



Challenges in Geographic Information System and Erosion Model Application in Watershed Management: The Bohol Watershed, Philippines

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Abstract

The use of geographic information system and erosion model techniques in land management assessment in the Upper Inabanga Watershed, Philippines is presented. The WEPP (Water Erosion Prediction Project) erosion model was applied to assess erosion at watershed and farm-scale levels. Erosion was predicted using simulated conventional and, alternatively, conservation-oriented agriculture practices, in terms of on-site and off-site effects of the agricultural practices. From instrumented trial hillslopes, sediment yield decreased from 32.8 t·ha⁻¹ to 12.8 t·ha⁻¹ under conventional farming to conservation-oriented practices, respectively. At the watershed level under current land use, this was translated into a decrease in sediment discharge from 11.9 t·ha⁻¹ to 10 t·ha⁻¹. With land use change in which 58% of the watershed area was allocated to agriculture cultivation, conservation oriented practices decreased sediment discharges from 32.1 t·ha⁻¹ to 3.9 t·ha⁻¹. The WEPP event-by-event output showed the temporal variation of soil loss over the simulation period. The study gives valuable insight to understanding erosion processes at different scales and conservation planning within watersheds. The study concludes that simulation and prediction of erosion under a wide range of scenarios and identification of specific locations of erosion prone areas is valuable for decision-making purposes and for designing conservation strategies.

Keywords

Erosion; GIS; model; Philippines; watershed; WEPP

I. Introduction

Overview

Agricultural land degradation in the Philippines is a major environmental and development issue (Cramb, 2000). It has been estimated that 79% of Philippine lands are under threat of severe degradation. The island environment of Bohol Province is particularly threatened by severe erosion especially in the upper agricultural watersheds. Soil erosion, one of its forms, is advancing at an alarming rate partly due to deforestation and inappropriate agricultural practices. Other factors such as cyclones and frequent thunderstorms also result in high sediment rates throughout the country (White, 1995).

Bohol Island is the 10th largest island in the Philippines, situated in the Central Visayas Region. Geographically located within 123°40'-124°40' longitude and 9°30'-10° 17' latitude, the island is approximately 625 km southeast of Manila (Figure 1). Annual rainfall is about 2000 mm while the temperature ranges between 23 – 33°C. The island has an area of 411,700 ha and is home to 1.14 million people. The population is growing at a high rate of 2.95% per annum as compared to the national average of 2.38%, based on 1995-2000 census data (NSO, 2002). Bohol is an agricultural province where 45% of the land area is cultivated for crop production, however, PCARRD (1984) reported that more than half of the island land area was already eroded. The island is considered the leading food granary of the Central Visayas Region. Farming is the main source of income followed by fishing and seaweed farming (AusAid, 2001).

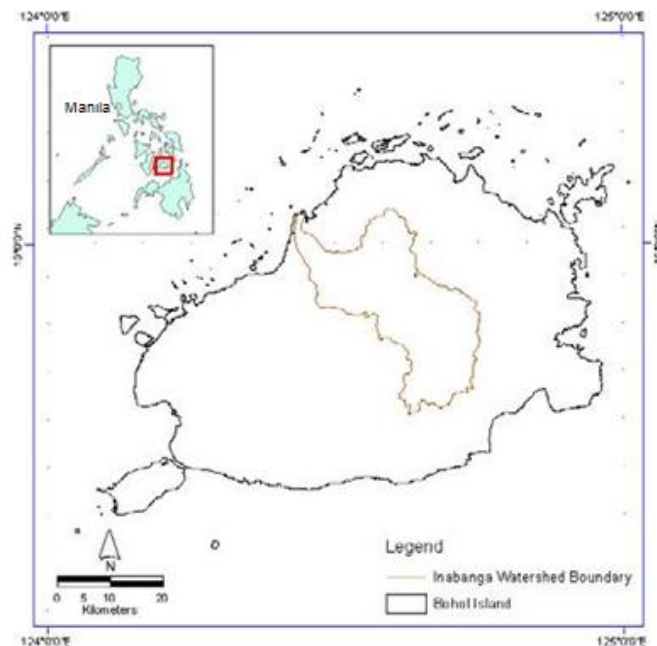


Fig. 1. Location of the Bohol Watershed Project.
Inset is the map of the Philippines and the location of Bohol Island

The primary objective of this study was to assess soil erosion over the watershed and evaluate land management options for the watershed. The process-based erosion model, WEPP (Water Erosion Prediction Project) and its GIS interface, GeoWEPP, were applied to estimate soil loss, sediment yield

and runoff under different management scenarios across the watershed and on a hillslope or farm-scale level. Model inputs and outputs were prepared, analyzed and presented using GIS techniques.

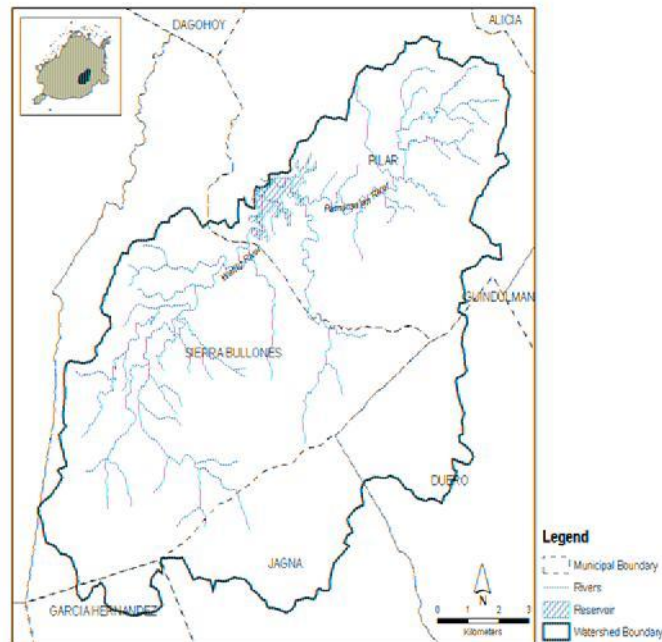


Fig. 2. Geographic location of the Upper Inabanga Watershed showing the municipal boundaries and the river system as well as the Malinao Reservoir. Inset is the Island of Bohol in the Central Philippines.

Ella (2005) applied the WEPP erosion model to a Maagnao Watershed study in Mindanao. Management scenarios varying the percentages of cropped areas were developed. Results of the simulations showed that increasing the percentages of cropped area also increased the sediment yield from the watershed. When the watershed was entirely uncultivated, sediment yield was estimated at $1.9 \text{ t}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$. On the other hand, when the entire watershed was subject to cultivation, sediment yield was predicted at $48 \text{ t}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$. Although constrained by the available input data, the study by Ella (2005) provided an initial step into the application of a process based erosion model in the Philippines. Initial results of the study indicated the potential impact of land use change in the study watershed. Recommendations and approaches from the study of Ella (2005) and Cox and Madramootoo (1998) were used in formulating and undertaking the study reported in this current investigation.

II. Methodology

A. The Upper Inabanga Watershed

The Upper Inabanga Watershed is the catchment basin of the Malinao Dam Reservoir (Figure 2). It lies across the boundaries of five major municipalities, namely: Sierra Bullones, Pilar, Garcia Hernandez, Jagna, and Duero covering about 138 km^2 . The Malinao Dam Reservoir is the convergence point of the two major tributaries. The two major tributaries are the Pamacsalan River in the eastern part and the Wahig River in the southwestern side. The highest elevation of the catchment is at 861 m.

WEPP and GeoWEPP model

The WEPP model (WEPP Science Ver: Jan 14, 2005) developed by USDA-ARS (1995) is a process-based continuous erosion model. It is a prediction technology based on fundamentals of hydrologic and erosion mechanics science.

The model has two format modes: the hillslope and watershed applications. As applied in the hillslope mode, the model is subdivided into nine conceptual components, namely: climate generation, winter processes, irrigation, hydrology, soils, plant growth, residue decomposition, hydraulics of overland flow and erosion (Flanagan et al., 1995). The model accommodates the spatial and temporal variability in topography, surface roughness, soil properties, crops, and land use conditions on hillslopes.

The watershed application integrates erosion at hillslope, channels and impoundment (Ascough et al., 1995). This application was developed to predict erosion effects from agricultural management practices within small agricultural watersheds. Erosion from both hillslope areas and concentrated flow channels are able to be simulated by the watershed application.

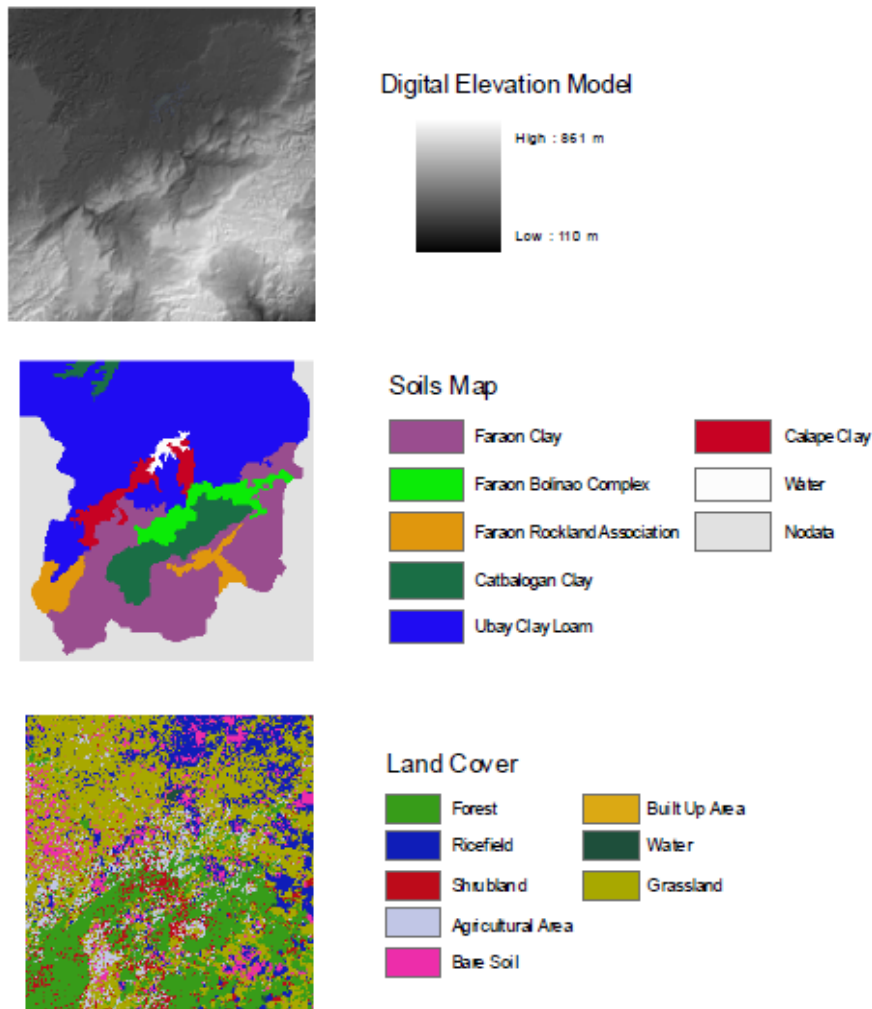


Fig. 3. Input raster maps. Data used in creating the input raster maps were taken from the ACIAR LWR1/2001/003 research project.

The Water Erosion Prediction Project (WEPP) model has been considered to represent a major improvement to the previously and most widely accepted method of estimating sediment loss, the USLE (Universal Soil Loss Equation) (Flanagan and Nearing, 1995). The model represents a new erosion prediction technology based on fundamentals of stochastic weather generation, infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics (Flanagan et al., 1995).

Inputs for WEPP and GeoWEPP models

Inputs to WEPP are grouped into four data files: climate, soils, crop management, and slope files. In the WEPP watershed extension implemented using GeoWEPP (ArcX 2004-3), additional raster maps are needed such as soils map, land cover map and a digital elevation model (DEM) as shown in Figure 3.

Climate file

The break point climate data generator (BPCDG) program (Zeleeke et al., 1999) was used to generate a climate input file using a one-year 5-minute climate data. BPCDG was used in order to utilize the actual climate data from automatic weather stations and to develop the process of creating climate input files in a format acceptable for WEPP.

Slope file

The slope input file requires slope segment, slope gradient (in percent), slope length, and aspect values. In the WEPP hillslope application interface window, these inputs were manually encoded. In the watershed application using GeoWEPP, these values were automatically extracted from a DEM and saved in individual file.

The DEM was the source of slope and other topographic characteristics needed in running the WEPP model. In GeoWEPP, a topographic parameterization algorithm, TOPAZ (Garbrecht and Martz, 1999; Renschler, 2003), was employed to identify hillslopes and channels from a DEM. The DEM is one of the core inputs in running the geo-spatial interface of WEPP. The DEM was created from digitized contours lines and streamlines of a 1:50,000 topographic map using the Spatial Analyst Extension of ArcGIS9.

Soils input file and soil map

The soil input file of WEPP requires values on percentages of sand, clay, organic matter, and cation exchange capacity (CEC) for each layer profile. These values were taken from the laboratory analyses of the soil samples collected from the site and entered into the WEPP database through the WEPP window. Other soil parameters such as interrill and rill erodibilities, critical shear and effective hydraulic conductivity were computed using WEPP default equations while the initial saturation level was assumed at 70% as recommended in WEPP (USDA- ARS, 1995). To create a soil map, the Soil Series classification was used as the mapping unit. The procedure of Minkowski (2005) was followed in creating soilsmap.ascii and soilsmap.txt files.

Crop management file and land cover map

The crop management file consisted of a management editor, cropland initial condition database, operations database types and plant database. Under the management editor, the type of operation and date for each operation were specified. The cropland initial conditions set the conditions that exist on

January first of the modeling period. The plant database stores the parameters required for the plant growth model.

The land cover information from Landsat-7 ETM+ acquired on March 2002 from Geoimage Company was used as the existing land cover. The image was classified using NDVI (normalized difference vegetative index) and eight land cover types were identified for the study watershed: forestry (30.8%), grassland (32.2%), ricefields (11.2%), agricultural areas (11.5%), shrubland (8.2%), bare soil (5.8%), built-up areas (0.2%), and water (reservoir) (0.1%).

Since many of the crop management input data required by WEPP were not available from the study area, the WEPP and GeoWEPP databases that accompany with the models were used for crops that were similar in nature to those in the study area. This was based on the recommendations of a number of studies including those of Agus et al. (2004) and Chung et al. (2003).

B. Land Management Scenario Simulation

There were two land management scenarios simulated to estimate soil loss and runoff under specific field conditions. Simulations were executed representing soil loss and runoff at the watershed and farm-scale using: a) Current land use without conservation practice, and b) Current land use with conservation support practice (3-m wide contour). The 3-m wide contour has a 1% slope and a ridge height of half a meter. Additional scenarios for the watershed application include: c) Land use conversion to agriculture (except the forest and rice paddy areas) without conservation measures, and d) Same as scenario c) but contouring is applied to all agriculture areas.

The hillslope application of WEPP was used to assess the farm-scale effect of adopting soil and water conservation measures. From the watershed simulation, the hillslope with the highest soil loss and sediment yield was selected. Scenarios wherein a 1.6-m and 3-m wide contours were compared against the no-contour farm management.

The current version of GeoWEPP can only process less than a thousand hillslopes. To run the model, the raster size of the input data was resampled from 30-m to 60-m to trim down the number of hillslopes. The minimum critical source area and channel length were also set at 50 ha and 500 m, respectively. A total of 388 hillslopes and channels (or subcatchments) were delineated for the watershed.

III. Results and discussion

A. Erosion assessment at Upper Inabanga Watershed scale

The on-site effects of erosion are predicted using the flowpath method, as described in Cochrane and Flanagan (1999), wherein erosion is computed based on all possible flowpath within the watershed using the individual flowpath profile. Presented in Figure 4, on-site soil losses across the watershed were mapped and classified into 10 different categories. Under the existing land use, there are areas of deposition as well as soil losses.

Considering a tolerable soil loss value of $10 \text{ t}\cdot\text{ha}^{-1}$ (as used in PCARRD, 1984), 26.4%, 23.9%, 52% and 29.4% of the watershed would experience non-tolerable erosion under scenario A, B, C or D, respectively. Areas with non-tolerable soil loss are represented by orange to dark red colors in the erosion maps. Most of these high erosion areas were bare or cultivated/agricultural areas.

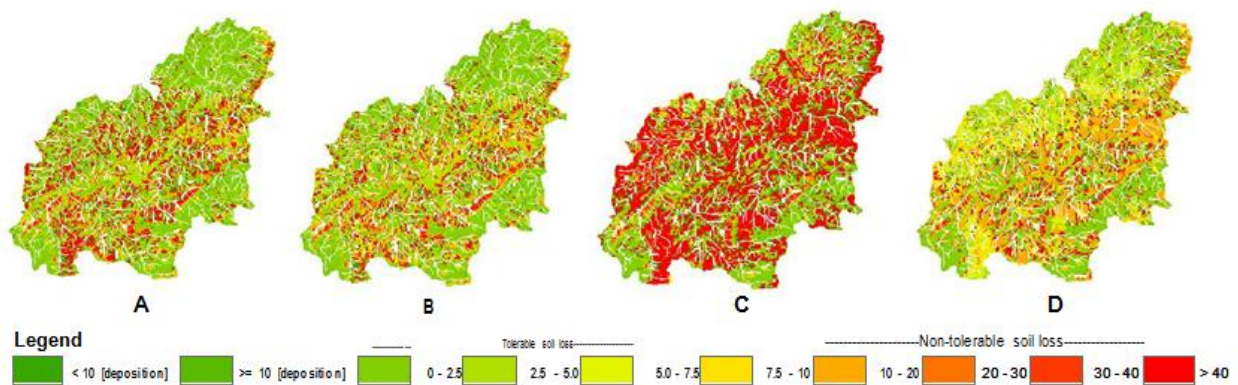


Fig. 4. On-site effects of erosion (in $t \cdot ha^{-1} \cdot yr^{-1}$) from four different land management scenarios. These scenarios are described above.

In terms of sediment yield and discharge at the outlet of the watershed given in Table 1, Scenario D, where 58% of the watershed area is under cultivation with contouring as conservation measure, resulted to a very low sediment delivery per unit area of $3.9 t \cdot ha^{-1}$ and runoff volume of 21.7 MCM. Although there is a slight increase in on-site soil loss, of 5.5% relative to scenario B, the increase of agricultural areas in scenario D (from 11.5% to 58% relative to scenario B) would result in higher productivity for the area.

Table 1. Off-site effects of erosion under different land use scenarios as predicted by GeoWEPP

Scenario	Sediment delivery ($t \cdot ha^{-1}$)	Discharge at the outlet (million m^3)
A	11.9	43.3
B	10	40.0
C	32.1	48.0
D	3.9	21.7

B. Erosion assessment at farm level

Table 2. Results of the hillslope simulation with and without conservation measures

Scenario	Soil loss ($kg \cdot m^{-2}$)	Sediment yield ($t \cdot ha^{-1}$)	Runoff (mm)
Conventional practice	147.6	32.8	521.7
1.6-m wide contour	1.3	12.6	14.3
3-m wide contour	1.3	12.8	9.6

The profile of the test hillslope, having an area of 10 ha and a slope length of 578 m, was determined by the model. The model predicted soil loss at equal intervals along the slope. In Figure 5, the soil loss graph shows erosion relative to the hillslope profile. Figure 5 (A) shows the high erosion segment area, which coincides with high slope segments. In Figure 5 (B), the conservation-oriented practice of 3-m wide contour farming with 1% slope was applied to the agricultural areas. The significant

decrease in soil loss along the profile is plotted and shows minimal deviation from the hillslope profile. Table 2 also summarizes soil loss, sediment yield and runoff from the hillslope under three management scenarios. The 3-m wide contour has the lowest runoff discharge at 9.6 mm while its soil loss and sediment is similar to the 1.6-m wide contour at $1.3 \text{ kg}\cdot\text{m}^{-2}$ and $12.8 \text{ t}\cdot\text{ha}^{-1}$, respectively.

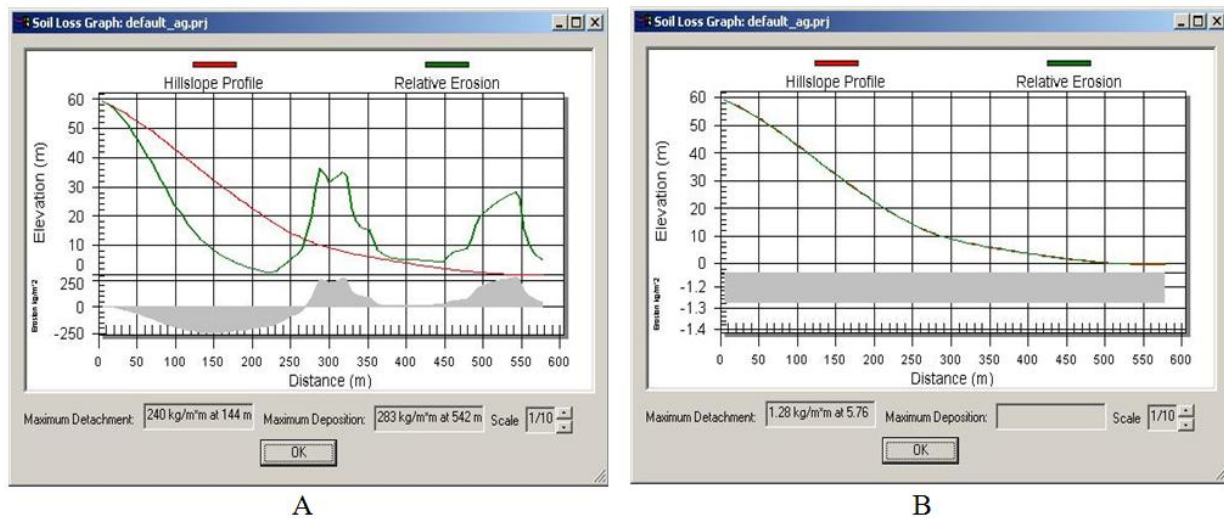


Fig. 5. Soil loss graph of the test hillslope: A) showing the relative erosion with no conservation farm practice and B) with 3-m wide contour farm practice

C. Application to agricultural planning

Under the existing land cover conditions, only 22.7 % of the Upper Inabanga Watershed area is utilized for agriculture: 11.5% is rice paddy and 11.2 for other crops. Under this condition, 26.4% of the area is experiencing high soil loss. However with increasing population, the watershed will in the future face the issue of allocating more agricultural areas for food production. One possible scenario is converting other land uses to agriculture except the forest and rice paddy areas. For this scenario 57% of the watershed areas will be cultivated for crop production. Without conservation measures, erosion hotspots will increase to 52% of the watershed area while sediment discharge will be around $52.1 \text{ t}\cdot\text{ha}^{-1}$. With a soil and water conservation strategy such as contouring, high erosion areas and sediment discharges decrease from $29.45 \text{ t}\cdot\text{ha}^{-1}$ and $3.9 \text{ t}\cdot\text{ha}^{-1}$, respectively. This scenario suggests that the agriculture area in the watershed could be expanded, however, with adoption of appropriate soil and water conservation practices in order to minimize erosion.

IV. Conclusion

The spatial and temporal variation of the onsite and off-site effects of erosion provide indispensable information in farm planning and in managing a watershed. The model simulations, though subject to further field verification and the availability of crop management data, enabled the evaluation of the potential impact of land use change over a watershed. The application of the WEPP erosion model and the use of GIS tools demonstrated their usefulness in the planning and managing of resources in the Upper Inabanga Watershed. The ability to simulate and predict the extent of erosion under a wide range of scenarios and to identify specific location of erosion prone areas was deemed valuable for decision-making purposes and for designing conservation strategies. The methodology that was

- PCARRD (1984). The *Philippines Recommendations for Soil Conservation*. PCARRD Technical Bulletin Series NO. 28-A, Los Banos, Laguna.
- Renschler, C. S. (2003). Designing geo-spatial interfaces to scale process models: the GeoWEPP approach. *Hydrological Processes*, **17**(5), 1005-1017
- USDA-ARS (1995). "USDA- Water Erosion Prediction Project: Hillslope profile and watershed model documentation." USDA-ARS National Soil Erosion Research Laboratory, West Lafayette.
- White, S. (1995). Soil erosion and sediment yield in the Philippines. In: *Sediment and Water Quality in River Catchments*, I. D. L. Foster, A. M. Gurnell, and B. W. Webb, eds., John Wiley & Sons Ltd., New York.
- Zeleeke, G., Winter, T., and Flanagan, D. (1999). *BPCDG: Break point data generator using observed standard weather data sets*. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, Indiana.

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