(Presented at the 2005 American Water Resources Association Summer Specialty Conference, Honolulu, HI, June 27, 2005)

CHALLENGES IN USING AnnAGNPS FOR AN ISLAND WATERSHED

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ABSTRACT: The process of estimating sediment discharge from mountainous Pacific Island watersheds using established computerized watershed models can be complicated by extreme variability in the input parameters. The USDA's Annualized Agricultural Non-Point Source Pollution Modeling System (AnnAGNPS) is being used to model sediment discharge from the largely-forested, 23.7-square mile Hanalei Watershed on the island of Kauai in the Hawaiian Islands. The model outcomes will be used to develop tailored and targeted treatments in the watershed to reduce sediment discharge to the estuary, sandy beaches, and coral reefs. AnnAGNPS is a continuous simulation, surface-runoff, pollutant loading model, which subdivides the watershed into cells of homogeneous soil type, land use, land management, and precipitation. Cell processes include precipitation, runoff, soil moisture balance, crop condition and management, and soil erosion. In the Hanalei Watershed, the areal divergence in rainfall, which increases from an average of 60 inches annually to over 400 inches annually in a distance of nine miles, requires development of numerous climate datasets to account for its variability. Topographic relief in the Hanalei Watershed is extreme which complicates application of the Revised Universal Soil Loss Equation for sediment yield. Landslides and debris flows in the steep upper watershed areas are frequent and may be significant contributors to stream sediment. Published analytical and empirical coefficients for soil loss and runoff computations are generally unavailable for the soil, vegetation, and land management conditions in the Hanalei Watershed. Remote sensing and field surveys are being integrated into a data collection program.
KEY TERMS: Watershed model; AnnAGNPS, island

INTRODUCTION

The USDA Natural Resources Conservation Service (NRCS) is providing technical assistance to the community of Hanalei, Hawaii to assess and analyze stream sediment-related issues through the Cooperative River Basin Study program. The Hanalei Watershed is located in Kauai County within the State of Hawaii. The long-term objective of the activity is to develop watershed treatments to reduce sediment discharge rates from the Hanalei Watershed and lessen sediment impacts to the estuary, sandy beaches, and nearshore reef areas of Hanalei Bay.

The watershed-scale modeling supports many elements of the Watershed Action Plan, which was prepared and updated by the Hanalei Watershed Hui (Hanalei Watershed Hui, 2005). The Watershed Action Plan was initially developed in 1999 when the Hanalei River was designated by President Clinton as one of 14 American Heritage Rivers. While the five-year program life of the American Heritage Rivers has eclipsed, the community organization spurred by the focus of federal programs on the Hanalei River has matured and transformed itself into the Hanalei Watershed Hui, a community-based non-profit organization. The Watershed Action Plan includes elements for development of a hydrologic budget, sediment budget, and Watershed Master Plan.

AnnAGNPS

NRCS is using USDA's Annualized AGricultural Non-Point Source Pollution Model (AnnAGNPS) for modeling of the Hanalei Watershed (USDA ARS, 2005). At its core, AnnAGNPS simulates the hydrologic, erosional, and sediment and pollutant transport processes in a watershed drainage system on a daily time step using program components based on well-established USDA analyses methodologies. The physical watershed processes are driven primarily by daily rainfall which is input as a multi-year climate file. Runoff volume is estimated using the NRCS Runoff Curve Number method. Sheet and rill erosion is calculated using USDA's Revised Universal Soil Loss Equation (RUSLE) methodology. Hydraulic routing of runoff is accomplished using components of the NRCS's TR-55 hydrology program.

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Watershed subdivisions with homogeneous land and land cover characteristics (cells) generate runoff, erosion product, and pollutants and provide flow paths for runoff routing. Data that is input or processed for each cell include weather, precipitation, soil moisture, farm management operations, irrigation, runoff, and sediment yield. Cells are topographically determined to assure runoff flows downhill from cell to cell or from cell to reach. Runoff is routed through stream reaches to attenuate discharge peaks.

AnnAGNPS, version 3.4, is the current manifestation of an effort to use computers "to obtain uniform and accurate estimates of runoff quality with primary emphasis on sediment and nutrients" which was begun by the USDA Agricultural Research Service (ARS) in Minnesota in the mid-1980s (USDA ARS, 1987). In the ensuing years, ARS and NRCS have teamed to continue to develop the modeling tool. One notable improvement was the conversion of the single-event AGNPS model to the continuous-simulation AnnAGNPS. Recent versions have incorporated GIS technology to assist with data input and to display output.

Study Organization

The AnnAGNPS modeling of Hanalei began in July 2003, when NRCS Hawaii requested and obtained national technical support to adapt and utilize the watershed model for the Hanalei Watershed. A Hawaii-based technical coordination team was assembled that included personnel from NRCS, USGS Water Resources Division, USGS Biological Resources Division, University of Hawaii Department of Natural Resources and Environmental Management, and Hanalei Watershed Hui. At the national level, the USDA ARS National Sedimentation Laboratory, NRCS National Climate and Water Center, and the NRCS National Water Management Center also provided support. USGS participation was funded by an EPA Watershed Initiative Grant to the Hanalei Watershed Hui in 2003.

A week-long AnnAGNPS training workshop was conducted in Honolulu by NRCS and ARS experts in May 2004 to transfer technology to the Hawaii coordination team and others in Hawaii interested in the using model. Twenty-four students were trained at the University of Hawaii's Agricultural Sciences Building Computer Laboratory. In addition to the coordination team for the Hanalei project, participants from other federal, state, and county agencies and University students were enrolled. There is considerable interest by agencies and organizations in the ability to model watersheds in Hawaii, especially to evaluate pollutant loading of estuaries and nearshore marine waters.

In September 2004, a Cooperative Agreement was executed between NRCS and the University of Hawaii Department of Natural Resources and Environmental Management to develop the pilot AnnAGNPS model, the more detailed existing conditions model, and the forward-looking treated conditions model for the Hanalei Watershed. NRCS would provide basic data on climate, soils, and hydrology and erosion coefficients to the UH investigators. USGS would provide basic data on plant communities, streamflow measurements, and suspended sediment measurements. The Hanalei Watershed Hui would assist with data collection, review of products, and integration of the Hanalei community in the study process.

Hanalei Watershed

The Hanalei Watershed is the largely-forested, 23.7-square mile drainage area to Hanalei Bay located on the northern part of the island of Kauai in the Hawaiian Islands. The Hanalei River is 16.2 miles long along its thalweg. The long-term average stream discharge is 204 cubic feet per second (cfs) and the maximum daily flow has been recorded at 9,580 cfs. Rainfall varies spatially across the watershed and temporally from year to year. Average annual rainfall is approximately 60 inches at Hanalei Bay and over 400 inches at Waialeale mountaintop with an elevation of 5,148 feet.

The low coastal area, within a quarter-mile of the shoreline, is in commercial and residential use. The major agricultural activity is the production of wetland taro on more than 125 acres of flooded paddies. The U.S. Fish and Wildlife Service operates a 1.5-square mile wildlife refuge for endangered water birds in the lower valley. Approximately 90 percent of the watershed remains undeveloped, mostly in forest. However, alien invasive plants and animals, especially feral pigs, have displaced native plant communities in much of the watershed and appear to have affected sediment discharge rates.

The Hanalei Watershed Hui embraces the native Hawaiian concept of ahupua'a which connotes both a land boundary description and a land management system. The physical description of the ahupua'a is an, often, pie-shaped land division which stretches from the ocean to the mountaintop. The ahupua'a boundary can closely match the modern delineation of the watershed. More importantly, ahupua'a management reflects the traditional land stewardship philosophy practiced by native Hawaiians. Management of economic resources in the forest, agricultural, coastal, and ocean zones required the appreciation and knowledge of sustainable resource use and relationships between the ahupua'a zones (UH DURP, 2002).

Water is the central feature of the ahupua'a and is given both a spiritual dimension, as an incarnation of the god Kane, and a political dimension, by the royal appointment of a high-level konohiki or water manager. Recent advances in computational and data management technology permit resource managers to again evaluate the entire watershed as a linked system like that in the ahupua'a concept.

MAJOR MODELING ISSUES

The adaptation of AnnAGNPS, an agriculturally-focused model developed in the Midwest states, to the steep, humid, forested watersheds of Hawaii has raised a number of significant issues that need to be addressed. These issues include climatic variation, development of erosion and runoff coefficients for subtropical forests, incorporation of a variety of erosion and sediment sources, vegetative mapping and hydrogeologic concerns.

Climate

The AnnAGNPS model requires daily climate data including precipitation, maximum and minimum temperature, dew point temperature, sky cover, and wind speed. Typically, in the continental United States, National Weather Service first-order weather stations records are used to generate a synthetic climate file that will include all parameters. There is one first-order weather station on the island of Kauai located at Lihue. However, the location and weather orientation of the station, which is leeward, is quite different from the windward facing Hanalei Valley. The information from the Lihue station and rainfall record from other gauges nearby the watershed were used with consideration of their weather orientation.

An additional complication to the climate input is the extreme variability in precipitation along the axis of the watershed from the ocean to the mountaintop and also across the valley from ridge to ridge. Fortunately, AnnAGNPS permits the use of as many as 100 separate daily climate files to describe weather variability in the watershed. This feature will be extensively used for the Hanalei Watershed. The NRCS National Water and Climate Center is assisting by utilizing a statistical climate regression model known as PRISM (parameter-elevation regressions on independent slopes model) to generate the spatially-varied climate data for Hanalei Watershed.

NRCS and the Hanalei Watershed Hui are working to supplement the existing data with new rainfall and climate data sets. The Hanalei Watershed Hui plans to install rainfall gauges in the lower, middle, and upper watershed within the next year. NRCS is also seeking to install two Soil Climate Analysis Network (SCAN) weather stations. One of these sites would be located in the lower watershed near an existing USGS streamflow gauging station, and the other would be located near the back of the valley at a mid-elevation. The combination of this current and historic, long-term data should be useful in calibrating the model in the future.

Erosion and Runoff Coefficients for Subtropical Forests

AnnAGNPS uses coefficients developed for the Revised Universal Soil Loss Equation and the NRCS Runoff Curve Number method to calculate sheet and rill erosion and runoff quantities. These coefficients have been widely developed by USDA for agricultural and urban land uses. Across the nation, coefficients for naturally forested land have not been developed to a level of intensity comparable to agricultural land. In Hawaii, no adequate, systematic study of the erosion or runoff characteristics of the many types of forested areas found in the islands is available to estimate erosion and runoff coefficients. Other complicating factors are the steepness of slopes which range beyond analysis provided by RUSLE and the reconnaissance-level of soil survey description of the steep upper watershed areas.

NRCS, USGS Biological Resources Division, and Hanalei Watershed Hui have conducted field examinations to collect soil, vegetation, and cover information to develop the RUSLE and runoff coefficients. Trips into the upper watershed have required helicopter transport to avoid the time-consuming hike through the dense and tangled vegetation that grows on the valley bottom.

Other Erosion and Sediment Sources

Field observations by the data collection team in upper parts of the Hanalei Watershed confirm that sheet and rill erosion accounts for a significant portion of the sediment discharged from the valley. However, there are other sediment sources in the watershed that require inclusion in the model. While erosion of streambanks and gullys are handled in the AnnAGNPS program, sediment from landslides are not included in the current model. Thin-bedded landslides that extend longitudinally from valley crease to ridgetop are a prevalent feature in the watershed where slopes can be near vertical.

Considerable discussion has taken place on the significance of the sediment contribution of landslides and the methodology and parameters to evaluate landslides in the AnnAGNPS model. Monitoring of landslides using side-looking imagery has been started by USGS. NRCS is intending to develop and include a landslide component in the AnnAGNPS model. A separate effort to characterize and develop a process-driven description of Hawaiian landslides has been recommended and is seeking funding.

Addressing cumulative watershed effects is a difficult task in a highly variable watershed with extreme soil, climate and vegetation conditions (Reid 1998). The model does not address marine sources of sediment that have been documented in

Hanalei Bay. Historically, a considerable load of sediments has been attributed to trade-wind driven littoral currents (Calhoun, Fletcher and Harney 2001). The model also does not yet adequately address impacts of natural disturbance regimes such as hurricanes and pig damage.

Vegetative Mapping

A systematic assessment and mapping of vegetative types in the watershed is being conducted by the USGS Biological Resources Division. New technologies are being employed such as close-range multispectral imagery and side-looking, helicopter-mounted cameras. Investigators are confident that approximately 25 to 50 plant communities can be identified and characterized at the most detailed mapping level. Plant community mapping units will conform with National Vegetation Classification System standards. With this system, the detailed map units can be grouped into more generalized units within a specified classification hierarchy if needed for watershed modeling. The differentiation of the various plant communities using the data inputs to AnnAGNPS will present challenges to ensure subtle differences, such as canopy height or overall cover, are reflected in both the input and output.

The modeling of watershed treatments will also require innovative approaches due to the ecological relationships at work in the Hanalei Watershed. While the treatment actions may be well-understood, the extent of the outcomes may be less certain. For example, the elimination and exclusion of feral pigs will reduce erosion on the stream benches, but may or may not stimulate recovery of native plant species.

Hydrogeologic Interaction

Two issues regarding the interaction of runoff with the geology of the volcanic island are still in discussion and the implications not fully grasped. In the Hanalei Watershed, there seems be considerable interflow or runoff that flows both above and below the ground surface. The total water discharge at any point in the valley may not be fully accounted by surface runoff. The second issue is the considerable amount of bedload that is transported in the relatively steep stream system. While the bedload is not considered in the AnnAGNPS model it may have effects on stream capacity and dissipation of energy in the stream system that may, in turn, affect suspended sediment yield

SUMMARY

The USDA's AnnAGNPS watershed model has been used extensively for watersheds in the continental United States to evaluate long-term sediment and pollutant discharge. However, its application to Hawaiian and other subtropical and tropical watersheds is challenged by the physical differences in watershed characteristics, such as steepness, hydrogeologic interaction, high intensity rainfall, and spatial variation in rainfall. Furthermore, the relative shortage of available information about soils, plants, and climate that can be readily incorporated into the model requires intensive data collection effort.

We are fortunate, in the case of the Hanalei Watershed, that a convergence of federal and state efforts and programs has permitted the technical collaboration of experts, whose agencies alone would not be able to carry out the task.

An expectation of NRCS, arising from the Hanalei Watershed modeling effort, is the subsequent availability of a watershed analysis tool that can be applied to other areas in Hawaii, the Pacific Basin, and other subtropical and tropical islands.

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