WATER RESOURCES IMPACT

# MODELS AND SOFTWARE FOR SUPPORTING ECOLOGICALLY SUSTAINABLE WATER MANAGEMENT

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## INTRODUCTION

The Sustainable Rivers Project (SRP) is an ongoing partnership between the U.S. Army Corps of Engineers (Corps) and The Nature Conservancy (Conservancy) to improve the health and life of rivers by changing the operations of Corps dams (see article by Andrew Warner in this issue for more information about the SRP). Experiences at different SRP sites are helping to refine a roadmap for technical support of ecologically sustainable water management pursued by Corps projects (Figure 1). This collaboration between water managers and scientists has also fostered the development of specific tools through the Corps' Hydrologic Engineering Center (HEC) that provide information to help managers better understand the implications of reservoir operation decisions. (The mission of HEC is to support the nation in its water resources management responsibilities through programs in research, training, planning analysis, and technical assistance.) This article details a few of the tools being used to help study river flows at SRP sites and concludes with some perspectives on technical support for ecologically sustainable water management.

The tools described by this article do not represent the full spectrum of technologies being applied to make water management more ecologically sustainable. Rather, they represent the addition to this body of work resulting from the SRP sites and HEC engagement. For additional reading related to tools and approaches related to ecologically sustainable water management, the following papers and websites may prove helpful (Arthington and Pusey, 2003; King ***et al.,*** 2003; Hughes, 2001; www.fort.usgs.gov/ASTA/;www.catchment.crc.org.au/research/index.html).

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## DEVELOPING A TECHNICAL ROADMAP

Technical support for ecologically sustainable water management typically begins with establishing a solid hydrologic understanding of how the river has been altered. This requires the preparation and analysis of hydrologic data sets that compare river flows for regulated (with reservoirs and other alterations of the flow regime) and unregulated conditions (Figure 2). These data can be prepared through a variety of mass-balance, stochastic generation, or simulation approaches. Choice of method depends on the availability and condition of gage data as well as the budget and preferences of the study team investigating the river. Once completed, these data serve as a foundation for additional technical efforts, including processes for defining ecosystem flow recommendations. They also relate to the six linked models noted in Figure 1.

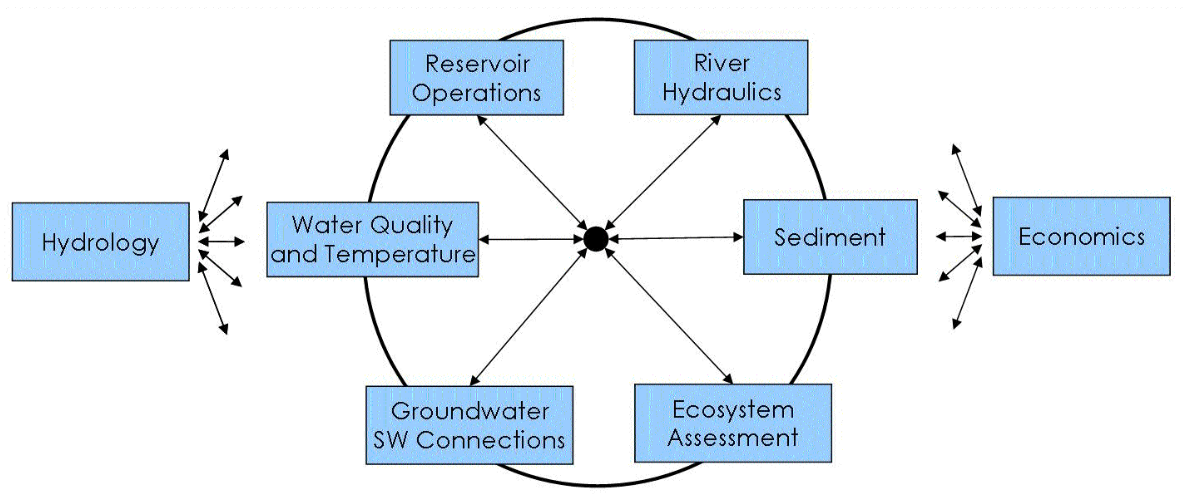



Figure 1. Connections Between Different Types of Models for Supporting Ecologically Sustainable Water Management.

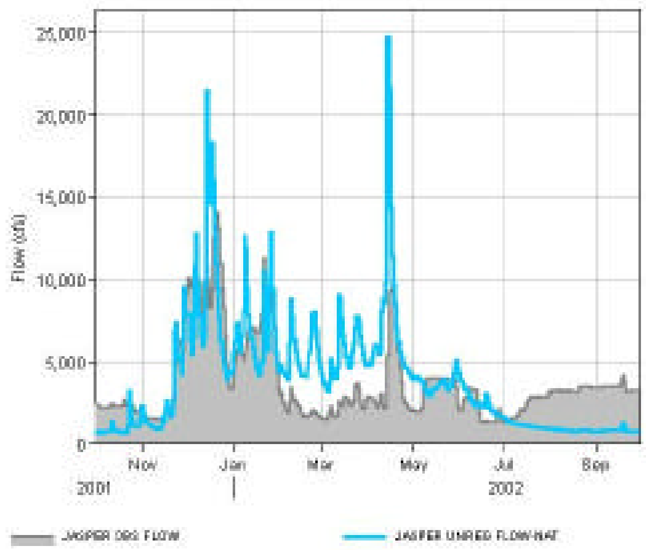



Figure 2. Regulated (Obs) and Unregulated Flows for the Middle Fork Willamette River at Jasper, Oregon. There are three major reservoirs upstream of this location. Note the reduced peaks to limit downstream flooding, increased flows in the spring and summer to meet downstream flow targets, and the seasonal capture (spring) and release of volume (fall) as the pools are brought up from and drawn down to winter levels, respectively. Data prepared by Portland District, USACE.

## Defining Ecosystem Flow Recommendations

The first SRP site to complete an ecosystem flows workshop was the Savannah River, where nearly 50 scientists collaborated to formulate ecological recommendations for flows in the Savannah River (see articles by Andrew Warner and Amanda Wrona-Meadows ***et al.,*** in this issue). During this workshop, many hydrographs were created, discarded, and morphed. Facilitators were pressed to track all of the recommendations and lacked an easy way to present results electronically. It was noted that a tool capable of rapidly displaying, adjusting, and documenting hydrographs would make the formulation process easier and if this tool was also capable of plotting historical hydrologic data to guide the scientists upon their request, then the product as well as the process would be improved. These comments and others inspired HEC and the Conservancy to collaboratively develop the Regime Prescription Tool (HEC-RPT).

The latest SRP site to complete an ecosystem flows workshop was the Willamette River (see article by Leslie Bach ***et al.,*** in this issue). It was the first to use HEC-RPT (Figure 3) to help groups of people reach informed agreements about how to manage the flow regime of a river. Recommendations formulated in HEC-RPT can be exported for analysis in other software, including reservoir operations, river hydraulics, and ecosystem assessments.

## Operations, Hydraulics, and Ecosystem Assessment

Generally, of the six linked models in the center of Figure 1, reservoir operations, river hydraulics, and ecosystem assessment are at the core of technical support for ecologically sustainable water management.

Reservoir operations models simulate the storage and release of waters in systems of reservoirs. These models are typically either rule-based simulation or goal-based optimization models, or a combination of the two. Simulated water releases in rule-based models are guided by rules specified by the modeler (e.g., a minimum flow rule might say "avoid releases less than 10-cfs"). Rules are created, prioritized, and modified to make simulated releases agree with how the reservoirs are actually operated. When the model is producing reasonable results, rule sets can be changed to test different management approaches (start with current operations and change from there). Optimization models take a different approach – they make decisions that optimize the net benefits of the water, subject to user defined constraints. This is a nice complement to rule-based approaches because it encourages study teams to consider a different perspective about operations (start at an optimized operation and change from there). HEC-ResSim (Reservoir System-Simulation) is a rule-based model being applied at a number of SRP sites (Figure 4).

River hydraulics models use channel topographies to translate flow rates to river depths, velocities, inundated areas, and a host of other output. Models are described by the number of dimensions in which water velocities are computed (1-d means that velocities are computed in line with the river channel at any given cross section, the second dimension adds a velocity component from bank to bank, and the third adds a vertical velocity within the water column) and by whether the model performs steady (flow values are simulated independently) or unsteady state (time series of flow are simulated) calculations. The River Analysis System (HEC-RAS) is a 1-d model that performs steady and unsteady state simulations (Figure 5). It also has recently added algorithms for computing stream temperatures and sediment transport. Hydraulic modeling is a critical step in understanding the physical connections between land and water, which enables a more detailed look at ecosystem dynamics.

Ecosystem assessment techniques and the software that support them run the gamut from simple regression equations that compute biomass based on variables like river flow and reservoir storage to complex models for simulating things like forest or fish population dynamics. Towards the middle of that spectrum is the Ecosystem Functions Model (HEC-EFM), a tool that helps translate changes in a flow regime to an ecosystem response using statistical and spatial analyses (Figure 6). As part of the progression of models, output from reservoir operations and river hydraulics models are fed into HEC-EFM, which then computes how those changes affect different aspects of the ecosystem. Statistical and spatial results are generated to estimate the direction and magnitude of ecosystem changes.

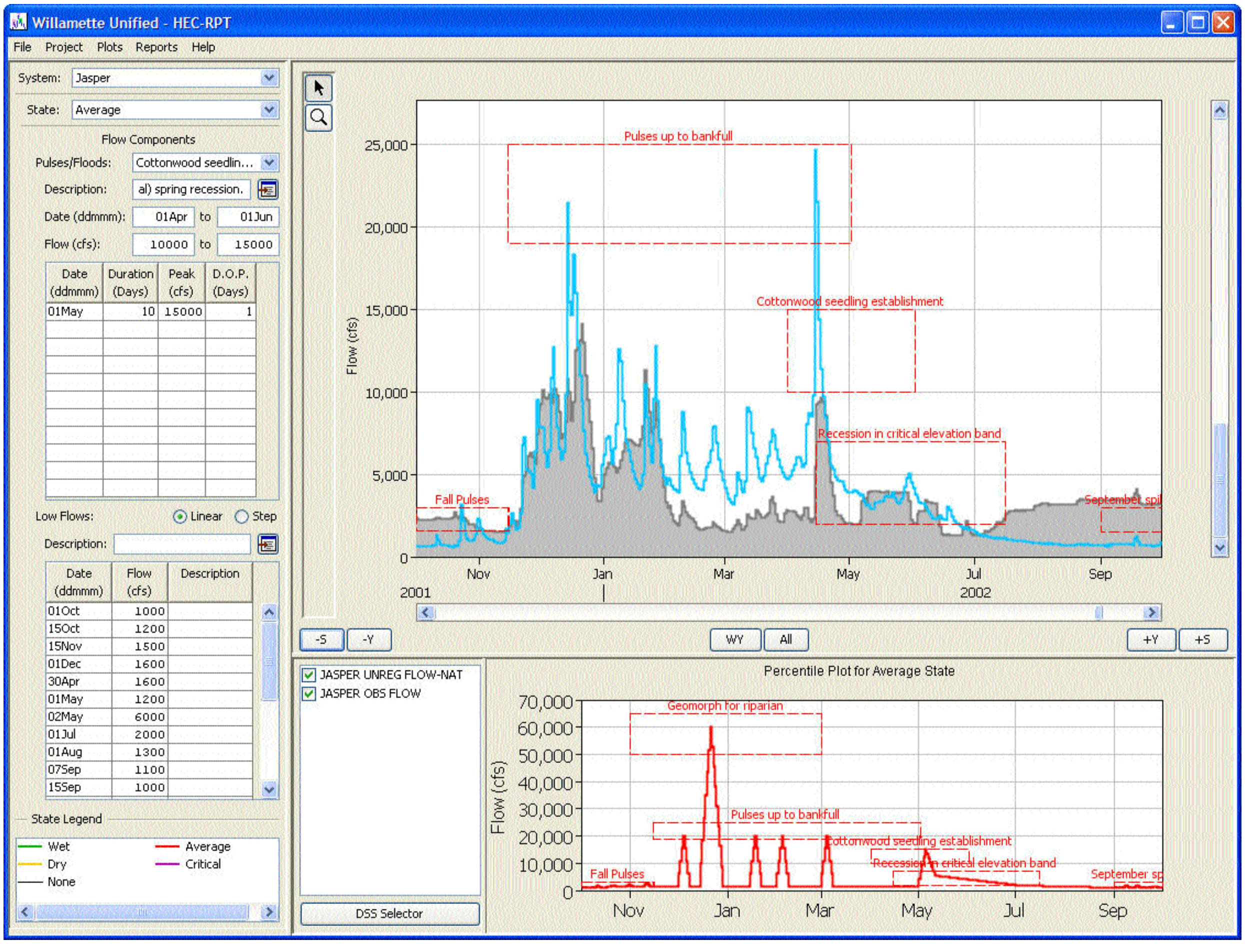



Figure 3. Main Interface of HEC-RPT With Results From the Willamette Flows Workshop. The software allows users to view historical data (note that the time series in the upper plot are the same as those in Figure 2) and electronically trace flow recommendations for the ecosystem and other perspectives on how the river might be managed.

## CONCLUSIONS

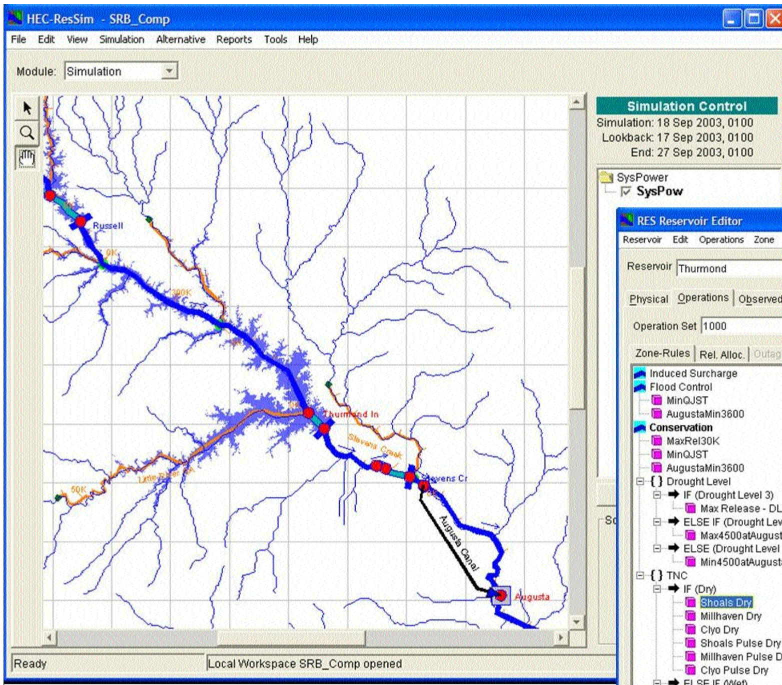
By fostering dialogue between water managers and biologists about how to make water management more ecologically sustainable, efforts like the SRP are helping to illuminate new opportunities to improve the methods and tools used in technical support of ecologically sustainable water management.

The tools detailed above are primarily engineering software. Development of models in the water management arena has typically been guided by the needs of engineering tasks like floodplain delineation and reservoir simulations for flood routing, hydropower, and water supply. Ecosystem concerns have not been dominant influences. This has created engineering software with much latent potential for environmental applications, as demonstrated (in a small way) by the partnered development of HEC-RPT, which adopted many of its components from existing software.

There is a growing awareness of the influence of water management activities on ecosystems. As awareness leads to improved scientific understanding (and vice versa), more strategies linking water and ecosystem management will be identified, which will in turn become new analytical challenges for software tools. Funding pathways that encourage ecologists and biologists to participate more in the evolution of engineering models are needed to accelerate the growth of these technical capabilities.

## ACKNOWLEDGEMENTS

Several HEC efforts in the environmental arena (including integration of stream temperature in HEC-RAS and continued development of HEC-EFM) are supported in part by the Corps' System-Wide Water Resources Program (SWWRP). HEC thanks SWWRP for its continued support. More information about SWWRP and the HEC tools is available at www.erdc.usace.army.mil/ and www. hec.usace.army.mil/, respectively.



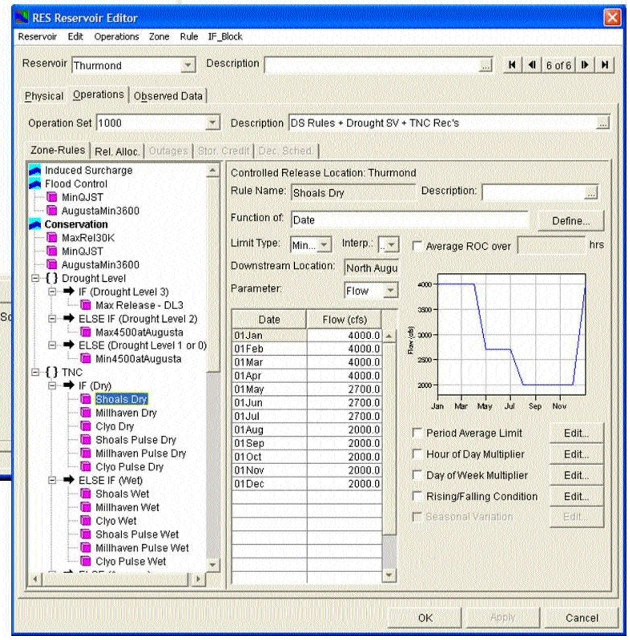




Figure 4. Main Interface (left) and Reservoir Editor (right) of an HEC-ResSim Application for the Savannah River Basin. Rules for operation of J. Strom Thurmond Reservoir are visible in the editor Application created by Jason Ward and Stan Simpson, Savannah District, Corps.

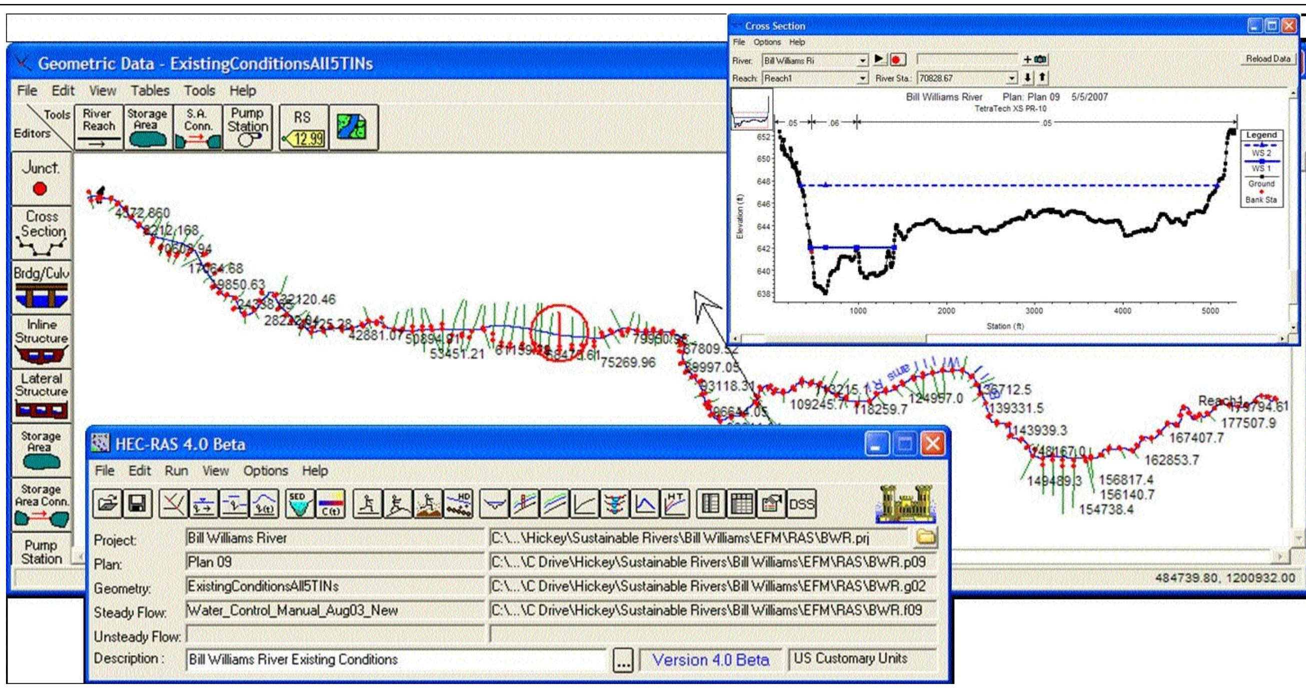



Figure 5. Main Interface (bottom), Geometric Data Editor (middle) and Cross Section View (top) of an HEC-RAS Application for the Bill Williams River, Arizona. Two steady state profiles are shown in the cross section view. The solid horizontal line is the simulated water surface for 7,000-cfs, the current maximum release rate of the upstream reservoir. The dashed line is the water surface for 100,000-cfs, which is close to the historical maximum flow in the pre-dam record. Application created by Van Crisostomo, Los Angeles District, Corps.

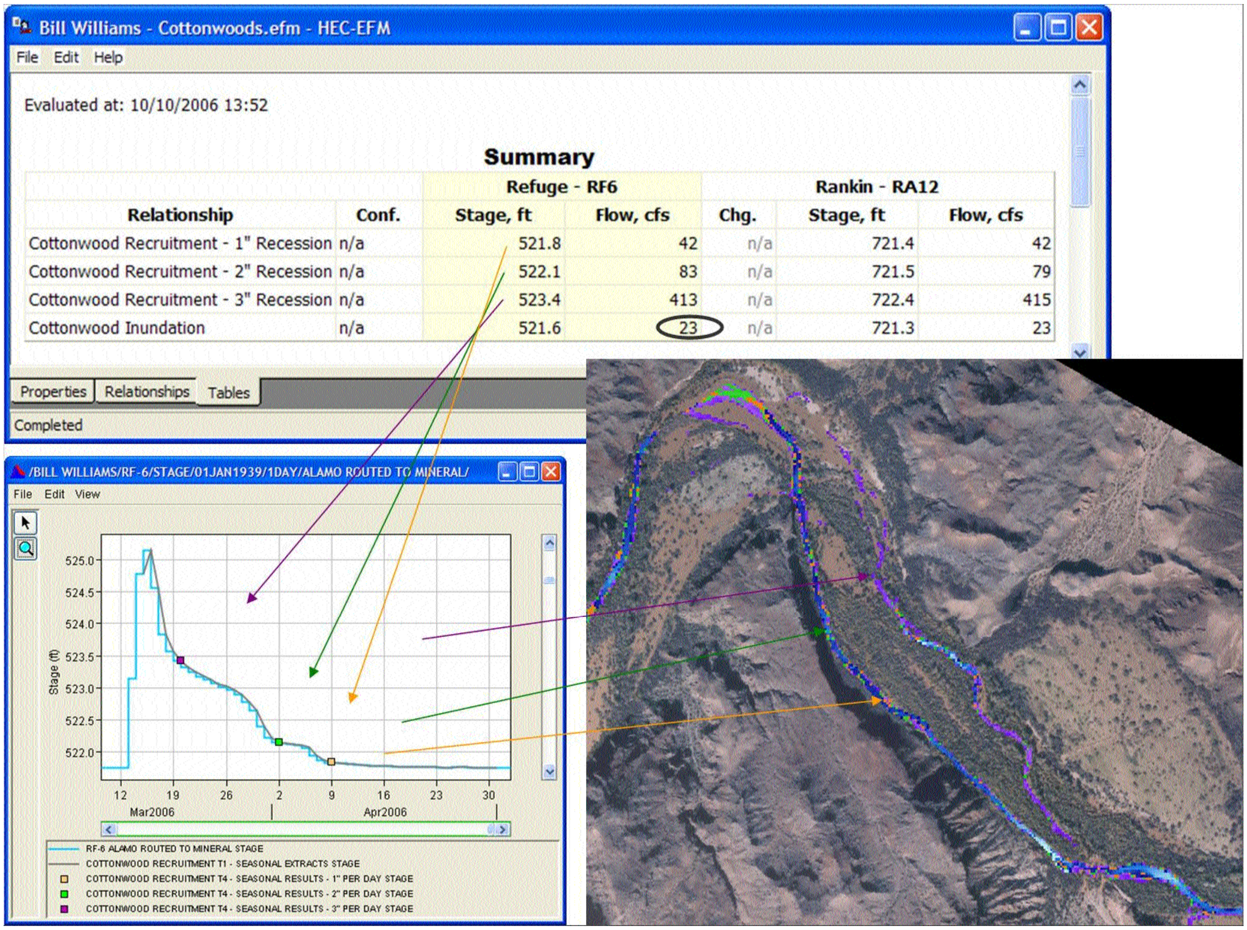



Figure 6. Figure shows an HEC-EFM Analysis of Simulated Cottonwood Establishment Produced by an Experimental Flow Release (bottom left) From Alamo Dam on the Bill Williams River, Arizona. Three recession rates (1 inch, 2 inches, and 3 inches per day) were tested as suitable for cottonwood recruitment. Each rate was used as a statistical parameter in HEC-EFM, which computed the point on the recession limb where the rate was last exceeded. These statistical results were output to the main interface of HEC-EFM (top) and then modeled using HEC-RAS and GeoRAS to generate spatial layers (bottom right) showing where cottonwood seedlings were predicted to establish.

## REFERENCES

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