A Proposed "Percent of Flow" Approach for Water Storage Projects in Oregon

Senate Bill 839 Science Subgroup Report
February 1, 2014

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Executive Summary

Senate Bill 839 calls for the protection of Seasonally Varying Flows (SVF) to maintain the biological, ecological, and physical functions of the watershed during periods outside of the irrigation season when public funds from the Water Supply Development Account are used for certain water storage projects. In this document, the science subgroup reviews studies and methods for the protection of seasonally varying flows and makes recommendations to the Seasonally Varying Flows Task Force.

The science subgroup conducted a literature review and consulted with other experts, finding a broad consensus that protection of a variable flow regime is critical to ecosystem function. Many states and Canadian provinces have adopted a percent of flow (POF) method to allow some allocation of water, while protecting natural flow variability. Following their lead, the science subgroup recommends a percent of flow approach for those water storage projects that receive funding from Oregon's Water Supply Development Account. Using this approach, funding recipients could potentially store up to 15 percent of daily flow, minus prior allocations, without extensive study or review. The amount of water remaining instream would follow the shape of, but be less than, the natural hydrograph. Examples are given for several different basins.

For publicly funded projects needing more water—or different timing—than the POF allocation, applicants may develop an in-depth assessment, in consultation with the Water Resources Department and a technical review committee. The in-depth assessment will identify elements to be addressed within the major categories of hydrology, biology, geomorphology, connectivity, and water quality. The funding applicant will develop hypotheses relating proposed changes in the flow regime to key elements in the above categories, and will then conduct quantitative analyses based on the hypotheses. A report on these studies will describe the results, including the magnitude, frequency and duration of seasonally varying flows to be protected. The State will review the report and respond to the findings.

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Introduction. Framing the Discussion

The Department shall establish seasonally varying flows using a methodology established by Water Resources Commission rules. (Senate Bill 839, 2013)

In 1992, the Water Resources Commission adopted the State's water storage policy, identifying water storage options as an integral part of Oregon's strategy to enhance public and private benefits from use of the State's water resources. The policy acknowledges that both structural and nonstructural methods should be used in Oregon to store water, with preferences for storage that optimizes instream and out-of-stream public benefits and beneficial uses. In 1993, the Oregon Legislature codified the State's policy on water storage facilities, declaring it a high priority to develop environmentally acceptable and financially feasible multipurpose storage projects, and to enhance watershed storage capacity through natural processes using non-structural means.

The need for stored water among municipal, agricultural and other water users is documented and growing. One factor that will continue to increase the need for storage in future years is climate change. In recognition of these present and future challenges, Oregon's Integrated Water Resources Strategy, adopted in 2012, calls for, among other things, improved access to built storage (Recommended Action #10B).

Purpose, Outcomes, and Timelines of This Process

In 2013 the Oregon Legislature approved Senate Bill 839, establishing a Water Supply Development Account (Account) to provide loans and grants for water supply development projects that have economic, environmental and social-cultural benefits. Both above- and below-ground water storage projects are eligible for funding, provided that seasonally varying flows are protected.

Seasonally Varying Flows (SVFs) – as defined in Senate Bill 839 – means the duration, timing, frequency and volume of flows, identified for the purpose of determining conditions for a new or expanded storage project, that must remain instream outside of the official irrigation season in order to protect and maintain the biological, ecological and physical functions of the watershed downstream of the point of diversion, with due regard given to the need for balancing these functions against the need to store water for multiple purposes.

The design of reasonable and understandable requirements for storage projects will help ensure that both instream and out-of-stream needs are met, while also considering the economic feasibility of proposed storage projects.

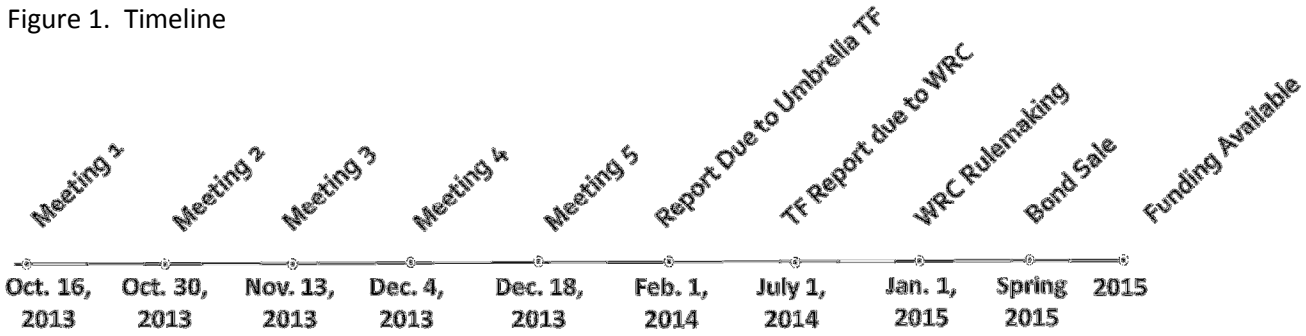
To assist in developing these requirements, the bill calls for the creation of a Seasonally Varying Flows Task Force that shall, by consensus, develop a recommended methodology for determining seasonally varying flow requirements for water storage projects funded by the Water Supply Development Account. In developing the methodology, the Task Force, as directed by Senate Bill 839, must consider the financial feasibility of new water storage projects and that such projects might not be appropriate or feasible in many locations.

The bill also required the creation of a science subgroup to consider the flows needed during periods outside of the irrigation season to support the biological, ecological, and physical functions in watersheds. The subgroup

must provide a report to the Task Force by February 1, 2014. The report must describe flows necessary to support instream needs including, but not limited to: (a) stream channel development and maintenance; (b) connectivity to floodplains; (c) sediment transport and deposition; (d) migration triggers for upstream movement of adult fish and downstream movement of fry and juvenile fish; (e) fish spawning and incubation; (f) juvenile fish rearing; and (g) adult fish passage. These terms are defined in Appendix C Definitions.

Senate Bill 839 further directed the following sequence of events: (1) the Task Force shall submit a report to the Governor, an interim committee of the Legislative Assembly, and to the Water Resources Commission no later than July 1, 2014; (2) the Water Resources Commission shall adopt rules to establish a methodology for use in determining the seasonally varying flows, giving consideration to adoption of the methodology described in the Task Force report; and (3) the Commission shall complete adoption of the rules in time for them to take effect on January 1, 2015.

Figure 1. Timeline



The science subgroup has a narrow mandate: to determine seasonally varying flow requirements that will apply to water storage projects that may seek State funding from the Water Supply Development Account, and that:

- require a new water storage or aquifer recharge permit or limited license;
- store water outside of the official irrigation season[1]; and
- impound surface water on a perennial stream; divert water from a stream that supports state or federally listed sensitive, threatened or endangered fish species; or divert more than 500 acre-feet of surface water annually.

[1] Irrigation Seasons are defined in Oregon's Basin Plans, adjudication decrees, and administrative rules, identifying the time period when water may be appropriated and applied to agricultural lands. For example, the irrigation season in some areas of the Willamette Valley is April 1 through September 30, while other areas are limited to May 1 through September 30. However, some basin plans define the irrigation season as any time water can be put to beneficial use, while other plans do not define the irrigation season at all. The "storage season" is generally considered to be any time outside of the irrigation season.

Chapter 1. When Water Is Available for Storage: Diverting a Percent of Flow

All streams and rivers should have instream flows that maintain or restore, to the greatest extent possible, ecological functions and processes similar to those exhibited in their natural or unaltered state. (Instream Flow Council 2008)

A strong consensus now exists within the scientific community around the need to maintain some semblance of natural flow variability to sustain the ecological health of river ecosystems and the array of goods and services they provide to society. (Richter 2009)

The seasonality and variability in streamflow provides spawning and rearing habitat, cues fish behavior, and drives physical habitat functions such as stream channel development, sediment transport and river-floodplain connectivity. While scientists know that significant diversion of streamflow—even during annual periods of high flow—will eventually affect ecological or geomorphological functions, it is difficult to identify the precise thresholds at which these impacts occur (Richter et al. 2011; Arthington et al. 2006).

Numerous authors (e.g. Acreman and Ferguson 2010; Arthington et al. 2006; King et al. 2008; Poff et al. 2010; Richter et al. 2011) note that in the midst of increased economic development, it is in society's best interest to protect natural freshwater systems that are being tapped for water supplies. However, they also observe that these calls for protection are often stymied by data collection and modeling protocols that require considerable time, expertise, and money to implement. Analyses can range from hundreds of thousands to millions of dollars, depending on the data set, modeling technique, complexity and size of the project. As noted by Richter et al. (2011), the end result is often a paralysis of decision-making, which results in a lack of necessary water development and/or a lack of protective flow regimes.

In recent years, some jurisdictions around the world have used a "percent of flow" (POF) approach to overcome that paralysis, and to advance both economic development and instream flow protection. The approach is practical and science-based, limiting water withdrawals to protect natural flow variability, particularly when site-specific data and analyses are limited or do not exist.

Why are other states and countries using the "percent of flow" approach?

It is now widely accepted that a naturally variable flow regime is critical to sustaining freshwater ecosystems (Poff et al. 1997; Bunn and Arthington 2002; others as cited above). The National Research Council (2005) advises using natural-flow characteristics as a reference for determining instream flow needs. This general scientific understanding of the importance of the natural flow regime provides a basis for establishing an approach that protects instream flows and allows for water development, without significant up-front investment or detailed studies. A growing number of states and countries are using withdrawal limits as a tool to protect instream flows. These withdrawal limits are defined as a "percent of flow" (POF), meaning that a certain percent of daily natural streamflow may be diverted for storage and use. An important facet of this approach is the maintenance of the shape of the natural hydrograph, allowing for all types of flows to pass through the system, albeit at a slightly lower volume, and thereby preserving the natural flow variability. This approach also means the hydrograph is never "flat-lined" by the removal of all flows above the base flow. The general approach is based on a recognition of the relationship between flow alteration and ecological or

functional response. It involves an effort to define an acceptable degree (limit) of flow alteration that still provides ecological protections.

A number of jurisdictions are using this approach, such as the states of Florida, Maine, and Virginia, as well as Canadian Provinces, and members of the European Union. These jurisdictions allow water users to divert a certain percent of daily flow. In most of these cases, allowable diversions hover between 10 and 20 percent of natural flows, and they include a base flow that is also protected during periods of low flows. They have selected these percentages based on their examination of flow-ecology relationships, risk thresholds, or empirical models. For example, Florida used data on habitat availability for fish and macroinvertebrate diversity, changes in the number of days of inundation of floodplain features, and inundation of instream woody habitats to determine percent of flow reductions on several streams (Kelly et al. 2010; 2010a; and 2010b). Maine has established percent of flow standards to protect aquatic life resources and water quality standards based on different condition goal classes for streams, and thus different levels of acceptable risk (Maine Department of Environmental Protection 2010). In the United Kingdom, maximum levels of abstraction were established as a percent of natural flow depending on river type and flow rate using information on flow needs for macrophytes, macroinvertebrates and fish.

The Province of Alberta based its percent of flow approach on evaluations of fish habitat reductions, reduction in recruitment for riparian vegetation, and changes to magnitude, frequency and duration of channel-forming flows (Locke and Paul 2011). Alberta officials were looking specifically to identify those flow alterations that would trigger a reduction in average habitat of less than 10 percent; a weekly loss in average habitat of less than 15 percent; and an instantaneous habitat loss of less than 25 percent. Factoring in uncertainty and a desire to protect the aquatic ecosystem, Alberta chose a 15 percent flow reduction to avoid triggering these losses.

Many of the entities named above limit withdrawals of water to certain months or seasons. For each identified time period, some jurisdictions also vary the percent of streamflow that may be withdrawn.

The Percent of Flow Approach Proposed for Oregon

The science subgroup sought an approach that allows an acceptable degree of flow alteration, while still demonstrating full protection of the aquatic ecosystem. The science subgroup used the studies noted above, as well as correspondence and discussion with colleagues in these jurisdictions to better understand the rationale, details, and results associated with a percent of flow approach.

As a result of its deliberations, the science subgroup recommends using a simple "percent of flow" approach, paired with current water availability methods, to shape the timing and quantity of diversions. For project proponents and stakeholders who wish to pursue other methods, the State would consider results from more in-depth analyses as described in Chapter 2.

A simple "percent of flow" approach involves three steps: (1) determining water availability; (2) establishing a base flow requirement; and (3) using a percent of flow approach to shape diversions.

(1) First determine whether and, if so, when water is available for storage, using the **"50 percent exceedance criteria,"** evaluated based on natural streamflow. The State does this already for any new storage requests. The subgroup recommends continued use of the "50 percent exceedance criteria" to determine whether water is available for storage, and, if so, during which months of the year.

    Natural streamflow refers to the flow in rivers and streams that would have occurred in the absence of any man-made effects on, or regulation of, flow. In systems with human impacts, natural flow is a calculated value based on the recorded flows of contributing rivers, physical factors concerning the

reach (for example, evaporation, channel losses), water diversions, consumptive use, and return flow. In pristine environments, natural flows equal recorded flows.

Recommendation #1. Use the Department's water availability model and 50 percent exceedance criteria to determine whether water is available for storage, and during which months.

To provide consistency with Oregon Administrative Rules 690-410-0070 (2)(c), the Water Resources Department generally evaluates water availability for storage using the median flow for any given month as a cap for allocation. All of the natural streamflow measurements for the month over a 30-year period are ranked in order of magnitude and the median daily flow for the month is identified (i.e., 50 percent of the measured flows lie above this value, and 50 percent lie below). This is a statistical calculation, based on historic data. Then already-existing water rights, including instream rights, are subtracted from that median flow to determine whether there is still water available for storage during that month. The Water Resources Department repeats this process, called the "50 percent exceedance criteria," to evaluate the availability of water for each month.

(2) Next, for streams without base flow protections in place**, establish a base flow** as a lower protective threshold, below which no withdrawals can occur during the storage season. Again, the state currently does this.

Recommendation #2. Establish base flows as a lower protective threshold, below which no withdrawals can occur.

Base flows are defined in order to be sufficient in volume for rearing and spawning for key species over long periods of time, as well as sufficient to overcome the potential for threats to aquatic life from harmful pollutants or stream heating. Base flows, as a component of seasonally varying flows, must be protected throughout this process. Before allocating water storage, the state will establish base flows within the prescribed reach.

(3) Finally, **use a "percent of flow" approach** to shape how much water may be diverted during the time period when water is available. The science subgroup recommends a "15 percent of natural flow" approach, meaning that up to 15 percent of the natural flow could be allocated for water storage projects. This refers cumulatively to all water storage projects operating on a stream, not each individual project. In practice, "natural flow" would be a measured daily flow adjusted for existing allocations[2]. A program that uses such an approach would leave 85 percent of the natural flow instream.

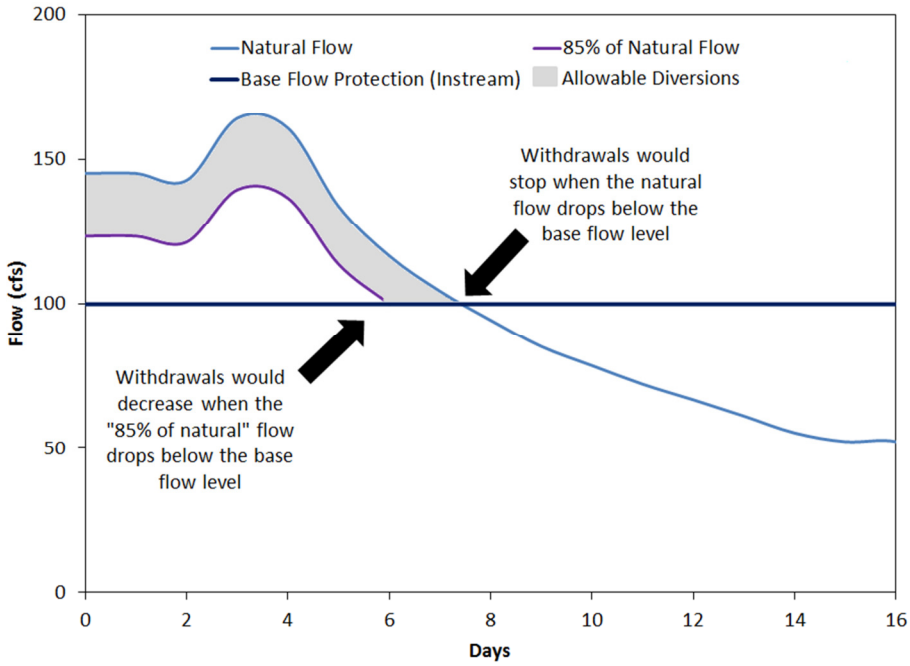
Recommendation #3. Use a "percent of flow" approach as a simple tool to shape the timing and quantity of diversions.

The following pages provide a number of examples describing how the "percent of flow" approach would work in Oregon.

[2] Assume that existing allocations can be reliably estimated on a daily basis.

In a simple example, the stream depicted in Figure 2 by its hydrograph (topmost, blue line), experiences high flows of about 170 cubic feet per second (cfs) and low flows of about 50 cfs during the time period of interest. In this example, there is no other water use activity on this stream, and the Water Resources Department has determined that water is available for storage during this time period. The Department of Fish and Wildlife has established base flow requirements of 100 cfs, in order to support biological activity.

Figure 2. Example of the Percent of Flow Approach in Oregon



A new water storage project, receiving funding from the Water Supply Development Account, could request permission to divert up to 15 percent of this flow for storage. The gray shaded area on this graph represents the allowable diversion. This scenario begins with the diversion of 15 percent of flows, or 85 percent of flows left instream. On day two, when flows are 140 cfs, the water storage project could divert up to 21 cfs, and on day three, when flows have increased to 170 cfs, the water storage project could divert up to 26 cfs.

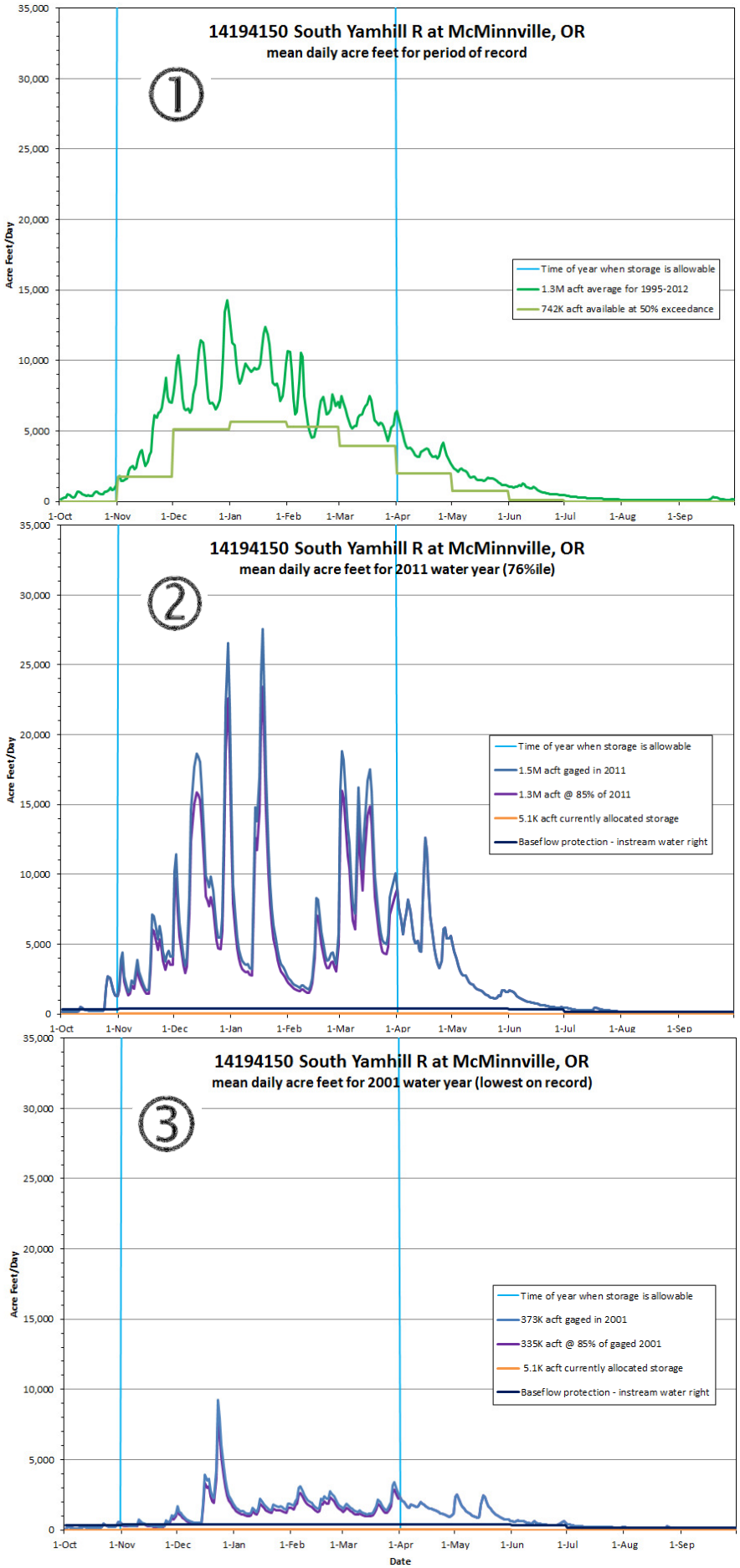
On day six, flows have dropped to approximately 118 cfs, still allowing diversion of 15 percent of the natural flow (18 cfs). On day seven, as natural flows continue to drop, the allowable diversions decrease to avoid violating the base flow (black line), and on day eight, the natural flow declines to approximately 100 cfs and diversions must stop.

Now assume in a new example that another water storage project already existed on this stream. The Water Resources Department would have to take into account the already-existing diversion to determine whether a new water user could access additional water for storage.

Recommendation #4. Install stream gages or other measuring equipment, according to Department specifications, to monitor and manage the system.

As demonstrated in these examples, near real-time stream gaging will be important to accurately manage diversions in the system. The examples also show that the rate of withdrawals would fluctuate in response to actual conditions in the stream; when streamflows are high, higher rates of withdrawal would be allowed.

Figure 3. Example Percent of Flow Approach on the South Yamhill River



The following hydrographs help to demonstrate in more detail how the percent of flow approach could work in Oregon. The set of hydrographs displayed in Figure 3 use a stream gage in the South Yamhill River to demonstrate the application of this method. Three additional examples in the Grande Ronde, the Powder, and the Rogue Basins can be found in Appendix D of this report.

① *When is water available in a basin?* Figure 3.1 displays the average daily flows from 1995-2012 for the Yamhill River at McMinnville (dark green line). The light green, stair-stepped line shows water available for storage between November and June, after prior allocations have been accounted for. The two light blue lines further bracket the period between November and April when storage is allowed, according to the basin plan. These light blue lines persist throughout Figures 3.2 and 3.3, marking the time frame when funding applicants could divert water for storage under the POF approach.

② *How would the State implement a percent of flow approach?* Figure 3.2 shows the average daily flows during 2011 in the Yamhill River at the McMinnville gage (dark blue line). 2011 was a high water year, with stream gages measuring a total of 1.5M acre feet of water passing through this system. Major rain events occurred during December and January, and additional runoff occurred in March, April, and May. The purple line indicates what streamflow levels would have measured if a new water user had been allowed to divert 15 percent of these flows for storage. Put another way, the purple line shows the stream retaining 85 percent of its flow. Diverting water according to this method helps retain the shape of the natural hydrograph and continues to protect the biological and physical functions of the stream. It prevents "flat-

lining" of the hydrograph. Finally, the black line near the bottom of the figure marks already existing base flow protections. If the natural streamflow (dark blue line) declined to or below this level, no storage would be allowed until the flow again rose above the base flow level. The orange line indicates current allocations for storage.

③ *What does the hydrograph look like for a low water year?* Figure 3.3 shows 2001 natural flows (dark blue line), the lowest water year on record for this gage. Readings recorded between November and May 2001 showed very low flows. During late November, natural flows (dark blue line) dip below the already existing base flow protections, eliminating new diversion and storage opportunities during that time period. Because the diversion is calculated as a percent of flow, years such as 2001 would result in less water instream, and therefore less or no water available for "percent of flow" projects. Without establishing and protecting a base flow, water diversions could have an adverse impact on biological and physical habitat conditions instream.

See Appendix D for further scenarios that demonstrate the variability that can occur between natural flows and the allowable 15 percent of flow diversions.

Chapter 2. More than a Percent of Flow Approach: In-Depth Methods to Request Additional Water

Instream flow studies must evaluate flow needs and opportunities in terms of hydrology, biology, geomorphology, water quality, and connectivity. (Instream Flow Council 2008)

The approach described in the previous chapter would allow water users to divert water for storage with very little time or investment in detailed biological or physical habitat studies. However, water users may want to access more water than the volumes resulting from the 15 Percent of Flow approach, or they may feel that more water is available outside of the time periods determined by the 50 percent exceedance criteria.

In such cases, water users may present more in-depth analysis to the Water Resources Department, along with a well-researched request for water diversions that exceed those allowed with the Percent of Flow approach and the 50 percent exceedance criteria. This chapter lays out a Seasonally Varying Flows In-Depth Assessment Framework that would be accepted for consideration but does not provide detailed guidance on the specific methods of analysis. The level of detail and extent of the proposed analysis will depend upon the specific request, and each proposal should be reviewed and approved by a technical review committee under the auspices of the Water Resources Department.

The Seasonally Varying Flows In-Depth Assessment Framework approach is summarized in the following flow chart, with more detail provided in the text outline that follows. The basis of the In-Depth Assessment Framework is grounded in the current scientific understanding of relationships between flow regimes and biological functions and physical processes, specifically those identified in Senate Bill 839. The approach is based on assessment methods and frameworks that have been developed, promoted, and used by a variety of researchers and management entities[3].

All of these approaches require collection and analysis of hydrological, hydraulic, physical, and biological data and an understanding of the linkages between flow alteration and these hydrological, hydraulic, physical, and biological functions. The hydrologic evaluation will describe differences between natural and altered hydrographs through an examination of flow regime characteristics (e.g., magnitude, duration, timing, rate of change, frequency, and inter- and intra-annual variation). Hydraulic analysis will provide information on water depths and velocities in the channel and floodplain, important for habitat conditions and biological processes. Physical processes include those that form and maintain stream channels and key elements of habitat for selected species, transport sediment, and create channel-

Recommendation #5. Use the State approved in-depth assessment framework for projects proposing a departure from the percent of flow approach.

[3] Examples include Arthington et al. 2006; Poff et al. 2010; King et al. 2008; Texas Instream Flow Program (http://www.twdb.texas.gov/surfacewater/flows/instream/); Florida Minimum Flows and Levels Program (http://www.dep.state.fl.us/water/waterpolicy/mfl.htm); Colorado Non-Consumptive Needs Program (Sanderson et al. 2012); https://www.google.com/#q=water+flow+evaluation+tool).

floodplain connectivity. The biological component includes development of an understanding of relationships between aquatic communities, life histories, habitat and the hydrology and hydraulics of the system. The analysis to develop Seasonally Varying Flow components that will protect the biological and physical functions in watersheds as directed by Senate Bill 839, requires an interdisciplinary, integrated approach. The in-depth analysis required here follows the direction of Senate Bill 839, but leaves out some of the typical parameters of such studies. If desired, the full Seasonally Varying Flows Task Force could consider incorporating other parameters.

Figure 4. Seasonally Varying Flows In-Depth Assessment Framework (for Site-Specific Assessments)

Step 1. Describe Ecological Context and Identify Analysis Elements

Identify geographic scope, reach location, geomorphic context, target species and other background information including existing water use and allocation.

Develop hypotheses for Flow-Function or Flow Alteration-Function Relationships for the functions identified in SB 839, which include but are not limited to: (a) stream channel development and maintenance; (b) connectivity to floodplains; (c) sediment transport and deposition; (d) migration triggers for upstream movement of adult fish and downstream movement of fry and juvenile fish; (e) fish spawning and incubation; (f) juvenile fish rearing; and (g) adult fish passage.

Review the hypotheses and proposed assessment methods with the State.

Step 2. Compile Data and Conduct Evaluations

Hydrology, e.g.:
- natural and altered hydrographs
- recurrence intervals
- exceedance probabilities

Hydraulics, e.g.:
- modeled depths, velocities
- wetted area
- modeled water surface elevations

Physical Processes, e.g.:
- channel flushing, maintenance, forming flows
- floodplain/habitat connectivity flows
- sediment transport flows

Biology, e.g.:
- migration triggers
- spawning, incubation
- juvenile rearing
- adult fish passage

Step 3. Quantitative Analysis, Interpretation, and Integration

Analyze and evaluate Flow-Function response relationships based on site-specific data and modeling, literature, and/or expert knowledge using accepted methods

Quantify potential impacts of flow alteration on stream functions listed in Step 1.

Test original hypotheses; confirm approach with the State.

Step 4. Draft Report

Recommend flows that allow flow alteration while demonstrating full protection of the aquatic ecosystem.
Identify factors addressed, including relevant time blocks.
Include monitoring and evaluation plan.
Draft copy of report to State for review and comment.

Step 5. State Will Review the Report and Respond to the Findings

The Seasonally Varying Flows In-Depth Assessment Framework includes the following steps, which need to be further discussed with the Technical Review Team to determine level of detail and extent of analysis. Note that acronyms and other terms are further defined in the Appendices.

1. Describe Ecological Context and Identify Analysis Elements
   a. Compile and evaluate existing information, including:
      - stream channel condition (e.g. channel alteration, erosion/cut banks, sedimentation);
      - riparian zone/floodplain condition;
      - resident, anadromous fish populations; ESA- or State-listed species;
      - identify related wildlife issues.
   b. Determine geographic scope of the study and overall objectives, such as:
      - subject watershed, general information;
      - subject stream, general information;
      - identify stream segment affected by proposed development;
      - describe existing water uses and allocations in the basin, using available information.
   c. Identify key species and functions:
      - the specific target species to be evaluated including, life stages and periodicity;
      - biological functions to be protected (i.e. migration, spawning, rearing, passage);
      - physical functions to be protected (i.e. channel development and maintenance, floodplain connectivity, sediment transport).
   d. Develop hypotheses for Flow-Functions or Flow Alteration-Functions response relationships that will determine the specific analysis. See Appendix F for example hypotheses regarding Flow Alteration - Function relationships.
   e. Identify data collection and analysis methods to be used.
   f. Review proposed approach with State's Technical Review Team before proceeding.

Recommendation #6. Establish a Technical Review Team that can help funding applicants with the review and design of in-depth assessments.

Recommendation #7. Use pre-application meetings that are available to applicants to review and adjust hypotheses and proposed assessment methods.

2. Compile Data and Conduct Evaluations
   a. <u>Hydrology</u>. Hydrologic analysis may be a combination of streamflow gage analysis and hydrologic modeling, depending on data availability. The approach will generally involve determining natural and current flow conditions, considering existing allocations, and understanding how proposed diversions would alter the flow regime. The following hydrologic data types may be used to complete the final quantitative analysis (taken from Locke and Paul 2011):

      1) Recorded daily streamflow data;
      2) Precipitation data;
      3) Evaporation data;
      4) Water use data (diversions and return flows);
      5) Reservoir data;
      6) Routed daily streamflow data.

      Many of these data may be publically available (See Appendix F, "Additional Resources to Conduct In-Depth Studies"), although the quality of the data must be assessed before use.

      Preparation of hydrologic data for use in flow-function quantitative analysis may involve a variety of analytical methods, for example:

1) Flood frequency analysis (2-, 5-, 10-, 100- year return periods);
2) Flow duration analysis;
3) Evaluation of flow components (magnitude, frequency, duration, timing, rate of change, etc.);
4) Flow naturalization;
5) Hydrologic and statistical modeling including record extension, synthetic hydrograph creation, basin-wide routing and other input data needed for previously mentioned analyses.

The USGS and WRD have established standards for these analyses. Guidance and documentation can be found on the agencies' websites.

b. Hydraulics. Hydraulic analysis is used to determine the relationship between streamflows and water surface elevations, channel depths, velocities, and wetted area. Approaches and models currently available for completing this analysis include 1-dimensional models such as HEC-RAS, PHABSIM, DHI Mike 11; and 2-dimensional models such as River2D, and DHI Mike21. The appropriate model and analysis will depend on the specific functions to be assessed, as well as data availability. The basic assessment method includes:

1) Determine approach to be used;
2) Collect data required to build and calibrate the model(s)—channel cross sections or spatial bathymetry, channel roughness, calibration depths, velocities, water surface elevations, as well as data from 2a;
3) Develop, calibrate, run and analyze output from models to determine water surface elevations, flow depths and velocities, wetted area, etc.;
4) Link with field data from 2c and 2d to determine relationships between flow and SVF functions.

c. Physical Processes. A number of physical process functions occur as part of the natural hydrograph, and these functions must be preserved under a SVF hydrograph. Streamflows that accomplish these functions can be determined from hydrograph analysis or more in-depth analysis based on empirical data and hydraulic modeling. Stream channel and floodplain geomorphology reflect the effects of geomorphic flows that have occurred under the hydrograph for many years. The categories of geomorphic flows are mentioned below, and are described more fully in Appendix C Definitions.

1) Analyze the natural hydrograph to determine key geomorphic flows, including magnitude, duration, frequency, and timing for specific functions, e.g,:

   a) Flushing flows, often a 1-year recurrence interval peak flow;
   b) Channel maintenance flows, often within the 1.5 to 2 year recurrence interval peak flow range;
   c) Channel forming flows, 10 to 25 year recurrence interval peak flows;
   d) Floodplain connectivity flows - For many systems, this can be approximated by the 10-year recurrence interval peak flow, but verification that this will accomplish floodplain connectivity is required;
   e) Habitat connectivity flows - Moderately high, generally between mean annual and 1-year recurrence interval flows.

2) Analyze sediment, using empirical data and hydraulic modeling, e.g.:

   a) Collect empirical sediment/substrate distribution data;
   b) Use hydraulic modeling methods described in previous section (2b. Hydraulics) to develop the required metrics for sediment transport analysis;

c) Relate results of sediment transport analysis to goals for physical processes described above that form and maintain habitat;
d) Determine flows required to transport relevant sediment classes in terms of magnitude, duration, frequency, and timing to accomplish geomorphic functions described above.

3) Collect and analyze relevant water quality data, e.g. stream temperature, dissolved oxygen.

d. Biology. Based on the species information identified in 1c, collect data on fish assemblages and invertebrates within the affected stream segment and evaluate habitat as a function of streamflow. The basic assessment method includes:

1) Determine approach to be used;
2) Identify study sites;
3) Evaluate habitat requirements, habitat utilization, life history, passage criteria, and other ecological factors at the reach scale;
4) Identify habitat suitability functions for species/lifestages to be modeled; these would include depth, velocity, substrate, cover, and temperature suitabilities. Link with hydraulic models from 2b.
5) Identify periodicity for target species/lifestages for time series analysis under 3 below;
6) Identify flows needed to maintain spawning, incubation and rearing, upstream and downstream migration, passage and connectivity; include species-specific passage criteria (under 2d3 above); use data from 2a to describe conditions associated with current, historic, and proposed flow regimes.

3. Quantitative Analysis, Interpretation, and Integration
   a. Analyze and evaluate flow-function or flow alteration-function response relationships for the entire range of flows observed from the hydrograph, including base flows and elevated flows based on the hypotheses identified in 1d.
   b. Complete statistical analyses to develop relationships.
   c. Identify specific time blocks, describing base flows and elevated flows. Integrate flow/habitat output, migration and passage flows, channel maintenance flows, floodplain connectivity flows, sediment transport flows with relevant time periods for time series output.
   d. Describe specific SVFs to be protected by time period, magnitude, duration, etc. Include target values for each flow element.
   e. Characterize and quantify potential impacts of development strategies. Propose a flow prescription that is sufficiently protective of key components of SVF.
   f. Review results and interpretation with State.

4. Draft Report
   a. Develop a comprehensive document including executive summary, site description, summary of methods, results, and proposed flow prescription with justification.
   b. Include a monitoring and evaluation plan. During the life of the project, on-going monitoring and reporting will be required to ensure that the project is fulfilling its objectives in protecting key elements of the hydrograph. Streamflow data collected upstream and downstream of the diversion will allow for smooth implementation of the flow prescription. Upstream gages will help determine the amount of water for diversion on a daily basis, and downstream gages will monitor critical elements of the flow regime identified in the flow prescription. A report of this analysis should be submitted to the Water Resources Department on some regular basis, to be determined in collaboration with WRD, but at a minimum of every two years. This monitoring and reporting should be conducted for the life of the project.
   c. Provide a draft copy of the report to the State for review and comment.

5. The State's Technical Review Team will review the report and respond to the findings.

Chapter 3. Comparing Approaches

Currently in Oregon, applications for a water storage permit are reviewed by the Water Resources Department to determine whether water is available, using the "50 percent exceedance criteria." If water is available, the Department may issue a storage permit for an amount up to the median monthly flow. Any already-existing water allocations and base flow conditions are subtracted and protected as part of this process. The Oregon Department of Fish and Wildlife has the option to protect high flows, or peak flows, for channel maintenance purposes, relying on guidance developed in 2007. Permit conditions written by the Water Resources Department describe time periods when water cannot be diverted or any other conditions that the State has placed on the permit.

The approaches proposed in Chapters 1 and 2 were developed for water storage projects seeking funding from Oregon's Water Supply Development Account. The approaches build upon the 50 percent exceedance criteria already used in Oregon, and then—to determine the amount and timing of the diversion—provide a choice between a simple percent of flow approach, as described in Chapter 1, and a more in-depth approach, as described in Chapter 2. Figure 5 shows a comparison between the current approach for determining water availability and the proposed Percent of Flow approach.

Figure 5. Comparison of the Current Approach and the Percent of Flow Approach

Step 1: Water Availability	Step 2: Shaping the Diversion	Option to Request More
Current Approach		
Determine whether and, if so, in which months water is available using 50 percent exceedance criteria	Allocate up to median monthly flow, accounting for existing allocations, base flow requirements,[4] and peak flow guidance from the Oregon Department of Fish and Wildlife.	Submit additional data to the Water Resources Department for consideration.
"Percent of Flow" Approach		
Determine whether and, if so, in which months water is available using 50 percent exceedance criteria	Allocate up to 15 percent of daily flow as described in Chapter 1, accounting for existing allocations and base flow requirements[4].	Apply Seasonally Varying Flows In-Depth Assessment Framework from Chapter 2.

[4]Note that in either case, base flows must be protected when new allocations are requested.

Ongoing Need for Monitoring

While the percent of flow approach to allocating water has been utilized in other jurisdictions, it remains a relatively new method for preserving critical elements of seasonally varying flows and associated ecological functions. It is a precautionary approach that provides a pathway for decision-makers, allowing the diversion of water for storage without jeopardizing critical physical and biological processes.

While it is expected that this approach will protect the natural variability within the hydrograph, much uncertainty still exists about how that variability may be related to key ecological functions. For example, are relationships basically linear or are there key thresholds beyond which we see a significant loss in physical and biological function? In order to ensure that this approach provides the expected ecological protection, it will be essential to establish on-going monitoring of both hydrological and ecological conditions.

Recommendation #8. Conduct a pilot program, monitoring conditions in projects that are early adopters, in order to evaluate the effectiveness of this approach.

While pursing economic development opportunities that come with water storage, the State must continue to monitor, evaluate, and protect the streamflows that support critical ecological functions. The Oregon Legislature has recognized the importance of protecting key elements of the natural flow regime, while developing additional water storage projects for its communities.

The science subgroup therefore recommends that the State conduct a pilot program early in the implementation process to monitor the results of this approach.

Conclusion. Observations and Recommendations

Instream flow prescriptions must maintain spatially complex and diverse habitats,
which are available through all seasons.
(Instream Flow Council 2008)

The link between natural flow variability and the integrity of freshwater ecosystems is well established. Many ecosystem services provided by healthy rivers and streams depend on the natural flow regime. Human use of this water can disrupt key elements of natural flows by altering the magnitude, frequency, timing, duration, and rate of change of flow in streams. These changes in flow regime are contributing to the degradation of natural physical and biological processes in streams that support habitat and species persistence. However, the exact relationships between flow and ecological processes are not well understood. Despite the widespread acceptance of the importance of the natural flow regime, the determination of specific flow levels needed for target physical and biological processes remains a daunting task. Great uncertainties are associated with the question, "How much can we change the flow regime before we see a detrimental impact to stream ecosystems?"

This report represents the science subgroup's recommended solution to the present state of uncertainty in managing environmental flows. The percent of flow method for allocating water withdrawals essentially provides a precautionary approach that is protective of the natural variability within the hydrograph, and is presumed to be protective of the ecology. It should be stressed that ongoing monitoring of the effects of this approach is a critical component of this program.

The State should be prepared to conduct a pilot monitoring program to evaluate the effectiveness of this approach, with details to be determined based on the specific storage project.

Summary of Recommendations

- *Recommendation #1. Use the Department's water availability model and 50 percent exceedance criteria to determine whether water is available for storage, and during which months.*

- *Recommendation #2. Establish base flows as a lower protective threshold, below which no withdrawals can occur.*

- *Recommendation #3. Use a "percent of flow" approach as a simple tool to shape the timing and quantity of diversions.*

- *Recommendation #4. Install stream gages or other measuring equipment, according to Department specifications, to monitor and manage the system.*

- *Recommendation #5. Use the State approved in-depth assessment framework for projects proposing a departure from the percent of flow approach.*

- *Recommendation #6. Establish a Technical Review Team that can help funding applicants with the review and design of in-depth assessments.*

- *Recommendation #7. Use pre-application meetings that are available to applicants to review and adjust hypotheses and proposed assessment methods.*

- *Recommendation #8. Conduct a pilot program, monitoring conditions in projects that are early adopters, in order to evaluate the effectiveness of this approach.*

Appendix A. Acknowledgements

Convenor:
Mr. Brett Brownscombe, Natural Resources Policy Advisor, Office of Governor John Kitzhaber

Special thanks to the Science Subgroup members who provided their time and expertise to develop this report.

Members included:

Mr. Don Anglin, U.S. Fish and Wildlife Service
Dr. Leslie Bach, The Nature Conservancy
Dr. Tim Hardin, Oregon Department of Fish and Wildlife
Dr. Valerie Kelly, U.S. Geological Survey
Mr. Ken Stahr, Oregon Water Resources Department

Staff:

Dr. Brenda Bateman, Technical Services Administrator, Oregon Water Resources Department
Ms. Racquel Rancier, Senior Policy Coordinator, Oregon Water Resources Department
Ms. Rachel LovellFord, Hydrologist, Oregon Water Resources Department
Ms. Erin Oost, Hydrologist, Oregon Water Resources Department
Ms. Alyssa Mucken, Integrated Water Resources Strategy Coordinator, Oregon Water Resources Department
Ms. Arla Heard, Administrative Specialist, Oregon Water Resources Department
Ms. Sheila Buchholz, Office Specialist, Oregon Water Resources Department

Appendix B. Acronyms

af	acre-feet
BC	British Columbia
cfs	cubic feet per second
DLCD	Department of Land Conservation and Development
ESA	Endangered Species Act
HEC-RAS	Hydrologic Engineering Centers' River Analysis System
HEC-RPT	Hydrologic Engineering Centers' Regime Prescription Tool
IFIM	Instream Flow Incremental Methodology
NWS	National Weather Service
OAR	Oregon Administrative Rule
ODFW	Oregon Department of Fish and Wildlife
ORS	Oregon Revised Statute
PHABSIM	Physical Habitat Simulation
POF	Percent of Flow
SB	Senate Bill
SEFA	System for Environmental Flow Analysis
SVF	Seasonally Varying Flows
TF	Task Force
TNC	The Nature Conservancy
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WRC	Water Resources Commission
WRD	Water Resources Department
WUA	Weighted Usable Area

Appendix C. Definitions

50% Exceedance Criteria	The Water Resources Department generally evaluates water availability for storage at the estimated natural median (50 percent exceedance) flow for any given month. Staff then subtracts already-existing water rights, including instream rights, from that median flow to determine whether there is still water available for storage, and how much.
Adult Fish Passage	Adult fish passage is required for both local and long distance migrations and movements. Migrations or local movements are typically associated with spawning, overwintering, feeding, and/or location of seasonal suitable habitats. There are numerous sources of information describing species-specific passage requirements, particularly, depths and velocities. In addition to depth and velocity criteria, both total and continuous percentages of cross section width that meet the criteria are usually specified (Thompson 1972, Bovee 1974, White 1975). Streamflows that provide target passage conditions are a function of the stream channel morphology, slope, and hydraulic characteristics.
Assemblage	All of the various species that exist in a particular habitat.
Aquatic Life	All organisms living in or on the water. This includes plants from the smallest phytoplankton through algae, periphyton, and emergent vegetation as well as animal life from zooplankton through benthic invertebrates, fishes, and amphibians, reptiles, birds, and mammals.
Base Flows	These flows are defined in order to be sufficient in volume for rearing and spawning for key species over long periods of time, as well as sufficient to overcome the potential for threats to aquatic life from harmful pollutants or stream heating. Base flows, as a component of seasonally varying flows, must be protected throughout this process.
Connectivity	Maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes.
Fish Spawning and Incubation	The physical and hydraulic conditions required or preferred for spawning vary by species. Relevant components include depth, velocity, substrate, and water temperature. Depths, velocities, and the corresponding streamflows required for spawning are species or guild-specific. The incubation period spans the time from egg fertilization to hatching of the fry and is variable among species.
Floodplain Connectivity Flows	These fall within the upper range of channel forming flows. Verification that the 10-year recurrence interval peak flow will accomplish floodplain connectivity is required, and may be possible using existing data. If existing data are not available, topographic surveys and stage-discharge relationships would be needed to determine streamflows required to establish floodplain connectivity.

Habitat Connectivity Flows	These flows, for side channels and other important off-channel habitats, are a key part of seasonally varying flows. Recent studies in major tributaries of the Willamette River have shown that ESA and State-listed species such as Chinook salmon and Oregon chub thrive in side channels and ponds that maintain a hydraulic connection with the main channel over relatively long periods each year. These habitats have been topographically mapped, and their connectivity monitored in relation to fish populations (Bangs 2014). Flows needed to connect these habitats in the Willamette Basin are variable, and appear to fall between mean annual flow and one-year recurrence. The timing and duration of connectivity flows should follow the shape of the naturally occurring hydrograph, and may require the input of fishery experts to determine requirements for local conditions.
Hydrologic Engineering Centers' River Analysis System (HEC-RAS)	U.S. Army Corps of Engineers' 1-D hydraulic modeling software, often used to determine water levels needed for overbank flow and other water level related analysis.
Hydrologic Engineering Centers' Regime Prescription Tool (HEC-RPT)	Software designed to facilitate entry, viewing, and documentation of flow recommendations in real-time, public settings. Not intended to perform detailed quantitative analysis, but to complement other HEC software (including reservoir system simulation, river hydraulics, and ecosystem functions) by making it easier to create flow time series that can then be imported and used in analysis.
Instream Flow Incremental Methodology (IFIM)	A problem-solving approach for quantifying the benefits and impacts to aquatic resources as a function of incremental flow changes. IFIM analyses may include geomorphology, temperature, riparian vegetation, and many other factors. The PHABSIM model, a subset of IFIM used for quantifying fish habitat, is defined below.
Irrigation Season	The "irrigation season" is defined in Oregon's Basin Plans, in adjudication decrees, and by administrative rules, spelling out an exact time period when water may be appropriated and directly applied to agricultural lands. For example, some areas of the Willamette Valley have their irrigation seasons defined as April 1 through September 30, while other areas are limited to May 1 through September 30. Some basin plans define the irrigation season as any time water can be put to beneficial use, while other plans do not define the irrigation season at all. The "storage season" is generally considered to be any time outside of the irrigation season.
Juvenile Fish Rearing	The juvenile lifestage begins with external feeding and continues until the subadult lifestage begins and/or until sexual maturity has occurred. Food consumption, growth, and survival are the primary factors for rearing juvenile fish. During this time period, rearing fish use a wide variety of habitats, which may be different for feeding, growing, resting, or avoiding predators. The physical and hydraulic conditions required or preferred by rearing juvenile fish vary by species. Relevant components include depth, velocity, substrate, cover, and water temperature. Depths, velocities, and the corresponding streamflows required for rearing are species or guild specific.

Measured Flow	Discharge that is measured instantaneously and not averaged over longer time periods such as days, weeks, or months. Instream flow values are generally designated in cubic feet per second (cfs), but regardless of the unit of measure, they are typically not reported as an average discharge rate over time.
Migration Trigger	Initiates upstream movement of adult fish and downstream movement of fry and juvenile fish. Life histories of most resident and anadromous fish include local and/or long distance migrations to satisfy rearing, growth, and spawning functions. In some cases, these migrations have been associated with changes in streamflow. When this is the case, the timing, or predictability of flow events can be critical, ecologically, because the life cycles of many aquatic and riparian species are timed to either avoid or exploit flows of variable magnitudes (Poff et al. 1997). Increasing flows have been observed to initiate upstream and downstream migrations, elevated flows have been observed to initiate spawning activity, and elevated flows allow access to floodplain and side channel habitats (Robison et al. 2010). Downstream juvenile migration of salmon and steelhead has been positively correlated with streamflows in the Columbia and Willamette basins (Friesen and Buckman 2003). The natural timing of high or low streamflows provides environmental cues for initiating life cycle transitions in fish, such as spawning (Montgomery et al. 1983, Nesler et al. 1988), egg hatching (Naesje et al. 1995), rearing (Seegrist and Gard 1972), movement onto the floodplain for feeding or reproduction (Junk et al. 1989, Sparks 1995, Welcomme 1992), or migration upstream or downstream (Trepanier et al. 1996, Poff et al. 1997). In some cases, these biological "triggering" flows have been estimated based on correlations between fish movement and changes in streamflow.
Natural Flow	Flow in rivers and streams that would have occurred prior to man-made impacts, or regulation. In affected systems, natural flow is a calculated value based on the recorded flows of contributing rivers; physical factors concerning the reach (for example, evaporation, and channel losses); water diversions; consumptive use; and return flow. In pristine environments, natural flows equal recorded flows.
Percent of Flow Method	An approach that determines the appropriate levels of allowable flow depletion expressed as a percent reduction from natural flow according to a stated objective for the river, for example, full protection of the aquatic ecosystem.
Physical Habitat Simulation (PHABSIM)	Set of programs to predict the microhabitat conditions in rivers as a function of streamflow, and the relative suitability of those conditions to aquatic life. PHABSIM is a subset of IFIM, defined above.
River2D	Two-dimensional depth averaged finite element hydrodynamic model. River2D has been customized for fish habitat evaluation studies, and similar to PHABSIM, it predicts suitable microhabitat conditions as a function of streamflow, but uses detailed, reach-based bed topography rather than cross-sections.

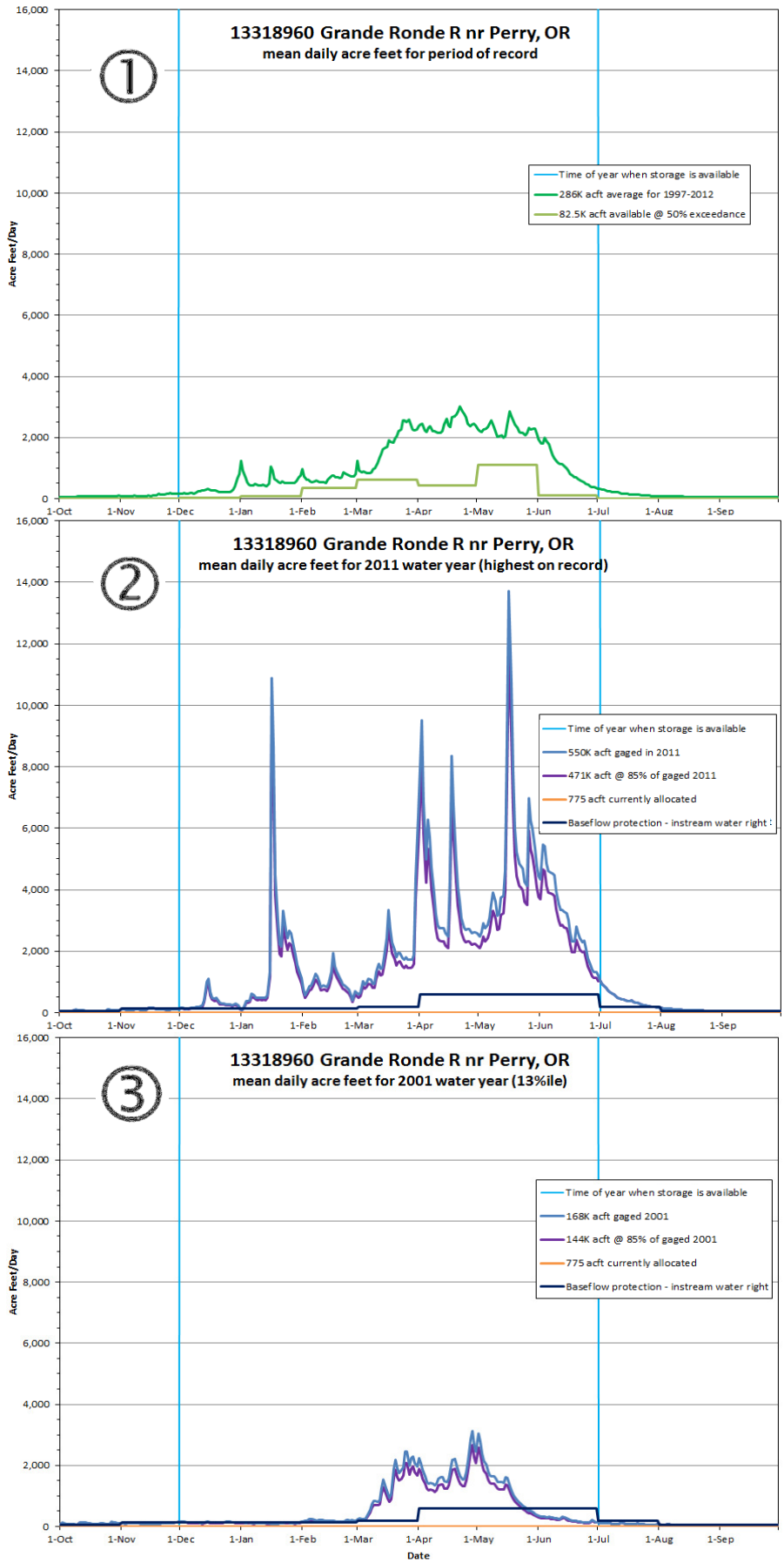
Seasonally Varying Flows	As defined in Senate Bill 839 – means the duration, timing, frequency and volume of flows, identified for the purpose of determining conditions for a new or expanded storage project, that must remain instream outside of the official irrigation season in order to protect and maintain the biological, ecological and physical functions of the watershed downstream of the point of diversion, with due regard given to the need for balancing the functions against the need to store water for multiple purposes.
Sediment Transport and Deposition	Sediment transport is a geomorphic process that roughly maintains a dynamic equilibrium between the sediment supplied to a stream or watershed and the sediment transported out of the system. This equilibrium is required to maintain the channel morphology (with variation) and physical habitat of the stream channel. Fine sediments that enter the system are typically transported downstream during high flows as suspended sediment and deposited on floodplains, in estuaries, or in backwater/off-channel areas. Fine sediment transport is important for maintaining the function of spawning gravels and for providing a productive habitat for invertebrate production. Coarser sediments and bedload are also transported downstream during high flow events, but are typically deposited within the stream system because of their larger sizes. The redistribution of coarse sediments removes accumulations from tributaries in mainstem channels, replenishes spawning substrates, and maintains the physical complexity of the substrate and associated physical habitat for fish and invertebrates. Streamflows that facilitate sediment transport and deposition are a function of sediment size, stream channel morphology, slope, and water column hydraulics.
Stream Channel Development and Maintenance Flows	These flows are elevated streamflows that create or maintain stream morphology, channel form, and physical habitat. These flows provide the necessary scour of the stream channel to reshape alluvial features and maintain healthy streamside vegetation. They are important for bank erosion/deposition, gravel bar formation, wood recruitment, prevention of vegetation encroachment in the channel, and maintenance of general channel form (IFC 2008). At this flow level, bedload movement of gravels and cobbles occurs and fines at deeper levels in the streambed are scoured away. These flows are higher flows and less frequent than flushing flows. Occurring naturally in an unaltered watershed, they can be observed in the natural hydrograph. Channel development and maintenance flows typically include flushing flows for in-channel functions, channel maintenance flows for in-channel and riparian functions, and channel forming flows for side-channel and floodplain functions. Schmidt and Potyondy (2004) estimated the channel maintenance flow as 0.8-1.0 of bankfull discharge, or the discharge that has a recurrence interval between one and two years. The ODFW guidance (Robison 2007) gives basic requirements for calculating flows for channel maintenance.
Stream Channel Flushing Flows	Regularly recurring streamflows with sufficient power to “flush” finer sediments (silt, sand) and organic matter from the interstitial spaces between larger gravel/cobble substrates, and from pools and other slower-velocity rearing areas. These flows help to renew the spawning and incubation functions of the substrate and maintain the complexity of rearing areas. Flushing flows have

	been approximated by a number of methods, but they are most commonly described as a function of mean annual discharge or bankfull discharge. Wald (2009) recommends mean annual discharge as a flushing flow level, and Schmidt and Potyondy (2004) cite about 40 percent of bankfull flow, which roughly translates to the one-year recurrence interval peak flow. The recommended duration for flushing flows ranges from 6-12 hours (Wald 2009) to a duration that reflects the pattern of the natural hydrograph, and several times per year.
Stream Channel Forming Flows	These flows form and maintain side channels, scour floodplain surfaces, redistribute sediment, refill off-channel wetlands and oxbow lakes, and recharge groundwater storage in hyporheic and floodplain aquifers (Trush et al. 2000). Wald (2009) recommends the 10-year recurrence interval peak flow, and Schmidt and Potyondy (2004) set the 25-year recurrence interval peak flow as a "cap" to accomplish channel forming and riparian functions, while limiting the consequences of flood damage. The timing and duration of channel forming flow events should follow the shape of the naturally occurring hydrograph; they are higher flows that are less frequent than channel maintenance flows. These flows are generally applicable only to stable, alluvial streams that have the ability to change their shape and are neither aggrading nor degrading. They are often referred to as the bankfull flow, dominant flow, or effective flow.
System for Environmental Flow Analysis (SEFA)	Software that supports the Instream Flow Incremental Methodology (IFIM). SEFA includes PHABSIM, and also has components for hydrologic analysis, water temperature modeling, habitat selectivity criteria development, sediment scour, transport and deposition analysis, riparian habitat evaluation, and habitat time series analysis.
Water Year	A time period of 12 months for which runoff totals are measured. The beginning and end of the water year differs from the calendar year because part of the precipitation that falls in late autumn and winter accumulates as snow and does not run off until the following spring or summer's snowmelt. In Oregon, the water year runs from October 1 to September 30, and is designated by the calendar year in which it ends.

Appendix D. Sample Percent of Flow Hydrographs

The following hydrographs from the Grande Ronde, Powder, and Rogue rivers, together with the Yamhill example in Chapter 1, highlight the geographic and hydrologic variability found within Oregon. Additionally, the selected sites show different levels of water availability and use. The combination of irrigation season, current allocation, base flow, and measured flow determines how much water is available for storage under the percent of flow approach in any given water year and at what time. Each selected river system is represented by three hydrographs: 1) mean daily flow over the period of record (see graph legend), 2) mean daily flow for the 2011 high flow water year and 3) mean daily flow for the 2001 low flow water year.

Figure 6. Example Percent of Flow Approach in the Grande Ronde River Basin



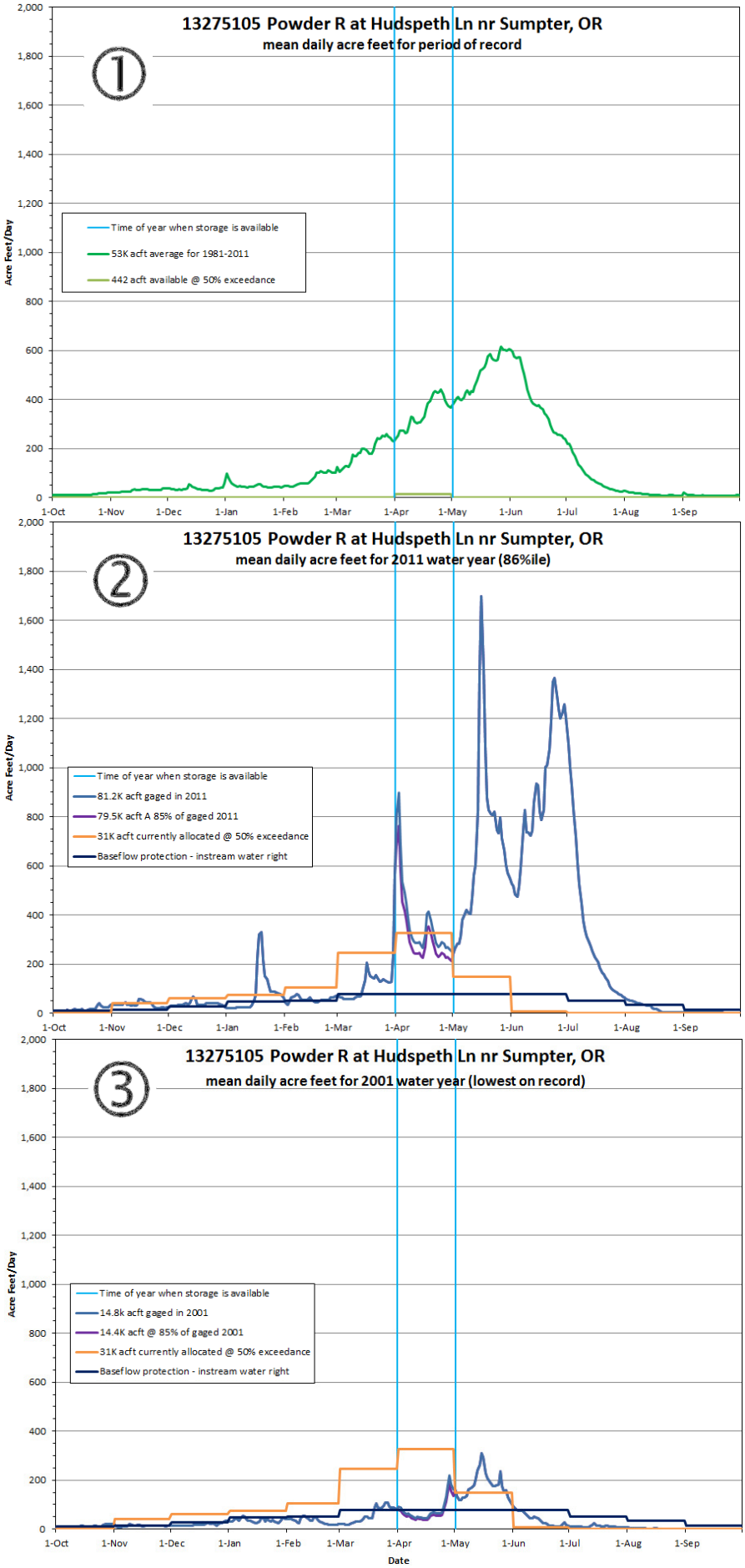
The Grande Ronde River

① *Average Basin Conditions*. In the Grande Ronde River near Perry, Oregon, spring rain and a snowmelt peak occur frequently from March through June as shown by the long-term average streamflow (Figure 6.1, dark green line). The 50 percent exceedance criteria (light green line) signals that historically, water has been available for storage from December through July, with the greatest volume of water expected during the month of May. This water availability line, along with the light blue lines marking the non-irrigation season, demarcates the time of year when water users may divert and store water using the percent of flow approach. The irrigation season is determined within the Grande Ronde by administrative order to be the time period, "…when [irrigation is] necessary for beneficial use in connection with irrigation of their respective lands."

② *Example High Flow Year.* 2011 was a high flow year, with high precipitation events in January, April, and May, and runoff from snowmelt coming in June (Figure 6.2, dark blue line). The accompanying purple hydrograph delineates the 85 percent of streamflow that stays in the stream under the "percent of flow" approach. Base flow protection (black line) within the Grande Ronde at this site is generally far below the 2011 flow levels and there are opportunities for current storage allocations (orange line) to be met. In 2011, 15 percent of the natural flow (difference between dark blue and purple lines), minus the small existing allocations, could likely be diverted during the entire December 1 to June 30 period.

③ *Example Low Flow Year.* Figure 6.3 features 2001 streamflows (dark blue line), which were among the lowest on record. Toward the end of May, the "85 percent" (purple line) drops below the base flow protection (black line), effectively ending storage opportunities through the end of the non-irrigation season. Despite the low flow conditions in 2001, current allocations within the basin likely would not restrict storage opportunities until the end of May, when flows drop below the base flow protection level. Current allocations represent a very low percentage of the total flow.

Figure 7. Example Percent of Flow Approach in the Powder River Basin



The Powder River

① *Average Basin Conditions.* The Powder River near Sumpter, Oregon shows a similar snowmelt peak in May and June but lacks early spring rain, giving the Powder's long-term average hydrograph a relatively narrow spring peak (Figure 7.1, dark green line). The non-irrigation season is again defined based on "beneficial use" instead of specific dates. The 50 percent exceedance criteria (light green line), identifies April as the only month available to new water users for stored water. This greatly limits the time of year when water for storage is available within the basin (bracketed by light blue lines).

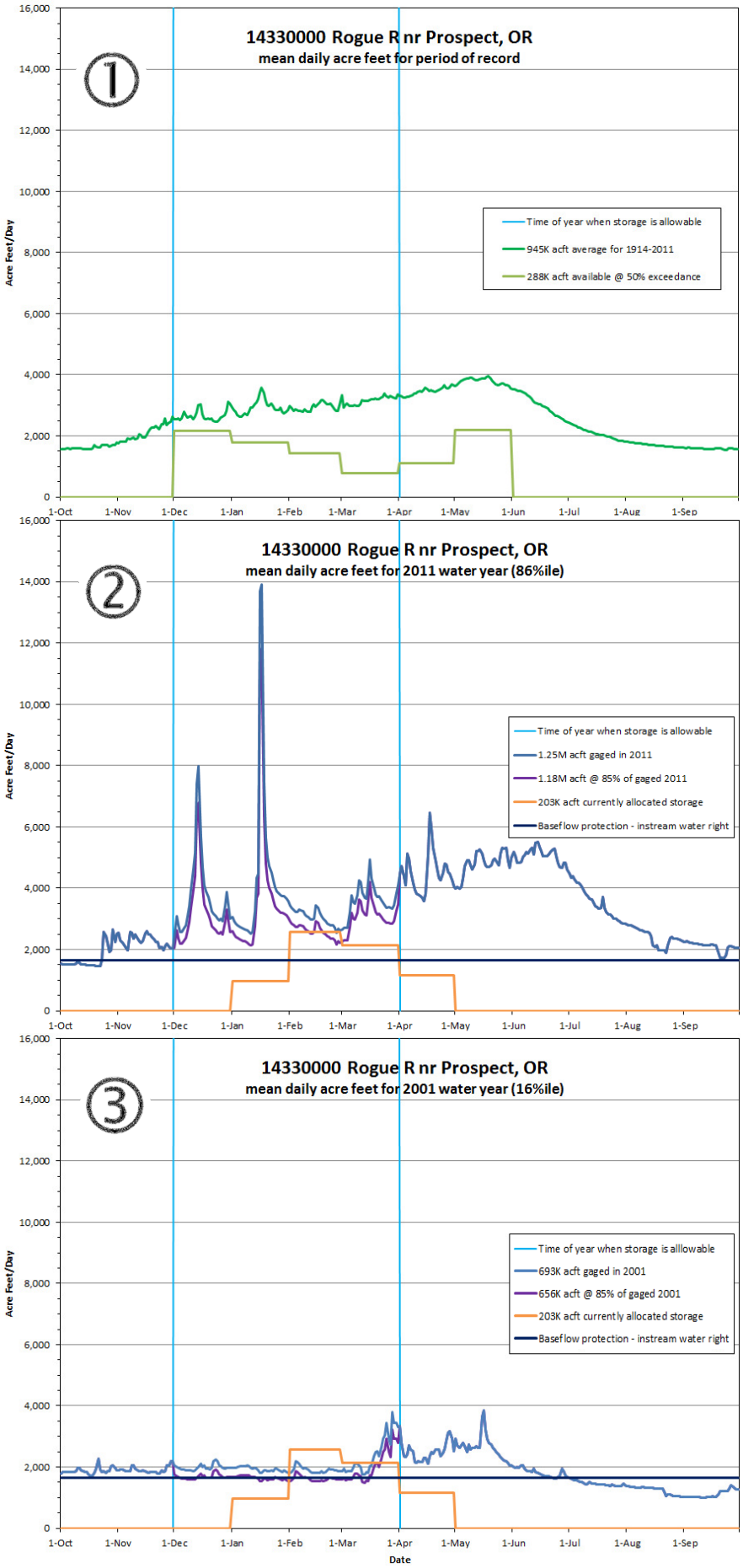
② *Example High Flow Year.* The Powder River experienced high flows in 2011, with the greatest flows occurring in May and June (Figure 7.2, dark blue line). Gages measured a total of 81,000 acre feet of water in the system during 2011. Again, the hydrograph shows the 85 percent of streamflow that would stay instream (purple line) under the "percent of flow" approach during April. The measured values do not drop below the base flow protection levels (black line) during the month of April, so water would be available for storage during the entire non-irrigation season. Note that previous allocations (orange line) during April are relatively high, and may affect the ability of subsequent water users to withdraw water under the proposed "percent of flow" approach.

Figure 7.2 is a prime example of a scenario in which water users may feel there is additional water available <u>outside</u> of the storage time period the state has identified (see dark blue hydrograph during May, June, and July). In this case, the science subgroup recommends using an "In-Depth

Assessment Framework," by which water users can present data requesting more diversion of water, while still demonstrating full protection of the aquatic ecosystem.

③ *Example Low Flow Year.* Finally, Figure 7.3 features substantially lower 2001 streamflows (dark blue line). Recall that April is the only month identified as having water available. Because the 85 percent flow values (purple line) fall below the base flow protection level (black line) during most of the month of April, storage could only occur at the start and end of the month. It is again notable that prior allocation levels (orange line) would likely preclude new water storage from using the "percent of flow" method in this year.

Figure 8. Example Percent of Flow Approach in the Rogue River Basin



The Rogue River

① *Average Basin Conditions.* The dark green line in Figure 8.1 represents the long-term average daily flow for the Rogue River near Prospect, Oregon. The 50 percent exceedance criteria (light green line) shows available water between December and June. However, the light blue lines further restrict when storage is allowed because of how administrative rules for the Rogue River Basin define the irrigation season; adhering to Senate Bill 839 would limit funding applicants using the "percent of flow" approach to water diversions between December 1 and March 31. Applicants could use the "In-Depth Assessment Framework" to apply for storage rights for additional water.

② *Example High Flow Year.* Gages measured 1,250,000 acre feet of water in the Rogue River during 2011 (Figure 8.2, dark blue line). The highest flows were recorded during the months of December and January. The hydrograph shows 85 percent of flow staying instream (purple line) under a 15 "percent of flow" approach.

Also displayed is an orange line, depicting water already allocated in the system, approximately 203,000 acre feet. These existing allocations would affect the ability of new water users to withdraw water under the proposed "percent of flow" approach. Finally, the black line displays the base flow protection levels for this reach of the Rogue.

③ *Example Low Flow Year.* Figure 8.3 features the 2001 flow (dark blue line), which was low, staying below 4,000 acre feet per day. Under the percent of flow approach, water users would be limited to withdrawals

during the periods when the 85 percent line did not drop below the base flow requirements (black line). In 2001, storage opportunities would have been limited between the start of December and mid-March with the greatest opportunities for storage at the end of March. There would also be restrictions triggered by the fact that significant allocations (orange line) already exist in this system.

Appendix E. Two Examples of the "Percent of Flow" Approach: Alberta and British Columbia

Province of Alberta. The Canadian Province of Alberta recognized the need to protect its aquatic resources in light of increasing demands on water resources by other users. Alberta also recognized that an important aspect of aquatic resource protection included maintaining the characteristics of the natural hydrograph reflected by seasonally varying flows. Since site-specific, detailed studies were not available in most areas, Alberta developed a science-based method to establish flow recommendations to provide full protection to rivers and streams (Locke and Paul 2011). The method is based on current scientific understanding of aquatic ecosystems, the current scientific literature on the science of instream flow needs, and a review of numerous site-specific studies carried out in Alberta and other jurisdictions around the world. The rationale behind the method is that by maintaining water quantity within the stream and also the natural streamflow fluctuations that occur including peak events, there is a very low probability of ecological effects to the aquatic environment.

Alberta used fish habitat reduction thresholds based on a review of a number of metrics and studies (Clipperton et al. 2002) to evaluate the effects of a range of flow reduction scenarios in 24 stream reaches in Alberta. The percent reduction from natural flows that did not violate habitat reduction thresholds was identified for each stream, and the most common reductions fell in the 15 – 30 percent range. Alberta's conclusion was that "given the uncertainty of the science, plus a desire to protect the aquatic ecosystem, the most conservative percent of flow reduction from all studies carried out in Alberta to date is recommended" (Locke and Paul 2011).

In Alberta, the percent of natural flow for allocation was set at 15 percent instantaneous reduction from natural flow. In addition to the recommended allowable flow reduction of 15 percent of the natural, unaltered flow, Alberta's method also establishes an ecosystem base flow. The allowable flow reduction (15 percent of the natural, unaltered streamflow), along with the ecosystem base flow, was developed based on limiting fish habitat reductions, limiting riparian vegetation recruitment reductions, and limiting changes to the magnitude, frequency, and duration of channel-forming flows.

Province of British Columbia. The Canadian Province of British Columbia (BC) identified a need to determine how much water could be extracted from any particular stream in light of an array of proposed water uses (Hatfield 2004). They adopted the "natural flow regime" approach that consists of quantitatively describing and preserving key aspects of the natural hydrograph (Poff et al. 1997; Richter et al. 1996, 1997; Trush et al. 2000). The presumption is that preserving key aspects of the natural hydrograph is the most likely approach to maintain the physical aspects of streams on which fish and other ecosystem components depend. They developed a two-tier process that included a low-risk, coarse screening tier, and a more detailed, in-depth assessment tier. BC proposed that the coarse screening tier would be used in the absence of detailed physical and biological information. For proposals that include a higher level of water diversion and use than recommended by the coarse screening tier method, the in-depth assessment tier methods would be required.

BC developed a process for the coarse screening tier to calculate seasonally adjusted thresholds for alterations to natural streamflows that were expected to result in low risk to fish, fish habitat, and productive capacity. The process for determining streamflow thresholds was developed with the input of biologists, hydrologists, and water managers from provincial, federal, and private sector groups, and makes use of the best available technical and scientific information in order to be as rigorous and defensible as possible. They used basic information on biology and hydrology to predict a schedule of instream flow requirements that protect available

habitat for fish, and provide for necessary ecological functions. In addition, their process for determining streamflows relates to the natural availability and variability of water in the stream, and by design, results in low risk thresholds. BC concluded that effective risk management required the setting of conservative criteria, coupled with a commitment to a strong monitoring program to ensure that conservation goals were being met. BC's process focuses on preserving key features of the natural hydrograph, since it is these features that are responsible for maintaining fish habitat in alluvial streams (Trush et al. 2000). Streamflows that are calculated using the BC process are intended to maintain connectivity, protect low flow periods, and provide high flow events to maintain gross stream morphology and instream and riparian habitat. BC quantified the effect of application of their coarse screening method in terms of percent of flow for 19 test streams in the province. Results indicated that the coarse screening method allows for reductions of 12 to 32 percent of flow.

Appendix F. Additional Resources to Conduct In-Depth Studies

Figure 9. Example Flow Alteration – Function Relationships

Primary Flow Alteration	Predicted Functional Response
Decreased duration of floodplain inundation	• Decreased abundance of young fish • Change in juvenile fish assemblage (all the various species that exist in a habitat) • Loss of floodplain specialists in mollusk assemblage • Reduced growth rate or mortality • Altered assemblages • Desertification of species populations • Reduced area of riparian plan or forest cover • Increase in abundance of non-natives
Shifts in seasonality of peak flows	• Disruption of spawning cues • Decreased reproduction and recruitment • Change in assemblage structure
Loss of seasonal flow peaks	• Reduced riparian plant recruitment • Invasion of exotic riparian plant species • Vegetation encroachment into channels • Reduced plant growth and increased mortality • Reduction in species richness and plant cover
Reduced variability	• Increase in crayfish abundance • Increase in schistosomiasis
Increased variability	• Decreased germination survival and growth of plants • Decreased abundance and change in species assemblage of waterbirds
Loss of extreme high and / or low flows	• Loss of sensitive species • Reduced diversity • Altered assemblages and dominant taxa • Reduced abundance • Increase in non-natives
Greater magnitude of extreme high and / or low flows	• Life-cycle disruption • Reduced species richness • Altered assemblages and abundance of taxa • Loss of sensitive species
Decreased frequency of peak flows	• Reduced reproduction • Decreased abundance or extirpation of native fish • Decreased richness of endemic and sensitive species • Reduced habitat for young fish • Shift in community composition • Reduction in species richness • Increase in wood production

Adapted from Poff et al. 2010

Figure 10. Publicly Available Data for Oregon

Data Type	Public Data Source
Evaporation Data	USBR Pacific Northwest Region- http://www.usbr.gov/pn/agrimet/index.html
Fish Distribution in Oregon	http://q.streamnet.org/Request.cfm?cmd=BuildPicklist&NewQuery=BuildCriteria&Required=Run&DataCategory=23&State=4&PicklistItem=Species
Fish Distribution by Quad Map	https://nrimp.dfw.state.or.us/nrimp/default.aspx?pn=fishdistmaps
Fish Distribution by Watershed, County, etc.	https://nrimp.dfw.state.or.us/website/odfw/viewer.htm
Fish Timing Tables by District	https://nrimp.dfw.state.or.us/nrimp/default.aspx?pn=timingtables
Lake and Reservoir Data	USACE Portland District- 503-808-4510 USACE Walla Walla District- 509-527-7020 USACE San Francisco District- 415-503-6804 WRD – http://www.oregon.gov/owrd/Pages/sw/index.aspx#Surface_Water_Data USBR - http://www.usbr.gov/pn/hydromet/arcread.html
Land-Use Information	DLCD- http://www.oregon.gov/lcd/Pages/index.aspx or local and county planning departments
Precipitation Data	NWS- http://www.cpc.ncep.noaa.gov/products/MD_index.shtml USBR Pacific Northwest Region- http://www.usbr.gov/pn/agrimet/index.html
Recorded Daily Streamflow Data	WRD – http://www.oregon.gov/owrd/Pages/sw/index.aspx#Surface_Water_Data USGS - http://or.water.usgs.gov/ USBR - http://www.usbr.gov/pn/hydromet/arcread.html
Water use data (diversions and return flows)	WRD Water Rights Mapping Tool - http://apps.wrd.state.or.us/apps/gis/wr/Default.htm

Appendix G. References

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