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Estimating the impacts of global change on erosion with stochastically generated climate data and erosion models

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Abstract The impacts of global change on local and regional environments are uncertain. However, climatic records for the last 40 years in the USA indicate increasing precipitation and decreasing maximum and minimum air temperature trends in the southeastern USA, while warmer temperatures and increasing precipitation trends were indicated in the northwestern regions. The magnitude of what these trends in climate, if continued, might have on runoff and erosion are estimated by stochastic generation of long term synthetic weather records input into continuous simulation erosion models. A weather generator, CLIGEN, and a data base of 1000 climate stations spaced on a 1° by 1° latitude and longitude grid were used to developed climate data input files for the WEPP (Water Erosion Prediction Project) and CREAMS (Chemicals, Erosion, Runoff and Agricultural Management Systems) erosion models. Gross erosion estimates calculated using long term generated data modified by temperature and precipitation trends were compared with stationary climate inputs to determine relative impacts.

INTRODUCTION

Detecting climate change has been clouded by uncertainties existing in the long term observational records. Most independent analysis of these data show a increase of 0.5°C in the mean global temperature over the past 100 years (Shiffer & Unninayar, 1992). Much of recent research efforts have been directed toward determining the cause of this increase. The consensus finding is that this change in observed climate is due to the enhanced greenhouse effect. Furthermore, these changes have been forecast by three-dimensional state-of-the-art climate models run on sophisticated supercomputers (Hansen & Lebedeff, 1987).

However, these studies have presented uncertainties to water resources investigators and planners because of the various mathematical assumptions made and the scale of the changes depicted from the output of these models. For water resource investigators to use existing hydrologic models to predict changes in secondary or tertiary hydrologic cycle elements, such as surface runoff and sediment transport, better estimates of the long term trends of not only temperature but also precipitation is required. At present, the output from these models is at too large a scale to be of particular use for precipitation trends that could be used in hydrologic modelling.

This paper presents results of analysis combining monthly temperature and precipitation trends calculated from approximately 1000 stations in the conterminous

USA for a 40 year period from 1950 to 1990. Monthly trends calculated from these stations are incorporated into a weather generator, CLIGEN, to produce scenarios of climate change for 14 sites across the USA. Climate data input files were generated at each site for two erosion models, WEPP and CREAMS.

METHODS

Tasks of this study are selection and model parameterization of the 14 erosion sites, modification of the weather generator, selection of climate change data trends, generation of the climate change scenarios, simulation of the water and sediment yields, and analysis and comparisons of results.

Site selection and model parameterization

Fourteen locations selected for model simulations correspond to climate station locations where trend analysis were available for the 40-year period. These sites listed in Tables 1 and 2 are located in each of the states of California (CA), Georgia (GA), Idaho (ID), Indiana (IN), Massachusetts (MA), Maryland (MD), Maine (ME), Minnesota (MN), Mississippi (MS), Oklahoma (OK), Oregon (OR), South Carolina (SC), Texas (TX),

Table 1 CREAMS model simulated impacts of generated climate change on runoff, evaporation, and soil loss.*

Location	Precipitation (mm):		Runoff (mm):		Evaporation (mm):		Percolation (mm):		Soil loss (kg m^{-3}):	
	NCH	CH	NCH	CH	NCH	CH	NCH	CH	NCH	CH
CA	283	337	17	23	263	285	12	29	1.4	1.8
GA	1233	1558	275	370	767	804	190	382	26.5	35.3
ID	633	843	124	169	420	526	90	147	10.8	15.1
IN	965	967	203	197	605	582	157	188	18.7	18.1
MA	1109	1306	285	315	576	645	247	346	26.5	29.1
MD	950	1086	114	184	688	675	146	225	14.9	17.0
ME	944	951	297	291	549	555	99	105	28.1	27.4
MN	608	730	153	195	412	460	38	76	14.7	18.2
MS	1491	1708	412	477	758	819	320	410	40.6	46.9
OK	620	742	111	126	471	543	38	73	10.5	11.8
OR	1479	1070	238	155	526	513	713	401	21.9	14.2
SC	1199	1548	257	347	715	787	226	413	24.5	32.8
TX	897	972	210	227	574	605	112	138	20.4	21.8
WA	254	312	24	25	223	214	8	20	1.9	1.3

* NCH and CH refer to no climate change and climate change, respectively.

and Washington (WA). Hypothetical erosion plots at each location using the same soil characteristics, slope steepness, slope length, and crop rotation were constructed. The slope of the plot is 9%, the slope length is 22.1 m with a continuous fallow cropping system. Six harrow tillage operations were applied during the simulation to keep them weed free.

The erosion models used are the WEPP hillslope profile model (Lane & Nearing, 1989), and the CREAMS hydrology and erosion models (Knisel, 1980). Parameters required for each of these models were developed from the plot characteristics described above. Each site has the same parameters for hydrology and erosion model components. Climate input files are site specific for each model.

The CREAMS model is made up of three sub-models: hydrology, erosion, and chemicals. Each model may be run separately, with output from the hydrology model being input to the erosion model, and then output from the erosion input to the chemical model. Runoff is computed in the hydrology using the SCS curve number method. In the case of the Miami silt loam, B hydrologic class soil, the average condition curve number was set at 86. Other parameters required by the hydrology component for runoff, evaporation, soil water storage, percolation, and peak flow calculation were derived from the soil, management, and plot configuration data given above. The erosion component of CREAMS requires storm runoff volume and peak flow rate passed from the hydrology component. Erosion by detachment is calculated for both interrill and rill areas using two modifications to USLE (Foster *et al.*, 1980).

Table 2 WEPP model simulated impacts of generated climate change on runoff and soil loss.*

Location	Precipitation (mm):		Runoff (mm):		Soil loss (kg m^{-3}):	
	NCH	CH	NCH	CH	NCH	CH
CA	283	337	23	26	1.5	1.8
GA	1233	1558	307	433	18.4	23.1
ID	633	843	99	141	5.1	8.6
IN	965	967	250	221	8.2	7.4
MA	1109	1306	346	353	14.9	14.6
MD	950	1086	180	201	5.8	7.3
ME	944	951	242	301	7.8	10.1
MN	608	730	356	395	10.2	12.1
MS	1491	1708	511	566	30.3	31.8
OK	620	742	133	141	7.6	7.2
OR	1479	1070	325	164	22.6	11.9
SC	1199	1548	313	375	16.0	16.8
TX	897	972	266	241	14.8	13.0
WA	254	312	5	10	0.1	0.3

* NCH and CH refer to no climate change and climate change, respectively.

The WEPP utilizes new technology for runoff and erosion simulation. Precipitation is partitioned into runoff and infiltration by disaggregating daily precipitation into a storm intensity pattern. CLIGEN is used to generate the required storm precipitation inputs of amount, duration, time to peak intensity, and maximum storm intensity. WEPP then disaggregates these variables into a single peak storm intensity pattern. The model is driven by four input files, climate, soil characteristic, slope, and crop management. WEPP technology differs from the other models listed above by having two separate soil erodibility factors, K_i for interrill, and K_r for rill erosion.

Climate data base and weather generator

The user requirements of the WEPP dictated the need to stochastically generate weather elements on a daily time step for continuous simulation of erosion from agricultural lands (Foster, 1987). To meet this need, a weather generator, CLIGEN, (Nicks & Lane, 1989) was developed. The basic data required to calculate the parameters for this generator were derived from National Weather Service sources. For precipitation and temperature parameters, daily records were obtained from the National Climate Data Center, Ashiville, NC. The archived data set records of all daily precipitation and temperature stations, including more than 25 000 stations, were obtained and were inventoried. A set of nearly 1100 station spaced on a 1° by 1° grid of latitude and longitude were selected for the conterminous USA (one in each grid cell), Alaska, Hawaii, Puerto Rico, and nine US Pacific Ocean islands. These stations have records extending from 1896 until the present, with the majority having digitized records from 1948. The distribution of these stations and the grid for the conterminous 48 states are shown in Fig. 1.

CLIGEN generates 11 daily weather elements that are required by most hydrologic simulation models. These are precipitation occurrence, amount, duration, maximum storm intensity, time to peak intensity; maximum, minimum, and dew point tempera-

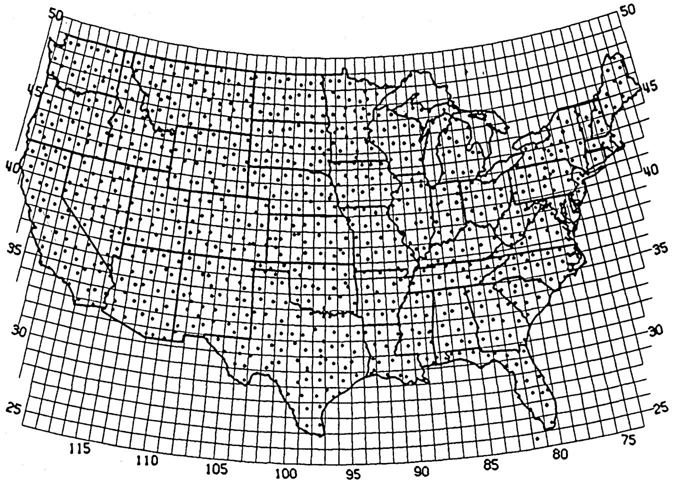

Fig. 1 Map of the United States showing the distribution of precipitation and temperature selected for parameterization for the CLIGEN weather generator.

tures; solar radiation; and wind speed and direction. Distribution parameter values for each of these elements have been calculated for more than 1000 stations.

A first order Markov chain is used to generate occurrence of wet or dry day from a four state array of wet-dry day probabilities. Precipitation amount is generated from a skewed normal distribution of daily mean precipitation for each of 12-monthly periods. Temperature values are generated from a normal distributions of maximum and minimum temperature. It is assumed that the time series of these values is stationary with respect to the time period used in calculating the moments of these distributions from the raw climate data. Therefore, no trend is attributed to the generated time series of these elements.

Modification of the generator to simulated trends that may be present in the data is accomplished by calculating the linear trend of the raw data for precipitation and air temperature elements using

$$Y_i = a_i u_i + b_i \tag{1}$$

where Y is the yearly adjusted mean of the raw variate, u the year number from the beginning of the series, a the trend coefficient and b the intercept of the regression for $i = 1, 2, 3, \ldots, 12$ monthly intervals. Then, the trend coefficients, $a_i s$, are entered into a version of the generator modified to calculate the yearly incremental adjustment for the respective monthly means. Long term simulations are run with incremental adjustments to the respective means with daily data output in the WEPP and CREAMS model weather data formats.

Trend calculations

Daily values of precipitation and maximum and minimum temperature were processed for nearly 1000 stations shown in Fig. 1 by a two pass method to fill in missing daily values. First the data were read and generator parameters were calculated for estimating the occurrence and amount of precipitation, and the minimum and maximum temperature for each of 12 monthly periods. Then the data were read again and the missing data generated using the statistical parameter calculated in the first pass. Next, monthly, seasonal, and annual linear trends were calculated for each station with complete records, observed and estimated by the procedures given above, for the period from 1950 through 1989. Trend coefficients, a, were calculated using equation (1). Average monthly temperatures were calculated from the maximum and minimum monthly values and trends calculated in the same manner. An example of annual trend values contoured and plotted for precipitation are shown in Fig. 2 (Nicks *et al.*, 1993).

RESULTS AND CONCLUSIONS

Tables 1 and 2 list the results for the CREAMS and WEPP for 30-year model simulation runs. At most sites in the CREAMS simulations runoff and soil loss increased due to increased precipitation. At three sites (Indiana, Maine, and Oregon) runoff and soil loss decreased with corresponding increases in soil evaporation and percolation below the root zone. Relative impacts of these generated climate changes on soil loss ranged from

Fig. 2 Annual precipitation trends for the period 1950 to 1990 (mm year^{-1}).

a −35% decrease at the Oregon site to a 40% increase in Idaho. The WEPP model runs (only runoff and soil loss are listed) produced a similar range of results, −47% decrease in Oregon to a 68% increase at the Idaho site.

The results of these model simulations based on calculated trends from observed data indicate that the technique may have some merit as a tool to project climate change to impacts on runoff, soil loss, and other hydrologic elements. However, the limited analyses presented here should be more closely studied. Linear trends can only be used in simulating climate inputs that are the same period length as the observed data. Perhaps other techniques, such as a moving average of the means, could be used to replaced the linear trends used here.

REFERENCES

Foster, G. R. (1987) User requirements USDA Water Erosion Prediction Project. *NSERL Report no. 1, USDA – Agricultural Research Service National Soil Erosion Research Laboratory, Purdue University, West Lafayette, Indiana 47907, USA.*

Foster, G. R., Lane, L. J. Nowlin, J. D., Laflen, J. M. & Young, R. A. (1980) A model to estimate sediment yield from field-sized areas: development of model. Chapter 3 in: *CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems* (ed. by W. G. Knisel), 36-64. US Dept Agriculture, Conservation Research Report no. 26.

Hansen, J. & Lebedeff, S. (1987) Global trends of measured surface air temperature. *J. Geophys. Res.* **92**, 13 345-13 372.

Knisel, W. G. (1980) *CREAMS A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems.* US Dept Agriculture, Conservation Research Report no. 26.

Lane, L. J. & Nearing, M. A. (1989) Profile model documentation: USDA Water Erosion Prediction Project, hillslope version. *NSERL Report no. 2, USDA – Agricultural Research Service, National Soil Erosion Research Laboratory, Purdue University, West Lafayette, Indiana 47907, USA.*

Nicks, A. D. & Lane, L. J. (1989) Weather Generator. In: Profile model documentation: USDA Water Erosion Prediction Project, hillslope version (ed. by L. J. Lane & M. A. Nearing), 2.1-2.19. *NSERL Report no. 2, USDA – Agricultural Research Service, National Soil Erosion Research Laboratory, Purdue University, West Lafayette, Indiana 47907, USA.*

Nicks, A. D., Lane, L. J., Gander, G. A. & Manetsch, C. (1993) Regional analysis of precipitation and temperature trends using gridded climate station data. In: *Advances in Hydro-Science & Engineering* (ed. by S. S. Y. Wang), vol. 1, Part A, 497-502. The University of Mississippi.

Schiffer, R. A. & Unninayar, S. (1992) *The Detection of Climate Change Due to Enhanced Greenhouse Effect: A Synthesis of Findings Based on the GEDEX Atmosphere Temperature Workshop.* NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA.