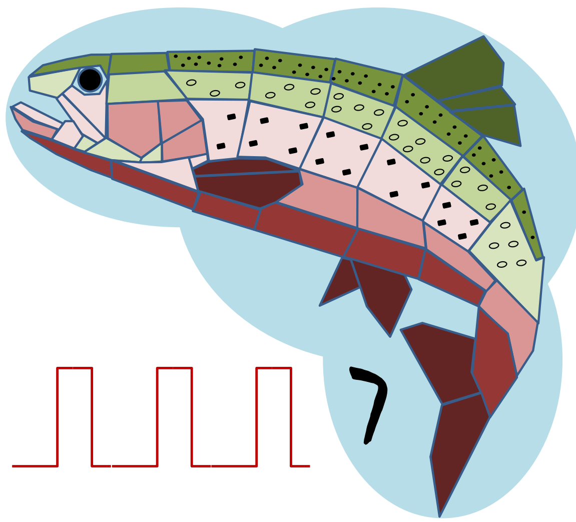
InSTREAM 7-SD
Model and Software Description



Version 7.3-SD

Prepared by:

Steven F. Railsback
Lang Railsback & Associates
Arcata, CA USA

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Revision History

Date	Changes	Version information
5 Feb 2021	First version of inSTREAM 7-SD	Version 7.0.2_SD (also referred to as F3, for 3rd fork)
6 May, 2021	Updated to correspond with inSTREAM 7.2: logistic relation between length and habitat selection radius; new value for trout-capture-R1; removal of high velocity mortality.	Version 7.2-SD
24 March 2022	Assumption added that flow changes do not trigger time steps if close to light-triggered step; Sect. II.B.	Version 7.3-SD of 2022-03-24

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I. Introduction

A. Report purpose

This brief report documents version 7.0.2-SD of the inSTREAM 7 stream trout model ("SD" referring to the sub-daily flow fluctuations it addresses). Because the standard version (currently 7.1) of inSTREAM 7 is thoroughly documented by Railsback et al. (in prep.), this report documents the differences between the two versions. These differences include an expanded purpose of the model (Sect. I.B), modifications of the model's formulation (its assumptions and methods; Sect. II), and a change to how input is prepared (Sect. III).

To aid users in understanding results of inSTREAM 7-SD, Sect. IV lists some of the complex and sometimes unexpected effects of fluctuating flows that the model can produce. Some of those effects are illustrated by the simple example application in Sect. V.

Following the convention used in the inSTREAM 7 documentation, whenever a specific part of inSTREAM 7-SD is discussed here a footnote indicates where in the model's software that part of the model is programmed.

B. Purpose of inSTREAM 7-SD

The general purpose of inSTREAM 7, and previous versions of inSTREAM, is to provide mechanistic understanding and prediction of how river management, especially instream flow and temperature regimes, affects trout populations. These models were intended especially for application where hydroelectric and other water projects control flows. InSTREAM 7-SD provides the ability to model how trout populations are affected by within-day changes in stream flow, such as those from load-following ("peaking") hydropower operations.

The standard version of inSTREAM 7 simulates four time steps per day to represent the daily light cycle. The time steps represent four light "phases": dawn, day, dusk, and night. The time at which each of these steps starts varies with date and latitude. InSTREAM 7 can use more than one flow and temperature input per day, but it does not represent how trout are affected by flow changes that occur within one of the four daily time steps; if, for example, hourly flow input is used with inSTREAM 7, it still simulates only four time steps per day and uses only the flow input with times closest to the middle of each time step.

The purpose of inSTREAM 7-SD is to model how individual trout respond to substantial changes in flow at any time during a day, and the resulting effects on population measures such as abundance and persistence. To do so, it modifies the standard version of inSTREAM 7 by starting new time steps at any time a substantial change in flow occurs.

InSTREAM 7-SD is intended for applications such as evaluating alternative load-following scenarios at hydroelectric plants. For example, it can be used to predict the relative effects of one vs. several flow peaks per day, or alternative restrictions on the rate and magnitude of flow changes. The model could also be applied to management issues unrelated to hydropower, such as the effects of short-term reservoir releases for whitewater recreation.

Several mechanisms through which sub-daily flow fluctuations have been hypothesized to affect fish populations were intentionally not included in this version of inSTREAM. One such mechanism is fixed home ranges: if trout are unable or hesitant to change feeding sites in response to flow changes, they could often find themselves in habitat that is highly inefficient for feeding during some flows. A second is that rapid flow changes could significantly interrupt feeding while individuals change habitat or activity and, where competition is high, re-establish feeding hierarchies. A third hypothesized mechanism that movement in response to flow changes is by itself a significant additional energy cost. (Some of these mechanisms were investigated using earlier versions of inSTREAM; Hayse et al. 2006.) These mechanisms were not included due to the lack of empirical evidence that they are important. However, the model could be a useful framework, with field or laboratory studies, for investigating such hypotheses.

C. Acknowledgements

Funding for development of inSTREAM 7-SD and this documentation was provided by Vattenfall, a Swedish hydroelectric generation company. The project was conceived and organized by professors John Piccolo and Ole Calles, Department of Environmental and Life Sciences, River Ecology & Management Research Group (RivEM), Karlstad University, Sweden.

II. Model Modifications

InSTREAM operates by executing its schedule of events (habitat updates, trout habitat and activity selection, trout survival and growth, spawning, and redd development and survival) once per time step. Adding the capability to simulate within-day flow fluctuations is therefore mainly a matter of adding time steps to be executed when the flow changes. Doing so requires defining exactly what change in flow triggers a model time step. The other modifications address minor changes needed to accommodate more than four time steps per day, and changes to the format of the time-series input that now can include within-day flow changes.

A. Flow changes that trigger time steps

InSTREAM 7-SD determines when a flow change significant enough to update the model occurs, from the time series of flow (and temperature and turbidity) input. Therefore, we must specify exactly what defines a such a flow change. InSTREAM 7-SD adopts the method used successfully in previous sub-daily versions of inSTREAM (Hayse et al. 2006): time steps are triggered when the percentage change in flow since the last time step exceeds a user-defined threshold. That threshold is defined by a new reach-scale parameter ***reach-flow-change-for-time-step*** (a positive real number).

The time-series input for inSTREAM 7-SD (explained more fully below) can specify the flow at any time within a day, including multiple times per day. The model examines this input and schedules flow-triggered time steps at the time of any input record with a flow that differs from the current simulation flow by a fraction that equals or exceeds ***reach-flow-change-for-time-step***. This reach parameter has typical values of 0.1 or 0.2 (i.e., flow changes of 10% or 20% trigger new time steps). In mathematical terms, the criterion for scheduling a model time step at time *t* is that this inequality is true:

$$\text{abs}\left(\frac{Q_t - Q_s}{Q_s}\right) \geq \boldsymbol{reach\_flow\_change\_for\_step}$$

where Q_t is the flow in the input record for time t and Q_s is the flow currently being simulated, and abs() is the absolute value function. The value of Q_t is the flow in the reach's time-series input file associated with a date and time closest to (either before or after) t.

When multiple reaches are simulated, a new time step is triggered whenever a flow change in any reach meets this criterion. The value of ***reach-flow-change-for-time-step*** for a reach can be used to control the reach's ability to trigger time steps: a reach given a very high value for this parameter, for example, will rarely or never add time steps to simulations.

B. Step timing

This section describes how inSTREAM was modified to add the time steps that represent within-day flow fluctuations. InSTREAM 7's step-timing submodel is executed at the start of each simulated day to create a list of times at which the day's time steps end[1]. InSTREAM 7-SD augments the four light phase time steps by adding time steps at the times of any within-day flow changes that exceed ***reach-flow-change-for-time-step***.

The step-timing submodel first builds its list of four time steps triggered by the daily light cycle, without change from the previous model version. Then, the following steps are conducted separately for each reach in the simulation because each reach can have its own flow input.

The submodel next identifies all the time-series input records for the current simulation date. Here, "date" means the period from time 00:00 to 23:59 of the simulated day. If there is only one such record, the submodel adds no addition time steps because the input represents a daily flow with no within-day variation.

If the time-series input does include more than one record for the current day, then the submodel examines each and determines which of them, if any, meet the above criterion for triggering a time step, where Q_s is the flow corresponding (in the time-series input file) to the time at which the previous time step started, whether that previous time step was triggered by light or flow. For each input record that does meet the criterion, a new time step is scheduled to start at the input record's time. However, such flow-triggered time steps are *not* added if they are within 0.25 hour (15 minutes; before or after) of a time step caused by changes in light phase.

This approach is illustrated using three general kinds of time-series input. (All three kinds of input can be used in the same input file.) First, input can represent daily flows, as in the standard version of inSTREAM 7. The input illustrated in Figure 1would produce four time steps per day, at times determined by light. The "night" time step (which extends from the end of dusk the previous day to the start of dawn on the current day) would use the daily input (flow, temperature, turbidity) from the previous day; the three remaining time steps would use the input associated with the current day. (New time steps would *not* be triggered at 12:00 of any day, no matter how much the flow changes from the previous day, because inSTREAM 7-SD does not let flow changes trigger new time steps when there is only one flow input per day.)

[1] The step timing submodel is programmed in the procedure `update-time-and-habitat`.

Date and time	temperature	flow	turbidity
10/1/2009 12:00	13.1	6.37	2
10/2/2009 12:00	12.5	6.00	2
10/3/2009 12:00	12.1	6.32	2
10/4/2009 12:00	11.4	8.23	2
10/5/2009 12:00	11.1	12.03	2
10/6/2009 12:00	11.1	8.52	3
10/7/2009 12:00	11.6	6.83	2
10/8/2009 12:00	11.0	6.23	2
10/9/2009 12:00	10.4	6.09	2
10/10/2009 12:00	10.5	6.03	2

Figure 1. Example daily time-series input.

The second kind of time-series input provides values at regular sub-daily time intervals such as hourly or 15-minute data. With this kind of input, there are still four time steps per day that end at the end of each light phase, but also time steps that start at the time of any input that results in a change in flow exceeding ***reach-flow-change-for-time-step***. Using a value of 0.2 for ***reach-flow-change-for-time-step***, the example hourly input in Figure 2 produces time steps starting at:

- 5:42 (end of night), with flow set to 5.97 because the 6:00 input is closest in time to 5:42;
- 6:44 (end of dawn), with flow changing to the 7:00 value of 5.87;
- 13:00 (because the flow of 7.09 at 13:00 is >20% greater than the flow of 5.87 that started at 6:44);
- 15:00 (because of the flow increase then);
- 17:15 (end of day);
- 18:17 (end of dusk); and
- 19:00 (due to the flow decrease then).

Date and time	flow	temperature	turbidity
10/1/2002 0:00	5.9	12.55	2
10/1/2002 1:00	5.91	12.5375	2
10/1/2002 2:00	6	12.525	2
10/1/2002 3:00	5.87	12.5125	2
10/1/2002 4:00	5.91	12.5	2
10/1/2002 5:00	5.93	12.4875	2
10/1/2002 6:00	5.97	12.475	2
10/1/2002 7:00	5.87	12.4625	2
10/1/2002 8:00	5.97	12.45	2
10/1/2002 9:00	5.96	12.4375	2
10/1/2002 10:00	5.94	12.425	2
10/1/2002 11:00	5.89	12.4125	2
10/1/2002 12:00	6.8	12.4	2
10/1/2002 13:00	7.09	12.40833	2
10/1/2002 14:00	8.4	12.41667	2
10/1/2002 15:00	10	12.425	2
10/1/2002 16:00	10.5	12.43333	2
10/1/2002 17:00	10.3	12.44167	2
10/1/2002 18:00	10.2	12.45	2
10/1/2002 19:00	5.9	12.45833	2
10/1/2002 20:00	5.87	12.46667	2
10/1/2002 21:00	6	12.475	2
10/1/2002 22:00	5.91	12.48333	2
10/1/2002 23:00	5.94	12.49167	2

Figure 2. Example hourly time-series input.

The third kind of input can represent daily values, but with additional rows inserted to represent individual flow events. Figure 3 shows a period of daily flow input, but with two load-following flow peaks on 3 October. In addition to the four time steps per day for the light cycle, we would expect new time steps to start at 10:15 with flow of 14.0, at 12:20 with flow returning to 6.0, at 16:10 with flow of 15.0, and at 19:30 to return the flow to 6.0.

Date and time	temperature	flow	turbidity
10/1/2009 12:00	13.1	6.37	2
10/2/2009 12:00	12.5	6.00	2
10/3/2009 10:15	12.1	14.00	2
10/3/2009 12:20	12.1	6.00	2
10/3/2009 16:10	12.1	15.00	2
10/3/2009 19:30	12.1	6.00	2
10/4/2009 12:00	11.4	6.23	2

Figure 3. Example daily input with a sub-daily flow peak inserted.

However, these methods for determining when time steps start often produce fewer time steps than expected because time steps triggered by the daily light cycle use input from the time closest to their start, which could include a flow that would otherwise trigger a time step by itself. The example input in Figure 3 includes large increases in flow at 10:15 and 16:10 and large decreases in flow at 12:20 and 19:30; we expect all these changes in flow to trigger time steps such that flow goes to 15.0 m^3/s at 16:10 and returns to 6.0 at 19:30. However, that is not what happens. When dawn starts at 5:44, inSTREAM 7-SD looks for the time-series input nearest that time, which is the record for 10:15 with flow of 14.0 m^3/s. Therefore, no time step is triggered at 10:15 because flow is already 14.0. The flow changes at 12:20 and 16:10 do trigger new time steps. But when dusk starts at 17:12, it is assigned the flow of 6.0 from the 19:30 record: flow returns to 6.0 at 17:12 instead of 19:30 as expected.

To keep such artifacts of step timing from having strong effects, it is best to represent peaking either (a) with short regular input intervals, such as hourly or 15-minute values, or (b) when inserting input to represent specific peaks as in Figure 3, by including records for times just before and just after major changes in flow, especially when those changes occur near dawn and dusk (as in Figure 4).

Date and time	temperature	flow	turbidity
10/1/2009 12:00	13.1	6.37	2
10/2/2009 12:00	12.5	6.00	2
10/3/2009 10:10	12.1	6.00	2
10/3/2009 10:15	12.1	14.00	2
10/3/2009 12:20	12.1	6.00	2
10/3/2009 16:05	12.1	6.00	2
10/3/2009 16:10	12.1	15.00	2
10/3/2009 19:25	12.1	15.00	2
10/3/2009 19:30	12.1	6.00	2
10/4/2009 12:00	11.4	6.23	2

Figure 4. Example input of Figure 3 with records added to ensure that time steps triggered by light are not unintentionally given on-peak flows.

C. Input and output times

InSTREAM 7-SD assigns time-series inputs (flow, temperature, and turbidity values) for each time step by finding the time in the input file closest to the start of the time step.[2] This change from the standard version of inSTREAM 7, which uses the values closest to the middle of the time step, makes it easier to specify exactly when a within-day flow change occurs. However, it has two consequences that users should be aware of.

First, the time-series input file should be assembled so that the values associated with a time represent conditions that start at that time and continue until the next input record's time. For example, when hourly mean flows and temperatures are used the value for each hour should represent the mean of observations from that hour until the next (hourly input for 08:00 represents mean conditions between 08:00 and 09:00, input for 09:00 represents conditions between 09:00 and 10:00, etc.).

Second, model outputs that include flow, temperature, or turbidity must be interpreted carefully because inSTREAM labels output with the time that a time step *ends*. For example, an output

[2] Assigning input to time steps is programmed in the procedure `update-habitat`.

record labeled with the time 6:44 and light phase “dawn” represents the dawn period that ends at 6:44, but its flow and temperature are from the *start* of that period at 5:42. For this reason, flow, temperature, and turbidity values in model output may appear out of synch with the input file.

D. Other affected submodels

Two of InSTREAM 7’s submodels are scheduled to be updated once per day instead of every time step: spawning and emergence of new trout from redds. In the standard version of inSTREAM 7 these two submodels are executed on any time step with light phase “day”. To address the possibility of multiple day time steps, inSTREAM 7-SD executes these submodels only if the current time step is the first “day” step of the day (i.e., if the current light phase is “day” and the previous light phase was not “day”).[3]

III. Software Use

Use of the InSTREAM 7-SD software differs in only one small way from the files and procedures described in the inSTREAM 7 software documentation (Sects. 10-18 of Railsback et al. in prep.): the addition of the reach parameter ***reach-flow-change-for-time-step***. This parameter is in the reach parameter segment of the parameter file.

The following reminders about software are particularly relevant to inSTREAM 7-SD.

First, the trout population output files report the flow, temperature, and turbidity of each simulated reach, at each time the output is updated. Setting the output controls to produce output every time step (setting the model parameters ***file-output-frequency*** to `1` and ***file-output-units*** to `minutes`) makes the population output files useful for seeing when time steps occur and what the flow is during each. However, remember that the output time represents when the time step *ends*, and the flow (and temperature and turbidity) represents flow at the *start* of the time step. Therefore, the flow reported in an output file will not be the flow in the input file for the same time.

Second, analyses of within-day flow fluctuations often are concerned with how the fluctuations affect individual fish, such as how far they move among feeding and hiding locations each day. Such information can be obtained from inSTREAM’s optional individual fish output file, which reports the status, including location, of individual trout.

Finally, inSTREAM 7-SD uses inSTREAM’s default date and time format of `M/d/yyyy H:mm` (e.g., so the time-series input file must contain values such as `10/23/2001 14:00`, for 23 October). However, using other date and time formats (such as the `d/M/yyyy` convention used in Europe) for input or output requires only very simple changes to the model’s code. (These date and time format codes are case-sensitive, and in fact produce different and erroneous results if, for example, `YYYY` is used instead of `yyyy`.)

[3] The scheduling of spawning and emergence are programmed in the procedure `go`.

IV. Potential Effects of Sub-daily Flow Changes in InSTREAM 7-SD

Within-day flow fluctuations such as those from hydropower peaking can have a variety of simulated effects; interpreting model results and applying them to management decisions requires understanding which effects were important and, often, how they interact. This section supports such analyses by identifying some of the model mechanisms through which sub-daily flow changes can affect simulated populations.

A. Habitat selection, survival, and growth

Perhaps the first effect of flow fluctuations that many biologists think of is on the spatial and temporal availability of good habitat. Flow changes can affect how much good foraging (or hiding) habitat is available for how long per day, for different sizes of fish. For example, peaking could cause flow to alternate between levels at which much of the habitat is too slow and then too high for efficient drift feeding by adult trout, while a steady flow with the same daily mean would produce much more feeding habitat. InSTREAM 7-SD is designed to capture such effects.

Peaking flows typically increase the number of time steps per day, which by itself can have effects that are unexpected and difficult to quantify. InSTREAM 7-SD lets model trout adapt their location (habitat cell) and activity (feeding or hiding) every time step, so simulating more time steps per day provides increased ability to fine-tune these behaviors. Because these behaviors usually act to let model trout minimize predation risks while obtaining sufficient food to maintain their condition, more time steps can result in higher survival and, perhaps, lower growth (Railsback et al. 2020).

B. Spawning readiness

Model trout use several criteria to decide when and if they spawn. Two of these criteria can be affected by flow fluctuations: a limit on the maximum flow at any time over the previous 24 hours, specified by the parameter ***reach-max-spawn-flow***; and a limit on the degree to which flows vary within the previous 48 hours, specified by the parameter ***trout-spawn-max-flow-change***. Peaking flows can keep either of these criteria from being met and, therefore, prevent model trout from spawning. It is not clear how realistic these effects are.

C. Redd scour and dewatering

InSTREAM models scouring mortality of redds as a function of peak flow events. During cycles like hydropower peaking, the model treats each daily flow peak as a potental scouring event. Even if the peak flow is well below levels causing widespread scour, each daily cycle produces a small chance of each redd being scoured and, over weeks or months of redd incubation, widespread redd scour.

Flow fluctuations could also contribute to dewatering mortality of redds, which occurs when the cell containing a redd has zero water depth. Under some conditions, model trout might spawn in cells that are later dewatered by flow fluctuations.

D. Fry mortality

Very small model trout, such as newly emergent fry, can select their habitat over only small distances. Consequently, they are especially vulnerable to two kinds of mortality driven by flow variation. Stranding mortality occurs when flow decreases such that a fish’s cell becomes dry and the fish cannot reach a cell that is still submerged. High-velocity mortality becomes likely when a flow increase prevents a fish from reaching a cell where velocity is below its sustainable swimming speed. Under some conditions, sub-daily flow fluctuations could produce high mortality among small trout.

V. Example Application

This example application illustrates the use of inSTREAM 7-SD to assess effects of hydropower peaking operations. The example does not represent any real stream or power operation and is meant only as an illustration.

A. Sites

Physical habitat input (channel shape, hydraulics, cell habitat variables) represents two adjacent sites on Clear Creek, California, the “Restored” and “Degraded” sites of the salmon model application of Railsback et al. (2013). The “Degraded” site is a relatively straight, U-shaped channel with little shallow habitat, while the “Restored” site, following a habitat restoration project, includes riffle-pool sequences with extensive bars that provide both shallow and deep habitat over a wide range of flows (Figure 5).

Flows at these sites are largely controlled by releases from an upstream reservoir, although tributary inflow often exceeds reservoir releases during the winter wet season. Flows are typically relatively high during the wet season of November through May, and low and steady during the dry summer season. Actual reservoir releases to Clear Creek are not used for load-following or peaking.

The simulations represented fictional populations of rainbow trout. (The sites likely contain small numbers of this species but are not managed for it.)

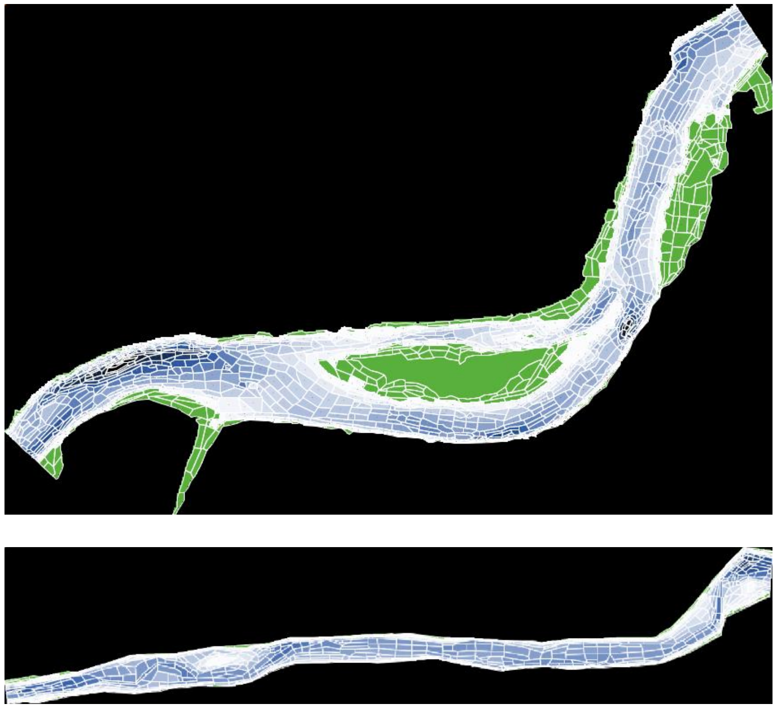

Figure 5. The “Restored” (top) and “Degraded” (bottom) sites as represented in inSTREAM 7-SD, with cells shaded by depth.

B. Flow scenarios

The example application used a range of peaking flow scenarios that were synthesized from actual flow records and assumptions about hypothetical peaking operations. The flow scenarios assumed that during the spawning and dry seasons—May through October—flows are unchanged from observed daily mean flows. For those months, the input to inSTREAM includes one flow per day, the observed daily mean, assigned to hour 12:00. During the November-April wet season, peaking operations were simulated every day.

Because peaking ends before the start of spawning, these scenarios avoid the effects on spawning and redds noted in Sect. IV. (Peaking effects on spawning and redds would otherwise be strong at these sites.) In this experiment, peaking affects populations only by changing trout habitat availability and, therefore, individual growth and survival. Because age-0 trout emerge from redds in mid-summer and peaking does not start until November, peaking in this experiment is unlikely to cause substantial stranding or high-velocity mortality of age-0 trout.

For November through April, the time-series input file included hourly values, which were generated with these assumptions:

- “On-peak” (high flow) operations start at 14:00 each day.
- The on-peak flows last for either two hours or four hours; therefore, “off-peak” (low) flows start at either 16:00 or 18:00 each day.
- The daily mean flow is always 8.9 m^3/s, equal to the observed long-term mean wet-season flow. Therefore, the total daily flow volume did not differ among scenarios.

- The on- and off-peak flows were specified by a "peaking ratio", the ratio of on-peak to off-peak flow. Because the daily mean flow was constant, higher peaking ratios produced both higher on-peak and lower off-peak flows.
- The observed daily mean temperature and turbidity were assigned to all hours. (Within-day variation in these variables could be represented in the input but was not in this example.) Turbidity is generally negligible and temperatures generally benign at these sites.

Ten peaking scenarios were simulated, with all combinations of (a) 2 and 4 hours on-peak per day, and (b) peaking ratios of 1.0 (no peaking), 2.0, 4.0, 6.0, and 8.0. Figure 6 illustrates the scenario with peaking ratio of 4.0 and two on-peak hours, over the last week of the dry season and first week of the winter peaking season. Figure 7 illustrates hourly flows during the peaking season for all scenarios.

The simulations extended for 10 years: October 2001 through September 2011. Five replicates (differing only in random numbers) of each scenario were executed.

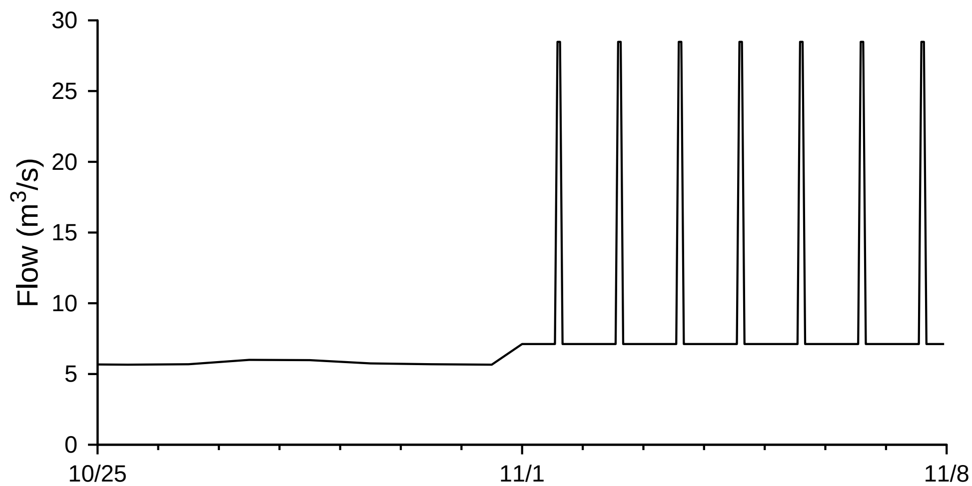

Figure 6. InSTREAM 7-SD input for an example peaking scenario. Through 31 October, the input consists of observed daily mean flows. Starting 1 November, hourly input specifies the on- and off-peak flows. With two peaking hours and a peaking ratio of 4.0, the off- and on-peak flows are 7.12 and 28.48 m^3/s.

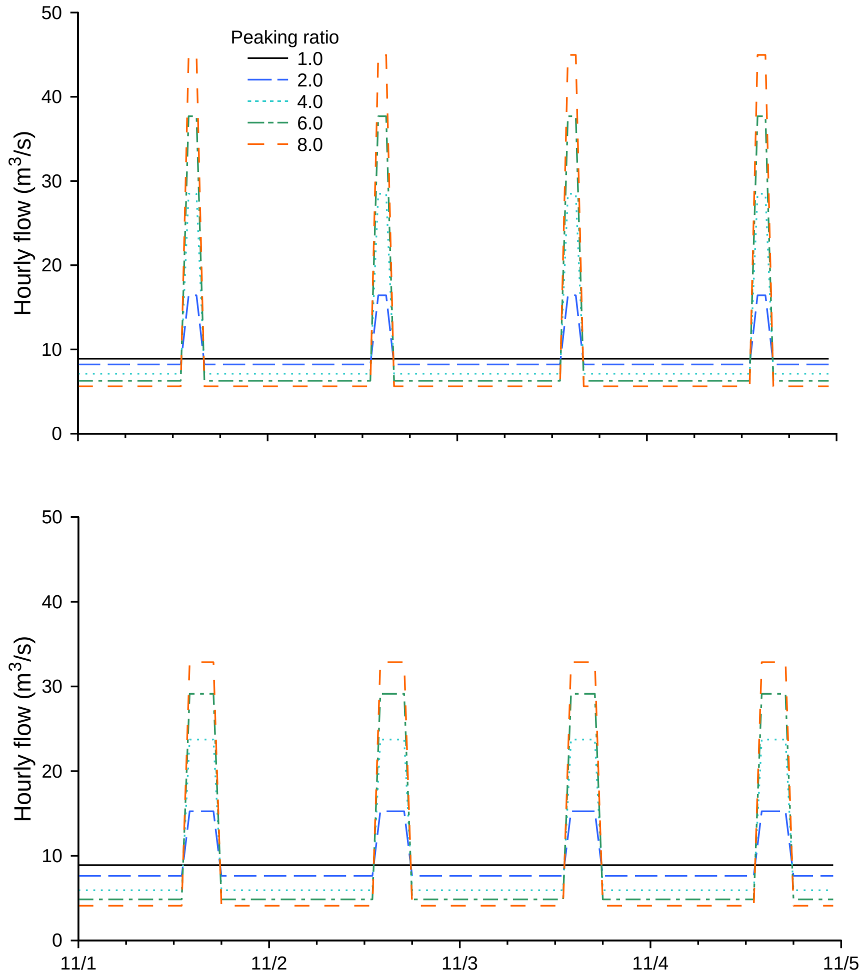

Figure 7. The peaking scenarios: hourly flow input for four days, for the scenarios with two (top) and four (bottom) on-peak hours per day. More hours of peaking per day reduces both on- and off-peak flows.

C. Results

The example analysis simply compared mean adult trout abundance among the flow scenarios. This measure was the mean abundance of age 1 and older simulated trout, on 30 September of the last 8 of the 10 simulated years. The five replicates were evaluated separately to indicate the variation due only to model stochasticity.

The simulation results differ between the two sites. At the Restored site, increasing peaking produced a slight increase in trout abundance with two-hour peaks and no clear effect with four-hour peaks (Figure 8). At the Degraded site (Figure 9) two-hour peaks resulted in a slight decreasing trend in abundance with peaking ratio; four-hour peaks produce more complex results, with sharply lower trout abundance only at a peaking ratio of 6. For all combinations of site and peaking hours, there was not a sharp difference between peaking ratios of 1.0 (no peaking) and 2.0, which indicates that there was little effect of the increased number of time steps per day. (Days with peaking had six time steps, instead of four per day without peaking.)

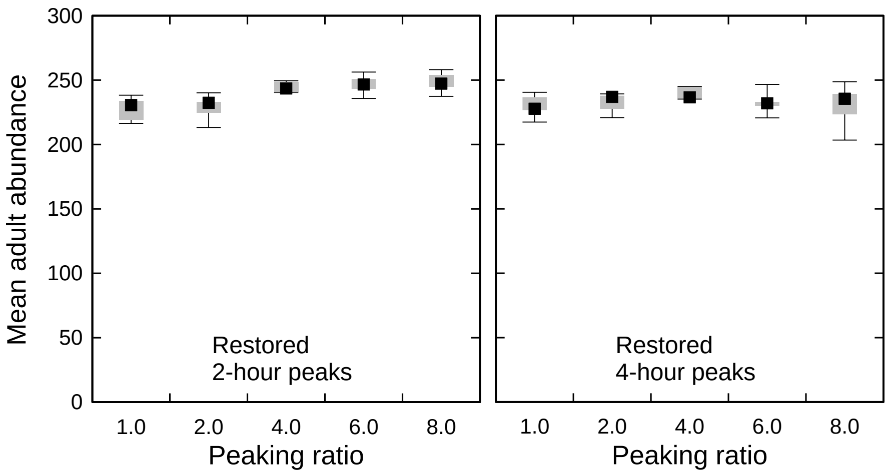

Figure 8. Initial results for the Restored site. For each peaking scenario, the symbol "whiskers", the grey box, and the black square indicate results for the five replicate simulations.

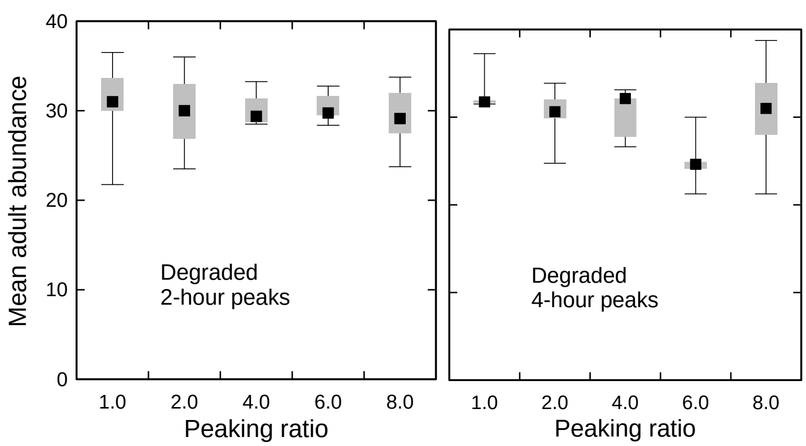

Figure 9. Initial results for the Degraded site, including a scenario with minimal peaking (peaking ratio of 1.05 in the right panel). Format as in Figure 8.

The most likely explanation of these differences between sites is that the changes in flow caused by peaking have different effects on trout abundance. As Figure 7 illustrates, increasing peaking ratios produce both high peaks and lower flows during the many off-peak hours. A second simulation experiment investigated how these changes affect trout abundance, in the absence of peaking. This experiment simply kept flow constant during the November-April peaking season, at levels ranging from 5 to 45 m^3/s, the range of flows occurring in the peaking scenarios.

The results of this steady flow experiment (Figure 10) do much to explain the peaking results. At the Restored site, trout abundances decreases steadily with increasing wet-season flow. The negative effects of two or four hours of higher flow are more than offset by the benefits of many hours at lower flow. The situation is opposite at the Degraded site: higher flow produces higher abundance, so the more hours of lower flow that result from peaking produce lower abundance. The negative effects of lower flow are not entirely offset by the benefits of several hours per day of higher flow. The anomolously low abundance for the four-hour peaking ratio of 6.0 at the Degraded site appears to result from stochastic recruitment failures in several replicates.

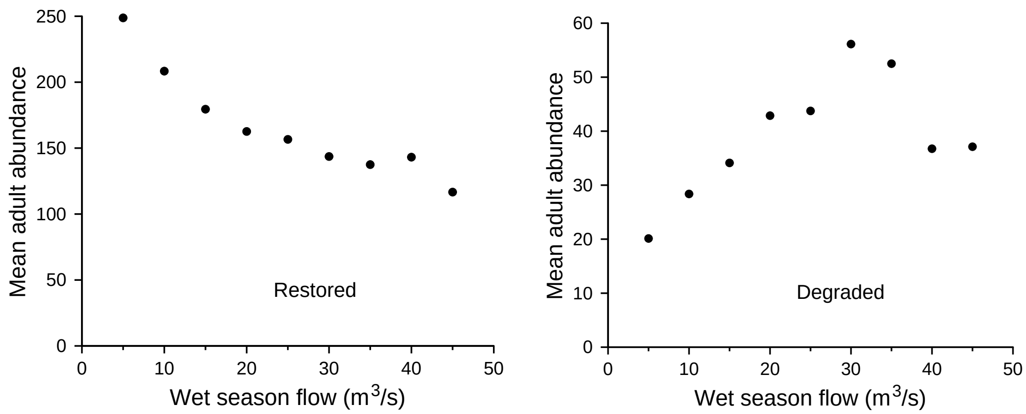

Figure 10. Simulation results with steady wet-season flows: the X axis is the constant November-April flow.

D. Conclusions from the example application

This simple example application illustrates the use of inSTREAM 7-SD to address site-specific effects of hydropower peaking and to develop general understanding of specific mechanisms by which peaking could affect downstream fish populations. Because the experiment avoided effects of peaking on spawning and newly emerged juveniles, the main effect of peaking it represented was changes in habitat availability during the daily flow cycle. When we assume that higher peak flow results in lower off-peak flow, as we did here, the strongest effect of peaking can be the many hours per day of reduced off-peak flow. This mechanism is not widely addressed in the fluctuating flow literature.

VI. Literature Cited

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