EVALUATING THE ROLE OF FLOODING IN A SOUTHWESTERN RIPARIAN SYSTEM

by

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Abstract

Although riparian system researchers intuitively understand the general role of flooding in these plant communities, very little quantitative analysis or physical modelling of these flooding effects has been undertaken. This paper describes a methodology for analyzing flood influences by utilizing vegetation monitoring along river transects and a sophisticated flood hydraulics computer model (HEC 2). The project is addressing important questions such as "What magnitude of floods will alter the physical structure and species composition of the plant community? Are major floods essential in creating open floodplain areas wherein regeneration of riparian plants can take place? How does flood timing during the growing season affect the germination of seeds and survival of seedlings?"

The flood hydraulics study described herein provides an analysis method that is readily transferrable to other riparian systems, and anticipated results may offer some quantification of flooding characteristics which translate to any system composed of similar plant species. For instance, if mortality thresholds of such physical forces as flow velocity, depth, tractive shear stress, and stream power can be identified for selected riparian species, such information may be quite valuable to those engaged in restoration of disturbed systems, in specifying reservoir releases needed to maintain riparian vegetation downstream of dams, and in instream flow protection efforts seeking to protect essential environmental processes which sustain natural riparian systems. (Key words: floods, riparian, hydraulic modeling)

Introduction

During the past decade, land managers in the western U.S. have witnessed a rapidly building momentum of concern focused on a tiny fraction of the ecosystems they manage: the riparian zone. Largely ill-defined and misunderstood prior to the 1970's, riparian systems are now attracting research attention in great disproportion to the overall land surface they occupy: in arid Southwestern states such as Arizona these riparian areas comprise less than 0.1% of the landscape. Much of the drive behind this focused research is in response to their present endangerment. In most of the West, more than 90% of this community type has been destroyed or severely degraded in the past century.

The Nature Conservancy (TNC), whose mission is focused on the protection of endangered species, communities, and ecosystems, has in recent years greatly accelerated their efforts to acquire and protect riparian lands held in private ownership. The Arizona Nature Conservancy currently manages 6 riparian preserves: on the Hassayampa River near Wickenburg; Aravaipa Creek below Klondyke; Patagonia Creek near Patagonia; the Bass, Hot Springs, and Redfield Creeks (Muleshoe Ranch Preserve) near Willcox; O'Donnell Creek (Canelo Hills Cienega Preserve) near Canelo; and a tributary to the San Pedro River (Bingham Cienega Preserve) near San Manuel.

Research at Hassayampa River Preserve

Since the acquisition of a 5-mile perennial stretch of the Hassayampa River below Wickenburg in December of 1986, a number of riparian research projects have been formulated and are now underway at the preserve. The overall unifying objective of these research efforts is to develop a more thorough understanding of environmental influences acting in the regeneration and sustenance of this globally-rare Fremont cottonwood-Goodding willow forest community (<u>Populus fremontii-Salix gooddingii</u> association). These inter-related research efforts are directed at the development of a conceptual ecological model of the riparian system, and research is targeted at defining specific linkages in the directional flows of energy and matter through the system. The study of flood hydraulics and flood timing described here is an example of such an investigation.

Floods in Riparian Systems

As our consortium of researchers working at Hassayampa began to formulate a rough framework of a conceptual ecological model, we identified some substantial gaps in our understanding of how flooding "drives" various processes in the system. What magnitude of flood will significantly alter the physical structure and species composition of the plant community (by removing or damaging seedlings, saplings, shrubs or trees)? Is there a flood threshold (such as a 10-year flood) which substantially removes trees in the seedling and sapling stages, thereby resetting the regeneration clock? What flood magnitudes benefit the creation and abundance of habitat critical to continued recruitment of these relatively short-lived riparian species? How does flood timing during the growing season affect the germination of seeds and survival of seedlings?

Although riparian researchers intuitively know that flooding plays a significant role in the evolution of riparian plant communities and in restructuring animal habitat opportunities (Reichenbacher 1984), a review of the literature revealed very little in the way of quantifying or modelling the physical influences of flooding in riparian systems. There is a plethora of general statements about the role of flooding, however, as exemplified by these:

> "As is widely recognized, hydroperiod is the key external or forcing function that determines (riparian) vegetative composition and productivity. What is perhaps not so well understood is that the intensity of flooding is as important as the frequency. Flooding can both enhance and stress a riparian ecosystem, depending on frequency, timing, and intensity." (Odum 1978)

> "Flow regulations may lead to substantial decreases in discharge and reduces flooding of floodplains. Aggradation of floodplains can, therefore, not occur, which is the trigger mechanism for shifting channels. Shifting floodplain channels are considered prerequisite for regenerating of certain riparian species. Flow regulations may also decrease the soil moisture of floodplains and thus aid in destroying the riparian plant communities." (DeBano and Heede 1987)

One investigation of the role of flooding in western riparian zones was conducted by a team of researchers from the University of New Mexico led by Dr. Loren Potter, under contract with the National Park Service to study the potential impacts of a proposed dam on the Yampa River upstream of Dinosaur National Monument. Contrasting the plant community characteristics they found on the dam-regulated Green River with those of the free-flowing Yampa, Potter's group summarized some important conclusions about the influences of natural flooding regimes on the riparian vegetation (Potter et al 1983):

> "Scouring can affect plants in several ways. The shear stress exerted by moving water on stems may exceed their elastic limits, causing breakage. If the root system of the plant is poorly developed or is in loose substrate, the entire plant may be pulled out. This may be aided by the movement of the substrate by the water, particularly if the substrate is sand. Finally, the particulate matter carried by the water can abrade aboveground plant tissues.

Abrasion is probably greatest at the plant base from larger particles moved along the bed, but not lifted into the current.

"Most plants found in the floodzone exhibited characteristics which enabled them to resist the effects of scouring. Since seeds and seedlings would be highly susceptible to removal, it is not surprising that the floodzone plants were almost exclusively perennials capable of vegetative reproduction. Most of these exhibited annual aboveground parts which could be scoured away each year and perennial below-ground tissues, either roots or rhizomes.

"Willow and tamarisk stems are capable of surviving the direct effects of scouring. The frequent occurrence of willow suggests that willow is more resistant. Young stems of these species are flexible, allowing them to resist breakage. The absence of stems much exceeding 1 cm in diameter in the floodzone indicates an age limit to this resistance. Both species are capable of sprouting from roots.

"Young cottonwoods were limited to the upper part of the floodzone and the quieter water of side channels, indicating less resistance to scouring than either willow or tamarisk.

"...If the peak flow is higher than normal, seedlings may become established above the floodline and escape scouring if floods in the following year are not excessively high."

Although such literature references are instructive (in a qualitative sense) for understanding general hydrologic and hydraulic processes active in floodplain areas, there is a near complete absence of quantitative data to document these effects, particularly in a form which could possibly translate or be extrapolated to other river systems. The river hydraulics study described herein is an attempt to gain some new insight and definition into the physical effects of floods of various magnitudes.

Study Methodology

The river hydraulics study now underway at Hassayampa utilizes a computerized flood simulation model known as "HEC-2." When using the HEC-2 model, the user specifies the peak magnitude of the flood to be modelled and also provides input data describing the physical characteristics of the floodplain reach through which the flood is to be simulated. The model then computes various energy relationships to create instantaneous "snapshots" of the flood at user-input floodplain "cross-sections," by providing output information such as flow depth and velocity.

The HEC-2 model, developed by the U.S. Army Corps of

Engineers, is most frequently applied in urban floodplain studies designed to evaluate the extent of inundation resulting from a flood of a targeted "return interval" (such as a 100-year event). The HEC-2 thereby provides the basis for most floodplain management planning and for assessing federal flood insurance rates. The HEC-2 model is now available in PC-compatible software.

Rather than using the model to anticipate the impacts of future floods, the model is used in this study to recreate actual flood events along a 3-mile stretch of the Hassayampa River within The Nature Conservancy's preserve, in order to assess the impact of the flood on riparian vegetation. Riparian vegetation characteristics are being concurrently measured in 153 monitoring plots situated along 15 river cross-sections. Specific vegetative parameters being monitored are listed in Table I. After a significant flood event, the HEC-2 model will be used to recreate hydraulic conditions acting on each of the vegetation plots.

Four hydraulic parameters are presently being investigated for their abilities to explain vegetational changes following significant flood events. Flow velocity and depth at the location of each vegetation plot are being considered along with "tractive shear stress" and "stream power."

Tractive shear stress is calculated as:

$$TSS = mDS$$

where TSS is tractive shear stress in pounds per square foot; m is the specific weight of water in pounds per cubic foot; D is depth of water over the plot in feet; and S is the slope of the energy grade line in feet per feet.

Stream power is calculated as:

$$SP = (TSS)V$$

where SP is stream power in pounds per foot-second; TSS is tractive shear stress as above; and V is velocity over the plot in feet-per-second.

It is anticipated that mortality thresholds may be identified for particular species of riparian plants in the seedling, sapling, tree or shrub phases. This analysis will be very useful in understanding the regenerative processes active on the floodplain, hopefully leading to better understanding of the forest community's structural and species diversity.

Recommendations for Other Users

Some recommendations pertaining to needed equipment, expertise, and techniques may be of interest to other researchers wishing to apply this methodology to other riparian systems. PC-compatible software is available from a number of distributors.

The model should, however, be run by an individual trained in its use, as the estimation of values for numerous input variables will require some "professional judgement." Training in the use of HEC-2 is now available from a number of agencies and universities. The U.S. Army Corps of Engineers' Hydrologic Engineering Center (916-551-1748) can provide listings of software suppliers and training courses.

An accurate measurement of the peak flood discharge is essential. Our Hassayampa study utilizes an automated (continuous record) streamgage located within the study reach. In lieu of streamgage records, the peak discharge can be determined from indirect survey methods such as those described in Rantz (1982).

The HEC-2 model relies heavily upon a user-input physical description of the river's floodplain, as defined by a sequence of floodplain cross-sections. To ensure the accuracy of the cross-section data needed for this application, these cross-sections were surveyed (using standard two-person level-and-rod techniques) from one edge of the floodplain to the opposite edge, along a line running perpendicular to the direction of streamflow. Elevation readings are taken to define topographical variations across the floodplain, using up to 100 data points in the model.

In addition to the elevation data, a key descriptor of the floodplain cross-section is the "roughness coefficient" (also known as the "Manning's n-value"). This coefficient, representing the frictional resistance to water flow resulting from vegetative obstruction and substrate conditions, can be used to describe roughness variations for up to 20 different sub-sections within each floodplain cross-section.

A first approximation of these roughness coefficients is made from the field observations, but can then be calibrated for actual flood events by field surveying post-flood high water marks and adjusting n-values to yield a computer-simulated match for the high water elevation at each cross-section. This is greatly facilitated by establishing permanent "benchmark monuments" at one end of each floodplain cross-section during initial field surveys. At Hassayampa we are also attempting to relate these n-values to specific vegetation characteristics such as sapling and/or tree density, as measured in the vegetation sampling plots, such that growth or mortality changes will be continually reflected in the model simulations. The cross-section topography may also need to be re-surveyed to reflect changes following significant flooding.

The vegetation monitoring plots are located along each of the river cross-sections. Vegetative parameters are measured using square wooden plot frames or a measuring tape grid for larger plots.

Some final guidelines can be made pertaining to selection of an appropriate river reach for study. The river stretch encompassed by this study on the Hassayampa offers optimal field conditions for such a study, owing to a relatively narrow (600 to 1000 feet wide), confined river canyon and the substantial magnitudes of flash-flooding events (see Table II) generated within the 750-square mile drainage basin. Flow velocities exceeding 20 feet-per-second have been estimated for the 100-year event, although base flow conditions average only 2-8 cubic feet-per-second (cfs). Other researchers would be prudent to select a study reach within which some evidence of flooding impacts can be anticipated during relatively frequent (i.e. 2 to 5 year) flood events, so that results can be obtained within the expected lifetime of the study.

Summary

The development of a well-calibrated flood hydraulics model (HEC-2) for this study reach along the Hassayampa River, along with the availability of extensive vegetation sampling, promises to reveal new insights into the role of flooding in this Southwestern riparian system.

The flood hydraulics model described herein also provides an analysis method that is readily transferrable (although highly labor intensive) to other riparian systems, and anticipated results may offer some quantification of flooding characteristics which translate to any system composed of similar plant species. For instance, if mortality thresholds of such physical forces as velocity, depth, tractive shear stress, and stream power can be identified for selected riparian species, such information may be quite valuable to those engaged in restoration of disturbed systems, in minimizing adverse impacts from controlled (dam-regulated) hydrologic regimes, and in instream flow protection efforts seeking to protect essential environmental processes which sustain natural riparian systems.

Although we are just now beginning to "get our feet wet" in our research efforts at Hassayampa, we stand poised and ready for a few good tree-smashing floods that might teach us a thing or two.

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TABLE I. Vegetation parameters measured in study plots

2 x 2 decimeter subplots:
- seedling density - woody species
- seedling survival
- seedling height
- herbaceous cover (%)
- tree canopy cover (%)
- sediment deposition

1 x 1 meter plots:
- density of tree saplings and shrubs by height class
- survival of saplings and shrub species
- herbaceous cover (%)

2 x 10 meter plots:
- density of trees
- diameter of trees
- age of trees

TABLE II. Flood Frequencies for the Hassayampa River Preserve

Return Interval	Peak Discharge Estimate
2-year	2,550 cfs
5-year	8,090 cfs
10-year	14,600 cfs
25-year	27,100 cfs
50-year	40,300 cfs
100-year	57,300 cfs