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MODELING ENVIRONMENTAL FLOW NEEDS FOR RIPARIAN VEGETATION

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ABSTRACT: A System for Environmental Flow Analysis (SEFA) has been developed to provide ecologists, hydrologists, engineers and resource managers with an integrated set of tools for environmental flow assessment. SEFA is a combination of programs previously developed in the United States and New Zealand for instream flow needs analysis (PHABSIM, RHABSIM, and RHYHABSIM). SEFA has an element for riparian inundation analysis that considers the frequency, timing and duration of inundation flows. The procedure calculates the total number of days (or number of inundation events i.e. contiguous days of inundation) by season. The analysis uses a river model (part of SEFA) and information on daily streamflows. The river model can contain multiple channels. The analysis produces 1) relationships between flow and water height above a base flow for each cross-section and for the whole river reach, 2) the area that is inundated, and 3) the number of days or number of inundation events by season and by year. Additional elements for riparian vegetation analysis are in development; the two most important of these is an establishment model that considers the timing of events needed to create the river bed conditions required to establish vegetation and to allow the vegetation to develop once seeding actually occurs. The second element in development is the use of the various elements of SEFA to determine streamflows needed to remove undesirable from within the stream channel. Both the existing model and the future establishment removal additions are presented in the paper. KEY TERMS: environmental flow analysis, modeling, riparian vegetation analysis.

INTRODUCTION

Riparian areas are strips of vegetation adjacent to streams, rivers, lakes, reservoirs, and other inland aquatic systems that are affected by the presence of water. Riparian areas are between the river and the surrounding lands the river runs through and are defined by the plants that inhabit them. These riparian plants depend on a hydrological regime that includes both groundwater and surface water flows. Besides forested riparian communities, there are riparian wet meadows, marsh lands, slack water sloughs and. scrub lands. The term river corridor has also been used to describe the area associated with a stream. A diagram showing the various regions of the river corridor is presented as Figure 1. Most river corridors have three major components: 1) stream channel, a channel with flowing water at least part of the year; 2) floodplain, a highly variable area on one or both sides of the stream channel that is inundated by floodwaters at some interval, from frequent to rare; and 3) transitional upland fringe, a portion of the upland on one or both sides of the floodplain that serves as a transitional zone or edge between the floodplain and the surrounding landscape (Federal Interagency Stream Restoration Working Group,1998.) According to Naiman et al, 1993, the riparian corridor encompasses the stream channel and that portion of the terrestrial landscape from the high water mark toward the uplands where vegetation may be influenced by elevated water tables, or flooding, or by the ability of soils to hold water.

Modeling of environmental streamflows needs for riparian vegetation is a two edged sword; on the one hand the objective is to determine flows needed to maintain desirable vegetation and on the other hand the objective is determine flows needed to prevent undesirable vegetation from encroaching on the river channel (Figure 2). In Figure 2 the environmental flow issue might be to prevent trees and scrubs from establishing within the channel or it might be to prevent vegetation from growing on the bars at all times (i.e. the green area on the left of the main channel in Figure 2).

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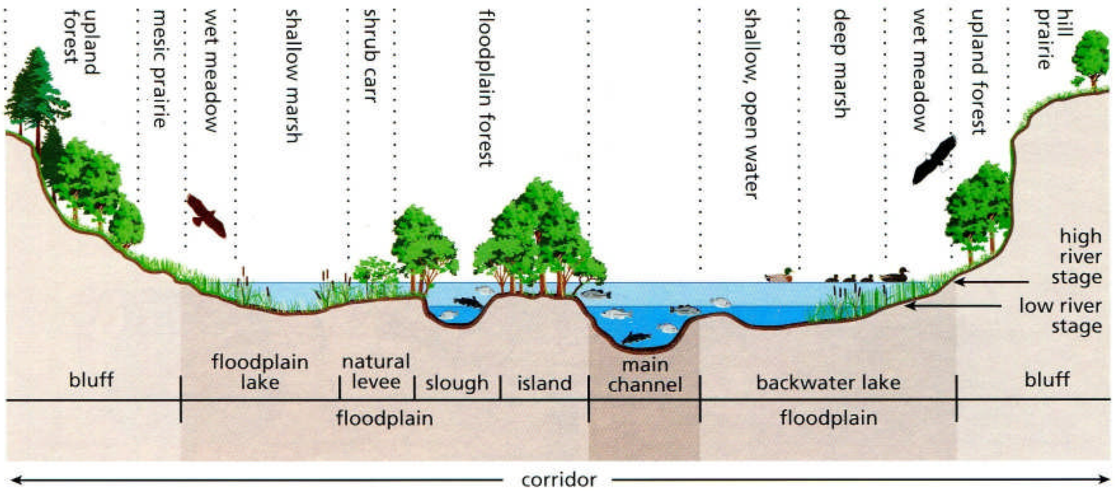

Figure 1. Cross section of a river corridor. The main components of the river corridor can be subdivided by structural features and plant communities. Source: Federal Interagency Stream Restoration Working Group (1998).

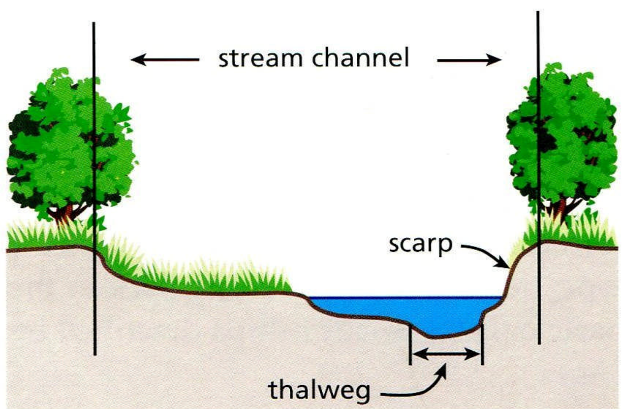

Figure 2: Cross section of a stream channel. The scarp is the sloped bank and the thalweg is the lowest part of the channel. Source: Federal Interagency Stream Restoration Working Group (1998).

SYSTEM FOR ENVIRONMENTAL FLOW ANALYSIS (SEFA)

SEFA was developed to provide ecologists, hydrologists, engineers and resource managers with an integrated set of tools for environmental flow assessment. SEFA is an improved replacement of the analytical components of the Instream Flow Incremental Method (IFIM). In addition to physical habitat analysis and the analysis of the time patters of habitat variation, SEFA includes sediment analyses (flushing flows and sediment deposition), water temperature modeling, dissolved oxygen modeling, time series analysis (instream habitat, and indicators of hydrologic alteration) and modeling of streamflow needs of riparian areas..

The physical habitat components of SEFA are a union of three programs or systems of programs used for the analysis of environmental flow requirements in rivers. The three programs, or collection of programs, are the Physical Habitat Simulation System (PHABSIM) (sometimes referred to as the 'WUA Method'); RHABSIM, and RHYHABSIM. PHABSIM is described in Milhous et al; 1988; RHABSIM in Payne, 1994; and RHYHABSIM in Jowett, 1989 and Clausen et al, 2004. A library of programs for the analysis of the time series of streamflows and physical habitat was also an element of the IFIM programs (Milhous, et al, 1990). The concepts of time series analysis have been incorporated into SEFA. A flow path showing the principle elements and the flow paths of SEFA are presented in Figure 3.

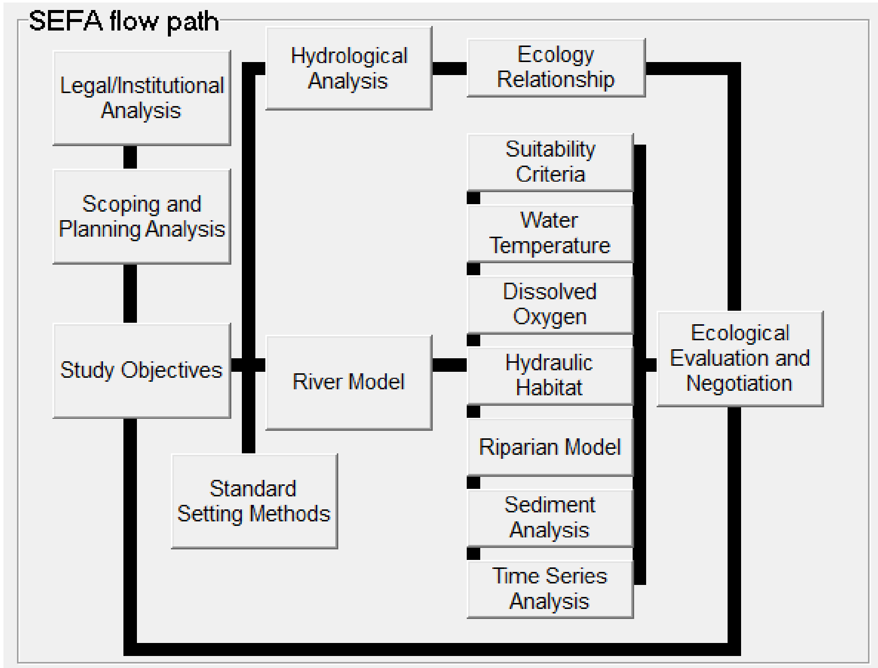

Figure 3. Flow paths of work in the System for Environmental Flow Analysis (SEFA).

APPLICATION OF SEFA CONCEPTS

Three types of riparian area analysis are presented in this section, the first is the use of riparian inundation analysis, the second is the analysis of the impacts of water management on the frequency of streamflows needed to remove vegetation from a channel, and the third is the establishment of riparian vegetation.

Riparian inundation analysis

Riparian inundation modeling usually considers the frequency, timing and duration of inundation flows. SEFA calculates the total number of days (or number of inundation events i.e. contiguous days of inundation) by season. Inundation is referenced to the water level at some flow, termed the base flow. The base flow would normally be a reasonably high flow, such as the mean flow. The inundation level is specified as the height above the water level at base flow. The results are a table showing the relationships between flow and water height above base flow for each cross-section and for the whole reach. The table also shows the area that is inundated. Another table gives the number of days or number of inundation events by season and by year (Table 1).

Table 1. Table created by SEFA to show the duration of inundation in a river.

Inundation Analysis

Inundation criteria used:

Minimum inundation flow (base flow) = 12 m³/s

Event : Inundation height above base flow > 1 m

Year season begins	Number of days event occurred											
	January	February	March	April	May	June	July	August	September	October	November	December
2005	3	0	0	0	6	8	1	0	5	26	0	0
2006	3	0	0	0	6	8	1	0	5	26	0	0
2007	3	0	0	0	6	8	1	0	5	26	0	0

Case Study: Impact of water management on streamflows required to remove vegetation

An important component of a suite programs for environmental flow analysis is the need for a model to determine streamflows required to establish vegetation and streamflows required to remove vegetation. The case study presented herein is to determine streamflows required to remove vegetation from river bars within the stream channel (see Figure 2). Specifically, the objective is to remove willows and other vegetation from bars in the Cache la Poudre River (Poudre River) in Colorado. The first activity was to determine criteria to remove the vegetation. An analysis of streamflows in the river indicated the bed material must be moved in order to remove the vegetation (Milhous, 2012). The dimensionless bed shear stress required is 0.035 and should be adequate to move the sediment and the vegetation growing on the sediment.

The next step is to determine the streamflows that cause a bed dimensionless shear stress of 0.035. There are two approached that could be used in the application of the SEFA concepts. The first is to do an analysis of all cells (locations) in the channel and determine the streamflows needed to remove vegetation from all cells where vegetation is established on the river bars. This approach insures that each cell is cleared of vegetation (this is a hydraulic approach). The second approach is to use average cross-sectional parameters and insure the river streamflows, on average, are adequate to remove the vegetation. This is more of a hydrological approach. The approach use in this section is the hydrological approach. The relation between the average bed dimensionless shear stress and the streamflow was determined using gaging station data and is presented in Milhous, 2009. The equation for discharge, $Q_{t,}$ as related to the dimensionless shear stress, ß, is $Q_t = 65990\beta^{1.82}$. The target dimensionless shear stress is 0.035 which yields a discharge of 147 m^3/s as the discharge required to move the substrate supporting the vegetation.

The objective of this case study is to investigate possible impacts of reservoirs on the North Fork of the Poudre River on the ability of the river to keep river bars free of vegetation. In 1910 North Poudre Irrigation Company completed Halligan Reservoir with a capacity of 6,400 acre-feet. In 1943, Greeley completed construction of the Milton Seaman Dam which impounded a reservoir of 5,000 acre-feet.

The annual peak discharges in the Poudre River measured at the mouth of Poudre Canyon are presented in Figure 4. The discharge of 147 m^3/s required to remove the vegetation is also shown on the figure.

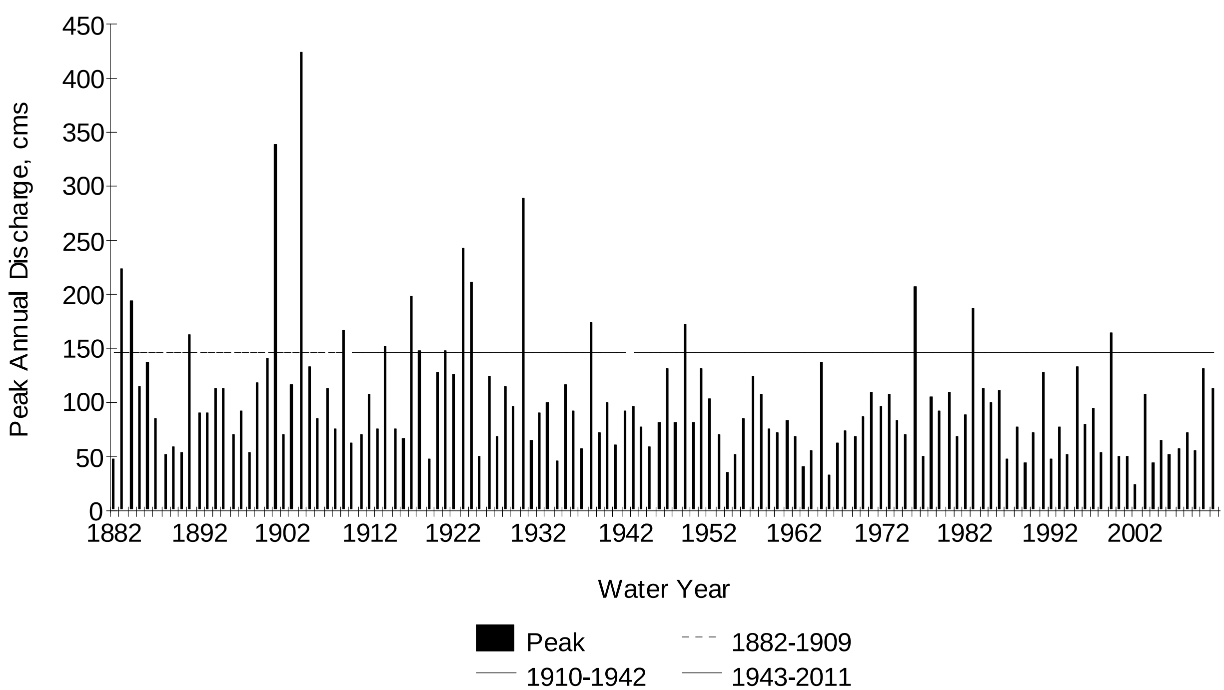

Figure 4. Peak Annual discharge of Cache la Poudre River at Mouth of Canyon (USGS Station Number 06752000). The horizontal line is for a discharge of 147 m^3/s. The time periods are defined by the years a major reservoir was completed on the North Fork. Halligan Reservoir was completed in 1910 and Milton H Seaman Reservoir was completed in 1943.

The return period for a discharge of 147 m^3/s for each of the three periods with different amounts of storage on the North Fork were analyzed using log-Pearson Type III analysis. The results are presented in Table2.

Table 2. Return period of the streamflow, 147 m^3/s, required to remove vegetation from bars in the Cache la Poudre River in the Fort Collins area. The time periods are defined by the years a major reservoir was completed on the North Fork.

Period	return period, years
1882-1909	3.5
1910-1942	5
1943-2011	14.3

The conclusion is that the reservoirs have had a significant impact on the ability of the Poudre River to remove vegetation from bars in the Fort Collins Reach of the Poudre River.

Case Study: Application of an Establishment Index

An algorithm has been developed to calculate two indices to the establishment of cottonwood in western river floodplains based on the daily streamflows. The logic is based on cottonwood trees where a clean substrate is required prior to the dispersal of seeds. The indices can also be considered to be indices to the establishment of riparian vegetation along many rivers. Two indices have been developed: 1) an index based on peak daily discharge and 2) an index based on the width of the cross section.

Index Model 1: The peak discharge during the establishment period is the index to riparian vegetation (cottonwood) establishment. The first assumption is that a clean substrate results if the flows cover a stream bed area during the germination period (in the Rio Grande this was taken as 1 April thru 15 July). The second assumption is that the seedlings survive if the streamflows during the remainder of the current water year and the whole of the following water year (for the Rio Grande this was 16 July through 30 September of the following water year) does not exceed the streamflows during the germination window.

Index Model 2: An index based on seedling survival. The width of a river is calculated using the simple power law W = A*(Q**B) where W is the width, Q the streamflow, and A and B are constants. If the streamflow available to prepare an area for cottonwood establishment during the establishment period is QEST, and the discharge following the establishment period limiting the area available for establishment is QDST. Then the width available for establishment (WEST) is WEST = A*((QEST**B) - (QDST**B)). Dropping the A term gives an index of ESTI = (QEST**B) - (QDST**B). For the Rio Grande index model the establishment discharge was the maximum average 5-day discharge in the period germination period. QDST was the maximum average daily discharge in the rest of the water year and the following water year. A minimum discharge can be specified that essentially prevents the index from being other than zero when the streamflows in the establishment period are less than the specified minimum. Typically the minimum discharge will be the bankfull discharge. For additional information see Milhous, 1994.

Index Model 2 has been applied to daily streamflows in the Poudre River (See Figure 5). The power term used in the calculations was 0.39 and the minimum discharge was the peak discharge exceed 1 in 2 years (87.8 m^3/s).

DISCUSSION

The System for Environmental Flow Analysis (SEFA) has many tools required to analyze and model streamflows required to maintain the best vegetation in a stream. Other tools will be added as a better understanding between streamflows and vegetation in the riparian area is developed. The inundation model is well developed and can be used for vegetation analysis within the channel and in the floodplain. Both the vegetation removal model and the vegetation establish model have been tested in the impact analysis of changes in water management.

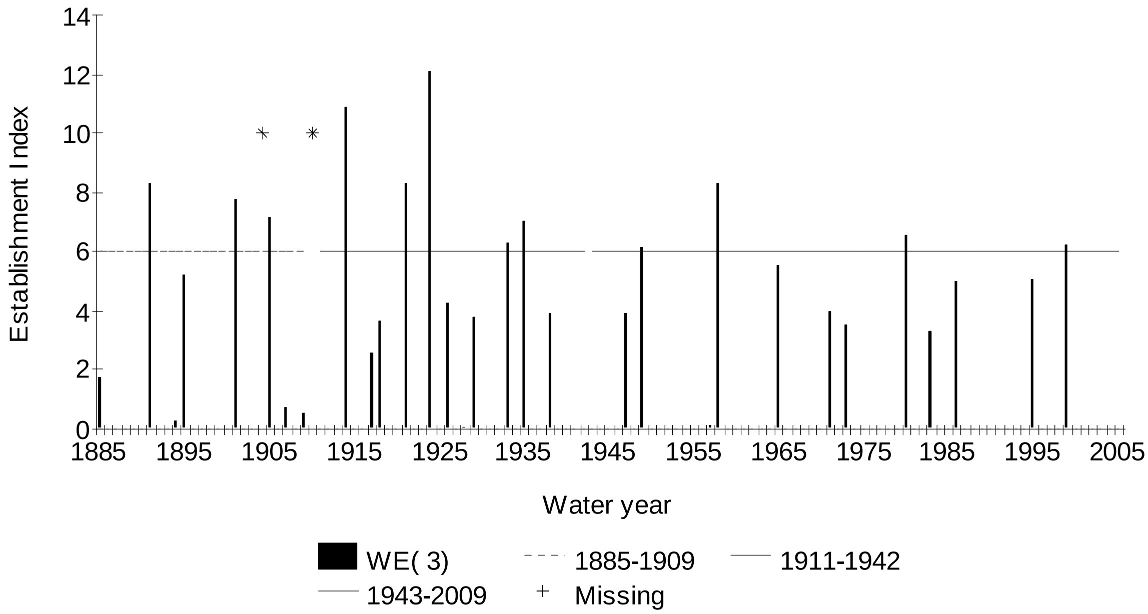

Figure 5. Index to the establishment of riparian vegetation in the Poudre River, Colorado. The minimum discharge for establishment was 87.8 m^3/s and the power term in the width equation was 0.39. WE(3) is the establishment index calculated using the maximum average discharge over three days.

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