain strong, cooperative relationships with landowners, especially on private land. A 2007 mosaicked orthophoto is also available to show cultural features.

3. Data Availability

[20] The GIS data layers listed in Table 1 are available from the Web site http://www.tucson.ars.ag.gov/dap main-

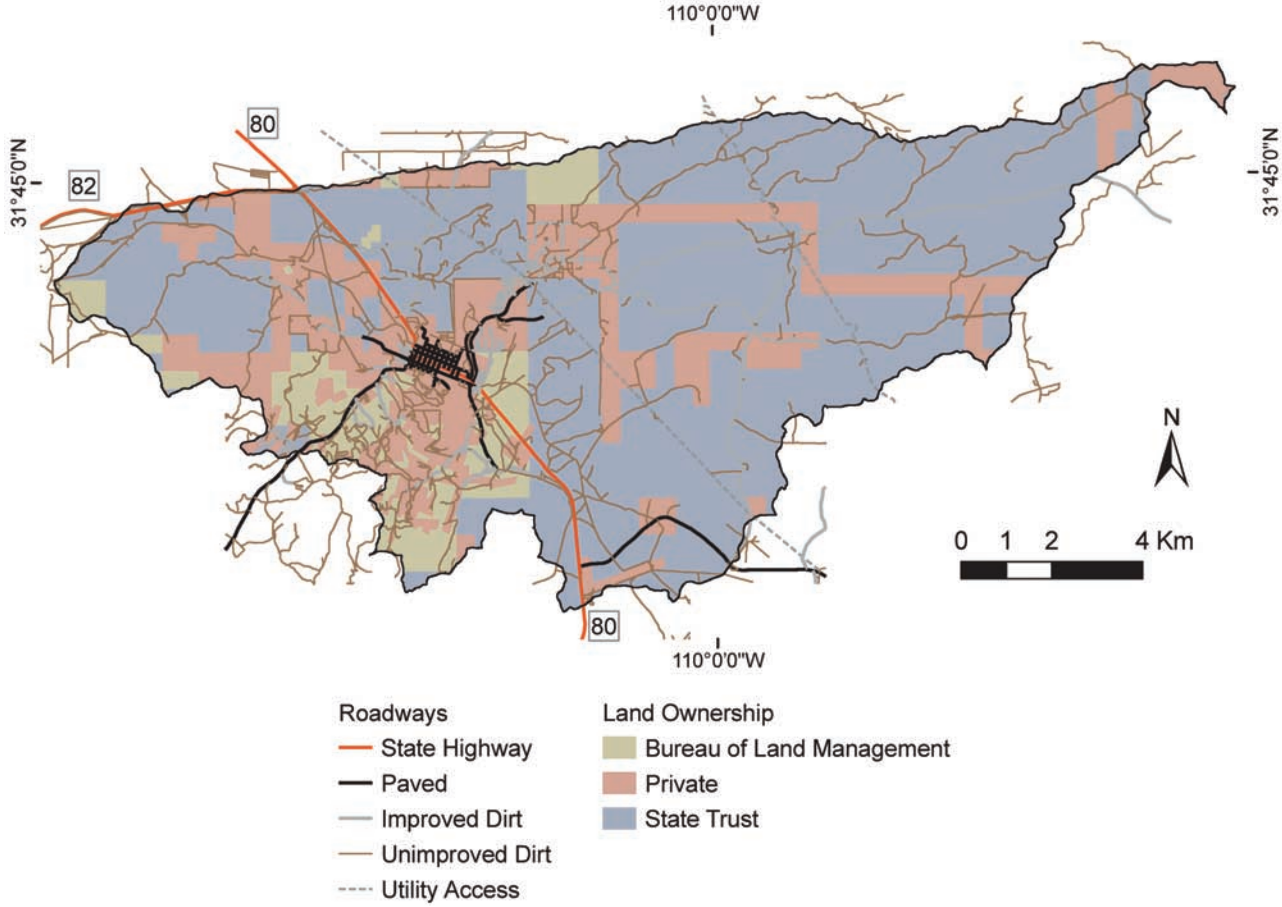

Figure 3. The roads and ownership layers of the Walnut Gulch Experimental Watershed.

tained by the U.S. Department of Agriculture Agricultural Research Service, Southwest Watershed Research Center in Tucson, Arizona, United States. The Web site provides the ability to view the GIS layers through a web browser before download as individual layers. GIS data layers are available in standard ESRI data formats (mention of a proprietary product does not constitute a guarantee or warranty of the product by USDA or the authors and does not imply its approval to the exclusion of other products that may also be suitable). *Moran et al.* [2008] describe an imagery database for WGEW that is available at the same Web site. In addition to these publicly available GIS layers, additional layers are under development. The Web address provided above also contains contact information for questions about obtaining other GIS information as it becomes available.

4. Examples of Data Use

[21] As a practical matter, the complexity of watershed processes requires computer-based simulation models to systematically test and refine our understanding of watershed response. The WGEW GIS data set contains digital representations of many important spatially distributed characteristics needed to represent physical processes related to precipitation, infiltration, recharge, runoff, erosion and sedimentation at the hillslope and watershed scales. With the GIS data set, analyses with a significant spatial component are greatly facilitated, such as those shown in Table 3. For a number of characteristics, both publicly available data layers and more detailed layers developed specifically for research at WGEW are available to evaluate the potential improvement in simulation model accuracy given better spatial input data. Experimental watersheds support the systematic study of distributed processes, and the GIS database for WGEW provides a very useful complement to the imagery and observed data sets described elsewhere in this special issue.

Table 3. Example Applications of WGEW GIS Data

Study	Topic
Tarboton et al. [1988]	Fractal nature of river networks
Tarboton [1997]	Evaluating flow direction and upslope areas
Goodrich et al. [1997]	Scale at which channel processes begin to dominate hillslope processes
Syed et al. [2003]	Position of the storm core relative to the watershed outlet becomes more important as the watershed size increases
Hsieh et al. [2003]	A spatially explicit stochastic daily precipitation model for southeastern Arizona
Garcia et al. [2008]	Spatial interpolation of precipitation
Miller et al. [1999], *Syed* [1999], *Miller* [2002, 2004], *Levick et al.* [2004], and *Levick et al.* [2006]	Effect of DEM and soil data layer spatial resolution on runoff simulations
Duan [2005]	Ranch economics

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References

Breckenfield, D. J., W. A. Svetlik, and C. E. McGuire (1995), Soil survey of Walnut Gulch Experimental Watershed, report, 131 pp., Soil Conserv. Serv., U.S. Dep. of Agric., Tucson, Ariz.

Duan, Y. (2005), A spatial decision support system for economic analysis of sediment control on rangeland watersheds, Ph.D. dissertation, Univ. of Ariz., Tucson.

Emmerich, W. E., and C. L. Verdugo (2008), Long-term carbon dioxide and water flux database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S09, doi:10.1029/2006WR005693.

Garcia, M., C. D. Peters-Lidard, and D. C. Goodrich (2008), Spatial interpolation of precipitation in a dense gauge network for monsoon storm events in the southwestern United States, *Water Resour. Res.*, *44*, W05S13, doi:10.1029/2006WR005788.

Goodrich, D. C., L. J. Lane, R. M. Shillito, S. N. Miller, K. H. Syed, and D. A. Woolhiser (1997), Linearity of basin response as a function of scale in a semiarid watershed, *Water Resour. Res.*, *33*(12), 2951–2965, doi:10.1029/97WR01422.

Goodrich, D. C., T. O. Keefer, C. L. Unkrich, M. H. Nichols, H. B. Osborn, J. J. Stone, and J. R. Smith (2008), Long-term precipitation database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S04, doi:10.1029/2006WR005782.

Hsieh, H., J. J. Stone, D. P. Guertin, and D. D. Slack (2003), Stochastic daily rainfall generation in southeast Arizona: An example from Walnut Gulch Experimental Watershed, in *First Interagency Conference on Research in the Watersheds, October 27–30, 2003* [CD-ROM], edited by K. G. Renard et al., Agric. Res. Serv., U.S. Dep. of Agric., Tucson, Ariz.

Keefer, T. O., M. S. Moran, and G. B. Paige (2008), Long-term meteorological and soil hydrology database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S07, doi:10.1029/2006WR005702.

King, D. M., S. M. Skirvin, C. D. Holifield Collins, M. S. Moran, S. H. Biedenbender, M. R. Kidwell, M. A. Weltz, and A. Diaz-Gutierrez (2008), Assessing vegetation change temporally and spatially in southeastern Arizona, *Water Resour. Res.*, *44*, W05S15, doi:10.1029/2006WR005850.

Levick, L. R., D. J. Semmens, D. P. Guertin, I. S. Burns, S. N. Scott, C. L. Unkrich, and D. C. Goodrich (2004), Adding global soils data to the Automated Geospatial Watershed Assessment Tool (AGWA), paper presented at 2nd International Symposium on Transboundary Waters Management, Sustainability of Semi-Arid Hydrol. and Riparian Areas, Tucson, Arizona, 16–19 Nov.

Levick, L., D. P. Guertin, S. Scott, D. J. Semmens, and D. C. Goodrich (2006), Automated Geospatial Watershed Assessment Tool (AGWA): Uncertainty analysis of common input data, paper presented at 3rd Federal Interagency Hydrologic Modeling Conference, Subcomm. on Hydrol. of the Interagency Advis. Comm. on Water Inf., Reno, Nev.

Miller, R. C. (2004), A rangeland watershed management spatial decision support system: Design, implementation, and sensitivity, Ph.D. dissertation, 309 pp., Sch. of Renewable Nat. Resour., Univ. of Ariz., Tucson.

Miller, S. N. (2002), Scale effects of geometric complexity, misclassification error and land cover change in distributed hydrologic modeling, Ph.D. dissertation, 170 pp., Sch. of Renewable Nat. Resour., Univ. of Ariz., Tucson.

Miller, S. N., D. P. Guertin, K. H. Syed, and D. C. Goodrich (1999), Using high resolution synthetic aperture radar for terrain mapping: Influences on hydrologic and geomorphic investigations, in *Wildland Hydrology*, edited by D. S. Olsen and L. P. Potyondy, pp. 219–228, Am. Water Assoc., Herndon, Va.

Miller, S. N., D. P. Guertin, and D. C. Goodrich (2001), Deriving stream channel morphology using GIS-based watershed analysis, in *GIS for Water Resources and Watershed Management*, edited by J. G. Lyons, chap. 5, pp. 53–60, Sleeping Bear Press, Ann Arbor, Mich.

Moran, M. S., C. D. Holifield Collins, D. C. Goodrich, J. Qi, D. T. Shannon, and A. Olsson (2008), Long-term remote sensing database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S10, doi:10.1029/2006WR005689.

Nichols, M. H. (2006), Measured sediment yield rates from semiarid rangeland watersheds, *Rangeland Ecol. Manage.*, *59*(1), 55–62, doi:10.2111/05-075R1.1.

Nichols, M. H., J. J. Stone, and M. A. Nearing (2008), Sediment database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S06, doi:10.1029/2006WR005682.

Renard, K. G., M. H. Nichols, D. A. Woolhiser, and H. B. Osborn (2008), A brief background on the U.S. Department of Agriculture Agricultural Research Service Walnut Gulch Experimental Watershed, *Water Resour. Res.*, *44*, W05S02, doi:10.1029/2006WR005691.

Skirvin, S., M. Kidwell, S. Biedenbender, D. King, S. Moran, and C. Holifield Collins (2008), Vegetation data, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, doi:10.1029/2006WR005724, in press.

Stone, J. J., M. H. Nichols, D. C. Goodrich, and J. Buono (2008), Long-term runoff database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S05, doi:10.1029/2006WR005733.

Syed, K. H. (1999), The impacts of digital elevation type and resolution on hydrologic modeling, Ph.D. dissertation, Univ. of Ariz., Tucson.

Syed, K., D. C. Goodrich, D. Myers, and S. Sorooshian (2003), Spatial characteristics of thunderstorm rainfall fields and their relation to runoff, *J. Hydrol.*, *271*(1–4), 1–21, doi:10.1016/S0022-1694(02)00311-6.

Tarboton, D. G. (1997), A new method for the determination of flow directions and upslope areas in grid digital elevation models, *Water Resour. Res.*, *33*(2), 309–320, doi:10.1029/96WR03137.

Tarboton, D. G., R. L. Bras, and I. Rodriguez-Iturbe (1988), The fractal nature of river networks, *Water Resour. Res.*, *24*(8), 1317–1322, doi:10.1029/WR024i008p01317.

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