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Multi-Year Precipitation Variations and Watershed Sediment Yield in a CEAP Benchmark Watershed

Jurgen D. Garbrecht,
Grazinglands Research Laboratory, 7207 West Cheyenne St., El Reno, Oklahoma 73036.

Abstract: A case study was conducted on the Fort Cobb Reservoir watershed in central Oklahoma to investigate impacts and implications of persistent multi-year precipitation variations on watershed runoff and sediment yield. Sediment yield was calculated from a sediment-discharge relationship representing 2004-2005 land use, agronomic practices and conservation measures. Several persistent multi-year precipitation variations, called wet and dry periods, occurred in central Oklahoma between 1940 and 2005. The difference in mean annual precipitation between wet and dry periods was 33% of the long-term mean. As a result of non-linear hydrologic linkages between precipitation, runoff and sediment yield, corresponding variations in watershed runoff and calculated sediment yield were comparatively larger. The difference in mean annual runoff between wet and dry periods was 100% of the long-term mean, and for mean annual calculated sediment yield it was 183% of the long-term mean. With regard to the Conservation Effects Assessment Project (CEAP), the sensitivity of runoff and therefore of sediment yield to wet and dry periods suggests that measures of conservation program effectiveness depend on climatic conditions used in their evaluation, and that great care should be taken to select a climate record representative of prevailing climate conditions. Furthermore, it was inferred that the calibration of simulation models used in the conservation effects assessment may be biased if performed with climatic data representing either just a wet or a dry period. In the presence of multi-year precipitation variations, a thorough model validation for both wet and dry periods is recommended to ensure accurate simulation results over the full range of prevailing climatic conditions.

Key words: Climate - Conservation Effects Assessment Project (CEAP) – Precipitation – Runoff - Sediment Yield - Soil Erosion

Sediment yield from agricultural watersheds is traditionally ascribed to land use, land management and agronomic practices. However, soil erosion and sediment transport and yield are in fact caused by rainfall and runoff, whereas land use, land management and agronomic practices affect the location's erosion potential. Thus, rainfall-runoff is a primary determinant in watershed sediment yield, and any lasting change in rainfall and runoff should be expected to lead to a corresponding change in sediment yield, assuming all other factors remain the same. Lasting changes in rainfall and runoff can be caused by persistent, multi-year precipitation variations which are defined as sequences of consecutive years that have annual precipitation values predominantly above or below the long-term average. Precipitation variations that last 5 or more years are termed wet or dry periods, or pluvial and drought periods.

Wet or dry periods in a precipitation record are not uncommon (Gray et al., 2004; Garbrecht and Rossel, 2002; NRC, 1998). Notable examples include the Dust Bowl years

(Worster, 1982), low-frequency precipitation variations in central Utah (Lall and Mann, 1995), and most recently the persistent drought in the Colorado River Basin and much of the western United States (Webb et al., 2004). These wet or dry periods can lead to substantial impacts on the water resources system due to cumulative effects of sustained precipitation departures from average conditions (Gray et al., 2006; Garbrecht et al., 2004; Woodhouse and Overpeck, 1998; Mantua et al., 1997; Lall and Mann, 1995).

Impacts of wet or dry periods are not limited to the hydrologic system. Watershed sediment yield and water quality variables also vary between wet and dry periods. If sediment yield variations between wet and dry periods are substantial, they may have implications for the implementation of conservation programs and measures in general, as well as for the quantification of environmental benefits of conservation practices of the Conservation Effects Assessment Project (CEAP) (Mausbach and Dedrick, 2004). CEAP is a multi-agency effort to quantify the environmental benefits of conservation practices used by private landowners participating in selected U. S. Department of Agriculture conservation programs. In this context, the magnitude of the impact of wet and dry periods on sediment yield is not well documented, and the implications for calibration and validation of CEAP simulation models and determination of appropriate climate conditions for scenario analyses have not been given detailed consideration.

In this study, impacts of wet and dry periods on runoff and sediment yield are investigated for the Fort Cobb watershed. Existence and size of multi-year precipitation variations in the Fort Cobb Reservoir watershed and associated impacts on reservoir hydrology were investigated previously (Garbrecht and Schneider, 2006). The Fort Cobb Reservoir controls runoff from a 787 [km^2] (304 [mi^2]) agricultural watershed in central Oklahoma, and is a multipurpose project for flood control, municipal & industrial water supply, and recreation. In 1998 the reservoir was identified as a water-body that did not meet the water quality standards set forth in the Clean Water Act of 1987, and it has been the object of non-point source pollution investigations (Storm et al., 2006; Yue and Derichsweiler, 2005). In addition to investigating runoff and sediment yield in terms of wet and dry periods, the present study also addresses issues regarding calibration and validation of CEAP simulation models. The broader question of which climatic conditions are appropriate for use in CEAP scenario analyses in the presence of wet and dry periods is raised in order to spur discussions among climatologists, conservationists, practitioners, policy makers, and affected producers and land owners. Chosen climatic conditions must lead to relevant and representative impact assessments of conservation practices and must also allow regional inter-comparisons of effectiveness measures of conservation programs.

Materials and Methods

The Fort Cobb watershed consists primarily of crop and range/pasture land. Based on agricultural statistic data by the Census of Agriculture and the National Agricultural Statistics Service (NASS), Storm at al. (2007) determined that for the period 1940-1957 approximately 25% of the watershed area was in range and pasture, 71% in crop land, 3% in forest and 1% miscellaneous. For the 1958-1970 period, the proportions were approximately 40% in range and pasture, 55% in crop land, 3% in forest and 2% miscellaneous. A separate digital landcover analysis in 2002 concluded that for the period 1999-2001 40% of the watershed area was in range and pasture, 51% in crop land, 7% in forest, and 2% miscellaneous (Storm et al., 2006). These land-use estimates showed that land use has been relatively stable from about 1960 through 2000, whereas during the 1940s and 1950s the crop land proportion was substantially higher, mostly at the expense of range and pasture land. Crop land itself changed over time as conservation measures were implemented and low-disturbance tillage farming practices were gradually adopted. Livestock grazing on range and winter-wheat grazing has increased over time, but management of impacted riparian zones has traditionally been minimal, though stream-bank protection efforts are currently underway (Ramming, 2007). Urban expansion is non-existent and impervious areas associated with a few small farming communities and the paved road network (about 500 [km] (310 [mi])) represent less than 1% of the watershed area.

Records obtained from the Oklahoma Resources Board showed that the number of permits for irrigation wells increased steeply in 1955 and reached 250 by 1960 (mostly for subsidized peanut crops). The "hand set" irrigation sprinkler system used at that time could irrigate about 12 to 24 [ha] (30 to 60 [ac]). Assuming all irrigation-well permits represent operational wells, the total potential irrigated area would be about 45 [km^2] (17 [mi^2]), or 6% of the watershed area. By the mid 1960s there were about 325 irrigation-well permits on record, and the "side-roll" irrigation system gradually replaced the "hand set" system. By the mid 1970s, 450 irrigation-well permits were on record and the "center pivot" system became the predominant irrigation method. By 2000 there were about 525 irrigation-well permits on record. However, one has to realize that many shallow and low-yield wells for the early "hand-set" and "hand-roll" irrigation system were discontinued in favor of deeper, high-producing wells for the center pivot system. Two hundred center-pivot circles were visually identified in 2002 from aerial photography. Each 1/4 section center-pivot system can irrigate up to 50 [ha] (123 [ac]), for a total potential irrigated area of about 100 [km^2] (39 [mi^2]) or 13% of the watershed area, assuming all center-pivot systems are operational.

Basic data for this investigation included precipitation, runoff (or inflow into the Fort Cobb reservoir) and sediment yield. Daily precipitation values for 1940 through 2005 were available for four National Weather Service (NWS) cooperative weather stations (Weatherford, Lookeba, Carnegie, and Fort Cobb in Figure 1). Missing values were filled with data from other nearby stations, and monthly and annual precipitation for the watershed were approximated by averaging monthly and annual precipitation at the four stations (Garbrecht and Schneider, 2006). Watershed runoff was reconstructed based on stream-flow observations and reservoir water-budget calculations. Daily stream-flow observations near the mouth of the watershed were available for January 1940 through March 1959 (U. S. Geological Survey [USGS] stream flow gauge #0732600; USGS, 2005). In April 1959, Fort Cobb Reservoir was completed by the Bureau of Reclamation (BoR) 3.7 [km] (2.3 [miles]) upstream of the USGS stream flow gauging station, so the gauged flow no longer represented natural watershed runoff. Monthly reservoir inflows for April 1959 through December 2005 were estimated by the BoR based on water budget calculations that included water supply deliveries, flood releases, evaporation, seepage, and change in storage. Effects of changing land use and irrigation on runoff have implicitly been accounted for by virtue of using observed values in the calculation of reservoir inflows. Details on the reservoir water-budget calculations are given in Garbrecht and Schneider (2006). Since the USGS stream-flow and the BoR reservoir inflows have a slightly different upstream drainage area, the USGS stream-flow was adjusted proportionally to drainage area to reflect the same upstream drainage area as the reservoir inflow, and both records were combined into a 1940-2005 monthly watershed runoff record. In the remainder of this paper, watershed runoff is equivalent to reservoir inflow, the terms are used interchangeably, and watershed runoff is expressed as a depth per unit watershed area to facilitate comparison with precipitation depth.

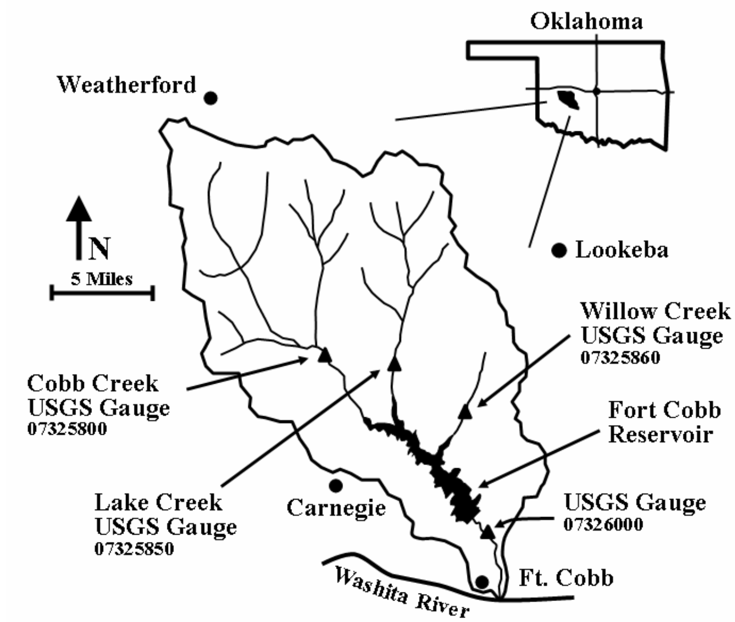

Figure 1. Fort Cobb Reservoir watershed outline and locations of National Weather Service cooperative weather stations, US Geological Survey stream gauges, and sediment gauging sites.

Instantaneous suspended sediment concentration was measured by the USGS in 2004 and 2005 for selected low and high rainfall-runoff events at three non-nested flow-gauging locations in the watershed (Figure 1). Gauge sites were Cobb Creek near Eakly (USGS 07325800), Lake Creek near Eakly (USGS 07325850), and Willow Creek near Albert (USGS 07325860), and corresponding upstream drainage areas were 342 [km^2]) (132 [mi^2]), 155 [km^2] (60 [mi^2]), and 75 [km^2] (29 [mi^2]). Instantaneous suspended sediment load per unit area was calculated from the observed discharge and suspended sediment concentration, and plotted against discharge per unit area (Figure 2). The plotted data shows that one instantaneous suspended sediment-discharge relationship reasonably characterizes the three gauge sites. Since this suspended sediment-discharge relationship (S-Q relationship) appears to be independent of drainage area for the three stations, it is assumed to equally apply for the watershed as a whole.

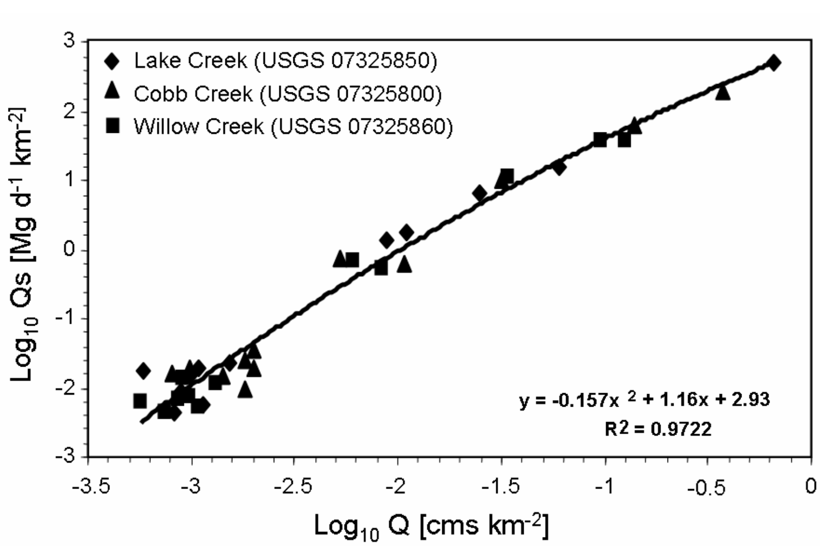

Figure 2. Observed instantaneous discharge and suspended sediment at the three gauging stations above the reservoir for selected storms in 2004-2005 (data source USGS), and resulting instantaneous sediment-discharge relationship.

The S-Q relationship can be used with daily runoff to estimate watershed sediment yield. Since the S-Q relationship is based on 2004-2005 observed data, it can only quantify sediment yield for watershed land use, agronomic practices and conservation measures that were in place in 2004-2005. Therefore, any sediment yield calculated with runoff records predating 2004 represents a sediment yield that would have existed if the watershed land use, agronomic practices and conservation measures were the same as in 2004-2005. This is fundamental to this study. All calculated sediment yield values for 1940 through 2005 are based on the 2004-2005 S-Q relationship and represent sediment yield as if the 2004-2005 watershed land use, agronomic practices and conservation measures were in place the whole time. Thus, variations in calculated sediment yield reflect only variations in precipitation and runoff over the 1940-2005 period, which is in line with the main objective of this study.

Before the S-Q relationship can be used with the available monthly runoff record to estimate a sediment yield record it must be modified to be applicable with monthly runoff values. This modification is performed in two steps. First, a daily sediment yield record is developed using the S-Q relationship and the daily flow record from January 1940 to March 1959. No notoriously unreliable extrapolation beyond the high value of the 2004-2005 S-Q observations was necessary to calculate the daily sediment yield record for 1940-1959. In a second step, the 1940-1959 daily sediment yield was summed into monthly value and the daily runoff was averaged into monthly runoff values. This monthly sediment yield and runoff data was used to develop a monthly S-Q relationship (Figure 3). The 1940-2005 monthly sediment yield record was then calculated as follows: for the January 1940 to March 1959 period, the summed daily sediment yield was used for monthly values, and for the April 1959 to December 2005 period, the monthly S-Q relationship and available monthly runoff were used to calculate monthly sediment yield. Again, the calculated monthly sediment yield values are representative of the 2004-2005 watershed land use, agronomic practices and conservation measures. Annual watershed sediment yield for 1940-2005 was obtained by summation of the calculated monthly sediment yield values. From the remainder of this paper, sediment yield and reservoir sediment loading are equivalent and used interchangeably. Also, calculated monthly sediment yield representative of the 2004-2005 watershed land use, agronomic practices and conservation measures is simply referred to as calculated sediment yield.

Calculated sediment yield was summed for 1959 through 1993 and compared to a 1993 survey of accumulated sediment volume in the Fort Cobb reservoir. The surveyed sediment volume was 8.59 [10^6 m^3] (6'966 [ac-ft]) (Ferrari, 1994) and the herein estimated sediment volume was 4.22 [10^6 m^3] (3'421 [ac-ft]), assuming a specific weight of 1 [Mg m^{-3}] (62.4 [lb/ft^3]) for the deposited clay-silt mixture under submerged conditions. The lower calculated sediment volume as compared to the surveyed volume can be attributed to: (1) suspended sediment observations do not include bed-load, thus total sediment yield is under-estimated when approximated by suspended sediment values. Bed-load is the sediment that moves close to or rolls along the channel bed and cannot be measured by traditional depth-integrated sampling instruments. (2) Less crop land and more conservation practices were in place in 2004-2005 than in earlier years, and the 2004-2005 S-Q relationship under-estimates actual sediment yield for earlier years. In light of these known approximations, the magnitude of the calculated sediment yield appears to be reasonable and confirmed by the accumulated sediment volume in the reservoir.

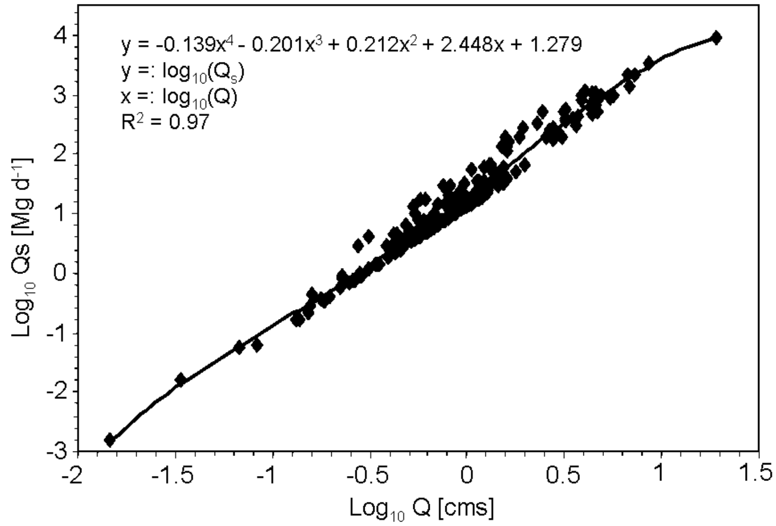

Figure 3. Monthly discharge and estimated suspended sediment load into the Fort Cobb reservoir for years 1940-1959 (based on USGS discharge data), and monthly sediment-discharge relationship.

Results and Discussion

Results. Annual and five-year sine-weighted moving average (WMA) of watershed precipitation and runoff are shown in Figure 4a and 4b. The WMA filters out year-to-year variations and brings out persistent above- or below-average departures lasting 5 years or longer. A graphical procedure based on the cumulative sum of residuals was used to identify multi-year wet and dry periods (Fernandez and Garbrecht, 1994). For the Fort Cobb Reservoir watershed this process identified three dry periods (1951-1956; 1963-1972; 1976-1980) and one wet period (1985-1997) (Garbrecht and Schneider, 2006). The remaining years outside the dry and wet periods were classified as near-neutral, meaning that precipitation values for these in-between years did not reveal variations long enough or of sufficient size to be classified as a dry or wet period.

The WMA of annual watershed runoff (Figure 4b) also revealed three below-average periods and one above-average inflow period, though lagging about one year behind the corresponding precipitation variations. This lag was likely due to a delay in groundwater and base-flow response to changes in annual precipitation (Garbrecht and Schneider, 2006). As a result, the first year of a dry or wet period was considered to be a transition year during which watershed response adjusted itself. Transition years were excluded from the definition of dry and wet periods. Thus, for the runoff and sediment analysis, the three dry periods are redefined as 1952-1956, 1964-1972 and 1977-1980, and the wet period as 1986-1997.

The pattern of multi-year annual runoff variations (Figure 4b) closely follow the pattern of the annual precipitation variations (Figure 4a), despite the aforementioned changes in land use and irrigation. Low pattern values in both precipitation and runoff appear around 1955, 1970 and 1980, and high pattern values in both appear around 1960, 1975 and 1990-1995. This suggests that while changes in land use, conservation and irrigation may affect runoff, multi-year annual precipitation variations tend to override these effects in the Fort Cobb watershed, and runoff variations are primarily a reflection of precipitation variations.

Annual and five-year WMA of calculated sediment yield are displayed in Figure 4c and show persistent variations similar to those of precipitation and runoff, as one should expect since sediment yield was calculated from a S-Q relationship. The task at hand is to quantify changes in calculated annual sediment load in terms of causative wet or dry periods. It should be noted here that the same S-Q relationship is used for wet and dry periods. Plausible arguments can be made

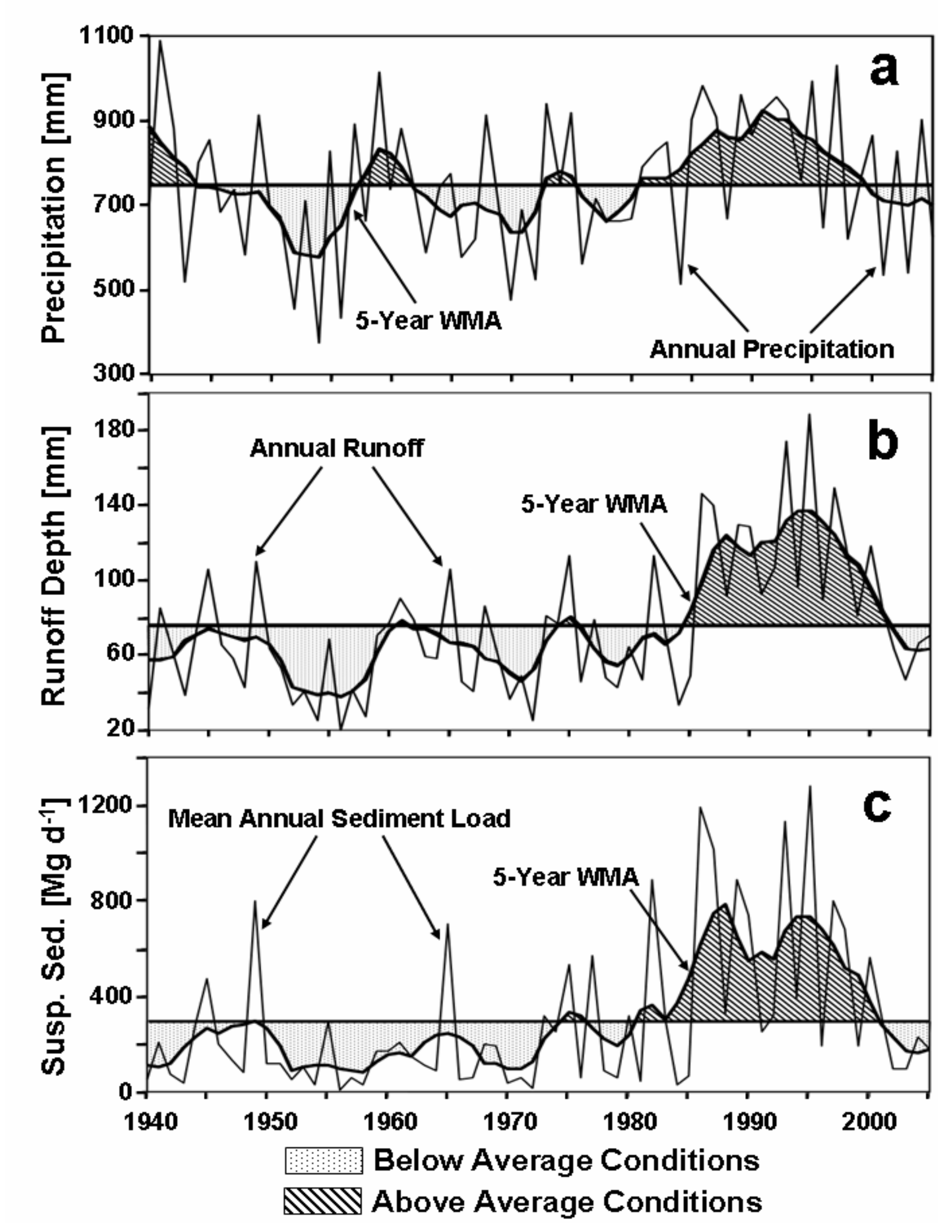

Figure 4. Annual and five-year weighted moving average of (a) precipitation (based on National Weather Service data), (b) reservoir inflow (based on Bureau of Reclamation data), and (c) estimated reservoir suspended sediment load.

for, as well as against, this assumption. However, in this study it is believed that the rather large differences in runoff characteristics between wet and dry periods (see next section), particularly frequency and size of events, may well override the effects of a potentially different S-Q relationship between wet and dry periods, just like precipitation variations appear to have overridden the effects of changes in land use and irrigation on runoff variations. In the event that this were not the case, i.e. the S-Q relationship for wet periods predicts higher sediment yield than for dry periods, then the assumption of a same S-Q relationship leads to sediment yield values that are lower for wet periods and higher for dry periods, and the subsequently presented findings and conclusion would be on the conservative side.

Mean annual precipitation, reservoir inflow, and estimated reservoir sediment loading for wet and dry periods are given in Table 1. Mean annual precipitation over the watershed was 639 [mm yr^{-1}] (25.2 [in yr^{-1}]) and 885 [mm yr^{-1}] (34.8 [in yr^{-1}]) for dry and wet periods, respectively. The difference between dry and wet periods was 246 [mm yr^{-1}] (9.7 [in yr^{-1}]) which equals 33% of the 1940-2005 mean. Corresponding mean annual watershed runoff was 52 [mm yr^{-1}] (2.05 [in yr^{-1}]) and 128 [mm yr^{-1}] (5.04 [in yr^{-1}]) during dry and wet periods, respectively, and the difference was 76 [mm yr^{-1}] (3.0 [in yr^{-1}]) or 100% of the 1940-2005 mean. With regard to calculated sediment yield, the mean annual sediment yield was 162 [Mg d^{-1}] (146 [tons d^{-1}]) and 710 [Mg d^{-1}] (644 [tons d^{-1}]) for dry and wet periods, respectively, leading to a difference of 548 [Mg d^{-1}] (497 [tons d^{-1}]) or 183% of the 1940-2005 mean.

Table 1. Summary statistics of mean annual watershed precipitation (P), mean annual watershed runoff (Q), and mean annual sediment load (S) for the defined dry and wet periods.

Period	Number of years	Mean annual P [mm yr^{-1}]	% Departure	Mean annual Q [mm yr^{-1}]	% Departure	Mean annual Qs [Mg d^{-1}]	% Departure
All Years							
1940-2005	66	750		75.5		299	
Dry Periods							
1952-1956	5	560	-25	37.3	-51	98	-67
1964-1972	9	666	-11	56.5	-25	155	-48
1977-1980	4	678	-10	58.7	-22	258	-14
Average		639	-15	51.7	-32	162	-46
Wet Period							
1986-1997	12	885	+18	127.7	+69	710	+137

Several inferences can be drawn from the data in Table 1. First, runoff is only 8 and 14% of precipitation for dry and wet periods, respectively. Second, the small percentage of precipitation that contributes to runoff may initially give the impression that dry and wet periods have little impact on runoff. However, non-linear precipitation-runoff production mechanisms are sensitive to precipitation variations (Garbrecht et al., 2004). Indeed, wet periods are characterized by more frequent and higher precipitation events which in turn gradually lead to wetter soil moisture conditions, lower infiltration rates, reduced soil water storage capacity, increased surface runoff potential, greater deep percolation rates, enhanced subsurface flow, and eventually also higher groundwater levels. Gradual development of a wetter watershed environment during wet periods leads to a corresponding increase in surface runoff and subsurface return flow. It is the combination of more frequent and higher precipitation events and increased surface runoff potential, as well as higher subsurface return flow that is the basis for the sensitivity of runoff to persistent, multi-year precipitation increases. The reverse is true for dry periods.

For the Fort Cobb Reservoir watershed, the 33% change in mean annual precipitation between dry and wet periods led to a 100% change in mean annual runoff. A log-log regression of annual runoff versus precipitation for both dry and wet periods suggests that runoff varies with precipitation to the power of 1.4. Thus, even small multi-year precipitation variations are amplified in the runoff record. Third, sediment yield is exponentially related to runoff (Graf, 1971; Vanoni, 1975) which suggests that one can expect an even larger difference in sediment yield between wet and dry periods than for runoff. Indeed, for the Fort Cobb Reservoir watershed, mean annual sediment yield changed by 183% between dry and wet periods. A log-log regression between annual sediment load and annual runoff showed that sediment yield varies with runoff to the power of 2.4, and a regression between annual sediment yield and annual precipitation showed that sediment yield varies with precipitation to the power of 3.4. Again, small changes in multi-year precipitation variations can lead to large impacts on sediment yield.

Discussion. The magnitude of the impacts of wet and dry periods on watershed runoff and sediment yield was demonstrated for the Fort Cobb Reservoir watershed. The findings of this case study have implications and raise questions with regard to the CEAP assessment of effectiveness of conservation measures.

First, in the presence of wet and dry periods, the non-linearity and sensitivity of the precipitation-runoff-sediment yield relationships make the CEAP assessment highly dependent on the particular climate period used in the evaluation. Potential reduction of sediment yield through conservation measures during dry periods and any related effectiveness measure can be sizably different from corresponding values achieved during wet periods. Thus, the climate period used in CEAP assessment studies can have a determining role on the findings and conclusions of a conservation effectiveness assessment. Furthermore, wet and dry periods are regional phenomena and are not synchronized across the continent. Some regions may experience a dry period while others experience wet periods. This makes regional comparisons of effectiveness of conservation programs difficult.

Ideally, the climatic record underlying a conservation assessment should contain a representative or balanced mix of wet and dry periods. Since assessment of effectiveness of alternative conservation practices relies on computer simulations, a balanced climatic record should be sought to drive the simulations and to produce representative measures of conservation effectiveness. What constitutes a representative and balanced climatic record varies from region to region, depends on the intended application, and is often open to interpretation. The selection of a balanced climatic record is best resolved on a case-by-case basis under consideration of study objectives and based on discussions among involved climatologists, scientists, conservationists, practitioners and policy makers. However, recognition that precipitation exhibits long-term trends (Groisman and Easterling, 1994; Groisman et al., 2001; Karl and Knight, 1998; Kunkle et al., 1999) suggest that a precipitation record of recent years may better represent currently prevailing climatic conditions than a record based on a more distant past. The length of a record depends on the intended use or application and on the temporal variability of the climate of the region under consideration. For the case of the Fort Cobb watershed, the most recent 40 years appear to reasonably represent wet and dry periods. In general the record should be long enough to include a few 5- to 10-year variations, if present. On the other hand, if the recent 20 or 30 years contain a climate variation longer than 15-20 years, then the variation may actually represent a shift or a trend in climate and may be a good representation of current or prevailing climate conditions. In this case, climatic records prior to the shift or trend should not be used. If an adequate-length climate record cannot be found, effectiveness of conservation measures should be reported with reference to the particular climate conditions used in the assessment.

Second, calibration and validation of runoff and sediment yield simulation models relies heavily on precipitation, runoff, and sediment yield observations. While long-term precipitation records are often available, corresponding long term runoff and sediment observations are less common, and model calibration/validation is performed with all available years of data, irrespective of wet or dry periods. In the presence of wet and dry periods, this can lead to a model being calibrated solely with data pertaining to a wet or dry period. In light of the non-linearity and sensitivity of the precipitation, runoff, and sediment yield relationships, and the recognition that calibration is a purely numerical fitting of model parameters, it is not clear that a model calibrated with data from a dry period performs equally well under wet period conditions, and vice versa. Runoff and sediment yield models are simplified and imperfect approximations of complex and interdependent processes and often include a mix of empirical and conceptual components that can reduce model performance when applied under climatic conditions other than those for which they have been calibrated. Long-term data sets from research watersheds, such as the CEAP benchmark watersheds, should be used to establish model performance expectations by calibrating the model with short data sets representing wet *or* dry climate periods, and validating the model for wet *and* dry climate periods. Such a study is currently underway and findings will be reported in a separate publication.

Summary and Conclusions

The impacts of wet and dry periods on watershed runoff and sediment yield were evaluated for the Fort Cobb Reservoir watershed in central Oklahoma. Sediment yield was calculated from a sediment-discharge relationship that represented 2004-2005 land use, agronomic practices and conservation measures. As such, calculated sediment yield values are those that would have existed if the 2004-2005 land use, agronomic practices and conservation measures were in place during the entire period of study. Three dry periods and one wet period were identified between 1940 and 2005. The difference in mean annual precipitation between wet and dry periods was 246 [mm yr^{-1}] (9.7 [in yr^{-1}]) or 33% of the long-term mean, and corresponding difference in mean annual watershed runoff was 76 [mm yr^{-1}] (3.0 [in yr^{-1}]) or 100% of the long-term mean. The difference in mean annual calculated sediment yield was 548 [Mg d^{-1}] (497 [tons d^{-1}]) or 183% of the long-term mean. This difference is solely due to wet and dry periods, since effects of land use, agronomic practices and conservation measures were removed by assuming a single sediment-discharge relationship for the period of study. These values show that small or moderate multi-year variations in precipitation can amplify into comparatively large watershed runoff and sediment yield variations. Similar inferences are likely applicable to soil erosion and sediment transport, as well as to the movement of agrichemicals, since many such substances are adsorbed to soil particles and transported with sediment.

The non-linearity and sensitivity of the cause-effect relationships linking precipitation, runoff, and sediment yield suggest that measures of potential sediment yield reduction as a result of conservation efforts depend on the climatic characteristics used in their derivation. It follows that in the presence of wet and dry periods, great care should be taken to select a representative climatic record that will lead to a balanced assessment of sediment reduction effectiveness of alternative conservation practices under prevailing climatic conditions. It was argued that the length of a representative climatic record should be determined on a case-by-case basis under consideration of study objectives and diverse perspectives from climatologists, scientists, conservationists, practitioners and policy makers. The sensitivity of runoff and sediment yield to persistent, multi-year precipitation variations also points to the need to (re-)assess the effectiveness of today's conservation measures under expected climate change scenarios of tomorrow.

It was further noted that runoff and sediment yield data for model calibration are often of relatively short duration and could potentially fall within either a dry or wet period. Thus, in the presence of dry and wet periods, a thorough model validation against data representing dry as well as wet periods is recommended. This would ensure that subsequent model simulations with a long precipitation record that includes wet and dry periods produce accurate results.

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