RIVER RESEARCH AND APPLICATIONS

*River Res. Applic.* **31**: 392–401 (2015)

Published online 17 March 2014 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/rra.2745

# HEC-RPT — SOFTWARE FOR FACILITATING DEVELOPMENT OF RIVER MANAGEMENT ALTERNATIVES

J. T. HICKEY[a*], S. J. NEWBOLD[b] AND A. T. WARNER[c]

[a] *Hydrologic Engineering Center, Institute for Water Resources, US Army Corps of Engineers, Davis, CA, USA*
[b] *Resource Management Associates, Fairfield, CA, USA*
[c] *The Nature Conservancy, North America Freshwater Program, University Park, PA, USA*

## ABSTRACT

The Regime Prescription Tool (RPT) is a software program designed to help groups of scientists, engineers, and water managers access hydrologic data and draft flow recommendations while formulating different ways to manage rivers. It is a communications tool and contributes in the early stages of planning by formalizing ideas and expert knowledge into a structure easily visualized and considered in more detailed analytical tools. Applying RPT helps organize and focus group conversations that seek to create consensus-based alternatives for water management. This paper introduces the software and its role in water resources planning. An RPT application used in the definition of environmental flows for the McKenzie River, Oregon, USA, is presented. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: HEC-RPT; Regime Prescription Tool; water resources planning; collaborative modelling; environmental flows

*Received 13 September 2013; Revised 22 January 2014; Accepted 6 February 2014*

## INTRODUCTION

River systems have diverse stakeholders that share an appreciation of the many services that a river can provide. These interests vie for an allocation of waters advantageous to their position throughout a continuum of water development from initial planning and construction of water resource infrastructure to an optimization of existing facilities and, ultimately, to a sustainable state of management or alteration to the point where the river ceases to exist.

Voices wax and wane responding to historical circumstances and rhetorical and political opportunities. Some change from a competitive to a protective tone as the services they advocate for achieve acceptable and reliable performance. Others fade as their position fails in competition, perhaps to return when social opinion and economic value become more aligned with their uses in hopes of affecting the allocation of water to restore services lost.

Maintaining open and clear communications where a diversity of perspectives can be heard and goals expressed in common terms is critical when trying to achieve a generally accepted balance among different uses of rivers. For water managers, decision-making that involves river conditions is often as much about managing conflict as it is about managing water.

*Correspondence to: J. Hickey, Hydrologic Engineering Center, Institute for Water Resources, USACE, 609 Second Street, Davis, CA 95616, USA. E-mail: john.t.hickey@usace.army.mil

This paper describes a software tool developed to help diverse interest groups develop a single set of river management recommendations that balance these interests.

The idea for the Regime Prescription Tool (RPT) was conceived during a workshop for the Savannah River (Georgia and South Carolina, USA), where nearly 50 scientists representing 13 organizations worked together to formulate a set of water management recommendations designed to sustain Savannah River ecosystems. During the workshop, recommendations were created independently for different ecotypes of particular importance in the Savannah Basin and then merged into a single set of recommendations (Richter *et al*., 2006).

Throughout this process, many hydrographs were created, discarded, and modified. 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 aid the formulation process, and if it were also capable of accessing and plotting historical hydrologic data to guide the scientists upon their request, then the product as well as the process would be improved.

This idea was conceptually refined by the Hydrologic Engineering Center (HEC) and The Nature Conservancy with an initial focus on defining the roles for the software in water resources planning. What capabilities should it have? How will it complement existing software? In what settings will it be applied? How will this software be unique? During this period, it was recognized that possible applications of the tool were not limited to defining ecological strategies. The tool also had potential to help capture and articulate, in hydrologic terms, the goals of diverse stakeholders engaged in river management planning.

The first public release of RPT was in October 2006 followed by version 1.1 in January 2007 and version 2.0 in February 2011. RPT is designed to help different interest groups engage in collaborative discussions of how rivers should be managed (USACE, 2012). The software is generic in the sense that it can display flow data and help define management alternatives, in terms of quantified flow recommendations, for any river. RPT is intended for use in real-time expert workshop settings where suggestions from group members are actively, visually, and quantitatively integrated into a collective recommendation. These recommendations can subsequently be exported for use in more detailed analytical tools such as reservoir simulation, river hydraulics, and ecosystem function models (Hickey, 2007).

## COLLABORATIVE DECISION SOFTWARE

The Regime Prescription Tool is typically applied as part of a broader planning process that encompasses problem definition, identification of alternatives, and assessment, implementation, and testing of those alternatives (Figure 1). RPT is used during alternative formulation. It allows desired management regimes (i.e. flow recommendations in the form of customized hydrographs) to be shaped based on expert knowledge and stakeholder input. Successful application of RPT produces flow recommendations that represent the collective ideas of the group of participants. Defining success of the broader process is difficult to do as succinctly, although 'realizing improvements to water resources management' would be a good opening.

Terms like group settings, expert knowledge, and stakeholder input are common in discussions of computer-aided negotiation (Thiessen *et al.*, 1998), consensus building through modelling (Stave, 2003; Giordano *et al.*, 2007), stakeholder-based modelling (Palmer *et al.*, 1999; USACE, 2009), and participatory modelling (Pahl-Wostl *et al.*, 2007; Voinov and Bousquet, 2010). These related paradigms (Imwiko *et al.*, 2007) are more about process than choice of technology and all espouse common principles of transparency, communicativeness, and engagement of involved parties (Korfmacher, 2001; Cockerill *et al.*, 2006; Cardwell and Langsdale, 2011; Sandoval-Solis *et al.*, 2013).

Many technologies have been applied in this field (Imwiko *et al.*, 2007; Voinov and Bousquet, 2010). Voinov and Bousquet (2010) identify more than a dozen software tools (STELLA, Vensim, Powersim, Delphi, Madonna, Simile, Extend, Goldsim, Simulink, Excel, and others) that have been used for stakeholder-based modelling. Several of these tools, like STELLA (Richmond, 2004), are generic platforms that

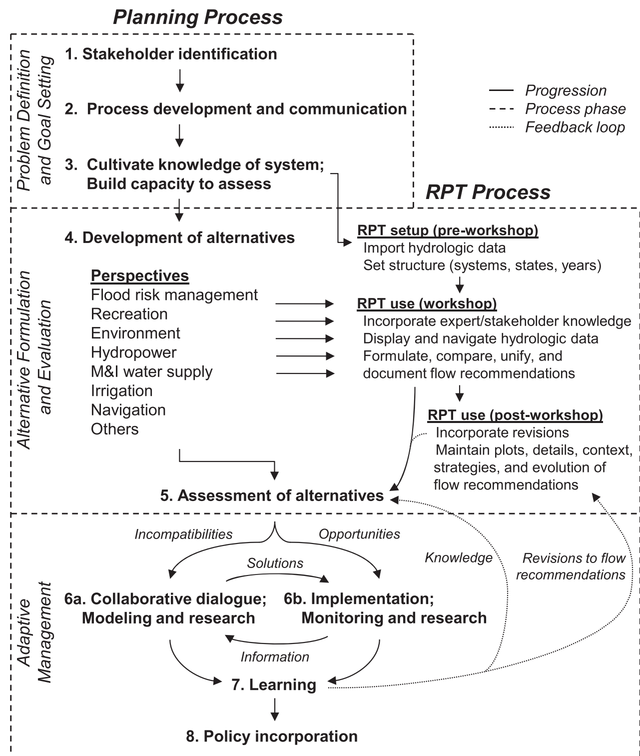


Figure 1. Roles of HEC-RPT in a generic planning process, adopted in part from Richter *et al.*, 2003. Correction added on 25 April 2014, after first online publication. Figure amended slightly to improve clarity

allow modellers to build applications based on input from participants (stakeholders, mediators, and experts) in a planning process. This is done purposefully to maintain transparency throughout the modelling process in hopes of building trust and knowledge amongst participants such that results of the planning effort will be more widely accepted and therefore more implementable.

The Regime Prescription Tool is also generic in the sense that it can be applied to many systems, and its applications begin as a blank slate and can be constructed in a participatory modelling setting. However, RPT is designed specifically for use in river systems that are or may be affected by flow management decisions. It assists only with alternative formulation and does not perform detailed alternative analyses.

The contributions of RPT to the planning process include simple access, visualization, and navigation of hydrologic data; tracking and maintaining a context of hydrologic conditions; electronic creation and shaping of flow recommendations; capturing justifications for and uncertainties associated with discrete components of flow recommendations; simple comparisons of flow recommendations from different stakeholder groups; and assistance with integration of different flow recommendations into a single alternative.

All these functions adhere to the aforementioned principles. Alternatives are built piece-by-piece per participant



DOI: 10.1002/rra

input (transparency and engagement), display of data and alternatives are inherently visual and responsive to participant inputs (transparency and communicativeness), alternatives are compared visually to identify incompatibilities with historical data and potential conflicts with other alternatives (transparency, communicativeness, and engagement), and alternatives are unified as much as possible through further shaping of the alternatives per negotiation and compromise amongst participants (transparency, communicativeness, and engagement).

## SOFTWARE FEATURES AND USE

In RPT, the basic framework (Figure 2) for flow recommendations is that flows are as follows: (i) created for different subjects of interest (systems); (ii) related to a hydrologic condition or season (states); and (iii) expressed as combined time series of low flows, pulse flows, and flood flows (flow components).

### *Spatial or topical framework (systems)*

A ‘system’ describes a subject of interest for which flows will be recommended. There tends to be several systems within one project; there is no limit to the number of systems per project. A system may refer to a location on a river (e.g. an important gage location), an important ecosystem connected to the river (e.g. a floodplain forest community) or a guild of species (e.g. fishes), or to different points of view for river management (e.g. water supply, hydropower operations, or recreation). Systems of an RPT project usually share a common typology. For example, flow recommendations from the Savannah River workshop were formulated for three river reaches, each having a different type of ecosystem and each being analogous to a system in RPT: (i) Augusta shoals—a relatively short (~7 km) reach, whose defining and namesake characteristic is a multitude of in-channel rock structures that are partially exposed at low flows, that provides habitat for a unique assemblage of fishes, mussels, and plants; (ii) mainstem river and floodplain—a long (~65 km) unleveed reach with a broad and heavily forested floodplain; and (iii) estuary—a reach of roughly 20 km between the floodplain reach and the Atlantic Ocean comprised of riverine, floodplain, and tidal freshwater and saltwater marsh habitats (Meyer *et al*., 2003; Richter *et al*., 2006).

### *Hydrologic framework (states)*

‘State’ refers to a prevailing hydrologic condition associated with a set of flow recommendations. There tends to be multiple states within one project, and there is no limit to the number of states per project. The same set of states is used for all systems in a project. Flow recommendations are prepared for each state in each system. States can be defined by ‘name and year’, where each water year is assigned a single state, or by ‘scripting’ with time series, which allows users to import time series, perform calculations with those time series, and, ultimately, use a logic statement to determine state. For example, flow recommendations from the Savannah River workshop were formulated for three hydrologic states: wet, average, and dry (Meyer *et al*., 2003; Richter *et al*., 2006).

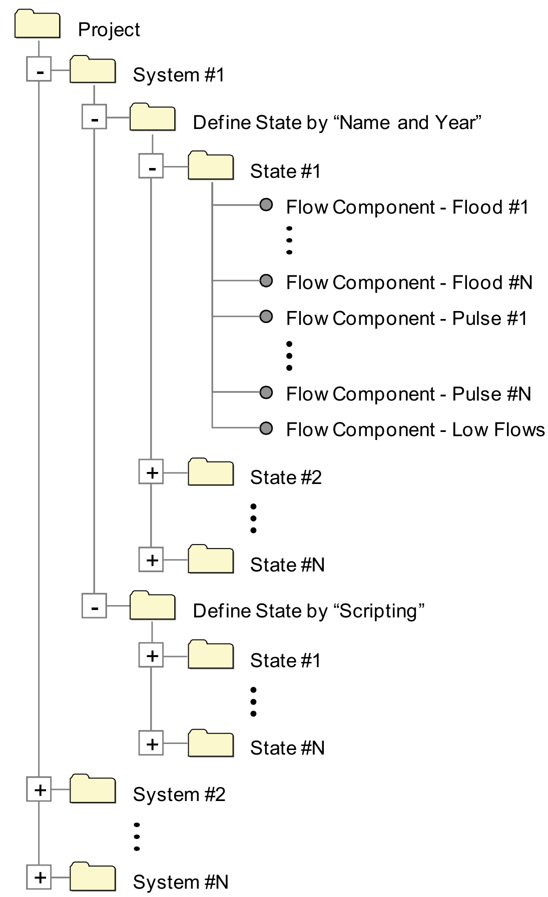


Figure 2. Structure of an RPT application

### *Flow recommendations (flow components)*

‘Flow components’ are the building blocks of a recommended flow time series. There are three types of flow components available in RPT—low flows, pulse flows, and flood flows. Low flows are the foundation of the time series. Low flows are defined for each day in a water year (for each state in each system). Pulse flows and flood flows deviate from this base. A flow recommendation (for one state in a system) can have many pulses and floods but only one series of low flows. Both pulses and floods are defined by timing, duration, magnitude, and duration of peak. In RPT, flow recommendations are formulated as daily time series. This bottom-up approach, now known as ‘the Savannah Process’, was developed by The Nature Conservancy (Richter *et al.*, 2006) and was adapted in part from the ‘building block methodology’ (King *et al.*, 2000) and the ‘holistic approach’ (Arthington *et al.*, 1992) methods for defining environmental flows, which were formalized and first used in South Africa and Australia in the 1990s.

### *Supporting capabilities (banding, volume tracking, predefined plots, importers, and notes)*

The RPT software has several features that support the definition of flow recommendations. ‘Banding’ can be used to draw flow recommendations as ranges of acceptable flows, which is a helpful way to illustrate seasonal flexibilities (wide band) and rigidities (narrow band) for flow recommendations. ‘Volume tracking’ allows users to compare the volumes of water that would be needed to meet a set of flow recommendations with the corresponding volumes of water in an imported time series, which can provide a real-time accounting of how much of a river’s flow would be required to wholly implement a set of flow recommendations. ‘Predefined plots’ offer point and click summaries of historical data and comparisons of flow recommendations. ‘Importers’ allow systems from multiple applications to be combined into a single project for quick comparisons of the similarities and potential conflicts between the flow recommendations of different management perspectives. ‘Notes’ fields are provided throughout the software (for systems, states, and flow components) to allow documentation of the framework, strategies, and justifications for flow recommendations during formulation (Figure 3).

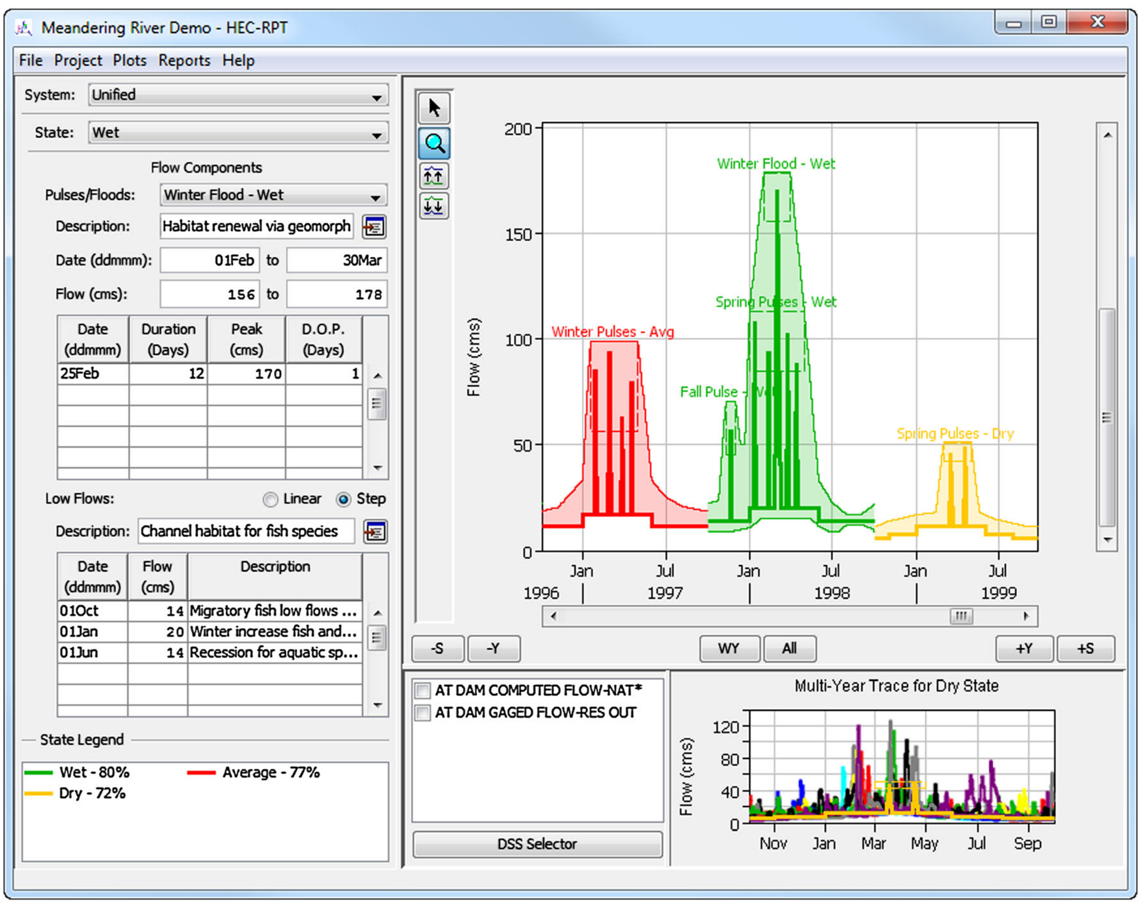


Figure 3. Main interface of RPT. Flow recommendations, banding, and states are shown for the RPT demonstration project. The upper right hand plot shows flow recommendations for average (1997), wet (1998), and dry (1999) water years (with details, left hand side of image, for a wet state flow component entitled “Winter Flood – Wet”). The lower right hand plot window displays a multi-year trace of all historical dry years in the unimpaired flow regime. Multi-year traces are one of several predefined plot options in RPT. This figure is available in colour online at wileyonlinelibrary.com/journal/rra

## APPLICATION FOR ENVIRONMENTAL FLOWS

The first application of RPT was performed in 2007 for the Coast and Middle Forks of the Willamette River, Oregon, USA (Gregory *et al*., 2007). This case study discusses a more recent application for the McKenzie River, also in Oregon, that occurred in 2010. Both supported definition of environmental flows, which are flows in a water system that sustain local ecosystems and the goods and services they provide (TNC, 2006; Hirji and Davis, 2009).

The McKenzie River drains a 3400-km$^2$ area in western Oregon (Figure 4). It joins the Willamette River near Eugene, Oregon, which then flows north to meet the Columbia River on its westward path to the Pacific Ocean (Risley *et al*., 2010a). There are three storage reservoirs in the McKenzie basin, two diversion dams, one reregulation facility, and a series of canals that divert and return river flows to generate hydropower. The two biggest reservoirs, Blue River and Cougar, are owned and operated by the US Army Corps of Engineers. Both have multiple operating purposes including flood risk management, recreation, irrigation, water quality, and fish and wildlife. During periods of high flows, Blue and Cougar are operated both to reduce potentially damaging flows along the McKenzie and as part of the Willamette flood risk management system, which involves 11 storage reservoirs operating for a series of communities located along the mainstem from Eugene to Salem. Cougar is also used to generate hydropower (USACE, 1992).

As in the encompassing Willamette basin, reservoirs in the McKenzie are primarily on tributaries or relatively high in the watershed such that most drainage areas are unregulated by dams. Accordingly, key hydrologic dynamics (e.g. seasonality and variability) and geomorphic processes (e.g. sediment transport and channel migration) are muted but present. In a comparison of the McKenzie River channel forms existing in 1939 and 2005, Risley *et al*. (2010a) note a general reduction in the length of secondary channels and area of active gravel bars and hypothesize that these trends are related to a combination of interacting anthropogenic factors including hydrologic alteration, channel clearing, land conversion, timber harvest, and their effects on sediment transport.

The McKenzie provides drinking water for roughly 200 000 people and power to nearly 20 000 households in the city of Eugene and its surrounding areas (www.eweb.org, Eugene Water and Electric Board). It is also a popular

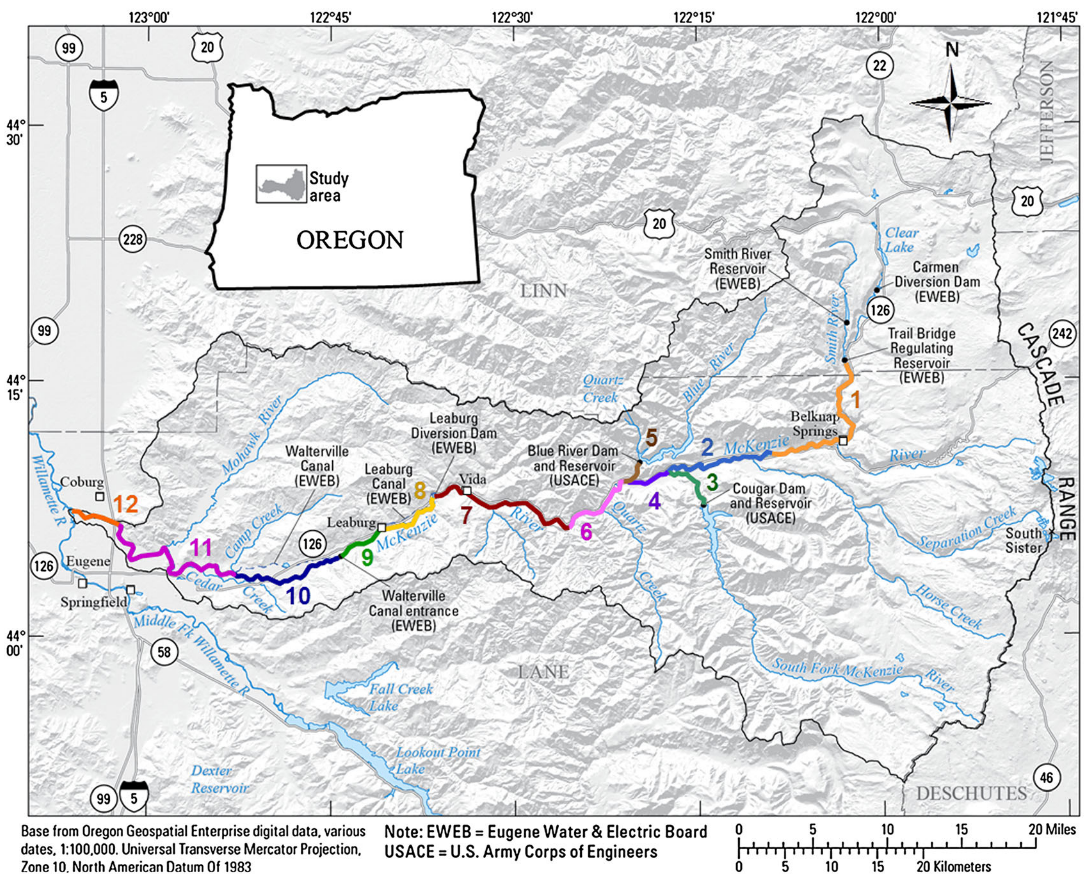


Figure 4. Major tributaries, dams, and river reaches of the McKenzie River basin, Oregon, USA (as in Risley *et al*., 2010a). This figure is available in colour online at wileyonlinelibrary.com/journal/rra




DOI: 10.1002/rra

and scenic area for outdoor recreation, offering excellent opportunities for boating, hiking, and, especially, fishing for the eight species of salmon and trout that inhabit the basin's lakes and rivers. Ecologically, the McKenzie is strongly connected to the Willamette, perhaps most visibly during the seasonal runs of salmon and steelhead that use the McKenzie for spawning and rearing.

In 2008 and in recognition of the range of services provided by the McKenzie, The Nature Conservancy, the Corps of Engineers, the Eugene Water and Electric Board, and the US Geological Survey (USGS) began an environmental flow study for the river. The study generally followed the sequential process for developing environmental flow recommendations detailed in Richter *et al*., 2006, which is now referred to as the 'Savannah Process' after its initial application for the Savannah River in 2003. Milestones included development of a summary report on the hydrology, geomorphology, and ecology in the McKenzie River basin (Risley *et al*., 2010a), convening of a workshop to define environmental flows, and completion of a report to document the workshop, its structure and products (Risley *et al*., 2010b). The RPT software was used to help facilitate the workshop by recording and archiving the flow recommendations and associated justifications and uncertainties set forth by the scientists, engineers, and water managers who participated in the 2-day workshop. The rest of this section describes the three phases of the McKenzie River application of RPT: initial development, use during workshop, and role of software in preparing the workshop report.

### *Initial development*

Initial development of an RPT application is typically done by a small group of people in anticipation of a larger meeting of stakeholders and experts to discuss water management alternatives. The small group usually includes conveners and future facilitators of the larger group as well as the RPT modellers. Conveners and facilitators are primarily interested in planning the formulation process (objectives, activities, structure, and schedule) to be used during the larger meeting and in understanding the capabilities and role of RPT. Modellers are responsible for aligning the RPT application with the anticipated formulation process, preparing and analysing hydrologic data and becoming proficient enough with the software and application to be comfortable using it in real time. The first two steps for the modellers are identifying systems and states.

For the McKenzie, RPT systems were adopted from the hydrologic section of the summary report where Risley *et al*. (2010a) characterized the river as 12 reaches of distinct streamflow and geomorphic conditions. Each reach was treated as a system in RPT. Time series of regulated and unimpaired flows were imported for each system. Regulated flows were obtained from USGS streamflow gauging stations. Unimpaired flows, computed as estimates of streamflows that would have occurred if Blue and Cougar had not been constructed, were obtained from the Portland District of the Corps of Engineers (Risley *et al*., 2010a).

States were based on a statistical analysis of the flow record for the McKenzie River near Vida gauge, 1925–2004 (USGS 14162500). Mean flows were computed for the full water year, a winter–spring season, a spring season, and a summer–fall season. Results for each statistic were then ranked from highest to lowest and split into bins, where the upper bin included the wettest 27 means, the middle bin had the 26 means closest to the 50th percentile, and the lower bin had the driest 27 means. The lower bin was then further split into categories for dry (14 means) and critically dry (13 means).

States were defined for 'wet', 'average', 'dry', 'critical', and 'none' using the by name and year method in RPT (Risley *et al*., 2010b). A year was associated with a state based on how consistently its statistics sorted into the bins. Any water year whose statistics (at least three of the four means) fell into the upper bin was designated as 'wet', middle bin 'average', and so on. Years where less than three of the four means fell in the same bin were designated as 'none'.

This system–state framework served as the RPT starting point for the McKenzie flow recommendations workshop. Details are specific to the McKenzie, but there is much in common with other applications. To the knowledge of the authors, all RPT applications have been initiated by efforts that do the following: (i) seek to forward a dialogue about river management; (ii) use hydrologic data to support discussion; and (iii) incorporate a framework anticipated to be an effective structure for flow recommendations, logical from the perspective of the participating stakeholders, and of value and pertinent for water managers.

### *Use during workshop*

In water resource planning, the overwhelming majority of software applications are done without others seeing every keystroke of the modeller, much less having a group of people telling the modeller what to do and then voicing their concurrence or objections to its incorporation. This makes RPT use in real-time settings both challenging and insightful. Challenging to keep pace with the amount of information that can be shared easily through oral communications in group settings and insightful to be part of and support a dynamic process where many voices contribute to a collective set of ideas. The roughly prioritized roles of RPT in these settings are as follows: (i) to record suggestions of



DOI: 10.1002/rra

the group; (ii) display and navigate hydrologic data sets; and (iii) compare and support unification of suggestions from different groups.

The McKenzie Environmental Flows Workshop started with a review of its purpose (defining the river flows needed to support a healthy and functioning ecosystem) and expected outcomes (a quantified set of flow recommendations). This was followed by presentations about the hydrology and associated ecosystems of the river. To simplify the challenge, the 12 reaches and their systems were aggregated into 4 sections (Figure 4): South Fork McKenzie River below Cougar (reach 3), Middle McKenzie (reaches 4–7), McKenzie between Leaburg and Camp Creek (reaches 8–10), and Lower McKenzie (reaches 11–12). Reaches 1 and 2 were not considered because of a lack of hydrologic alteration. Also, attendees were instructed to focus attention on the flows and related processes needed to support nine native species of particular importance, which included five fishes (spring Chinook salmon, bull trout, Pacific and western brook lamprey, and the Oregon chub), one amphibian (red-legged frog), one reptile (western pond turtle), and two riparian trees (black cottonwood and white alder). Species were selected based on information in the literature and communications with regional and local biologists (Risley *et al*., 2010a).

Fifty-five participants associated with 15 organizations (six federal and two state governmental agencies, three non-governmental organizations, two universities, one public utility, and one private sector consulting firm) attended the workshop. Several attendees, perhaps around 12, were interested primarily in workshop goals and processes and departed after these introductory plenary sessions.

Remaining participants were then split into four subgroups, each with a similar mixture of expertise in hydrology, geomorphology, riparian and floodplain ecology, and fisheries and aquatic biota. Flow needs for each of the four river sections were formulated by two or more subgroups. The South Fork McKenzie River reach was worked on by subgroups 1, 2, and 4, the Middle McKenzie by subgroups 2 and 3, the McKenzie between Leaburg and Camp Creek by subgroups 2 and 3, and the Lower McKenzie by subgroups 3 and 4. Subgroups worked independently and were instructed to define flows for the 'average' state, detail how those 'average' recommendations pertained to the different states, and continue on to other states as time allowed. Each subgroup was assigned a facilitator and an RPT modeller.

Subgroups began the formulation process by overlaying life stages and related habitat requirements of the key species with unimpaired flow patterns of the McKenzie. Connections between the species and the flows were identified, debated, and, if there was agreement, incorporated into the flow recommendations. As part of this process, RPT was used to build, display, and annotate the flow recommendations electronically, in real time (Figure 5). When a flow component (flood, pulse, or low flow) was proposed, its magnitude, duration, and timing were entered into text fields along the left hand side of the software's main interface. Plots in RPT update automatically with each new entry, which allowed the groups to immediately review and revise their recommendations.

A strength of RPT is its ability to display and navigate hydrologic data sets. For the McKenzie, data were imported to RPT that showed how the river has been managed since construction of the dams, as well as how the river would have flowed without reservoirs. Imported data can be made visible or hidden with the click of a button and were used throughout the workshop as visual references while crafting recommendations.

After flow recommendations were formulated, the workshop returned to a plenary setting where subgroup recommendations were unified into a single set of flow recommendations for the McKenzie. A modeller used the import systems feature in RPT to bring recommendations for all sections and subgroups into the same project. Subgroup recommendations for each river section were plotted using RPT and presented by the subgroup facilitators. Members of the subgroups that had defined recommendations for that river section worked to integrate their recommendations by adjusting the timing and/or magnitude of recommended flows without sacrificing ecological purposes (Figure 5). This process also offered attendees from the other subgroups an opportunity to learn about and question the information and strategies underpinning recommendations for river sections they had not worked with initially. Aided by the visual comparisons in RPT, subgroup recommendations were quickly melded into a single unified set of flow recommendations that was then displayed to ensure continuity between river sections.

### *Help with workshop report*

For conveners, facilitators, and modellers (and attendees), meetings like the McKenzie Environmental Flows Workshop tend to be somewhat consuming experiences. Much effort goes into organizing and orchestrating the meeting, with effective documentation of the products often being given a lower priority than the other important tasks that were deferred during preparation and participation. With lag, specifics about conclusions reached lose clarity, which has proven a challenge when revisiting workshop materials during documentation and implementation of flow recommendations.

Information stored in RPT applications has proven a valuable reference while preparing workshop summary reports, assessing the implications of environmental flow implementation, and guiding monitoring plan development. For the McKenzie, flow recommendations were stored as a progression of values, justifications, and uncertainties thereby

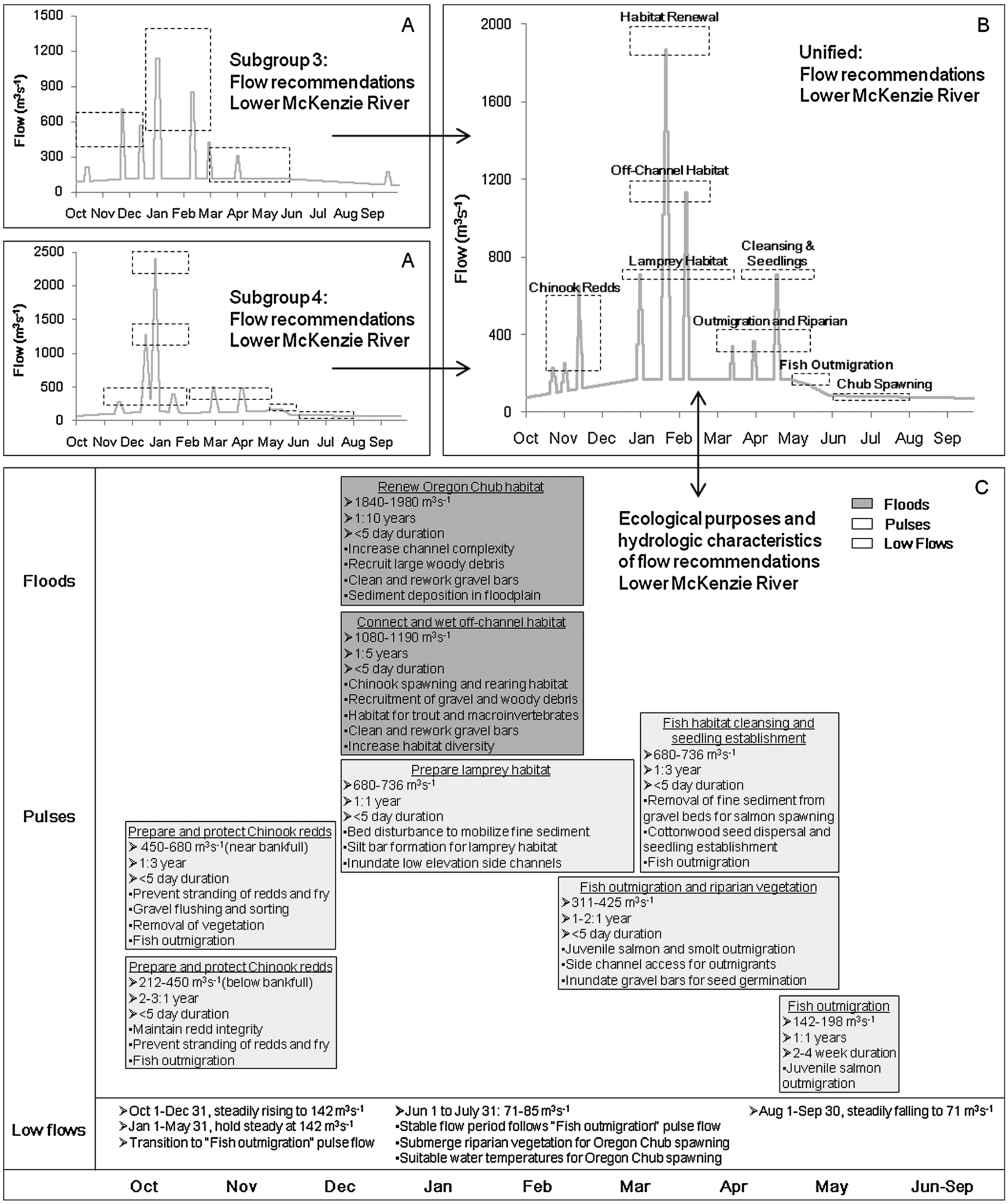


Figure 5. Formulation (A), unification (B), and justification (C) of flow recommendations for the Lower McKenzie River. Subgroups 3 and 4 were groups of scientists, engineers, and water managers that worked independently (A) and then collaboratively to merge their recommendations into a single set of flows (B) and supporting purposes (C)

recording a temporal status during formulation and unification. Electronic notes were taken for all key parts of the RPT structure, especially for individual flow components (e.g. purpose, recommended frequency, contingencies, and uncertainties), all of which were available for incorporation into the workshop summary.

*Since the workshop*

In 2012, environmental flows were defined for the Santiam River (Bach *et al.*, 2012; Risley *et al.*, 2012). This completed the sequence of environmental flow definitions for all main tributaries of the Willamette River initiated in 2007 for the Coast and Middle Forks. In each year since



DOI: 10.1002/rra

2007, components of those initial definitions have been implemented on the Middle Fork Willamette (Warner *et al*., 2014). Implementation has been opportunistic in the sense that flow changes are being made within the bounds of operational flexibility for Middle Fork reservoirs and have been enabled by hydrologic conditions conducive to environmental releases (e.g. storms generating inflows that could be stored temporarily and then released with timing and shapes per environmental components for transport of juvenile salmon, creation of lateral habitat on floodplain margins, and maintenance of bars, pools, and riffles). Associated monitoring has been conducted as possible (Konrad, 2010).

Focus is now shifting to efforts that will support a more complete and basin-wide implementation of environmental flows. Work is progressing on a strategic monitoring plan designed to validate environmental flow recommendations and reinforce informational loops between scientists and water management decision-makers. An overall implementation plan is being developed to help maintain the integrity of the recommendations during the current partial implementation phase and to guide the search for solutions for flow components that are beyond existing operational flexibilities. Environmental flow efforts are also aligning with ongoing endangered species consultations and other basin planning activities, including floodplain restoration. Particular recent advancements have been made in the modelling arena, where environmental flow needs for tributaries and endangered species requirements at mainstem locations are being assessed with reservoir simulation models.

## CONCLUSIONS

Both the McKenzie and Coast and Middle Fork Willamette applications of RPT were used to facilitate definition of environmental flows and thereby build consensus among regional environmental experts. The software has also been applied outside the USA. In China, RPT was used to help facilitate a workshop to define managed river flows to sustain ecosystems in the Upper Yangtze River's Native Fish Reserve, which includes more than 350 km of the mainstem Yangtze upstream of Three Gorges Dam reservoir and downstream of a cascade of dams now under construction. During that workshop, participants reached an initial consensus on flow conditions needed to support key native fishes in the Reserve (CTGPC and TNC, 2009). An application for the Patuca River, Honduras, relied on traditional ecological knowledge, incorporating information on indigenous fishing, transportation, and water needs for subsistence agriculture and integrated that information into a unified flow recommendation for consideration in the operation of a proposed hydropower reservoir (Esselman and Opperman, 2010).

Throughout its development, RPT has emphasized simplicity and visual responses to user commands and input. It is not intended to perform detailed quantitative analyses. This may seem a bit odd for software in water resource planning, where tools are typically designed to assist with computationally challenging questions. Instead, RPT contributes in the early stages of plan formulation, synthesizing ideas and expert knowledge into a structure easily visualized and considered in other specialized software. RPT helps organize and focus group conversations that seek to create consensus-based alternatives for water management. Seasonal requirements, flow dynamics linked with purpose, changing sensitivities, comparisons of diverse perspectives, alignment of common services, identification of potential conflicts, and annotated details for flow strategies and uncertainties are all detailed and archived in RPT. Moreover, all are developed in real-time group settings to encourage a collective agreement and improved understanding of the variety of services provided by managed rivers.

ACKNOWLEDGEMENTS

Development of RPT was initially partnered by The Nature Conservancy, and the Portland District and HEC of the US Army Corps of Engineers. Mary Karen Scullion, Brad Bird, and Bruce Duffe, Portland District, were instrumental in commencing this project. Since then, RPT has been supported through a model maintenance programme sponsored by a cooperative of Corps District offices. The Nature Conservancy (www.nature.org) contributed to design and has led several applications of RPT. Software coding was performed by Resource Management Associates, Inc. (www.rmanet.com). The McKenzie River Environmental Flows Workshop was led by Leslie Bach, The Nature Conservancy, Karl Morgenstern, Eugene Water and Electric Board, and John Risley, USGS. Application of RPT was prepared and conducted by John Risley.

Preparation of this manuscript was performed as part of the lead author's doctoral programme of study in Civil and Environmental Engineering at the University of California Davis. Dr Jay Lund served as his advisor.

The RPT software and guidance for use are available free of cost, via the Web at www.hec.usace.army.mil.

## REFERENCES

Arthington AH, Bunn SE, Pusey BJ, Bluhdorn DR, King JM, Day JA, Tharme RE, O'Keefe JH. 1992. Development of a holistic approach for assessing environmental flow requirements of riverine ecosystems. Proc., International Seminar and Workshop on Water Allocation for the Environment, Pigram, J. J., and Hooper, B. P. (eds). The Centre for Water Policy Research, University of New England, Armidale, Australia.

Bach LB, Nuckols J, Blevins E. 2012. *Summary report: environmental flows workshop for the Santiam River Basin, Oregon*. The Nature Conservancy: Portland Oregon.

Cardwell HE, Langsdale S. 2011. Collaborative Modeling for Decision Support–Definitions and Next Steps. In *Proceedings of the World Environmental and Water Resources Congress*, Beighley RE II, Kilgore MW (eds). ASCE: Reston, Virginia; 2805–2814.
China Three Gorges Project Company (CTGPC), The Nature Conservancy (TNC). 2009. Lower Jinsha River ecological flows workshop, Beijing, China, April 25-26, 2009, and Yichang, China, October 30-31, 2008: conclusions and recommendations. Beijing, China: The Nature Conservancy.
Cockerill K, Passell H, Tidwell V. 2006. Cooperative modeling: Building bridges between science and the public. *Journal of the American Water Resources Association (JAWRA)* **42**(2): 457–471. DOI: 10.1111/j.1752-1688.2006.tb03850.x
Esselman PC, Opperman JJ. 2010. Overcoming information limitations for the prescription of an environmental flow regime for a Central American river. *Ecology and Society* **15**(1): 6.
Giordano R, Passarella G, Uricchio VF, Vurro M. 2007. Integrating conflict analyses and consensus reaching in a decision support system for water resources management. *Journal of Environmental Management* **84**(2): 213–228. DOI: 10.1016/j.jenvman.2006.05.006
Gregory S, Ashkenas L, Nygaard C. 2007. Environmental flows workshop for the Middle Fork and Coast Fork of the Willamette River, Oregon. The Institute for Water and Watersheds, Oregon State University, Corvallis, Oregon, USA. 38 pps.
Hickey JT. 2007. Models and Software for Supporting Ecologically Sustainable Water Management. Water Resources IMPACT.
Hirji R, Davis R. 2009. *Environmental flows in water resources policies, plans, and projects: Findings and recommendations*. Environmental Department. World Bank: Washington, DC. DOI: 10.1596/978-0-8213-7940-0
Imwiko A, Kiefer JC, Werick WJ. 2007. Literature review of computer-aided collaborative decision making. CDM for Institute for Water Resources, U.S. Army Corps of Engineers. 146 pps.
King JM, Tharme RE, de Villiers MS (eds). 2000. Environmental flow assessments for rivers: manual for the Building Block Methodology. Water Research Commission Report TT 131/00, Pretoria, South Africa.
Konrad CP. 2010. Monitoring and evaluation of environmental flow prescriptions for five demonstration sites for the Sustainable Rivers Project. US Geological Survey Open-File Report 2010-1065.
Korfmacher KS. 2001. The politics of participation in watershed modeling. *Environmental Management* **27**(2): 161–176. DOI: 10.1007/s002670010141
Meyer JL, Alber M, Duncan W, Freeman M, Jackson R, Palta M, Sharitz R, Sheldon J. 2003. Ecosystem flow recommendations for the Savannah River below Thurmond Dam - Final report from April 1-3, 2003 scientific stakeholders workshop. University of Georgia.
Pahl-Wostl C, Craps M, Dewulf A, Mostert E, Tabara D, Taillieu T. 2007. Social learning and water resources management. *Ecology and Society* **12**(2): 5.
Palmer RN, Werick WJ, MacEwan A, Woods AW. 1999. Modeling water resources opportunities, challenges and trade-Offs: The use of Shared Vision modeling for negotiation and conflict resolution. ASCE WRPMD'99. June 1999, 1–13.
Richmond B. 2004. An introduction to systems thinking - Chapter 1 - STELLA software. isee systems. ISBN 0-9704921-1-1.
Richter BD, Mathews R, Harrison DL, Wigington R. 2003. Ecologically sustainable water management: Managing river flows for ecological integrity. *Ecological Applications* **13**(1): 206–224. DOI: 10.1890/1051-0761(2003)013[0206:ESWMMR]2.0.CO;2
Richter BD, Warner AT, Meyer JL, Lutz K. 2006. A collaborative and adaptive process for developing environmental flow recommendations. *River Research and Applications* **22**: 297–318. DOI: 10.1002/rra.892
Risley J, Bach L, Wallick JR. 2010b. *Environmental flow recommendations workshop for the McKenzie River, Oregon*. The Nature Conservancy: Oregon; 51.
Risley JC, Wallick JR, Mangano JF, Jones KF. 2012. An environmental streamflow assessment for the Santiam River basin, Oregon: U.S. Geological Survey Open-File Report 2012-1133, 60 pps.
Risley J, Wallick JR, Waite I, Stonewall A. 2010a. Development of an environmental flow framework for the McKenzie River basin, Oregon. U.S. Geological Survey Scientific Investigations Report 2010-5016. 94 pps.
Sandoval-Solis S, Teasley RL, McKinney DC, Thomas GA, Patiño-Gomez C. 2013. Collaborative modeling to evaluate water management scenarios in the Rio Grande Basin. *Journal of the American Water Resources Association* **49**(3): 639–653. DOI: 10.1111/jawr.12070
Stave KA. 2003. A system dynamics model to facilitate public understanding of water management options in Las Vegas, Nevada. *Journal of Environmental Management* **67**(4): 303–313. DOI: 10.1016/S0301-4797(02)00205-0
The Nature Conservancy (TNC). 2006. Environmental flows: Water for people, water for nature. Boulder, CO.
Thiessen EM, Loucks DP, Stedinger JR. 1998. Computer-aided negotiations of water resources conflicts. *Group Decision and Negotiation* **7**: 109–129. DOI: 10.1023/A:1008654625690
U.S. Army Corps of Engineers (USACE). 1992. Authorized and operating purposes of Corps of Engineers reservoirs. PR-19. Hydrologic Engineering Center, Institute for Water Resources, Davis, CA. 193 pps.
U.S. Army Corps of Engineers (USACE). 2009. The Shared Vision Planning primer: How to incorporate computer aided dispute resolution in water resources planning. Institute for Water Resources. IWR Report 2008-R-02.
U.S. Army Corps of Engineers (USACE). 2012. Regime Prescription Tool (HEC-RPT), User's Manual, Version 2.0. CPD-84. Hydrologic Engineering Center, Davis, CA. 40 pps.
Voinov A, Bousquet F. 2010. Modelling with stakeholders. *Environmental Modelling & Software* **25**: 1268–1281. DOI: 10.1016/j.envsoft.2010.03.007
Warner AT, Bach LB, Hickey JT. 2014. Restoring environmental flows through adaptive reservoir management: Planning, science, and implementation through the Sustainable Rivers Project. *Hydrological Sciences Journal*. DOI: 10.1080/02626667.2013.843777