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Abstract. The SITES Water Resource Site Analysis Computer program is used by USDA NRCS and others for design and analysis of dams. The current program evolved from the DAMS2 program of the 1980’s with new features added for both functionality and ease of use. An Integrated Development Environment (IDE) was added as a user interface to assist the user in the generation of the required input data and evaluation of the output. SITES is a single event model that assists the engineer in the hydraulic and hydrologic analysis of multiple dam sites. It develops inflow hydrographs and uses the storage-discharge relationships at a dam site to flood route hydrographs through existing or potential reservoirs. The program can be used to proportion dams with water storage and release features that have drainage areas from a few acres to over 100 square miles. SITES will evaluate dams with subdivided watersheds or those that have upstream dams in series. A unique feature of the software is the ability to develop ratings for, and evaluate the integrity of, vegetated earth spillways. The current version, SITES 2005, was developed through the cooperative efforts of the Natural Resources Conservation Service, the Agricultural Research Service, and Kansas State University. It is intended for use in performing the analysis required for rehabilitation of existing dams as well as the design of new dams.

Keywords. Dam, Design, Analysis, Rehabilitation, Hydrology, Hydraulics, Erosion
Introduction

The Sites Water Resource Site analysis Computer program is used by the United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) and others for the design and analysis of dams. The program evolved with the changing technology used in the design of flood control dams and the changing computational power through the last third of the twentieth century. The present version, SITES 2005, was developed through the cooperative efforts of the USDA Natural Resources Conservation Service (NRCS), USDA Agricultural Research Service (ARS), and Kansas State University (KSU). The SITES 2005 software package is a part of the NRCS set of models and tools for hydraulics and hydrology that may be downloaded from the web at http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models.html without additional cost or licensing.

The USDA became involved in the design of flood control dams beginning with the Flood Control Act of 1944 known as PL-534 (Caldwell, 1999). This was followed by the Pilot Watershed Program and by the 1954 Watershed and Flood Prevention Act, PL-566. As a result of these programs, the NRCS has assisted in the construction of approximately 11,000 watershed dams. With the passage of PL 472 in 2000, attention was focused on the rehabilitation of the dams that were approaching the end of their planned service life and both the construction and rehabilitation activities are continuing. The Agricultural Research Service has worked as a partner with NRCS throughout the period of construction and rehabilitation to provide the technology needed for the design of safe, economical structures. The SITES program represents one part of that cooperative effort.

The first NRCS effort to provide an integrated computer program for the hydrologic and hydraulic design of dams was the DAMS program provided to users in 1967 (USDA-NRCS, 2006). This was during the peak period of dam construction under the PL-566 program. An improved version of the software was released in 1971 as DAMS2. The 1971 version, like the 1967 version, was intended for operation on a main frame computer, but incorporated a more flexible input format along with other improvements. In 1982, an interim personal computer version of DAMS2 was released. That version was updated periodically including significant revisions in 1989.

In 1996, the software was updated to include earth spillway design and analysis and the name changed to SITES (Stability and Integrity Technology for Earth Spillways). The spillway erosion technology incorporated into the program was the result of a long term cooperative effort of ARS and NRCS that included field data collection involving an Emergency Spillway Flow Study Task Group, data analyses, and mathematical model development by the Design and Analysis of Earth Spillways team. The 1998 version of SITES included an Integrated Development Environment (IDE) developed through cooperative efforts with Kansas State University. This environment provided additional analysis capabilities through a more user-friendly operating environment. Both the environment and the computational portions of the program were further updated in the development of version 2005. The 2005 version provides a graphical user interface for developing runoff hydrographs from complex watersheds, routing these hydrographs through a reservoir, proportioning the dam appropriately, and evaluating the expected performance of an earth or vegetated earth spillway subjected to the resulting hydraulic attack. The IDE provides the capability of comparison of design alternatives or input parameter sensitivity in both tabular and graphical formats.
SITES System Architecture

The overall SITES system architecture is described by Neilsen and Temple (1999). In its present form, the SITES software consists of three separate executable routines. These are an Integrated Development Environment, an Integrity Check Routine, and a Simulation Model.

The Integrated Development Environment (IDE) performs the system management function and interfaces the computational routines with the user. The IDE consists of a top-level interface that performs the file management functions, an input interface that guides the user through data entry, a build interface that invokes the other executable routines to check data and perform computations, and a view interface that allows graphical and text viewing of the results of the computations. Data entered through the input interface are stored in a formatted text file for access by a data integrity check routine and the simulation model. Text files created by the simulation model are accessed by the view interface and interpreted for viewing in raw, tabular, or graphical form.

The data Integrity Check Routine is accessed from a build menu in the IDE and examines the data file for inconsistent or missing information. If problems are identified, an error table is created with links back to the input data screens in the input interface. Identified errors in the data file may then be corrected before invoking the simulation model. The data integrity check routine is useful in identifying missing or incorrectly entered information, but is not capable of identifying all possible errors in the input data. Additional errors may also be identified by the simulation model during execution. The user should also verify all data entries.

The Simulation Model accesses a data file created through the input interface, performs the hydrologic and hydraulic computations, and outputs the results to text files that are accessed by the view interface. The calculations performed may include development of a reservoir inflow hydrograph, routing of the hydrograph through the reservoir, and evaluation of the stability and/or integrity of a vegetated earth spillway. A number of input and output options are provided to allow the results to focus on design or analysis.

The results of the calculations for multiple passes through the simulation model may be viewed in tabular or graphical format using the view interface of the IDE. A summary table of the key output parameters from repeated passes through the simulation model may be customized to allow evaluation of parameter sensitivity and any two parameters in the summary table may be plotted in Cartesian coordinates for viewing graphically. Selected output information from each simulation run in the project may also be viewed in graphical or text formats.

Software Application

The SITES software has a broad range of capabilities and options. These are described in detail in the User Guide for the software (USDA-NRCS, 2006) along with guidance on getting started, developing the needed input parameters, and interpreting the output information. Help is provided in the software package for each of the screens and input fields in the input interface. The following discussion is intended only to be an overview of the application that identifies the more unique features of the software.
Hydrology

Although SITES may be used simply for the development of a hydrograph describing the runoff from a watershed, the primary purpose of the hydrologic computations in SITES is the development of a reservoir inflow hydrograph for a dam that is to be designed or evaluated. These computations can be bypassed by direct entry of the inflow hydrograph(s). When SITES is used to develop the reservoir inflow hydrograph, the curve number approach described by USDA-NRCS (2004) is used in generating the hydrograph runoff volume. The watershed may be a simple watershed with a single area, or a complex watershed with multiple sub-watersheds and/or reservoir sites connected by channel reaches.

For the complex watersheds, the SITES IDE uses a schematic of the form shown in figure 1 to assist in management of the input and output data. Following construction of the schematic, the input interface guides the user through a set of appropriate input screens for each element. The relation of the elements in the schematic are also used to structure the data such that the appropriate hydrographs are added and routed through upstream reservoirs or channel reaches.

![Figure 1. Watershed schematic from SITES 2005 illustrating the watershed elements available.](image)

Hydrograph Routing and Dam Design

SITES 2005 retains many of the dam design features developed for the DAMS software with its focus on design of structures to conform to NRCS criteria as outlined in TR-60 (USDA-NRCS, 2005). When the option of application of the software to a TR-60 structure is selected, it is possible to route the three design hydrographs, i.e. the principal spillway hydrograph (PSH), the auxiliary spillway stability design hydrograph (SDH), and the freeboard hydrograph (FBH) in a single pass through the simulation model. For this condition, the PSH is used to set the elevation of the crest of the auxiliary spillway and to determine the reservoir water surface elevation at the beginning of the SDH and FBH according to NRCS criteria. The SDH is used to set or check the width of the auxiliary spillway such that the exit channel will be stable at the peak discharge. The FBH is then routed to determine the required top of dam elevation. Options are also available to route multiple hydrographs for design of structures subject to the NRCS NHCP-378 (USDA-NRCS, 2002) criteria or to route a storm simulation for any existing or proposed site.
In routing a hydrograph through a reservoir, a level water surface is assumed. The inflow, outflow, and storage are balanced for each time step. In computing outflow, provision is made for a principal and auxiliary spillway. Spillway elevation-discharge ratings may be entered directly or, for conditions typical of NRCS structures, may be computed from spillway properties. Reservoir storage information may be entered in the form of an area- or volume-elevation table. Hydrographs may be routed through channel reaches using the Convex, modified ATT-KIN, or Muskingum-Cunge procedures. The required input varies with the procedure selected.

**Earth Auxiliary Spillway Evaluation**

One of the unique features of SITES is the ability to rate and evaluate vegetated earth auxiliary spillways of the type widely used on NRCS structures. These spillways are trapezoidal channels of constant width constructed through, or with, earth materials and vegetated with grass as appropriate for site conditions. The vegetal cover conditions accounted for include a uniform grass cover, grass cover with minor discontinuities, grass cover with major discontinuities, and bare earth. The spillway profile may consist of multiple reaches with varying slope and/or cover conditions, but a level crest reach is required for full analysis.

In determining the elevation-discharge rating for a vegetated earth auxiliary spillway, SITES applies the vegetal retardance curve index, described in USDA Ag. Handbook #667 (Temple et al., 1987), in a mixed direct-step standard-step backwater procedure. The location of the hydraulic control is determined by comparing the critical slope at normal depth for any given discharge to the channel slope. For non-vegetated reaches, a value of Manning’s n is entered directly.

Velocities and erosionally effective stresses are computed for the purpose of evaluating exit channel stability. NRCS TR-60 (USDA-NRCS, 2005) describes the procedure used by NRCS in determining a minimum bed width for the auxiliary spillway using the SDH described above. Normally, the constructed exit channel of the spillway is required to meet stability criteria for the peak discharge in the spillway determined by routing of the SDH.

The integrity of the earth spillway for design conditions, normally the FBH, may also be evaluated. The model used in predicting the breach potential of the spillway for integrity analysis is described by USDA-NRCS (1997). This model uses a three-phase approach to spillway erosion evaluating the time of failure of the vegetal cover, if any; the concentrated flow erosion resulting in development of a vertical or near-vertical headcut; and the upstream advance of the headcut with the potential of causing spillway breach. Multiple headcut development scenarios are evaluated to determine the worst case condition for potential breach. An estimate of the potential extent of spillway erosion is obtained by combining the erosion from all scenarios evaluated (fig. 2). In the case of breach prediction, computations are terminated and the time of breach reported in the output. SITES does not perform the computations for predicting spillway outflow once erosion lowers the elevation of the hydraulic control.
Summary

The SITES Water Resource Site Analysis Computer program is a single event model that assists the engineer in the hydraulic and hydrologic analysis of dam sites. The software has evolved with the changes in NRCS needs and changes in computational hardware and software. SITES 2005 is designed for use on the personal computer and includes features for evaluating dams in watersheds with multiple dam sites in series, sub watersheds, and channel reaches upstream of the site being evaluated. Unique features of the software include the ability to apply NRCS criteria in dam proportioning, the ability to rate commonly used principal (pipe) spillways and vegetated earth spillways, and to evaluate the stability and integrity of earth spillways. SITES 2005 was developed through the cooperative efforts of the NRCS, the ARS, and KSU. SITES 2005 includes an Integrated Development Environment that assists the user in organizing input, interpreting output, comparing alternatives, and analyzing parameter sensitivity.

References


