SOUTHWEST WATERSHED RESEARCH CENTER
&
WALNUT GULCH EXPERIMENTAL WATERSHED

Southwest Watershed Research Center
Tucson, Arizona

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USDA

MISSION STATEMENTS

United States Department of Agriculture (USDA)

USDA Mission: The United States Department of Agriculture provides leadership on food, agriculture, natural resources, quality of life in rural America and related issues based on sound public policy, the best-available science and efficient management. The USDA improves the Nation's economy and quality of life by:

- Enhancing economic opportunities for U.S. farmers and ranchers
- Ensuring a safe, affordable, nutritious, and accessible food supply
- Caring for public lands and helping people care for private lands
- Supporting the sound, sustainable development of rural communities
- Expanding global markets for agricultural and forest products and services
- Working to reduce hunger and improve America's health through good nutrition.

Agricultural Research Service (ARS)

ARS Mission: Conduct research to develop and transfer solutions to agricultural problems of high national priority and provide information access and dissemination to

- ensure high-quality, safe food and other agricultural products
- assess the nutritional needs of Americans
- sustain a competitive agricultural economy
- enhance the natural resource base and the environment
- provide economic opportunities for rural citizens, communities, and society as a whole.

Southwest Watershed Research Center (SWRC)

SWRC Mission: To develop knowledge and technology to conserve water and soil in semi-arid lands.

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RESEARCH PROGRAMS

SWRC scientists conduct research in collaboration with local landowners and ranchers, local government and organizations, university partners, other state, federal and international scientists and agencies. SWRC research ranges from understanding, describing and modeling hydrologic processes to applications of technology at the field level.

Field research in support of these program areas historically has been conducted primarily at the two main SWRC instrumented research areas Walnut Gulch Experimental Watershed (WGEW) and the Santa Rita Experimental Range (SRER). Paralleling the shifting and expanding nature of research conducted by SWRC scientists, field research has been geographically extended regionally to rangelands, forests and riparian areas in southeastern Arizona, nationally to other states and internationally to Mexico, China and Kazakhstan.

Research at the Southwest Watershed Research Center is currently conducted within the USDA-Agricultural Research Service's National Program 201: Water Resource Management. The two major emphasis areas at SWRC are 1) Hydrology and 2) Erosion and Sedimentation.

1. Hydrology

Arid and semiarid regions constitute over a third of the world's landmass yet are under increasing population pressure. In the semiarid southwestern U.S. population is projected to increase over 50% by 2030 in comparison to 5-15% in other U.S. regions. This will dramatically increase society's need to manage its water, soil, and nutrient resources to support people, agriculture and the environment. Hydrology research at SWRC is designed to improve our ability to manage watershed resources under the stress of increasing population and climatic variation. Methods of investigation include field and laboratory experimentation, as well as the development and use of state-of-the-science watershed models. The goal of this project is to improve the ability to manage watersheds for reliable water supply, water quality, and ecosystem health by improving our ability to quantify semiarid water budget components; developing new model components and develop decision support systems that utilize remotely sensed data more fully; and, which consider the influence of ecosystems and their feedbacks. The specific objectives are:

1. Quantify, and provide tools to estimate the impacts of urban development on the urban-rural interface as it affects surface runoff and groundwater recharge. This objective focuses on quantifying hydrologic impacts of rapid land-use change occurring in the semiarid southwest due to significant population growth and human relocation from other parts of the country. The urban-rural interface is changing the character of rangeland watersheds drastically. Ironically, as compared to development in more humid watersheds, this may lead to greater groundwater recharge.

2. Develop improved watershed model components and decision support systems that more fully utilize and assimilate remotely sensed data for parameterization, calibration, and model state adjustment. Objective 2 is directed toward developing remote sensing and modeling tools to estimate evapotranspiration and CO2 fluxes and to extrapolate our findings from objectives 1 and 3 to larger and more diverse regions.

3. Quantify primary semiarid water and energy balance components with emphasis on determining how surface processes and states influence water and carbon fluxes over a selected range of primary semi-arid vegetation types. A major component of objective 3 is to quantify the hydrologic and carbon cycle impacts and feedbacks of less rapid, non-development related, vegetation change that is occurring in many semiarid regions throughout the world with the encroachment of woody species into grasslands.

The products of the proposed research include better technologies and strategies to manage water and carbon resources and the information necessary to inform national policy on watershed management for both the present and future. The expected benefit of the program, working in conjunction with other scientific, political, and action agencies, is the long-term ability of our watersheds to sustain their residents, agriculture and the environment.

2. Erosion and Sedimentation

Erosion research at the SWRC addresses the lack of knowledge and decision tools to quantify the climatic and management effects on the sustainability of rangelands as affected by runoff and erosion. Federal action agencies have requested that a hydrologic and erosion model be developed to contribute to the ecological site description and National Resource Inventory data bases, to assess the efficacy of conservation practices for the Conservation Security Program, and to provide estimates of runoff and erosion for rangeland monitoring and ranch planning. To achieve these goals, three overall objectives have been identified.

1. The first objective is to provide data bases, knowledge, and information on rangeland erosion at a range of spatial scales for the development, validation, and implementation of erosion decision tools. Within this overall objective, we are quantifying erosion, determining sources and sinks of sediment, and working to understand the biotic and abiotic influences on sediment yield at scales ranging from plots to watershed. The resulting data and knowledge will be used to validate hydrologic and erosion relationships and for parameter estimation equations for the rangeland erosion model. We also use remote sensing techniques to provide parameter estimation for large scale applications of the erosion model and rangeland health assessments.

2. The second objective is to develop decision tools, including a rangeland specific hydrology and erosion model, for the planning and evaluation of sustainable rangeland management. Objective 2 consists of the development of a Rangeland Hydrology and Erosion Model , as well as an Economic Decision Support System

(EDSS). The Erosion Model will be developed for a wide range of erosion related applications from the national scale – evaluating NRI data, the state scale - parameterizing NRCS ecological site descriptions, and the local scale - ranch planning. The EDSS will be used to calculate the cost benefit ratios of upland conservation management.

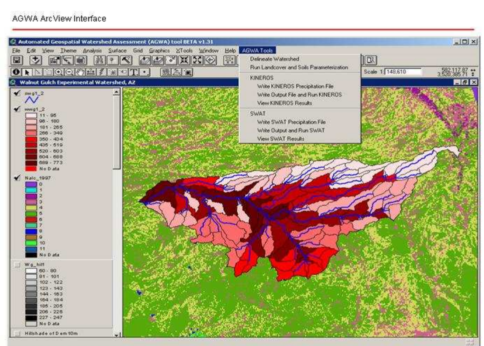
3. Finally, the third objective is to develop design criteria for local ranchers and other land managers for conservation structures, to document the effectiveness of conservation structures on the land, and to provide the erosion model with data on conservation practices so that they are appropriately considered in assessing their impacts.

The anticipated products of this work will be 1. A method for interpreting semiarid sediment yield measured at the watershed outlet with respect to internal watershed erosion, transport, and deposition processes. 2. Sediment source identification, sediment tracking, and sediment budgets for model validation. 3. Criteria for the design of small rock-dam structures for purposes of sediment retention in semi-arid rangeland landscapes. 4. New approaches for assimilating remote sensed data in the parameterization of rangeland hydrology and erosion models. 5. A hydrology and erosion model specifically developed for rangeland applications for use by action agencies and landuse managers. 6. Decision support tools for NRCS and public land managers on rangelands.

HYDROLOGY

H1. Automated Geospatial Watershed Assessment Tool (AGWA)

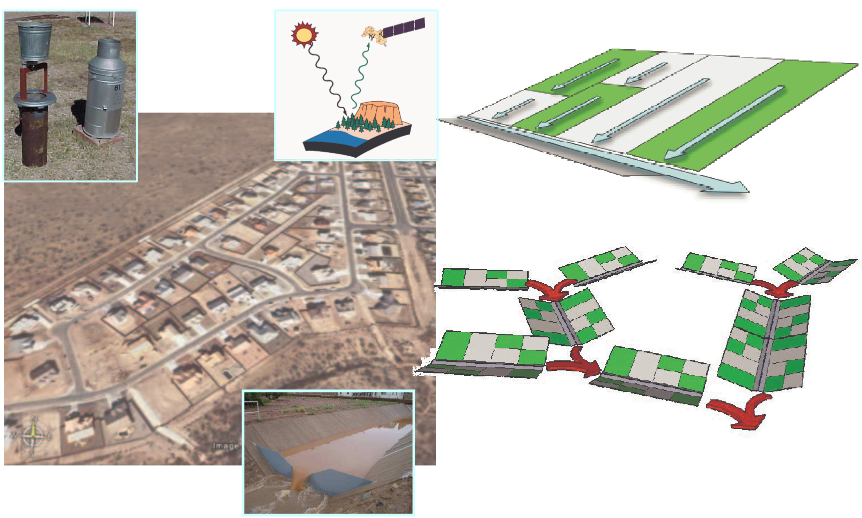
The Automated Geospatial Watershed Assessment tool (AGWA) is a geographic information systems (GIS) interface jointly developed by the USDA ARS, the U.S. Environmental Protection Agency, the University of Arizona, and the University of Wyoming to automate the parameterization and execution of the Soil Water Assessment Tool (SWAT) and KINEmatic Runoff and EROSion (KINEROS2) hydrologic models. The application of these two models allows AGWA to conduct hydrologic modeling and watershed assessments at multiple temporal and spatial scales. AGWA uses commonly available GIS data layers to fully parameterize, execute, and visualize results from both the SWAT and KINEROS2. Through an intuitive interface the user selects an outlet from which AGWA delineates and discretizes the watershed using a Digital Elevation Model (DEM) based on the individual model requirements. The watershed model elements are then intersected with soils and land cover data layers to derive the requisite model input parameters. AGWA can currently use STATSGO, SURRGO and FAO soils and national available NLCD, MRLC and GAP land cover/use data. Users are also provided the capability to use their own soil and land cover/use data. The chosen model is then executed, and the results are imported back into AGWA for visualization. This allows managers to identify potential problem areas where additional monitoring can be undertaken or mitigation activities can be focused. AGWA can difference results from multiple simulations to examine relative change from alternative of input scenarios (e.g. climate/storm change, land cover change, present conditions and alternative futures). The AGWA tool is being converted into an Internet-based service to provide ready access to environmental decision-makers, resource managers, researchers, and user groups. In addition, a variety of new capabilities are being incorporated into AGWA. They include pre- and post-fire watershed assessments options for user defined land cover change; implementation of stream buffer zones, simulation of nitrogen and phosphorus movement; and installation of retention and detention structures. AGWA is currently be used for watershed assessment and to support watershed planning. Applications include watershed-based planning for the Arizona Department of Environmental Quality, assessing the impact of energy development in Wyoming; assessing the impacts of landscape change in New York, Arizona, Oregon and Virginia; and analysis for alternative futures in the San Pedro River, Arizona. There are currently over 1500 registered AGWA users from 83 countries. For more information visit the AGWA website located at: http://www.tucson.ars.ag.gov/agwa/.



H2. Urbanization Impacts on Runoff and Recharge in Arid and Semiarid Regions

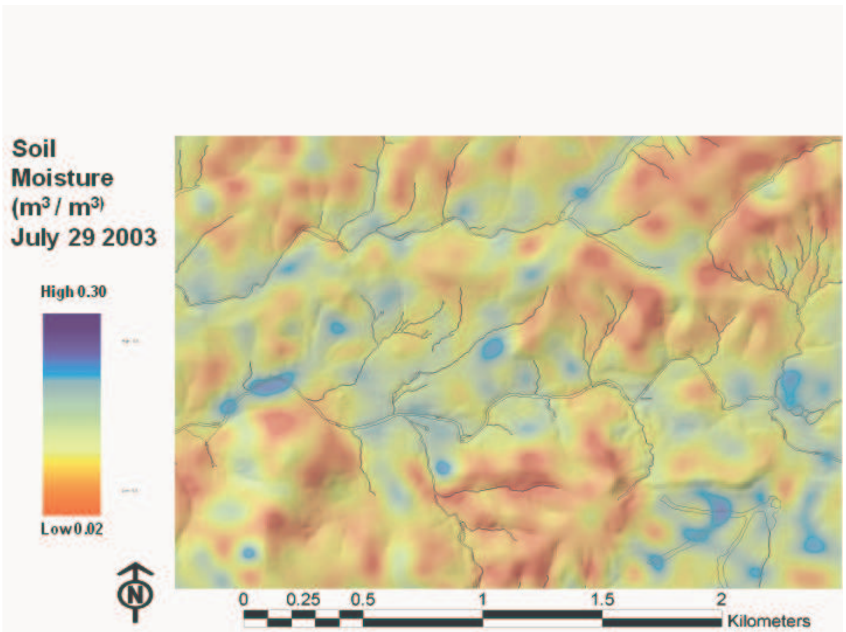
Urbanization of rangelands replaces natural surfaces with “built” surfaces – such as buildings, roads and parking lots – which are impervious to water infiltration. In addition, infiltration rates on remaining pervious surfaces can be significantly reduced due to compaction and grading. Managing the additional storm water due to urbanization to increase recharge is a critical management strategy that is being considered to meet increasing water demands in the desert southwest. To improve our ability to quantify increases in runoff from urbanization the SWRC in cooperation with the U.S. Geological Survey and the Upper San Pedro Partnership have carefully instrumented a pair of small watersheds. The upper watershed is in a natural undisturbed state on Ft. Huachuca and its outlet drains into the second watershed, which was recently developed as a residential subdivision. In addition to rainfall and runoff measurements, the watersheds are being characterized by a variety of both field and remotely sensed measurements. These include distributed infiltration measurements, high-resolution topography, the geometry and connectedness of developed surfaces and the acquisition of high-resolution remotely sensed imagery. Another objective of this research is to develop methods using remotely sensed data to estimate infiltration rates or adjustments to undisturbed rates for developed areas that are not impervious to enable extrapolation of findings to large areas of the southwest that have, and are, rapidly developing. This information is also being used to create and validate a conceptual urban computer model element for the KINEROS2 rainfall-runoff and erosion model and to develop methods to parameterize the urban element within the AGWA tool.

(Left) Ft. Huachuca/La Terreza watersheds, raingage, runoff flume, conceptualization of satellite remote sensing data acquisition. (Right) Simplified concept of a urban runoff element for the KINEROS2 rainfall-runoff computer model and detailed KINEROS2 developed watershed model representation.



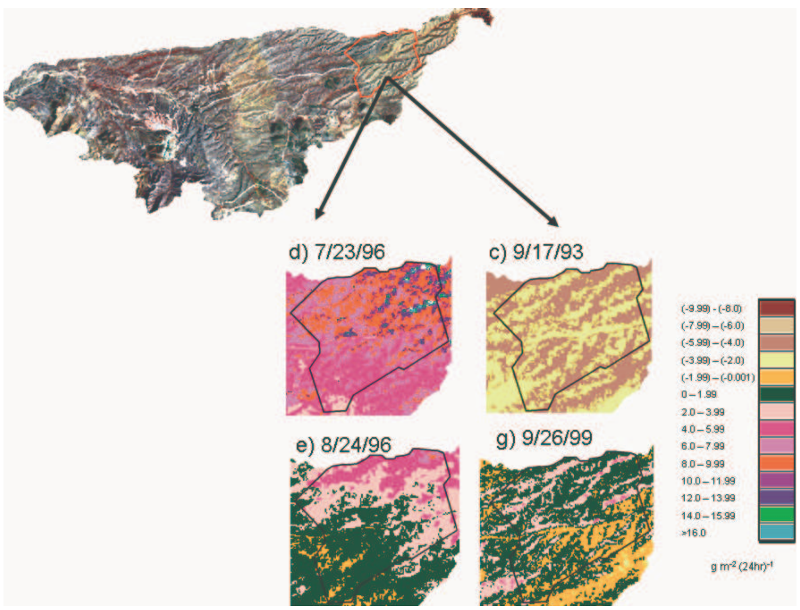
H3. Surface Soil Moisture Estimation Based on Satellite Images

Many resource management and action agencies have the need for information about root zone soil moisture in heterogeneous and inaccessible areas. A team of scientists banded together to develop a prototype soil moisture modeling system based on remote sensing technology, simulation models, and GIS. This team included scientists from the USDA ARS, US Army Engineer Research and Development Center (ERDC), the National Aeronautics and Space Administration (NASA) and University of Wyoming. SWRC scientists focused on mapping surface soil moisture (to 5 cm depth) at the 100-m resolution over watershed-size areas (1000-25000 km^2). Existing radar satellites may be capable of estimating soil moisture content over large areas and have several advantages over other techniques. These include the ability to `see through' clouds, and the ability to operate at night, in addition to covering vast areas at relatively high resolution. One aspect of the research effort involves ground-truthing soil moisture content at the time of satellite overpass. Another approach uses a physics based computer model to compute soil water content based on the received satellite signal. After surface soil moisture content is determined over large areas, it will be modeled forward in time and deeper in the soil using sophisticated NASA models that can predict root zone soil moisture between satellite overpass dates.



H4. Satellite-image based maps of semiarid grassland carbon dioxide flux

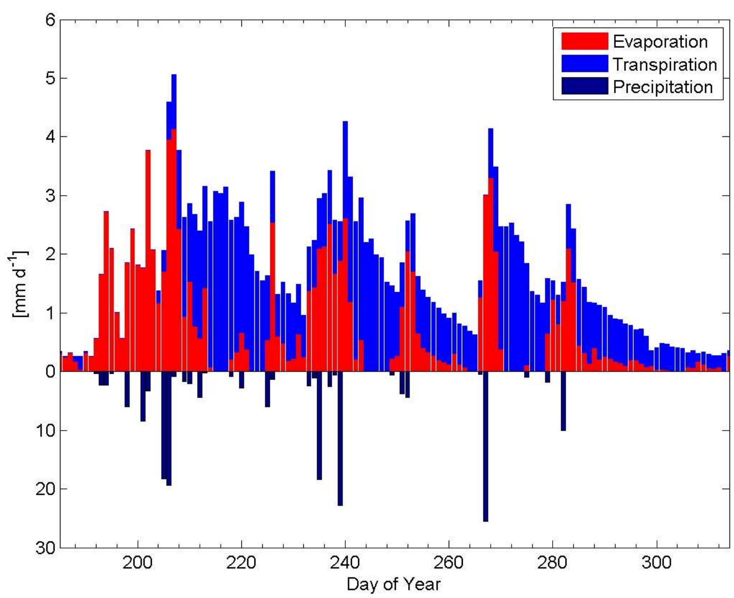
Increasing atmospheric levels of carbon dioxide (CO_2) and the potential impact on climate change has caused an increased effort to more accurately quantify terrestrial sources and sinks. Semiarid grasslands comprise a large portion of the world's rangeland ecosystem and may play a significant role in the carbon cycle. Grassland CO_2 fluxes are being measured in various places around the world as part of the ongoing effort to understand the global carbon budget. The WGEW contains instrumentation to monitor CO_2 flux over areas covering a few hundred meters. Using a combination of historical data available from this instrumentation, meteorological data and satellite imagery, scientists at the SWRC developed a model to estimate daily net CO_2 flux at a scale greater than can be obtained with tradition instrumentation. The use of this model to produce maps of distributed CO_2 flux for determining seasonal patterns of daily net CO_2 flux and annual net CO_2 flux has the potential to provide a better picture of both the current role and possible future role semiarid grasslands play in understanding the global carbon budget.



Grassland daily net CO_2 flux maps derived from Landsat TM imagery

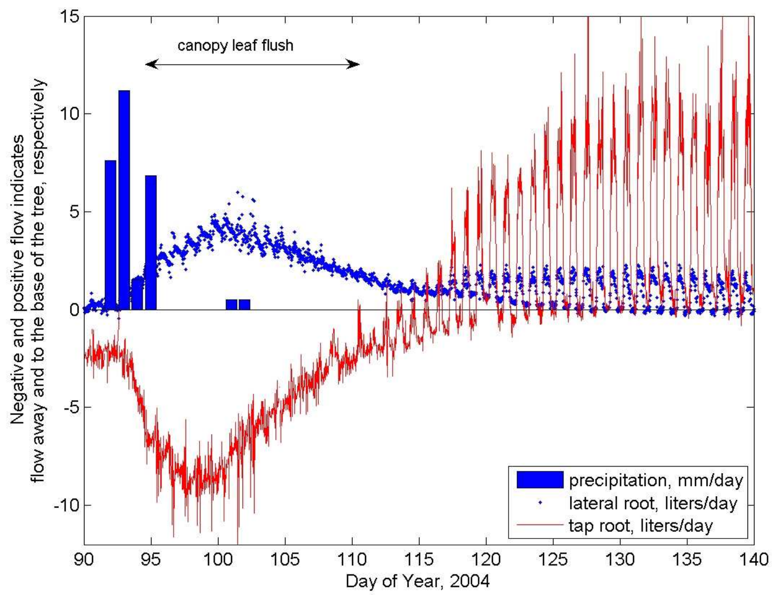
H5. Woody Plant Encroachment in Semiarid Regions

An important element to understand the consequences of woody plant encroachment in rangelands is to determine how the ratio of transpiration (T) to evapotranspiration (ET) is altered. The ratio of T/ET essentially tells us how much of the precipitation falling on an ecosystem is lost via non-biological processes like runoff and soil evaporation versus how much is acquired by the plants and used for plant growth. Scientists need data on E and T to test hypotheses about how this world-wide phenomenon of encroachment is altering the cycling of water and carbon in semiarid regions. Shown below is the partitioning of daily ET (total bar height) into soil evaporation and shrub transpiration for the 2004 growing season at the Lucky Hills Study Area, WGEW. Before the monsoon season began, both E and T were essentially zero. At the onset of the monsoon rains, E dominated ET as it took approximately ten days for the plants to recover from their down-regulated, dormant state and respond to the precipitation. Later, during interstorm periods, T was dominant and E was small. For the remainder of the growing season, E was significant only on, and shortly after, days with rainfall.



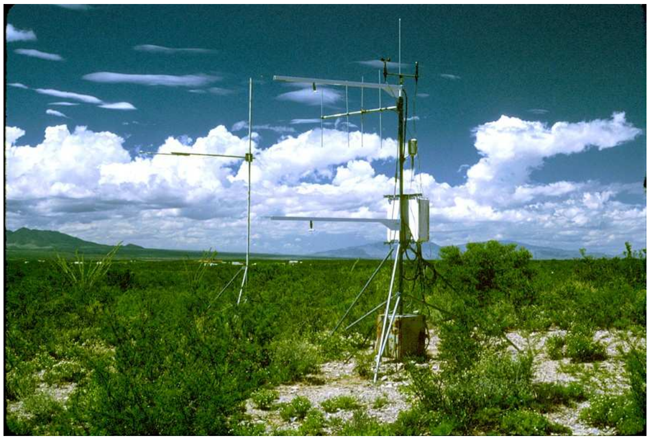
H6. Water "Banking" by Woody Plants

Recent studies have illuminated the process of hydraulic redistribution (HR), defined as the movement of soil moisture via plant root systems, but the long-term ecohydrologic significance of this process is poorly understood. We have investigated the HR by velvet mesquite in an upland savanna ecosystem on the SRER. Our goal was to quantify patterns of HR by mesquite roots and assess how this affects tree water use and productivity. We used the sap flow measurements to quantify flow in lateral and tap roots of mesquite. The response of a tree's large lateral or near-surface root and a deep, tap root to several days of rain are shown below. The mesquite responded to the rainfall with a positive lateral root flow and negative tap root flow. Since the trees had not come out of its winter dormancy, this moisture was effectively transported or "banked" deeper into the soil profile. After the canopy had leafed out, the flow in the roots became diurnal and much more positive indicating that the roots were supporting tree transpiration with the tap root likely using the water that was banked during its dormancy.



H7. Ecosystem Water Use Efficiency

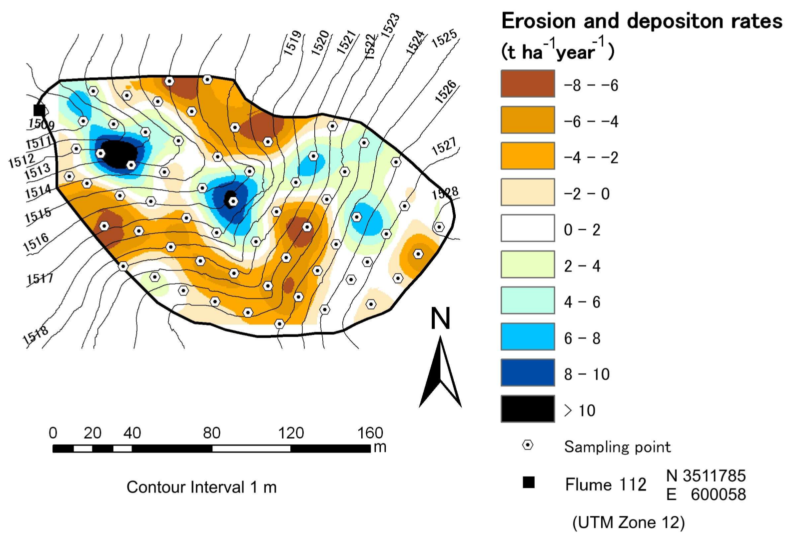
Ecosystem water use efficiency (EWUE) can be defined as the ratio of plant biomass produced to the amount of water used by the ecosystem to produce the plant material. The plant community that produces more plant material with the same amount of water has greater water use efficiency. In the arid rangeland areas of the western U.S., shrublands and grasslands are two of the major plant community types. Obtaining information on the relationships between plant communities and the amount of water used is critical to our understanding of how they function and interact. Shrublands have been increasing in some areas along with the loss of valuable grasslands. Knowledge about the EWUE of these two plant communities could help explain why this is occurring. Research on the WGEW in a shrub and grass land plant community is being conducted to investigate the production of plant material and the use of water in these diverse communities. Bowen ratio systems technology is being used to measure the movement of carbon into and out of the plant communities with carbon measured as carbon dioxide and water out as water vapor. The net uptake of carbon dioxide by the plants during photosynthesis and the subsequent production of plant material are used as a measure of plant biomass production. The measurement of water vapor leaving the plant communities represents water loss from evaporation from both the soil surface and from water leaving the plants during photosynthesis. Initial results are indicating that the grassland plant community is producing more plant material than the shrubland, with close to the same amount of precipitation input, making the grassland ecosystem more water use efficient. The warm season grass plants have a more efficient photosynthetic pathway to convert carbon dioxide into plant material than the shrub plants. This could explain some the higher EWUE of the grass plant community. The carbon dioxide concentration is increasing in the atmosphere and research has shown that the shrub plants are becoming more efficient at converting carbon dioxide into plant material as the concentration of carbon dioxide increases. As the carbon dioxide concentration continues to rise, the interaction between the grass and shrub plant communities is likely to change.



Bowen ratio system on the WGEW shrubland study site used to measure carbon dioxide and water vapor movement.

E1. Using Tracers to Quantify Erosion and Sediment Movement Within Walnut Gulch

Data on hillslope erosion rates in semi-arid rangelands are scarce. The WGEW provides an outdoor laboratory for evaluating and measuring erosion rates with different soils and vegetation regimes. Such data are used for developing and improving soil erosion models and for implementing national soil conservation programs. Current work at WGEW involves using new and innovative techniques for measuring the spatial distributions and rates of erosion on hillslopes. These techniques include the use of naturally occurring or anthropogenic isotopes, as well as special chemicals, rare earth elements, as tracers. The 137Cs isotope, which was deposited worldwide in conjunction with atmospheric nuclear bomb testing from the late 1950s and early 1960s, has been used to quantify hillslope erosion rates within WGEW. Samples of all soil series from across WGEW have been taken and will also be analyzed for ^{137}Cs concentrations. These values will then be used to compute medium-term historical soil erosion rates as a function of soil type and landscape position Rare earth element tracers are completely benign and require only miniscule application rates to be effective. They bond very well with fine soil material on the hillslopes, and thus make excellent sediment tracers that allow us to understand where sediment is generated and how the sediment moves within the watersheds. This work relies also on the measurements of sediment leaving the small watersheds, such as Lucky Hills and Kendall.



Map of spatial distribution of soil erosion for a small sub-watershed within WGEW based of data from ^{137}Cs measurements.

E2. A Rangeland Hydrology and Erosion Model

Government agencies have emphasized the need to provide sound, science-based technology to model and predict the benefits of conservation technical assistance, rangeland hydrology and erosion for National Resource Inventories, and for Ecological Site development. The need and ability to monitor and assess rangeland conditions is an important function for land managers and conservationists across the western United States. On rangelands, it is imperative that hydrologic components are linked with erosion dynamics and ecological functions in the plant community. SWRC is developing a new Rangeland Hydrology and Erosion Model (RHEM) for inclusion as a module in a comprehensive agency-wide erosion prediction and conservation planning technology for water and wind erosion. Central to this effort is a process-based hydrologic and soil erosion model, development of algorithms for parameterizing the model from system state assessments such as the National Resource Inventory or Ecological Site Descriptions, and coupling an ecological/plant productivity component. The end product will be a multi-tiered hydrologic and soil erosion prediction technology based on process-based hydrologic and erosion science. The work will be undertaken in two phases. Phase 1: A model will be developed for making estimates of runoff, soil erosion, and sediment yield rates as a function of soil, slope, and plant community and condition for single storms as chosen by the user. Data for parameterizing, testing and validating the model will come primarily from past experiments such as The Interagency Rangeland Water Erosion Team experiments of 1990-93 which included 156 plots at 26 sites in 10 western states of the US, the WEPP rangeland field experiments of 1988-99 which included 102 plots at 20 sites in 9 western states, and long-term small watershed data from the WGEW. Phase 2: The model will be expanded to include annualized and individual storm estimates of runoff, soil erosion, and sediment yield rates as a function of soil, slope, and plant community conditions. This phase will involve the use of weather generators, plant models, and evapotranspiration routines. Both web and stand-alone interfaces will be constructed.

A typical rangeland site for applying the new Rangeland Hydrology and Erosion Model

E3. Effects of Rangeland Fire on Runoff and Erosion Rates on Semiarid Ecosystems

Fire is a natural and important part of the regime of many ecosystems, including semi-arid southwestern grasslands. Although there has been considerable research conducted on the ecological effects of fires on rangelands, there has been relatively little research on the effects of fire on runoff and erosion rates on semi-arid ecosystems. Given that wild fires in semi-arid regions of the southwestern US generally occur in the few months before the onset of summer rainfall, the loss of cover caused by a fire along with the high intensity thunderstorms typical of summer rainfall could significantly increase runoff and erosion. Experiments are being conducted at wildfire sites on grasslands and oak woodlands in the San Raphael Valley and the Empire Ranch near Sonoita in southeastern Arizona to quantify immediate post fire runoff and erosion and the duration of the recovery to pre-fire conditions. The Walnut Gulch Rainfall Simulator (WGRS) is being used to apply rainfall at a range of intensities from 12 to 180 mm/hr on large (2 x 6 m) and small (.75 m^2) plots at the fire sites and unburned sites with the same vegetation and soil association. Among the variables being measured are runoff and sediment, flow velocity, ground and canopy cover, and microtopography. Results show that immediately after a fire, runoff may increase slightly but erosion increases significantly. Oak woodland vegetation tends to have larger increases in erosion than grasslands due to the more efficient manner in which water flows off the site. The erosion process on unburned grasslands appears to be dominated by raindrop splash and deposition while on oak woodlands deposition is at a minimum. Fire affects the erosion process by reducing ground cover thus increasing raindrop detachment and decreasing flow resistance which in turn increases the ability of the runoff to transport more sediment. Recovery of the runoff and erosion processes to pre-fire conditions ranges from three to four years.

Rainfall simulation with the WGRS on a grassland site

E4. Sediment Transport in Ephemeral Sand-bed Channels

Vast areas of rangeland in the semiarid southwestern US are characterized by ephemeral channels that transport sediment during occasional flows. Sediment, ranging in size from silts and clays to large gravels and cobbles, is transported during channel runoff associated with intense summer thunderstorms. Field experiments are being conducted on the WGEW to quantify sediment yields from semiarid watersheds and to improve our understanding of sediment transport processes. Pit traps have been added to the long-term runoff and sediment measurement stations in the Lucky Hills subwatersheds to contain coarse sediment that is transported during flash flows. This sediment is dried, sieved, and weighed to characterize the particle size distributions with respect to discharge. In addition, individual sediment particles are being tracked using an RFID (radio frequency identification) system. After a flow event, particles are located, and their position measured with a GPS system. The tracking system consists of transponders, an antenna, a reader, and software. Data gathered will be useful for developing sediment transport equations and improving mathematical models for simulating sediment transport under natural runoff conditions.

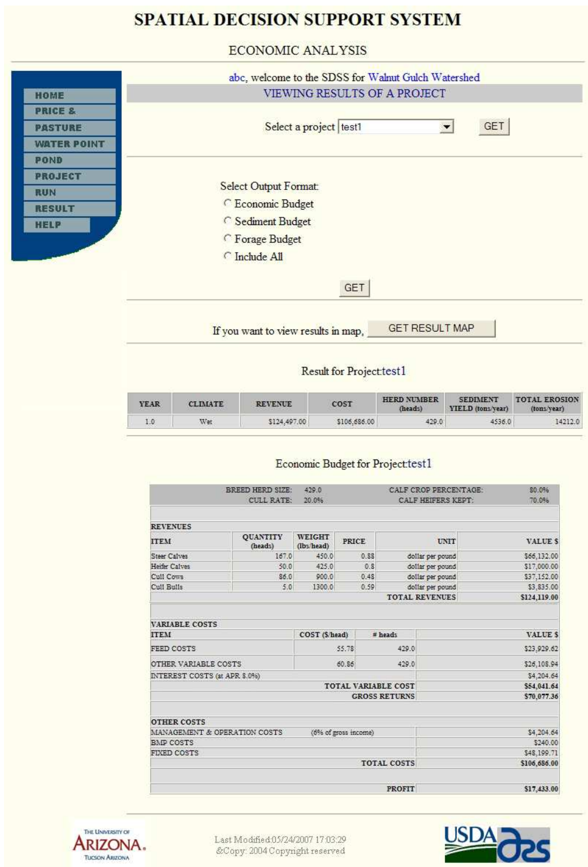
Santa Rita runoff measuring flume with traversing slot sediment sampler showing pit trap filled with sediment after a flow.

RFID transponder and synthetic rocks.

Synthetic rocks located using RFID.

E5. Economic analysis of rangeland management

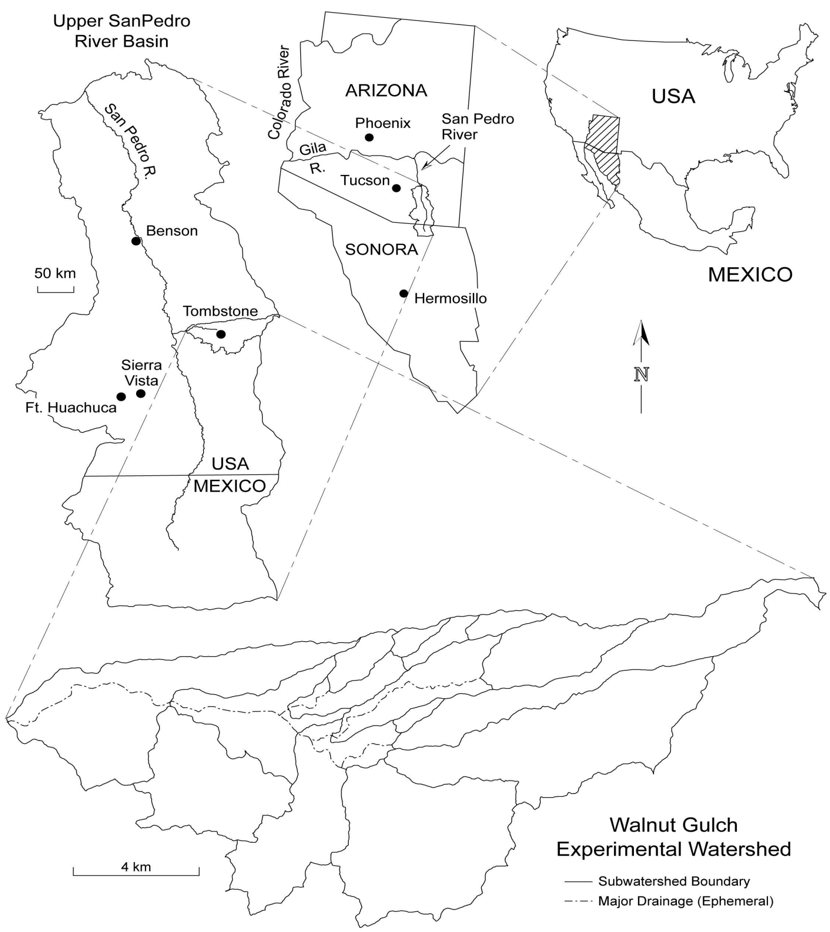
Implementation of soil and water conservation measures is often limited by the ability of such measures to justify the investment. With the University of Arizona, we have developed a prototype Spatial Decision Support System to evaluate how to integrate economic information with quantitative estimates of the physical effects of management alternatives. The prototype system integrates a mapping tool to locate conservation practices and structures, a budget generator, a simple erosion estimator based on the RUSLE2 model, and a constrained optimization model through a web accessible interface. The Walnut Gulch Experimental Watershed is treated as if it were a single ranch. The optimization model mimics a rancher selecting the stocking rate and other management practices for each pasture to maximize the rancher's net returns subject to constraints on the amount of erosion on the watershed. The prototype can be used to demonstrate the cost of constraints on the set of management alternatives available to the rancher. The development of economic tools to assess rangeland management will continue in parallel with the development of other models and tools. The prototype Spatial Decision Support System is available for review at http://tucson.ars.ag.gov/sdss/.



WALNUT GULCH EXPERIMENTAL WATERSHED

Description

The Walnut Gulch Experimental Watershed (WGEW) encompasses the 150 square kilometers in southeastern Arizona, U.S.A. that surrounds the historical western town of Tombstone (31^{o} 42'N, 110^{o} 03'W). The watershed is contained within the upper San Pedro River Basin which encompasses 7600 square kilometers in Sonora, Mexico and Arizona. The watershed is representative of approximately 60 million hectares of brush and grass covered rangeland found throughout the semi-arid southwest and is a transition zone between the Chihuahuan and Sonoran Deserts. Elevation of the watershed ranges from 1250 m to 1585 m MSL. Cattle grazing is the primary land use with mining, limited urbanization, and recreation making up the remaining uses. Walnut Gulch, being dry about 99% of the time, is an ephemeral tributary of the San Pedro River.



Location of Walnut Gulch Experimental Watershed

History

The Walnut Gulch Experimental Watershed was selected as a research facility by the United States Department of Agriculture (USDA) in the mid-1950's. Prior appropriation water laws resulted in conflicts between upstream land owner conservation programs and downstream water users. Technology to quantify the influence of upland conservation on downstream water supply was not available. Thus, scientists and engineers in USDA selected the Walnut Gulch watershed for a demonstration/research area which could be used to monitor and develop technology to address the problem. In 1959, facilities needed for soil and water research in the USDA were identified in a United States Senate document. This report created the national program of USDA-ARS research on soil and water processes. The Southwest Watershed Research Center in Tucson, Arizona was created in 1961 to administer and conduct research on the Walnut Gulch Experimental Watershed. Subsequent legislation (Clean Water Legislation of the 1970's) added water quality thrusts to the research program.

Research on the Walnut Gulch Experimental Watershed is currently conducted within the definitions of the Agricultural Research Service's National Programs. All SWRC research conducted at the watershed is within the Water Resource Management Program of the Natural Resources and Sustainable Agricultural Systems Category.

Walnut Gulch Experimental Watershed is also a partner in the ARS Experimental Watersheds and Watershed Program. Fourteen ARS research centers are operating over 100 long-term research watersheds. These exceptional outdoor laboratories make major contributions to national scale projects including GEWEX, AMERIFLUX, ARS Rangeland Carbon Flux, USDA-NRCS Soil Climate Analysis Network (SCAN), and the Surface Radiation Network (SURFRAD).

The long-term data bases and substantial infrastructure of the Walnut Gulch Experimental Watershed have attracted collaborative efforts with other federal and state agencies, universities, and foreign researchers. Collaborative research efforts have included ARS Hydrology Laboratory, ARS Water Conservation Laboratory, ARS Jornada Experimental Range, USDA Natural Conservation Research Service, US Geologic Survey, NASA, Arizona Department of Water Resources, Cochise County, University of Arizona, Arizona State University, and researchers from Mexico, Australia, Europe, Africa, and Asia.

Walnut Gulch Experimental Watershed is one of two ARS experimental watersheds on western rangelands and the only one on southwest semi-arid rangelands. Walnut Gulch Experimental Watershed has developed a reputation as the leading semi-arid research watershed in the world. The land comprising Walnut Gulch Experimental Watershed is under the ownership and control of Federal agencies, State of Arizona, private land owners or leaseholders. The research activities and access to the field sites are arranged in cooperation with the appropriate federal and state agencies and the private landowners or leaseholders.

SWRC has designed and developed instrumentation to specifically measure and monitor the hydrology of these semi-arid rangelands and has used this instrumentation to develop extensive, world renowned databases of the hydrology of semi-arid rangelands. From these sources SWRC scientists have produced over 1500 manuscripts and several computer simulation models so that the hydrologic knowledge gained can be transferred to a variety of users. Some of the hydrologic models developed, in whole or in part, include CREAMS, RUSLE, WEPP, KINEROS, EPIC, SPUR and CLIMATE. A complete list of publications, models and databases is available from the SWRC.

Instrumentation

The original rainfall and runoff instrumentation on Walnut Gulch Experimental Watershed was installed in 1954-55. The initial network of 20 precipitation recording gauges was expanded in the early 1960's to the 88 gauge network currently in place on the watershed. Five supercritical precalibrated flumes were constructed prior to 1955 to measure runoff from the heavily sediment laden ephemeral streams. All five flumes failed or were badly damaged within two years. They failed for hydrologic, hydraulic, and structural reasons. Following extensive hydraulic model research at the Agricultural Research Service (ARS) Outdoor Hydraulic Structures Laboratory in Stillwater, Oklahoma, the original five flumes were rebuilt using a design known as the Walnut Gulch Supercritical flume. Six additional flumes were added later.

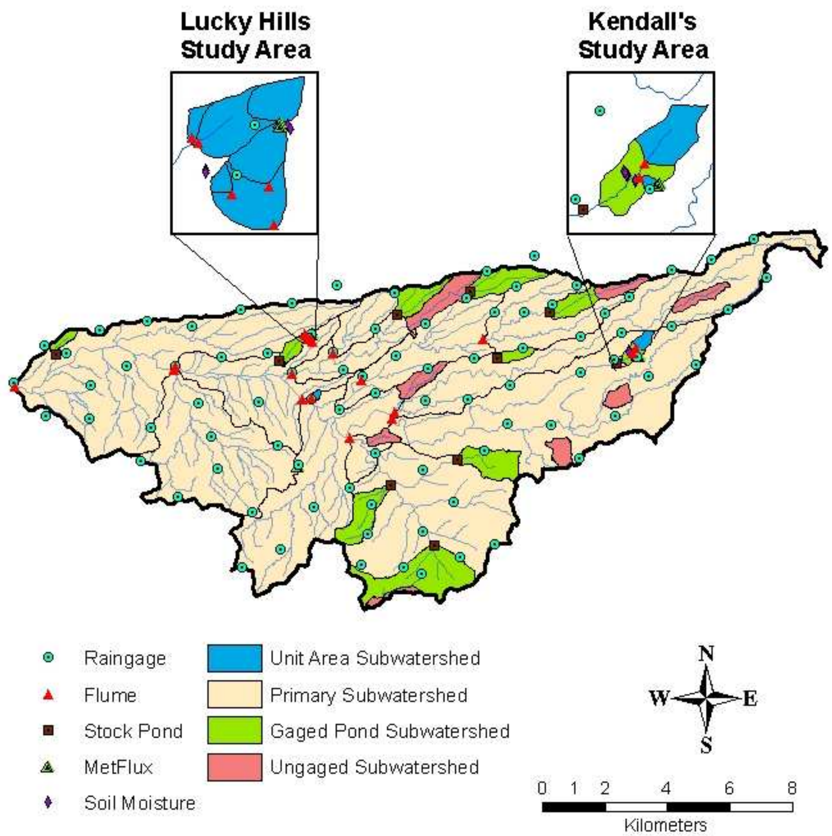
Hydro-meteorologic and soil erosion/sedimentation data are collected from 125 instrumented installations on WGEW. Precipitation is measured with a network of 88 weighing-type recording raingauges arranged in a grid throughout the watershed. Various runoff measuring structures are used to monitor small watershed (< 40 ha) runoff. These structures include a broad-crested V-notch weir, H-flumes, and Santa Rita supercritical flow flumes. Currently there are 8 small watersheds being monitored. Runoff from watersheds greater than 40 ha is measured using either livestock watering ponds or large supercritical flow flumes. The largest flume, at the outlet of the Walnut Gulch Experimental Watershed has a flow capacity of 650 cubic meters/sec. There are 10 stock pond watersheds and 11 large flume watersheds currently being monitored. Sediment from the small watersheds monitored with the V-notch weir or H-flumes is sampled with automatic pump samplers. Sediment from watersheds equipped with the Santa Rita supercritical flow flumes is sampled with a total-load automatic traversing slot sampler. Meteorological, soil moisture and temperature and energy flux measurements are made at two vegetation/soil complexes. Permanent vegetation plots and transects have been established to evaluate the impacts of management practices and global change on vegetation.

Because of the growing obsolescence of existing rainfall and runoff mechanical sensors with analog data-recording, impending reduction in staff and the labor intensive requirements to collect and process the charts, SWRC began a multi-year effort in 1996 to fully reinstrument Walnut Gulch Experimental Watershed with electronic sensors and digital data-logging capability combined with radio telemetry to allow remote data transmission and monitoring. This reinstrumentation greatly enhances our research and cooperative capabilities as well as maintaining the viability of hydrologic data collection and long term continuous record.

A high resolution, self contained, simple raingauge was designed by SWRC field technicians that has been laboratory and field tested under simulated and natural rainfall. The gauge consists of a precision, temperature compensated load cell, which measures the weight of a platform-mounted container that collects water during a precipitation event. As water accumulates in the container, the voltage output from the load cell changes. The programmed datalogger samples voltage every second and averages at 1 minute interval. To minimize data storage requirements and transmission time, only time stamps and voltages commensurate with precipitation detectable to 0.25mm precision are recorded. The capacity of the raingauge is 200mm (8 in) before it must be serviced. A very unique feature of the raingauge design is that all electronics, data logger, and radio/modem components are housed in a metal below-ground cylinder, thus reducing vandalism, lightning interference, and temperature effects.

The conversion from analog to digital output of the runoff measuring instruments was done by attaching a precision linear potentiometer to the output gear shaft of the currently used water-level recorders. The voltage output from the potentiometer is collected by a data logger which averages 1-second samples at 1-minute intervals and records flow data (time stamp and voltage) only when a minimum depth threshold has been exceeded (0.003m at small flumes, 0.015m at large flumes and stock tanks). At sites where automatic sediment sampling is done, the data logger controls the operation of the sampler and records each sample's begin time and total time to collect the sample. Samples are collected when flow depth is greater than 0.06m.

On a daily basis, all locations are automatically and sequentially queried and data are transmitted to a dedicated computer at the Tombstone field office. Data are archived, used to generate daily reports and written to the Tucson SWRC network server. Daily data radio transmission time and size can range from a minimum of 1.5 hour and 300 KB for non-event days to over 4 hours and 1MB for a day with rainfall/runoff.

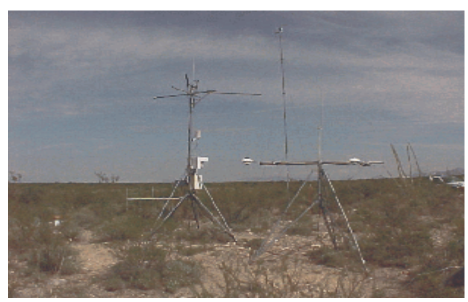


Walnut Gulch Experimental Watershed instrumentation.

Recording Weighing Bucket Raingauge

"Santa Rita" flume with traversing slot sediment sampler

Walnut Gulch Supercritical flow flume



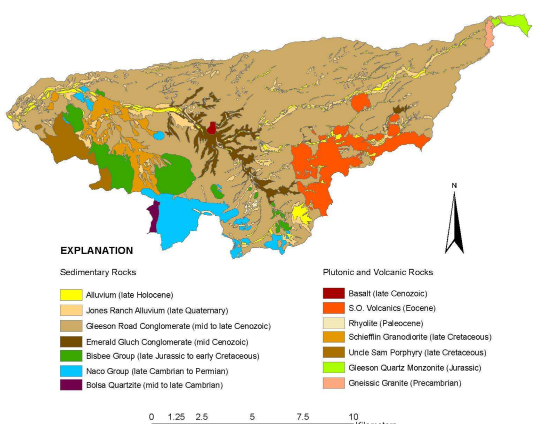
Meteorological station

Geology

The Walnut Gulch Experimental Watershed is located primarily in a high foothill alluvial fan portion of the larger San Pedro River watershed. The surface geology is dominated by fan deposits, but in southern and southeastern parts of WGEW a complex history of tectonism has resulted in igneous-intrusive and volcanic rocks, and highly disturbed Paleozoic and Mesozoic rocks in the Tombstone Hills. Cenozoic alluvium is very deep and is composed of coarse-grained fragmentary material, the origin of which is readily traceable to present-day mountain flanks on the watershed. The alluvium consists of clastic materials ranging from clays and silts to well-cemented boulder conglomerates with little continuity of bedding. This alluvial fill material is more than 400 m deep in places and serves as a huge ground water reservoir. Depth to ground water varies greatly in the watershed ranging from 50 m at the lower end to 145 m in the central parts of the watershed.

Topographic expression of the alluvium is that of low undulating hills dissected by present stream channels whose routes are controlled by geologic structures. Upland slopes can be as great as 65% while slopes in the lower lying areas can be as small as 2 to 3%. Major channel slopes average about 1% with smaller tributary channels averaging 2 to 3%. The remaining mountainous portion of the watershed consists of rock types ranging in age from pre-Cambrian to Quaternary, with rather complete geologic sections. Rock types range from ridge-forming limestone to weathered granite intrusions. The geologic structural picture of the mountainous area is complex, with much folding and faulting. This folding and faulting, along with igneous intrusions has resulted in large areas of shattered rock, which influence the watershed hydrology.

The watershed hydrology is, in places, controlled by past geologic events and structures. Intrusive igneous dikes in the Tombstone Hills influence ground water movement and change the surface drainage. The Schieffelin granodiorite alters the course of the Walnut Gulch main stream, acts as a probable ground water barrier between the ground water in the Tombstone Hills and the deep alluvial basin, and has caused numerous small perched water tables along its perimeter. Highly compacted conglomerate beds greatly alter the path of stream channels and, in places, divert streams at more than right angles. High angle faults form new paths for streamflow, making channels arrow-straight in some places and causing diversions in others.



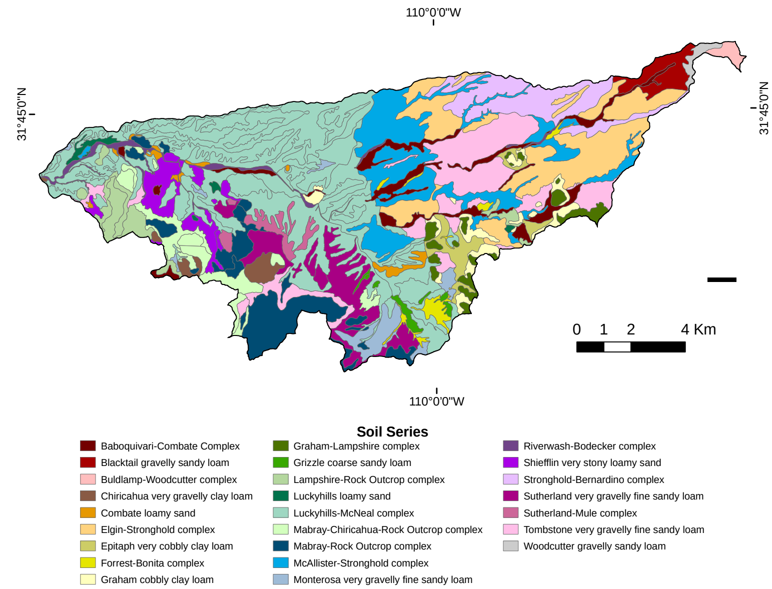
Soils

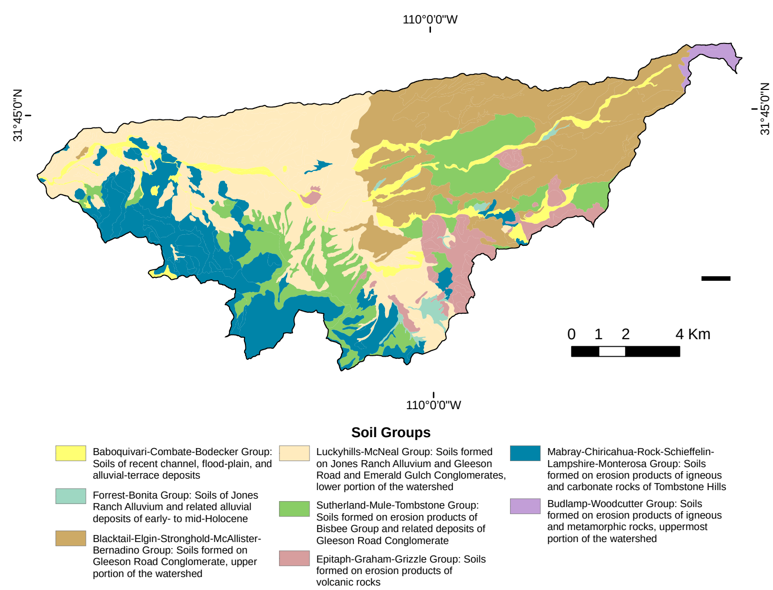
Soils of the Walnut Gulch Experimental Watershed are dominantly sandy, gravely loams that vary from deep, relatively mature, and well drained soils to thin, immature soils. All soils are strongly reflective of a semiarid climate and the parent material upon which they have formed, but vary in texture and composition with landform and the length of time that the surface has been exposed to biochemical weathering. The soil profile can contain up to 60% gravel in the uppermost 10 cm and less than 40% in the underlying horizons. Soil surface rock fragment cover (erosion pavement) can range from nearly 0% on shallow slopes to over 70% on the very steep slopes.

Geology exerts a major control on soil distribution, maturity, thickness, and permeability. Most soils of the watershed are unconsolidated, but locally near-surface soil horizons may be moderately to well consolidated owing to the deposition of calcrete. Where accelerated erosion of the last century has not stripped the upper horizons, soils tend to be thick, mature loams rich in sand and gravel and of high carbonate (calcrete) content. The warm, semiarid climate results in relatively slow biochemical reduction of bedrock. Soils of Holocene age are typically coarse, permeable, and poorly developed. Surfaces that were first exposed to weathering processes prior to Holocene time are deeper, more mature, and generally more argillaceous than the younger soils. Time has been inconsequential relative to soil-forming processes in areas of bare rock. In contrast, where surfaces of fan terraces remain and have been exposed to weathering processes throughout the late-Cenozoic and Quaternary periods, time has been sufficient to yield deep, argillic soils, even where climatic conditions have been generally arid to semiarid. Nowhere in the watershed has time been adequate to yield clayey soils, rich in iron and aluminum oxides and hydroxides, that are indicative of long-term warm, moist conditions.

Over two dozen soil series have been identified on the watershed. The major soil series presently defined on this area are Blacktail (fine, mixed, thermic, Aridic Argistolls), McAllister (fine-loamy, mixed, thermic, Ustollic Haplargids), Elgin (fine, mixed, thermic, Ustollic Paleargids), Sutherland (loamy-skeletal, carbonatic, thermic, shallow Ustollic Paleorthids), Monterosa (loamy-skeletal, mixed, thermic, shallow Ustollic Paleorthids), Stronghold (coarse-loamy, mixed, thermic, Ustollic Calciorthids), Luckyhills(coarse-loamy, mixed, thermic, Ustochreptic Calciorthids).

The soil series can be combined into soil groups with similar geologic parent material and/or geomorphic surfaces. The Baboquivari-Combate-Bodecker Group consists of permeable, immature soils formed on late-Holocene channel, flood-plain, and alluvial-terrace deposits in all parts of the watershed. Mature, poorly transmissive soils of the Forrest-Bonita Group are derived principally from early- to mid-Holocene cienega and inset deposits of alluvium. Deep sandy gravel loams of the Blacktail-Elgin-Stronghold-McAllister-Bernardino Group occur on beds of conglomerate. The soils of the Luckyhills-McNeal Group tend to be sandy and gravelly loams that are immature compared with soils where rilling and gully erosion have been less extensive. The Sutherland-Mule-Tombstone soils are very gravelly, mature loams that typically contain well developed pedogenic calcrete. Volcanic-terrain soils of the Epitaph-Graham-Grizzle Group are mostly thin, clay-rich loams containing abundant gravel and cobble clasts of basalt or andesite and tuff. Most soils of igneous and carbonate rocks in the Tombstone Hills, the Mabray-Chiricahua-Rock-Schieffelin-Lampshire-Monterosa Group, are very immature, shallow gravel and cobble loams. In headwater areas of the watershed are shallow clay-, sand-, and gravel-loam soils of the Budlamp-Woodcutter Group.


110°0'0"W
31°45'0"N
31°45'0"N
0 1 2 4 Km
110°0'0"W
Soil Series
Baboquivari-Combate Complex
Blacktail gravelly sandy loam
Buldlamp-Woodcutter complex
Chiricahua very gravelly clay loam
Combate loamy sand
Elgin-Stronghold complex
Epitaph very cobbly clay loam
Forrest-Bonita complex
Graham cobbly clay loam
Graham-Lampshire complex
Grizzle coarse sandy loam
Lampshire-Rock Outcrop complex
Luckyhills loamy sand
Luckyhills-McNeal complex
Mabray-Chiricahua-Rock Outcrop complex
Mabray-Rock Outcrop complex
McAllister-Stronghold complex
Monterosa very gravelly fine sandy loam
Riverwash-Bodecker complex
Shiefflin very stony loamy sand
Stronghold-Bernardino complex
Sutherland very gravelly fine sandy loam
Sutherland-Mule complex
Tombstone very gravelly fine sandy loam
Woodcutter gravelly sandy loam


110°0'0"W
31°45'0"N
31°45'0"N
0 1 2 4 Km
110°0'0"W
Soil Groups
Baboquivari-Combate-Bodecker Group: Soils of recent channel, flood-plain, and alluvial-terrace deposits
Forrest-Bonita Group: Soils of Jones Ranch Alluvium and related alluvial deposits of early- to mid-Holocene
Blacktail-Elgin-Stronghold-McAllister-Bernadino Group: Soils formed on Gleeson Road Conglomerate, upper portion of the watershed
Luckyhills-McNeal Group: Soils formed on Jones Ranch Alluvium and Gleeson Road and Emerald Gulch Conglomerates, lower portion of the watershed
Sutherland-Mule-Tombstone Group: Soils formed on erosion products of Bisbee Group and related deposits of Gleeson Road Conglomerate
Epitaph-Graham-Grizzle Group: Soils formed on erosion products of volcanic rocks
Mabray-Chiricahua-Rock-Schieffelin-Lampshire-Monterosa Group: Soils formed on erosion products of igneous and carbonate rocks of Tombstone Hills
Budlamp-Woodcutter Group: Soils formed on erosion products of igneous and metamorphic rocks, uppermost portion of the watershed

Vegetation

Major watershed vegetation includes the grass species of black grama (Bouteloua eriopoda), blue grama (B. gracilis), sideoats grama (B. curtipendula), bush muhly (Muhlenbergia porteri), and Lehmann lovegrass (Eragrostis lehmanniana); and shrub species of creosote bush (Larrea tridentata), white-thorn (Acacia constricta), tarbush (Flourensia cernua), snakeweed (Gutierrezia sarothrae), and burroweed (Aplopappus tenuisectus). These represent the two main vegetation structural types, "shrub-dominated" and "grass-dominated" on WGEW. Shrub-dominated indicates 20% or more of site vegetation cover contributed by whitethorn acacia, creosote bush and tarbush, which together constitute the bulk of total vegetation cover at such sites. Grass-dominated refers to open sites with widespread, appreciable grass cover and indicates less than 15% of site vegetation cover contributed by shrubs, primarily species other than white-thorn, creosote and tarbush such as mormon tea (Ephedra trifurca) and soaptree yucca (Yucca elata).

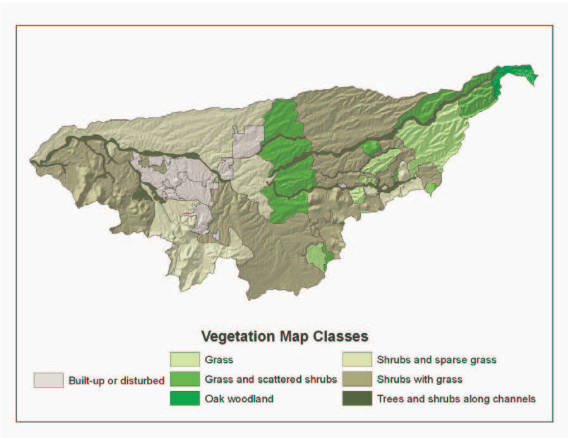
Native and exotic grasses are found at all elevations throughout WGEW. Important native forage species include black grama, sideoats grama, slim tridens and bush muhly. The most widespread invasive species is Lehmann lovegrass appearing between 1967 and 1994 and establishing in disturbed areas such as road right-of-ways. Woody vegetation at WGEW consists of shrubs, subshrubs and trees. Prominent shrub species included whitethorn acacia, creosote bush and tarbush. Common subshrubs include desert zinnia (Zinnia acerosa), mariola (Parthenium incanum) and fairy-duster (Calliandra eriophylla). Trees are found along limited riparian zones and in open woodland at higher elevations including mesquite, oak and juniper species. Other vegetation life forms at WGEW include annual and perennial forbs, cacti, and other xerophytes including yucca and agave species. These typically form a small portion of total vegetative cover, although forbs can be transiently abundant following sufficient precipitation.

Although historical records indicate that most of the Walnut Gulch Experimental Watershed was grassland approximately 100 years ago, shrubs now dominate the lower two-thirds of the watershed. However, since 1967 there is no evidence of widespread shift from grass dominated to shrub dominated conditions at WGEW. In fact, vegetation has changed very little overall in total cover and composition. Any ongoing vegetation change appears to be incremental rather than wholesale.

Total absolute vegetation cover is spatially variable and typically low in this semiarid area. Shrub canopy ranges between 30 to 40% on shrub-dominated areas and grass canopy cover ranges from 10 to 80% on grass-dominated sites. Vegetation spatial distribution is closely linked to soil type and variations in annual and August precipitation. Average annual herbaceous forage production is approximately 1200 kg/ha.

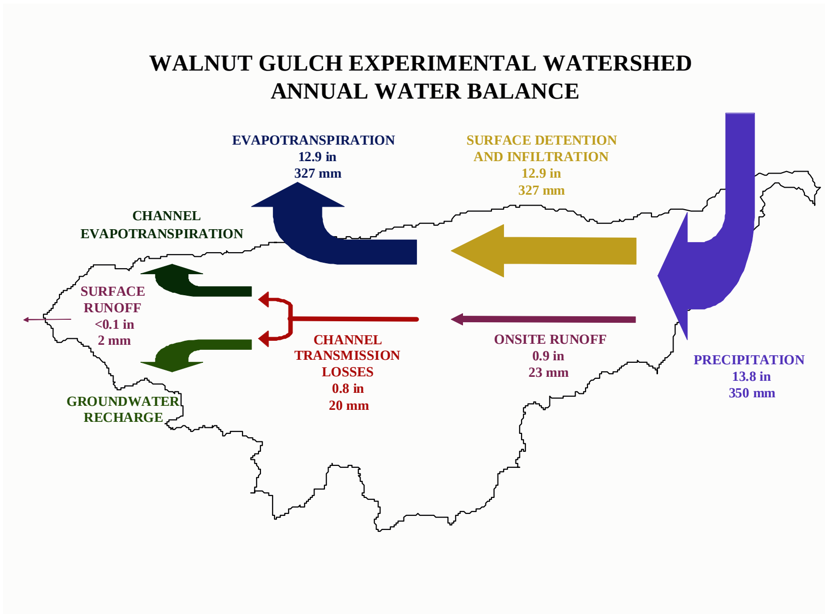
Shrub dominated lower part of watershed.

Grass dominated upper part of watershed.



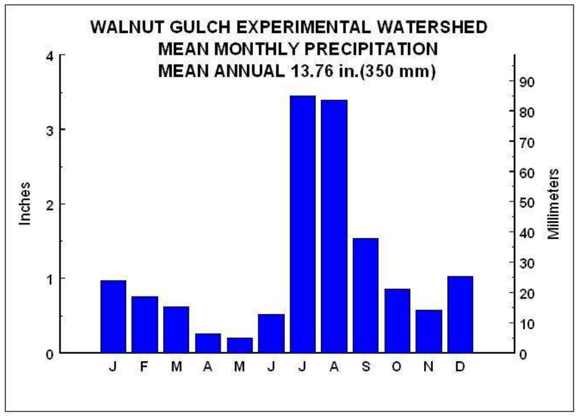
Water Balance

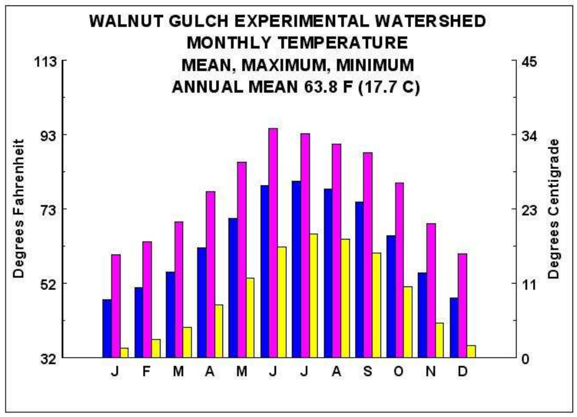
The Walnut Gulch Experimental Watershed water balance, although variable from year to year as well as across the area, is obviously controlled by precipitation. The annual water balance is illustrated for average conditions. Given the average 350 mm input precipitation, approximately 327 mm is detained on the surface for subsequent infiltration. Essentially all of the infiltrated moisture is either evaporated or transpired by vegetation back to the atmosphere. Based on data collected from small watersheds, less than 1.5 hectare, approximately 23 mm of the incoming precipitation is in excess of that which is intercepted and/or infiltrates. We refer to this as "onsite runoff". As the runoff moves over the land surface and into dry alluvial channels, transmission losses begin. Approximately 20 mm of transmission losses occur and about 2 mm of surface runoff is measured at the watershed outlet. The 20 mm of transmission losses result in some ground water recharge and some evaporation and transpiration from vegetation along the stream channels. Quantities for ground water recharge and evaporation and transpiration of channel losses are not shown because their quantification is difficult and very site specific. This is an area of active research. The geology along and beneath the stream channels create some reaches that are underlain by impervious material, whereas in other locations, the channels extend to regional ground water and permit appreciable recharge. Where the channels are underlain by impermeable material, riparian aquifers connected to the channels support phreatophytes. Runoff from the entire watershed is about 2 mm.

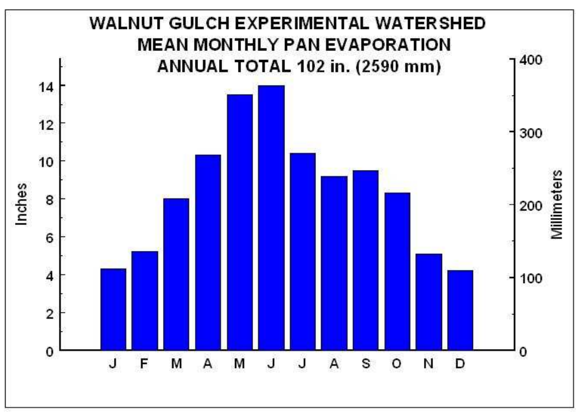


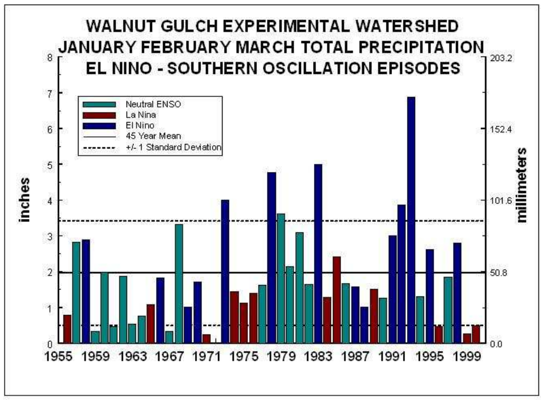
Climate

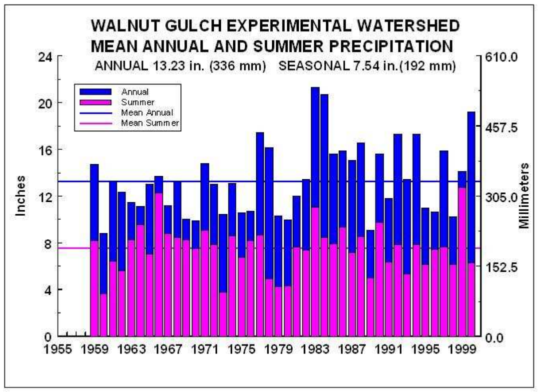
Walnut Gulch Experimental Watershed lies in the transition zone between the Sonoran and the Chihuahuan Deserts. The climate is classified as semi-arid, with mean annual temperature at Tombstone of 17.7°C and mean annual precipitation of 350 mm. On average there are 53 days of precipitation per year and most accumulation is as rainfall. The precipitation regime is dominated by the North American Monsoon with slightly more than 60% of the annual total coming during July, August and September; about 1/3 coming during the six months October through March. Summer events are localized short-duration, high-intensity convective thunderstorms driven by the intense solar heating of the land surface and moisture inputs from the Gulf of Mexico and Gulf of California. Winter storms are generally slower moving, frontal systems from the Pacific Ocean. These frontal systems generate longer duration and lower intensity precipitation that covers larger areas. The two opposite phases of the ocean-atmosphere phenomenon El Nino-Southern Oscillation (ENSO), referred to as El Nino and La Nina, affect winter precipitation with greater than normal precipitation during El Nino periods and less than normal precipitation during La Nina episodes. Virtually all runoff is generated by summer thunderstorm precipitation and runoff volumes and peak flow rates vary greatly with area and on an annual basis. Potential evaporation (Class A USWB pan) is approximately 260 cm per year which is nearly 7.5 times the annual precipitation.

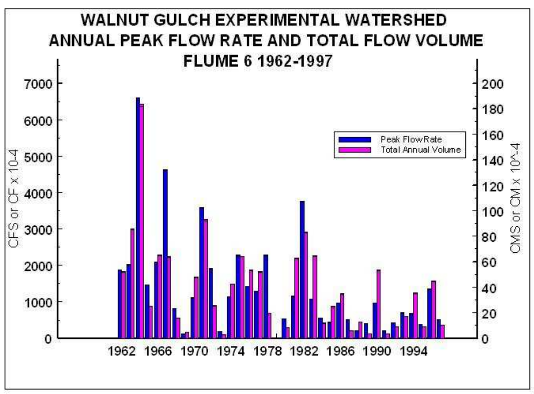

WALNUT GULCH EXPERIMENTAL WATERSHED
MEAN MONTHLY PRECIPITATION
MEAN ANNUAL 13.76 in.(350 mm)
Inches
Millimeters
0
1
2
3
4
0
10
20
30
40
50
60
70
80
90
J F M A M J J A S O N D


WALNUT GULCH EXPERIMENTAL WATERSHED
MONTHLY TEMPERATURE
MEAN, MAXIMUM, MINIMUM
ANNUAL MEAN 63.8 F (17.7 C)
Degrees Fahrenheit
Degrees Centigrade
32
52
73
93
113
0
11
23
34
45
J F M A M J J A S O N D


WALNUT GULCH EXPERIMENTAL WATERSHED
MEAN MONTHLY PAN EVAPORATION
ANNUAL TOTAL 102 in. (2590 mm)
Inches
Millimeters
0
2
4
6
8
10
12
14
0
100
200
300
400
J F M A M J J A S O N D


WALNUT GULCH EXPERIMENTAL WATERSHED
JANUARY FEBRUARY MARCH TOTAL PRECIPITATION
EL NINO - SOUTHERN OSCILLATION EPISODES
Neutral ENSO
La Nina
El Nino
45 Year Mean
+/- 1 Standard Deviation
inches
millimeters


WALNUT GULCH EXPERIMENTAL WATERSHED
MEAN ANNUAL AND SUMMER PRECIPITATION
ANNUAL 13.23 in. (336 mm) SEASONAL 7.54 in.(192 mm)
Annual
Summer
Mean Annual
Mean Summer
Inches
Millimeters


WALNUT GULCH EXPERIMENTAL WATERSHED
ANNUAL PEAK FLOW RATE AND TOTAL FLOW VOLUME
FLUME 6 1962-1997
Peak Flow Rate
Total Annual Volume
CFS or CF x 10-4
CMS or CM x 10^-4

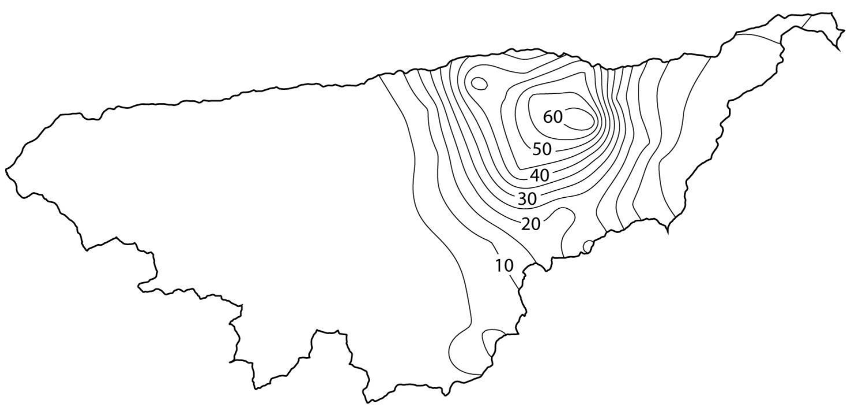
Precipitation

Precipitation varies considerably from season to season and from year to year on the Walnut Gulch Experimental Watershed. Annual precipitation varied from 170 mm in 1956 to 541 mm in 1983; summer rainfall (July, August and September) varied from 93 mm in 1960 to 325 mm in 1999; and winter precipitation (January, February and March) varied from 0 mm in 1972 to 175 mm in 1993. Nearly two-thirds of the annual precipitation on the Walnut Gulch Experimental Watershed occurs during the North American Monsoon as high intensity, convective thunderstorms of limited areal extent. The moisture source for these thunderstorms is primarily the Gulf of Mexico and the Gulf of California.

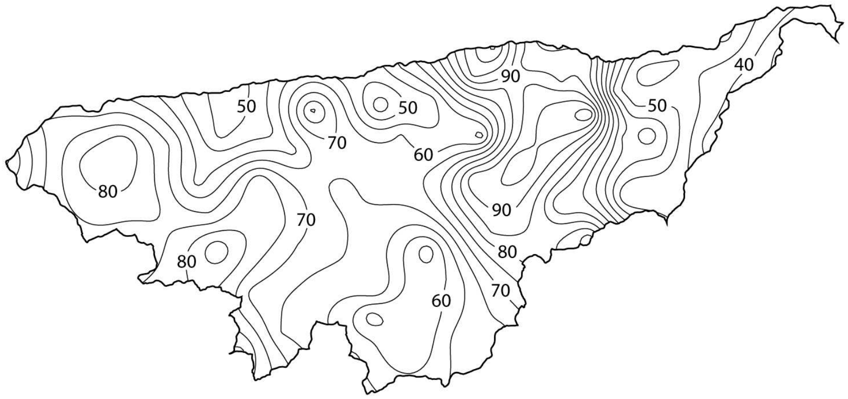
Winter rains (and occasional snow) are generally low-intensity events associated with slow-moving cold fronts, and are generally of greater areal extent than summer rains. Convective storms can occur during the winter as well. Runoff on the Walnut Gulch Experimental Watershed results almost exclusively from convective storms during the summer season.

Summing individual storm events to generate monthly and seasonal values for precipitation illustrates some water supply and forage management problems. The ensemble of individual storm events such as that shown below for August 27, 1982 resulted in the following August isohyetal map. The ratio of maximum point precipitation of 100 mm to the minimum of 40 mm (a ratio of more than 2:1) has been measured with considerable regularity. But more importantly, although these extremes were only 4 km apart, they occurred in the same pasture of one ranch. The maximum rainfall value produced good forage whereas the minimum rainfall produced less than normal forage.

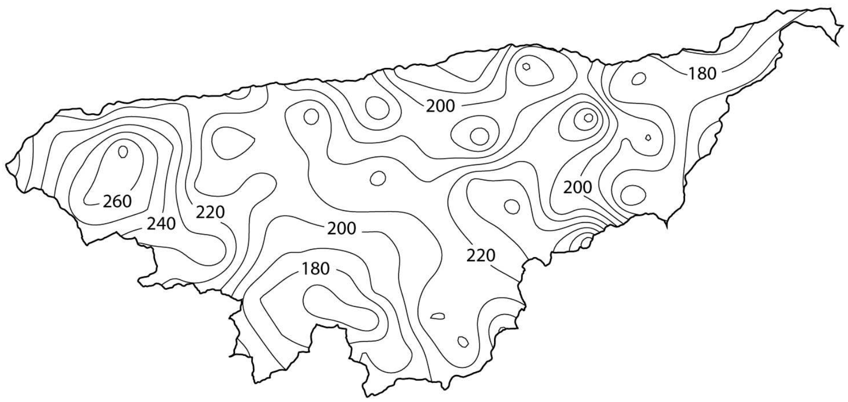
The precipitation variability during the summer season when most forage production occurs in the Walnut Gulch Experimental Watershed is indicated. Again, the variability is appreciable with the amounts of 240 mm and 170 mm being less than 5 km distant. Spatial precipitation variability is proportionally ameliorated by non-summer rains in either the early year (January-March) or late in the calendar year (October-December). Both seasons' precipitation can provide antecedent moisture for early season forage grasses.



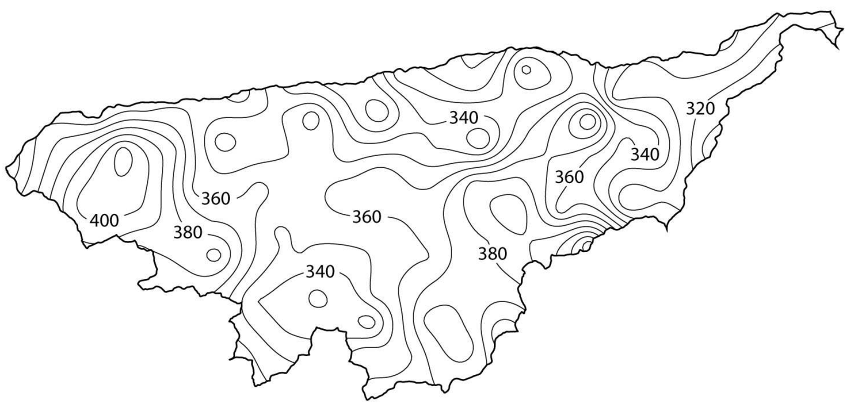
Precipitation (mm) Storm Event August 27, 1982



Precipitation (mm) August 1982



Precipitation (mm) Summer 1982



Precipitation (mm) Total 1982

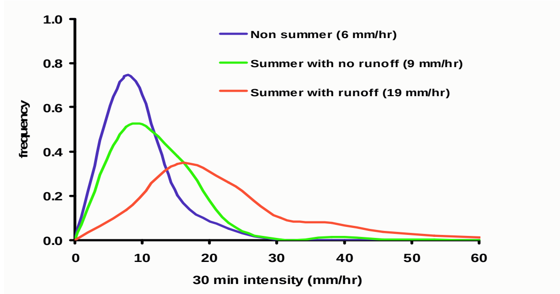
Runoff

Runoff at the Walnut Gulch Experimental Watershed is typical of many semi-arid regions in that the channels are dry for most of the year. Runoff only occurs as the result of rainfall and the hydrographs are "flashy" meaning that the flood peak arrives very quickly after the start of runoff and the duration of runoff is short. Almost all of the annual runoff and all of the largest events occur between July and September as a result of high intensity, short duration, and limited areal extent thunderstorms. Runoff occurs very infrequently in the early fall as a result of tropical cyclones and in the winter as a result of slow moving frontal systems both of which cover large areas and have rainfall of low intensities and long durations.

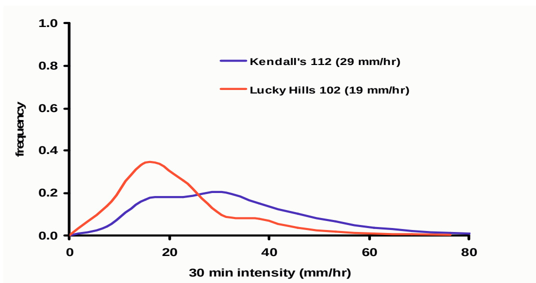
Although these fall and winter rainfall events generate little runoff at the Walnut Gulch Experimental Watershed, this is not the case for the San Pedro River just downstream from where Walnut Gulch enters the river. For the same period of record (1963-1996), the top six annual maximum peak flow events at the outlet of the Walnut Gulch Experimental Watershed occurred in the summer months, while for the San Pedro, two of the top six occurred in the fall and two occurred in the winter.

Watershed size or scale plays an important role on the dominant processes determining runoff characteristics. At the hillslope scale, the rates and amounts of runoff are influenced by rainfall intensity and soil-vegetation characteristics. Runoff occurs when the rainfall intensity is greater than the infiltration capacity of the soil, a process referred to by hydrologists as rainfall excess or "Hortonian Flow". The importance of rainfall intensity in the generation of runoff can be illustrated by plotting the frequency of the maximum 30 minute rainfall intensity for rainfall events in the non-summer months, for events in the summer months that do not produce runoff, and for events in the summer months that do produce runoff. As can be seen, the average 30 minute intensity for the summer runoff producing rainfall is twice and three times as large than for the non runoff producing summer and winter rainfall events respectively. The influence of the interaction between rainfall intensity and soils and vegetation can be illustrated by comparing the frequency of runoff producing summer events between the Lucky Hills shrub dominated watershed 102 and the Kendall's grass dominated watershed 112. In this case the average 30 minute intensity is 10 mm/hr greater for the Kendall's watershed meaning that it takes higher rainfall intensities to produce runoff on the grassed watershed. In contrast to runoff at the hillslope scale, runoff at the watershed scale is controlled more by infiltration of water into the alluvial channels (transmission losses) and the spatial distribution of thunderstorm rainfall. The result of these two factors leads to a decrease in unit runoff depth and peak discharge with increasing area.

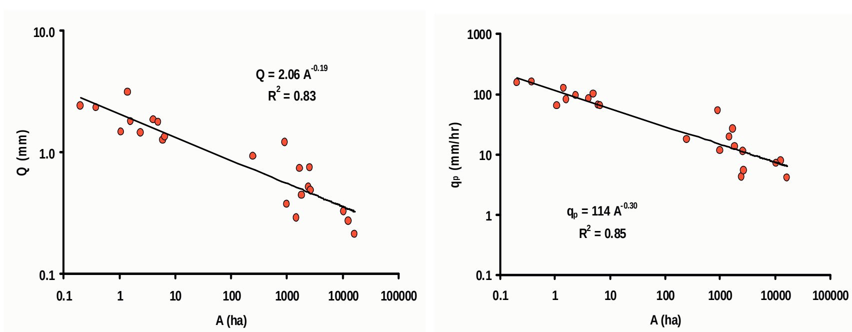
The runoff data from the Walnut Gulch Experimental Watershed have been used for flood frequency analysis, water yield estimations, and validation of hydrologic and sediment yield models. Current uses of the data include small and large scale water balance estimates, runoff and sediment yield linkages with the Upper San Pedro River Basin, and validation of remote sensing algorithms and simulation models integrated with Geographic Information Systems.



A comparison of the frequency of 30 minute rainfall intensity for events during the periods of non summer, summer with no runoff, and summer with runoff for Lucky Hills 102. Value in parenthesis is the average 30 minute intensity.



A comparison of the frequency of 30 minute rainfall intensity for events during the summer with runoff for a grass (Kendall's) and a shrub (Lucky Hills) dominated watershed. Value in parenthesis is the average 30 minute intensity.

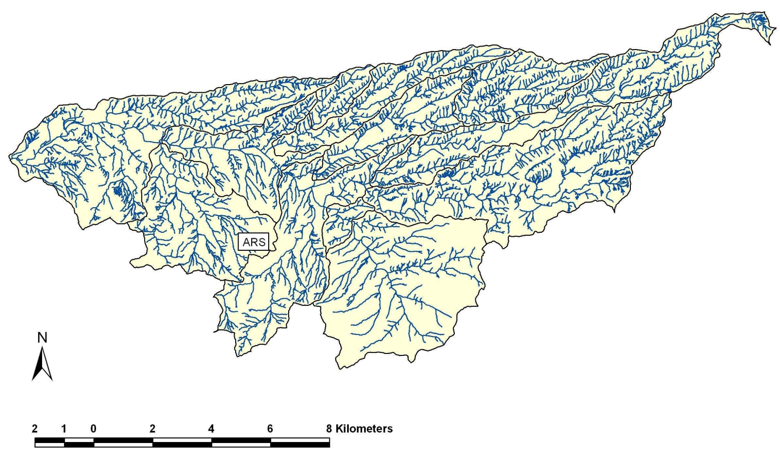


Relationship between average event runoff, Q, (left) and maximum peak discharge, q_p, (right) with watershed area, A, for the period of record 1963-1996.

Runoff Transmission Losses

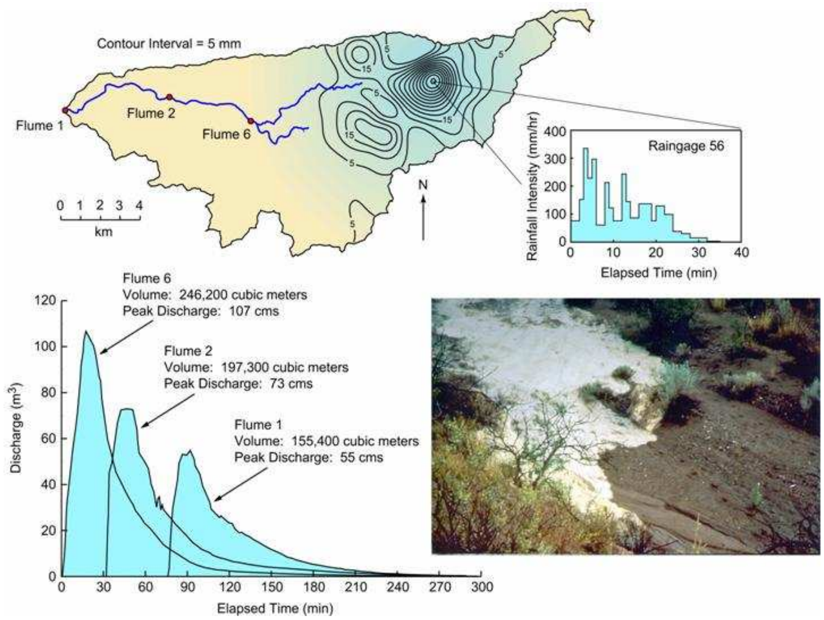
In semi-arid areas such as the Walnut Gulch Experimental Watershed, ranching, wildlife, increasing populations, urbanization, expanding industry, and needs of downstream water users all compete for limited water resources. The increased demand for water resources creates pressure to develop new sources of water and requires better methods of quantifying the water budget; assessing streamflow; and assessing the interaction between streamflow, flooding, infiltration losses in channel beds and banks, evapotranspiration, soil moisture, and ground water recharge.

An important component of the Walnut Gulch Experimental Watershed water budget is streamflow abstraction from infiltration in the channel beds and banks, called transmission losses. Transmission losses are important because water infiltrates when flood waves move through the normally dry stream channels, reducing runoff volumes and flood peaks, and affecting components of the hydrologic cycle, such as soil moisture and ground water recharge. The importance of recharge through the Walnut Gulch Experimental Watershed ephemeral stream channels has been confirmed by ground water mounding (increases in water levels in wells in and adjacent to the main channels) after flood events. Owing to the small diameter of the runoff producing storms, most flows traverse dry channels and large reductions in runoff occur. The entire watershed is highly dissected by a dense channel network providing significant opportunity for transmission losses.



Stream channel network

An example of transmission losses is presented. The August 27, 1982 storm, was isolated in subwatershed 6 on the upper 95 km^2 of the watershed (and not all of that produced runoff). The runoff measured at Flume 6 amounted to $2.46x10^5$ m^3 with a peak discharge of 107 m^3s^{-1}. Runoff traversing 4.2 km of dry streambed between Flume 6 and Flume 2 resulted in significant infiltration losses. For example, in the 4.2 km reach the peak discharge was reduced to 72 m^3s^{-1} and 48,870 m^3 of water were absorbed in the channel alluvium. During the course of the 6.66 km from Flume 2 to Flume 1, the peak discharge was further reduced, and 41,930 m^3 of runoff was infiltrated in the channel alluvium.



Erosion and Sedimentation

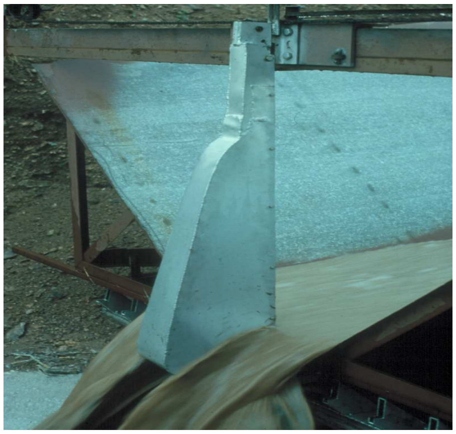
Erosion and sediment transport are highly variable across the Walnut Gulch Experimental Watershed, largely in response to variability in precipitation and runoff. The processes of erosion, sediment transport, and deposition on uplands and in ephemeral stream channels are being studied at several locations on the Walnut Gulch Experimental Watershed across a range of spatial scales.

At the plot scale, rainfall simulator experiments are being conducted to quantify the relationships between, rainfall, runoff, and sediment yield. Experiments are being designed to use rare earth elements as tracers to quantify the spatial variability of erosion at the plot scale. The patterns and rates of soil erosion and redistribution within small watersheds are being determined by analyzing the distribution of fallout ^{137}Cesium. Results are being coupled with sediment data collected as part of the long-term monitoring program. Traversing slot sediment samplers located at the outlet of Santa Rita critical depth runoff measuring flumes collect sediment samples. The traversing slot sampler was designed to measure sediment concentrations under high velocity, sediment laden flow conditions. Currently, sediment concentration samples are collected at seven small (0.18 to 5.42 ha) watersheds. Sediment concentrations and total event sediment yields are related to storm-runoff characteristics, and statistical relationships have been developed to estimate sediment yields for events with missing data. Sediment yields 0.07 to 5.7 t ha^{-1} yr^{-1}, with an areal average of 2.2 t ha^{-1} yr^{-1}. For six of the seven watersheds between 6 and 10 events produced 50% of the total sediment yields over the eleven year period. On the seventh watershed two storms produced 66% of the sediment because of differences in the geomorphology and vegetation characteristics of that area. Differences between sediment yields from all watersheds were attributable to instrumentation, watershed morphology, degree of channel incision, and vegetation.

Sediment yield is monitored at stock ponds located at the outlets of 10 small watersheds. These data are used to quantify long-term sediment yield rates and provide data critical to developing sediment budgets for semi-arid rangeland watersheds.

Collected field data and the Walnut Gulch Experimental Watershed sediment-monitoring network provide critical data for developing simulation models and rangeland assessment methods. These data have been used to develop equations to predict hydraulic geometry and erosion rates in small channels as functions of discharge, shear stress distribution, and soil properties. Collected data have been used in conjunction with current erosion prediction technologies, such as CREAMS, WEPP, and RUSLE, to improve the scientific understanding of small watershed erosion processes.

Plot scale rainfall simulator sediment yield experiment.



Traversing slot sediment sampler collects sediment samples during a flow event.

Sediment yield is monitored at stock ponds located at the outlets of several watersheds.

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Additional information about the Southwest Watershed Research Center program areas, staff contacts, publications, data access, the Walnut Gulch Experimental Watershed and other research locations is available online at http://www.tucson.ars.ag.gov/

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