User Guide for Modeling Community Erosion from Climate Change App

ESRI CLIMATE RESILENCE APP CHALLENGE 2014

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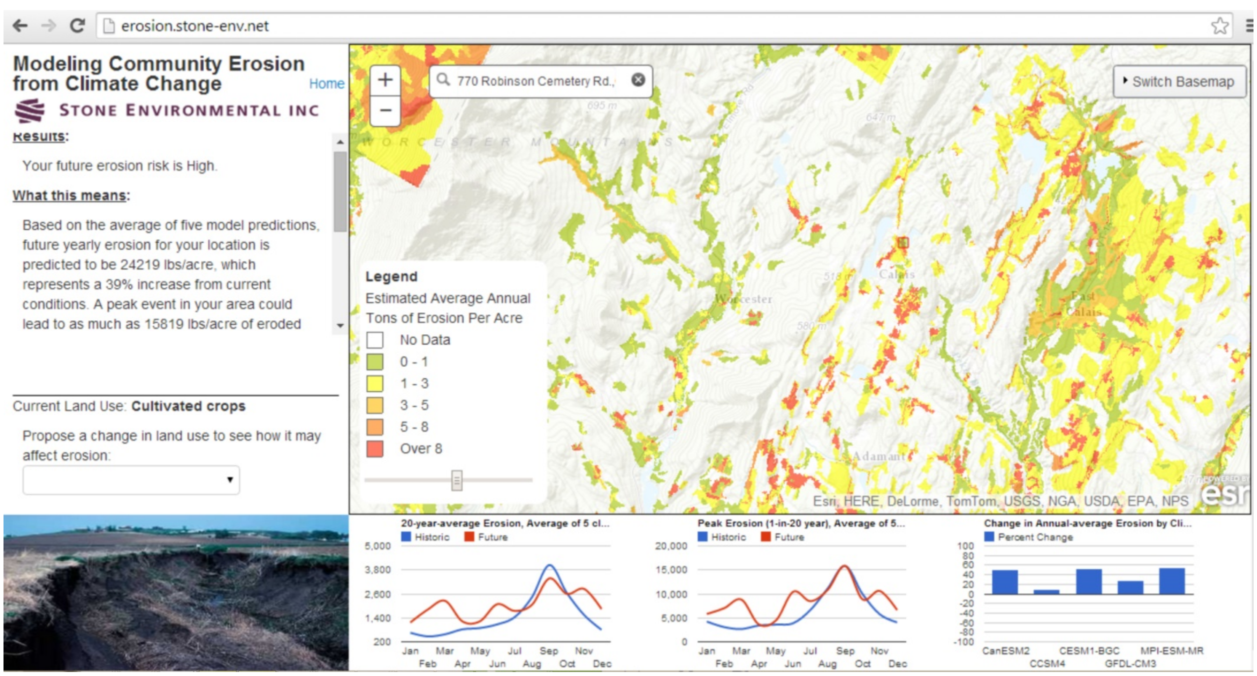
Introduction

The Modeling Community Erosion from Climate Change App enables community members and leaders to understand the impact climate change will have on soil erosion. It provides a basis for taking preventative action regarding infrastructure investments and soil conservation using high-resolution scientific data. The App helps stakeholders locate sites that are vulnerable to erosion including public, private, and agricultural lands, and roads. At user-selected sites, the App models present-day and future predictions of soil loss driven by climate change. Based on the type and severity of erosion, users are directed toward different soil conservation resources. The App also allows users to investigate erosion risk for a variety of future land covers. The modeled data provides information on changes in annual total erosion, seasonal variations, and soil losses due to extreme precipitation events, as well as insight into the uncertainty associated with the predictions by incorporating data from multiple climate models.

The underlying erosion model is the Modified Universal Soil Loss Equation (MUSLE, Williams 1975, Williams et al. 2008). Erosion is calculated on a daily-event basis using MUSLE. Key drivers in MUSLE are land use, soil characteristics, topography, crop management practices, and precipitation (from which runoff volume and peak runoff rate are calculated). At selected locations, MUSLE is evaluated using high-resolution precipitation data for historic (1981-2000) and future (2051-2070) time periods. Future precipitation data come from regionally-downscaled predictions made by five global climate models assuming greenhouse gas concentrations in the atmosphere continue to rise throughout the 21st century, the scenario known as RCP8.5 in the Coupled Model Intercomparison Project (CMIP5).



The Modeling Community Erosion from Climate Change Application makes innovative use of data by merging information from a wide array of public-sponsored data sources to make climate impact predictions at local scales. Developed for and during the Esri Climate Resilience App Challenge 2014, this application is available to help communities evaluate their resiliency to climate impacts on erosion. With continued development the application could be advanced further to incorporate additional climate model data, refine model algorithms, and add features to explore effects of conservation.

The application is built using ArcGIS platform including:

- ArcGIS Desktop
- ArcGIS Server (custom geoprocessing services, map services, image services)
- ArcGIS JavaScript API
- ArcSDE
- Python and ArcPy plus NetCDF python libraries
- ArcGIS REST API

In addition the following other tools were used in its development:

- Google Charts
- PostGreSQL

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Getting Started

Navigating the Modeling Community Erosion from Climate Change App is simple. Below are the navigation tips to explore erosion potential in your area.

1. **Access the application:** Navigate to erosion.stone-env.com in your web browser to access the app.

2. **Select location:** Get started with your analysis by locating your area of interest. You can pan and zoom on the map by using the scroll wheel of your mouse or by typing an address into the geocoder to change location (see Figure 1). Current-day conditions for annual average erosion are shown on the map to help you identify today's areas of high risk for further analysis.

Figure1. Geocoder

3. **Click to run:** Run the model by clicking on any map point. The erosion model runs with soils and land use information at the selected location and historic and future modeled precipitation data. Results are displayed comparing historic and future erosion conditions during the two 20-year time periods 1981-2000 and 2050-2070.

4. **Explore options:** Review the explanation of results and recommended next steps in the left pane. Propose an alternative land cover in the future to explore possible mitigation actions or to evaluate impacts of development.

Figure2. Explore optional land use.

5. **Understand uncertainty:** Consider the variability in annual erosion results driven by the five different climate models to assess the robustness of your predictions. By clicking on the graphs you can see the actual modeled results.

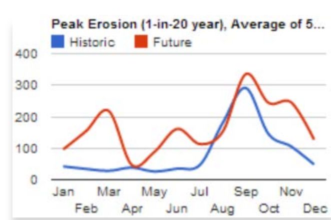

Figure 3 Charting of Results

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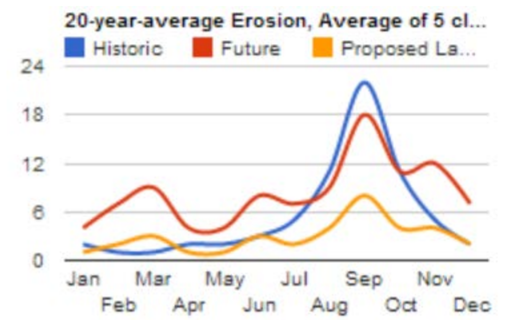
Graphical and Summary Results

By clicking on a point of interest in the map area, the erosion model is evaluated and a series of graphical and summary results are generated in the bottom pane of the browser. Detailed information on each results chart is provided below.

3.1
Monthly Erosion Chart

Monthly total soil loss in pounds per acre is displayed on the first chart for the 20-year historic and future time periods. Daily soil loss totals calculated by the erosion model for each of the five climate model precipitation data sets and summed to calculate monthly totals. Monthly totals are averaged for all 20 years to compute monthly erosion in a typical year for the two time periods. Finally, the period-average results from each of the five climate models are averaged to determine the climate model-average monthly soil loss.

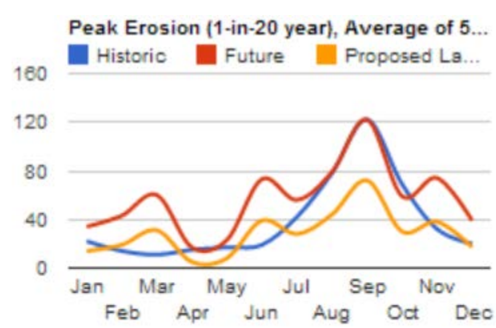


If a new land use is proposed, a third plotline will appear on the chart showing the erosion predicted in the future time period assuming the selected area becomes converted to the proposed use. This plotline is also an average of results across the five climate model input datasets.

This chart provides insight into changes in magnitude and seasonal patterns of erosion due to climate change. Use this chart to identify any shifts in the months experiencing high erosion or changes in the duration and variability of periods of high erosion.

3.2
Extreme Event Chart

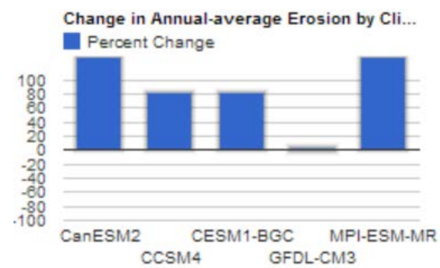
Soil loss in the peak event of the 20-year historic and future time periods is displayed for each month in the second chart. Peak soil loss is calculated for the five climate model precipitation datasets independently and then averaged across the climate models for the display.



This chart provides insight into changes in peak erosion from a single 1-in-20 year event. Use this chart to identify changes in peak event monthly frequency and magnitude. Keep in mind that even for areas where the average monthly and annual erosion risk is low, rare extreme events may cause damaging soil losses. Comparing the magnitude of the peak erosion to the monthly total erosion can help users evaluate the risk of extreme events.

3.3
Annual Erosion by Model Chart

Percent change in annual total erosion for each climate model input dataset is shown in the third chart. Annual average erosion is calculated in each period and the percent change in future over historic conditions is displayed for each climate model.



This chart provides insight into the robustness of future erosion predictions. Use this chart to understand when uncertainty in predictions in high (models may show different magnitudes or even sign) and when uncertainty is low (models all result in similar magnitude percent change).

3.4
Synopsis

A summary evaluation of results is provided in the left-hand pane. An erosion risk classification of low, medium, or high is given based on the following criteria:

Classification	Agriculture	Natural/Vegetated	Developed
Low	< 5,000	< 500	< 500
Moderate	5,000-20,000	500-5,000	500-5,000
Severe	5,000-20,000	500-5,000	500-5,000

The erosion classification is followed by a results synopsis and recommended next steps including a link to relevant conservation resources.

4 Methodology

The methods underlying the App make use of state of the art modeling and data sets. The following sections provide an overview of the erosion model and key input data sets.

4.1 Modified Universal Soil Loss Equation

This App is an application of the Modified Universal Soil Loss Equation (MUSLE, Williams, 1975 and Williams et al. 2008), an adaptation of the Universal Soil Loss Equation (USLE). In contrast to USLE which estimates annual average sediment loads, MUSLE may be used to estimate sediment yield from individual storm events. The key to erosion estimates in MUSLE is the use of storm- based runoff volumes and runoff peak flows as the source of erosive energy. The following form of the MUSLE equation is used in this application:

$$E = (2200)(1.586)(Qq_{peak})^{0.56}A^{0.12}K\ LS\ C\ P \qquad (1)$$

where:

E = sediment yield (pounds/acre)
Q = runoff volume (mm)
q_{peak} = peak runoff rate (mm/h)
A = watershed area (ha) (= 0.4047 for all simulations in this application, equiv. to 1 acre)
K = soil erodibility factor
LS = topographic factor accounting for slope length and steepness
C = crop management factor
P = erosion control practice factor (= 1 for all simulations in this application)

Runoff volume, Q, and peak runoff rate, q_{peak} are calculated empirically from daily precipitation data using the SCS curve number method and time of concentration estimates for regional storm-types.

4.2 Data Sources

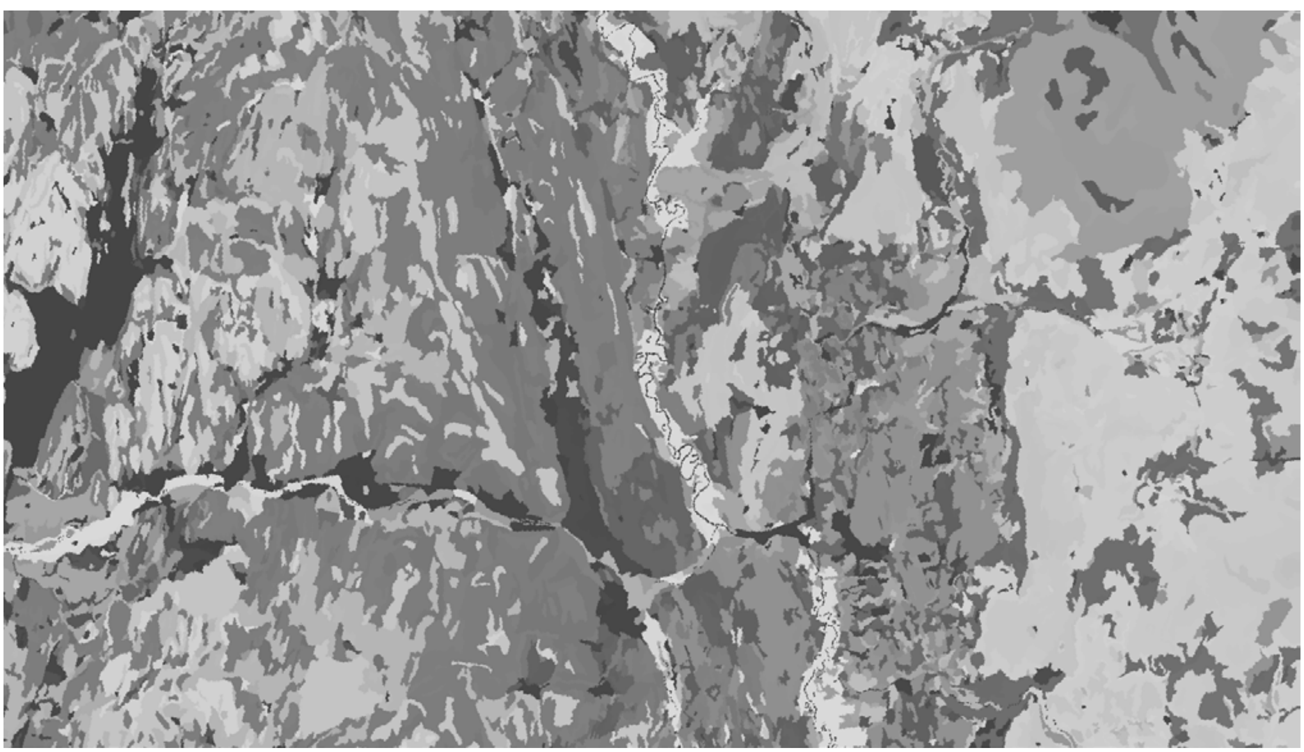
There are four key sources of data: *Climate, Soils, Land Use, and Storm Type*. Predictions from the MUSLE model rely on many key publically available datasets. The next sections describe the four key sources of data related to: climate, soils, land use, and storm type.

4.2.1
Precipitation

The climate driver in the erosion calculations is daily precipitation. The erosion app uses precipitation results from climate models driven by the future scenario known as RCP8.5, in which greenhouse gas concentrations continue to rise so that radiative forcing approaches 8.5 W/m^2 by the end of the 21st century. Two twenty-year time-series of daily precipitation data covering the contiguous United States were extracted from the statistically-downscaled output of five global climate models assessed in the Coupled Model Intercomparison Project (CMIP5). The five models from which data was selected are: The Geophysical Fluid Dynamics Laboratory (GFDL) Coupled Model 3.0 (GFDL-CM3), Environment Canada's Fourth Generation Atmospheric General Circulation Model (CanESM2/CGCM4), the European Network for Earth System Modeling's Max-Planck Institute for Meteorology Medium Resolution Grid (MPI-ESM-MR); Community Earth System Model Biogeochemistry (CESM-BGC), and Community Climate System Model (CCSM4). The precipitation data from the models was statistically-downscaled to $1/8^{th}$ degree was obtained for these models from the archive of Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections, led by the Bureau of Reclamation.

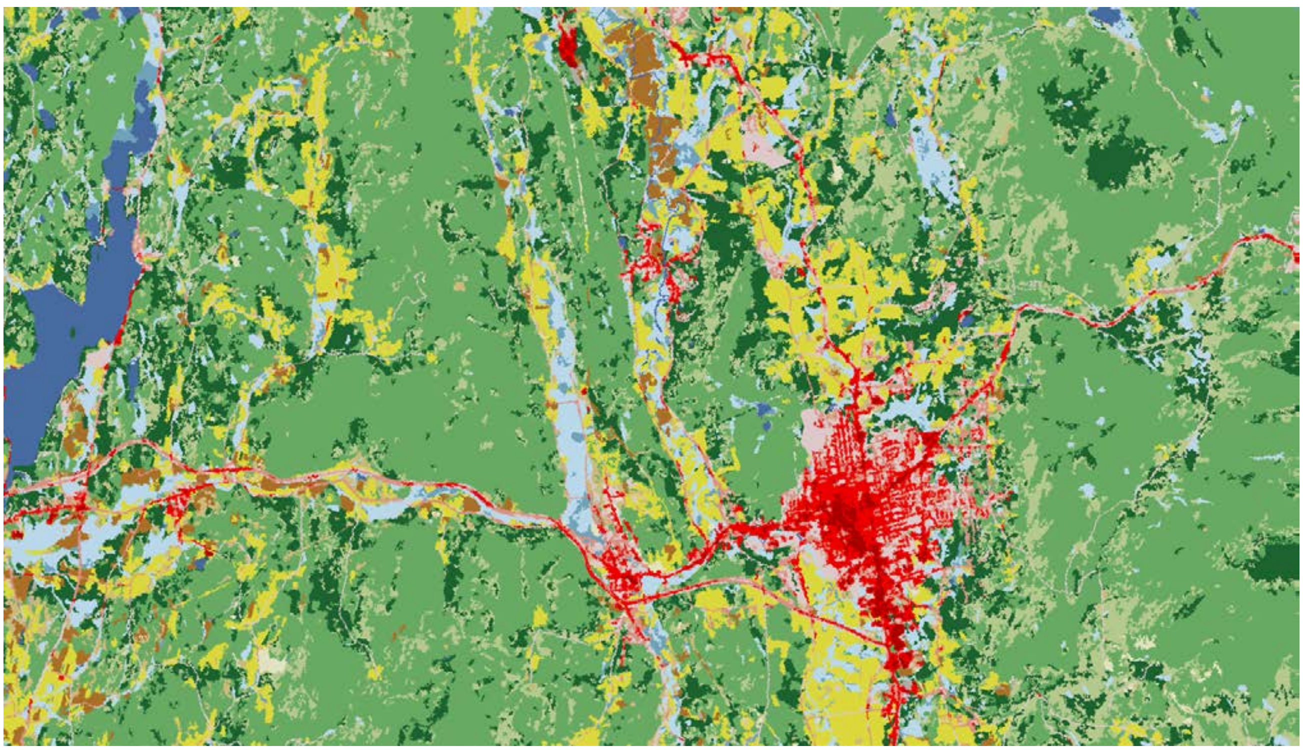
4.2.2
Soils

National soils data at 30-m resolution were extracted from the Gridded Soil Survey Geographic (gSSURGO) Database. Soils parameters extracted from SSURGO that are required as inputs to the erosion model are: K factor, hydrologic group, and percent slope. No estimates are made for any parameters with missing data. Grid cells with missing data for any of these parameters are not processed by the erosion model.



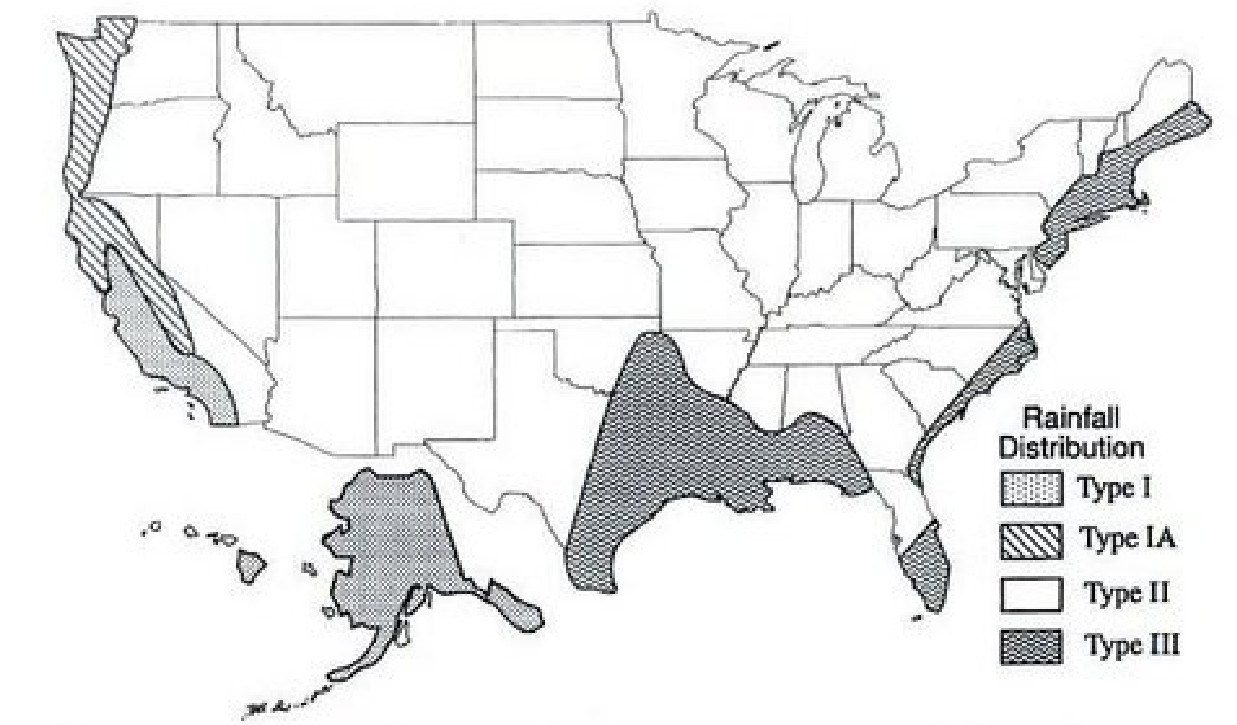
4.2.3
Land use

Land cover data at 30-m resolution are extracted from the National Land Cover Database (NLCD). To simplify the number of unique combinations of soils, land cover, storm type, and precipitation, land cover classes were aggregated into broader categories. These broad classes were related to cover type and hydrologic condition descriptions in the Soil Conservation Services Technical Release 55 to a set of assign curve numbers used in runoff volume calculations.



4.2.4
Storm Type

Storm-type regions were delineated manually following the [Rainfall Distribution with a SCS Type II Hyetograph.]



5 Uncertainty

Future climate predictions from global climate models are inherently uncertain. These uncertainties are propagated from modeled precipitation data to the erosion predictions made by MUSLE. Users can gain an understanding of the robustness of their results based on the degree to which erosion estimates based on precipitation from the five climate models vary. In many cases, all five models agree on both the sign and magnitude of changes in erosion from current to future conditions. Users should be cautious about drawing conclusions from modeled results when there is disagreement among the models in both magnitude and sign.

The erosion predictions made by the App are representative of values that could occur in an average year or as extremes in the 20 year periods. Actual erosion values may vary from the predicted results due to unpredictable natural variability in seasonal, yearly, and decadal precipitation patterns. Even in cases where all five models show strong agreement, erosion rates are subject to uncertainty due to natural variability.

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References and Resources

Background

Erosion http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/landuse/crops/erosion/
Soil Erosion and Degradation-Threats
http://www.worldwildlife.org/threats/soil-erosion-and-degradation

Modeling References

MUSLE: Sediment loss from water erosion - Modeling sediment loss
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_013359.pdf

Soil erosion models http://www.soilerosion.net/doc/models_menu.html
Universal Soil Loss Equation http://en.wikipedia.org/wiki/Universal_Soil_Loss_Equation
http://www.fftc.agnet.org/htmlarea_graph/library/20110809090940/tb150f2.jpg
http://www.fftc.agnet.org/library.php?func=view&style=type&id=20110809090940

Prevention

Controlling Soil Erosion http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_030104.pdf
Erosion and Sediment Control Best Management Practices
http://www.mdt.mt.gov/research/projects/env/erosion.shtml
Best Management Practices for Erosion and Sedimentation Control
http://www.maine.gov/mdot/env/documents/pdf/bmp2008/BMP2008full.pdf
Best Management Practices for Agricultural Erosion and Sediment Control
http://www.sonoma-county.org/agcomm/pdf/bmp_handbook3.pdf
Erosion Control Techniques http://www.ecy.wa.gov/programs/sea/pubs/95-107/erotech.html
How to Control Erosion http://www.wikihow.com/Control-Erosion
Conservation Practices, NRCS
http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849

http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/fotg/
Soil Quality Information Sheet Rangeland Soil Quality—Water Erosion
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_019216.pdf
NRCS Field Office Technical Guides (FOTG) http://efotg.sc.egov.usda.gov/
"Saving Runaway Farm Land", November 1930, Popular Mechanics One of the first articles on the problem of soil erosion control
http://books.google.com/books?id=xSgDAAAAMBAJ&pg=PA59&dq=Popular+Science+1931+plane&hl=en&ei=5r8JTaa6Ismr8AaNmb2iAQ&sa=X&oi=book_result&ct=result&resnum=8&ved=0CEAQ6AEwBzgU#v=onepage&q&f=true

Erosion Control Technology Council - a trade organization that mission is to educate and standardize the erosion control industry http://www.ectc.org/

International Erosion Control Association - Professional Association, Publications, Training

http://www.ieca.org/

WatchYourDirt.com - Erosion Control Educational Video Resource

http://watchyourdirt.com/

Soil Bioengineering and Biotechnical Slope Stabilization - Erosion Control subsection of a website on Riparian Habitat Restoration

http://riparianhabitatrestoration.ca/575/bioengintro.htm

Vetiver Network International - Soil and water management method

http://www.vetiver.org/

Story: Soil erosion and conservation

http://www.teara.govt.nz/en/soil-erosion-and-conservation

Water Erosion Control Practices

milford.nserl.purdue.edu/weppdocs/overview/practices.html

Te Ara: The Encyclopedia of New Zealand

Several mechanical methods are used to control and prevent erosion. Flumes. Flumes are artificial channels that control the flow of water down a slope .

Soil Erosion Solutions | eHow

www.ehow.com › Home & Garden

Soil Erosion Solutions. Properties built on a hillside or that have sharp slopes within their confines need to take steps to prevent or minimize erosion. Rains can ...

Soil Erosion and Degradation | Threats | WWF

www.worldwildlife.org/threats/soil-erosion-and-degradation