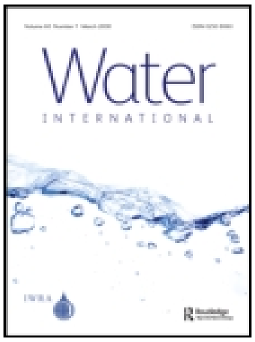

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Response by David Yates, Jack Sieber, David Purkey, and Annette Huber-Lee to Comments by Nesa Ilich on WEAP21 — A Demand-, Priority-, and Preference-Driven Water Planning Model: Part 1”

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for the first two months of irrigation season, and then drop below 50 percent in the third month due to high demand, low runoff, and depleted storage. This would render the supply in the first two months useless, since the crop would fail in the third month. This is a nightmare scenario from a planner's standpoint, and yet the only tool the users of WEAP21 have seems to be trial and error to find the right value of percent coverage for each demand and for each time step. This could be a rather laborious task and unreliable outcome for larger systems where modeling is needed to help deal with the complexity. Instead, if WEAP21 were setup to optimize reservoir operation over multiple time steps, it would be possible to get the LP solver to find the best coverage for a group of downstream water users as part of deriving an overall basin solution, such that the minimized deficits are shared in time and in space over the entire irrigation season. This would eliminate the need to define the percent coverage iteratively, and it would eliminate the danger of getting undesirable variations of the percent coverage from one time step to another. There is no mention in the paper of the ability of WEAP21 to optimize over multiple time steps. Indeed, it is not clear how that would be achieved given the existing complex setup of iterative calls of the LP solver. It would be beneficial to compare the quality (measured by the value of the objective function) of the solutions obtained with the current WEAP21 allocation algorithm and a standard single LP call in a classical LP framework where each component is assigned a unique priority. There is a high likelihood that the iterative setting of the constraints by the user currently employed within WEAP21 could introduce undesirable bias in the final solution, especially if the reservoir outflow constraints were to be incorporated into the model.

Response by David Yates, Jack Sieber, David Purkey, and Annette Huber-Lee to Comments by Nesa Ilich on "WEAP21 – A Demand-, Priority-, and Preference-Driven Water Planning Model: Part 1"

First, we would like to thank Dr. Ilich for his interest in our model and for some of his constructive comments. We hope that his commentary, along with our response will serve to clarify aspects of the WEAP21 model that might not have been clear in the December 2005 issue of *Water International*, with additional information available at http://www.weap21.org. We have carefully reviewed his comments and offer these responses.

As an overall comment, we would like to point out that the novelty of the WEAP21 refinements as presented in the paper were its integration of physical hydrology within a water management paradigm rather than the characteristics of either component, and we argue this alone is a unique contribution to the water resources community. While there is certainly room for methodological improvement, we attempted to address the unique gap between water management and watershed hydrology. Certainly someone will come along with a better mouse-trap or make ours better; this is simply a first attempt at the trap.

We feel that Dr. Ilich comments that "the hydrologic model does not offer any novel ideas that had not been previously published" are only partially true. We felt compelled to present the rather traditional surface and ground water balance models since together these are intimately connected with the river network and thus uniquely tied to the allocation logic. In addition, some of the methods have been previously published by the authors, making the hydrologic and water management integration more readily implementable from a software engineering perspective. In the paper, we described how physical processes (the surface, sub-surface, and river hydrology) allow for gaining and losing river reaches and how these, in turn, are coupled with the managed water system. Planning models alone cannot address the hydrologic accretions and depletions that occur throughout the watershed, which we argue is one of the contributions of the new WEAP21 model (e.g. a comprehensive mass balance which links the surface, sub-surface and river systems).

Dr. Ilich suggests the use of legacy rainfall-runoff models such as HEC-HMS or HSPF, but we defend our simplified hydrologic approach in the paper with reference to an article by Keith Beven who challenges the trend towards the kinds of physically-based models referred to by Ilich. It would be impractical to imbed HEC-HMS or HSPF into WEAP21 and achieve the kind of interaction between the physical hydrology and the managed system that the WEAP21 model exudes. Our more conceptual water balance and water quality models can achieve a level of accuracy that is appropriately suited to the water management questions which WEAP21 is trying to address, without being over specified as is the case of so many physically based models.

The criticism that the model could run into the trap of being "jack of all trades but master of none" is irrelevant. The true measure of the utility of a water planning model is its acceptability in the planning community and its ability to address and answer relevant planning questions. To date, there are over 100 licensed users of WEAP21 and many non-licensed users. The model has being applied by several water planning and environmental agencies, including California's Department of Water Resource Planning; Placer County Water Agency, El Dorado Irrigation District, Nevada Irrigation District, Santa Clara Water District, Portland Water, Colorado Springs Utilities, Philadelphia Water Department, Korea Institute of Construction Technology, the Nature Conservancy, the American Water Works Association Research Foundation, and others. These groups have recognized its merits as a useful, easy to use model that can address some of their planning questions.

In reference to the Alberta Water Management Agencies abandonment of a monthly time step in favor of a weekly one, Dr. Ilich states that "without channel routing, simulation of most large watersheds is limited to monthly (or at least bi-weekly) time steps." We recognized this limitation in the paper, by stating on page 496 that "Given there is no routing, the analyst should choose a model time step at least as long as the residence time of water corresponding to the period of lowest flow. Larger watersheds should adopt longer times steps (e.g. one month for example), while smaller watersheds can apply shorter time steps (e.g. 1-day, 5-day, 10-day, etc.) as all demands can be satisfied within the current time step." While the conclusions reached in Alberta may be locally justified, this has not been universally accepted. There are many examples of water planning agencies that effectively use a monthly time step. The large water planning model of the California water system (CALSIM) is monthly and is used to evaluate operational alternatives of large, complex river basins. The long-term planning model of the Colorado River system (CRSS) adopts a monthly time step to project basin-wide operations for 50+ years. To get at what time step should be used, a planner should ask "what is the appropriate time step necessary to adequately answer the proposed planning question."

Dr. Ilich noted that "It would appear from the definition of LP constraints that WEAP21 does not include any constraints associated with the maximum outflow capacity being a function of the average reservoir storage over a time step." It is true that there is no explicit constraint on the maximum outflow from a reservoir. This is mainly to handle large inflow events which are simply passed through the reservoir (e.g. over a spillway for example). As reflected in the title of our article, this is a demand-driven allocation model. One certainly can constrain reservoir releases as a function of reservoir surface area and downstream demands, and in fact, we have built planning models where downstream demand is a function of reservoir storage levels based on actual legal filings successfully translated into WEAP21 mathematical expressions. Dr. Ilich suggests that "in WEAP21, the reservoir outflows can take on any value, irrespective of the reservoir elevation, resulting for example in a scenario where sufficient reservoir inflows are routed through almost an empty reservoir to meet a downstream demand, while the reservoir remains empty." This is mathematically true, but without downstream demand that drives reservoir release, these releases will not be made. Ironically, not having this constraint can aid in finding modeling errors such as mis-specifying the units on an in-stream flow requirement. If the analyst incorrectly implements an instream flow requirement that should be 10 cubic feet per second but instead enters 10 cubic meters per second, this error can be quickly caught through an incorrect drawdown of reservoir storage. In addition, if there is no downstream demand, then reservoir releases will only be made if they violate the conservation storage rule (e.g. flood control).

"The use of the storage coefficient [we assume Dr. Ilich is referring to the buffer coefficient to achieve constrained reservoir releases] [...] along with the specification of preference ranking among the sources of supply [...] introduces so many arbitrary constraints that one cannot help but wonder about the 'optimality' of the final solution obtained from the use of the LP." There is no intent for the LP to yield an "optimal" solution; instead the LP is used to solve the allocation problem given the set of priorities and preferences, as opposed to a hierarchical if-then heuristic. Monetary costs and benefits are not included in the LP formulation, so there is no ability to maximize utility.

"The authors fail to fully document the benefits of calling the LP solver so many times to obtain a solution for a single time step." The troublesome word here is "fully." We gave (in our opinion) a substantial explanation of our solution algorithm on pages 496-498. Given the brevity of the article, we of course had to limit the discussion of the solution algorithm in an attempt to give readers a broad understanding of the many aspects of the model, but feel the description was adequate given page limitations. We would be happy to engage Dr. Ilich or other *WI* readers in a more expanded description of our allocation algorithm if requested, but with due respect the description found on page 496, in our estimation, is substantial.

"There is no mention in the paper of the ability of WEAP21 to optimize over multiple time steps. Indeed, it is not clear how that would be achieved given the existing complex setup of iterative calls of the LP solver." Again, it is not mentioned because we do not optimize in the traditional sense, and it was never our intention to do this. We have used an LP algorithm to solve the allocation problem given the priorities and preferences prescribed by the user. We do not intend to optimize over multiple time steps at this time.

Dr. Ilich has a valid point regarding WEAP21's non-optimal allocation logic, as there could certainly be the situation as he describes, where in an irrigation setting, water is supplied adequately in the first two months, but then a shortage in the third month could lead to crop failure. He goes on to suggest a nice application of a water planning model to "find an optimal set of allocations to determine an overall basin solution, such that the minimized deficits are shared in time and space over the entire irrigation season." We fully agree that this would be a nice feature to have in WEAP21. This might be achievable without the physical hydrology module, with significant re-thinking of the solution algorithm. Of course, with the addition of physical hydrology, the system becomes highly non-linear and unsolvable by a traditional LP algorithm.

The final comments by Dr. Ilich are bit unclear: "There is a high likelihood that the iterative setting of the constraints by the user currently employed within WEAP21 could introduce undesirable bias in the final solution, especially if the reservoir outflow constraints were to be incorporated into the model." It is not clear what bias Dr. Ilich is writing about, and as we noted above, reservoir outflow can be constrained based on downstream demands and reservoir operating rules.