Calculating Channel maintenance/elevated Instream Flows when evaluating Water Right Applications for out of stream and storage water rights

---

Prepared by: **E. George Robison**
Instream Flow Specialist
Water Quantity and Quality Section
Oregon Department of Fish and Wildlife
Salem Oregon

Roy Elicker Director

Guidance Document September 2007

Executive Summary

As water becomes unavailable for further appropriation through the current water availability system, water developers are turning to other flows to augment water supplies. Elevated and peak flows are becoming the focus for water appropriation and the state is beginning to see more water right applications proposing to allocate these flows. Peak flows are those flows that occur less frequently, but at a greater volume than the average flow. In given situations, diverting too much of the elevated or peak flows may jeopardize the habitat formation or other ecological attributes these flows provide. The streams these water rights are being requested for often have been heavily impacted by other diversions and storage projects.

The purpose of this memorandum is to provide guidance to ODFW staff as they make recommendations to Oregon Water Resource Department (OWRD) on the use of peak flows. The guidance could also be used by OWRD staff and private consultants to understand ODFW's reasoning for their recommendations and to determine when and how much of these peak flows should be retained instream. The guidance considers how much flow to provide for ecological and geomorphic functions of streams vs. how much can be appropriated to storage or for other off stream uses such as aquifer storage and recovery, groundwater remediation etc. The policy basis for setting aside a portion of elevated flows, as well as techniques for determining how much or which flows to set aside, are discussed.

The following guidance is for use especially when 1) applicants are asking for water beyond water availability during the storage season (i.e. skimming water from peak flows), 2) the reach where water is being diverted has outstanding fishery/aquatic values, and/or 3) the size of the storage/diversion project will take a significant portion of elevated flows even though water is generally available during the storage season. Evaluations using this guidance should be reserved for streams that can have geomorphic adjustment. Channels constrained by levees and rock walls, typical of channels in urban areas (i.e., Mitigation Category 6) can not properly utilize elevated flows for channel maintenance.

Elevated or peak flows serve several functions. The functions can be divided up between ecological triggering flows that trigger key behaviors such as migration or spawning and geomorphic maintenance flows which help build and maintain overall ecological habitat.   The ecological timing related discharges that are associated with biological behavior shifts are most often species and location specific. These ecological flows are normally needed on a seasonally reoccurring basis.   Some examples include:

1. Elevated flows to flush juvenile migrating fish downstream,
2. Elevated flows to initiate upstream migration of adults, or
3. Elevated flows to complete life cycle dynamics of aquatic insects and other aquatic organisms.

These flows are best defined through biological investigation and observation and typically the expertise and knowledge of the local fish/aquatic biologists provides specific information about fish and other aquatic organism's behavior and how fish and other aquatic life respond to differing stream flows. In contrast, the purpose of channel maintenance or flushing flows are to provide conditions conducive to creating or maintaining stream morphology and habitat and the concern is more focused on the physical structure of the stream and is long term in nature. Specific channel maintenance objectives include:

1. Move existing streambeds and gravels allowing for "cleaning" of gravels intruded with fines which improves spawning habitat and foods sources in the medium and long-term by providing higher quality macro invertebrate habitat;

2. Scour and fill against encroaching riparian vegetation which allows the stream to retain its bed form rather than loosing conveyance capacity and stream habitat;
3. Retain bed configurations including the formation of riffles, pools, and other channel unit habitats;
4. Create conditions for the replenishment of streamside vegetation such as cottonwoods to maintain long-term riparian functions, and/or
5. Maintain large wood movement and function by providing elevated flows to allow wood to be reconfigured and recruited through bank scour mechanisms.

Streamflow needs associated with habitat maintenance can be determined with more general methods. The basic steps recommended for use to determine channel maintenance flow needs are:

1. Determine the channel type: sand bed, gravel bed vs. course bed using channel measurements and/or channel habit unit types.

2. Prescribe flows to be reserved based on the stream bed type.

    a. For sand bed streams channel maintenance needs would cover the <u>full range of flows</u>. Not all flows would be needed to maintain the character of the stream, but a portion of each flow level would be needed.
    b. For gravel bed streams, trigger levels would need to be determined to estimate when channel bed movement events would occur. This estimated trigger can be different for different gravel bed streams based on the gravel size vs. stream characteristics but will vary from 80% of the "bankfull flow" to a streamflow that occurs only once every two years or more. If asking for a trigger level beyond a bankfull flow some analysis and justification would need to be provided regarding sediment size and streamflow forces that show a stable bed at higher flows. Flows greater than the trigger flow level would be preserved instream for channel maintenance functions along with transitional ramping flows to insure the stream does not drop too fast once the stream gets below the trigger level.
    c. Course bed and bed rock controlled streams, may only require water being protected during very high flow events recurring only once every two years or less.

3. Depending on the situation, a hydrologic analysis can also be conducted to determine how often the recommended protection flows occur over a historical record to examine the impact of peak flow reservation on allocations and whether the off stream diversion or storage allocation is even feasible when factoring baseflow water needs, water availability, and elevated flow needs. This step becomes critically important when little or no water is available.

The above steps represent a basic outline of what should be considered in determining peak flow needs and how analysis would vary based on channel type.

This guidance will focus on geomorphic maintenance flows, providing details on how to do the hydrologic and fluvial geomorphic analysis. This memorandum outlines statutes and rules that allude to the need to consider reserving elevated streamflows for a variety of needs including channel maintenance and triggering flows for migration and other behaviors necessary to maintain species survival and covers some of the policy considerations and justifications. Examples are given in Appendixes of how this analysis would be completed for coarse bed, gravel bed and sand bed stream types along with an example of how the State of Washington prescribes elevated flows on the Skagit River.

Table of Contents

List of Tables

List of Figures

Introduction

As water becomes unavailable for further appropriation through the current water availability system water developers are turning to other flows to augment water supplies. Elevated and peak flows are becoming the focus for water appropriation and the state is beginning to see more water right applications proposing to allocate these flows. Peak flows are those flows that occur less frequently, but at a greater volume than the average flow. In given situations, diverting too much of the elevated or peak flows may jeopardize the habitat formation or other ecological attributes these flows provide to the stream. The streams on which these water rights are being requested for often have already been heavily impacted by other diversions and storage of water.

The Water Resources Department currently allocates water using water allocation tables. These tables were created to provide some certainty as to how often water right holders might expect water to be available for use and to try to prevent over allocation of water resources. Allocation of water for immediate off stream use (live flow) is only allowed when water is available 80% of the time (80% exceedence meaning a junior water right holder can expect to have water available for use 8 out of 10 years). For water storage, the allocation levels are established as a policy rather than in rule using a 50% exceedence value which on average would provide water for storage every other year. In many basins, water for live flow and storage projects has been appropriated and no further water development can take place under the existing allocations. Since demand for water continues to increase, proponents of water development projects are beginning to look to the use of higher flood flow (or peak flow) storage as a way to further utilize water available less frequently than the 50% or 80% exceedence will allow.

The purpose of this memorandum is to provide guidance for ODFW staff when considering water right applications that request storage or use of peak flows. The memorandum specifies methods for determining when and how much of these peak flows should be retained to provide for ecological and geomorphic functions of streams while providing an analysis of how much can be appropriated to storage or for other off stream uses such as aquifer storage and recovery, groundwater remediation etc. The policy basis for setting aside a portion of elevated flows for instream use, as well as techniques for determining how much or which flows to set aside, are given.

The following guidance is for use especially when 1) applicants are asking for water beyond water availability during the storage season (i.e. skimming water from peak flows), 2) the reach where water is being diverted has outstanding fishery/aquatic values, and/or 3) the size of the storage/diversion project will take a significant portion of elevated flows even though water is generally available during the storage season. Evaluations using this guidance should be reserved for streams that can have geomorphic adjustment. Channels constrained by levees and rock walls along most of their banks (typical of channels in urban areas, i.e., Mitigation Category 6, OAR 635-415-000) can not properly utilize elevated flows for channel maintenance.

<u>Policy basis for reserving elevated and peak flows for instream use</u>

The ability for ODFW to condition off stream water rights reserving elevated streamflow for instream use comes from two distinct sets of laws and rules. General policies within water law provide for protection of fish, aquatic life and habitat as a public interest. There are also specific laws and rules that allow ODFW to apply for instream water rights as part of the water allocation process.

General Public Interest Policies

Allowance for stream discharge to maintain channel form and habitat is alluded to in several places in Oregon Statutes and rules. For instance, "Public Use" under ORS 537.332 (5)(b) includes *"Conservation, <u>maintenance</u> and enhancement of aquatic and fish life, wildlife, fish and wildlife <u>habitat</u> and any other ecological values"*. (underlined for emphasis) High flows are explicitly allowed in Water Resource Department rules in approving instream water rights even though they are higher than the mean estimated natural flow in OAR 690-077-0015 (4).

Currently, there are no instream water rights that have elevated streamflows included in the prescribed flow levels. All instream water rights are for minimum or optimum water levels that provide for fish habitat based almost exclusively on depth, velocity and substrate criteria. However, in rule, there are several places that allow for consideration of elevated flows even when there are not instream water rights established for them. When evaluating a given water right application, "*instream values*" still should be considered by the Water Resources Department even if there is not an instream water right or for issues that were not included in the original instream water right as a general policy (OAR 690-410-030 (2 (a)). Specifically, for water allocation, water right applications are to be conditioned to protect instream values (OAR 690-410-0070 (2(a))). This applies explicitly to water storage projects (OAR 690-410-0070 (2(c))).

Another area in the rules where channel maintenance flows can be considered is in the Division 33 rules for the Water Resources Department in regards to new water allocations specifically impairing sensitive, threatened or endangered species OAR 690-033-0000 (1) and (2). Evaluation criteria are given in OAR 690-033-0220 and flow management provisions are given in OAR 690-033-0230. If maintaining habitat for an endangered species is involved, then channel maintenance should be part of the considerations in determining what conditions to place on a water right application that removes water from the stream or even to reject the application outright.

Instream Water Rights

The provision for the application for instream water rights is given by ORS 537.332 to 537.360 which was created by the Oregon legislature in 1987. Currently, all instream water rights created under ORS 537 and 690-077 (approximately 1500 water rights) by the Department of Fish and Wildlife are for minimum and optimum flows for direct stream habitat exclusively for salmonid fish species. There are also instream flows created for water quality and recreation needs as well. However, maintenance and elevated flows for triggering migration are also in Fish and Wildlife instream flow rules. According to OAR 635-400-0015 (3) *"Habitat requirements for conservation, <u>maintenance</u> or enhancement of fish and wildlife migration, spawning, nesting, brooding, egg incubation, larval or juvenile development, juvenile and adult rearing and aquatic life shall all be considered when developing an instream requirement."* The concept of channel maintenance in instream water right determination is also repeated in OAR 635-400-0020 (3) (preamble, e, and h). However, the methodologies listed in OAR 635-400-0015 currently do not include any methodologies that specifically evaluate channel maintenance or flushing flows. This may be because there really were not, and can be argued, still are not readily available methodologies to calculate maintenance flows that are quantitative and repeatable to the degree that IFIM PHABSIM (Bovee et al. 1998) analysis or the "Oregon Method" (Thompson 1972) are for determining direct habit discharges. Furthermore, *"all applications for instream water rights shall be based on methods of determining instream flow needs that have been approved by administrative rule of the agencies submitting the applications"* OAR 690-077-0020 (3). An upgrade to the Fish and Wildlife rules to allow for methods for determining channel maintenance flows may be necessary to formalize this process if elevated flows are to become part of instream water right flow applications in the future.

Technical Basis of setting aside elevated instream flows

The technical basis for determining the streamflow's geomorphic function is the same whether ODFW is evaluating an application for storage or other use of peak flows or considering an application for an instream water right for peak flows. Oregon agencies have applied for instream water rights to provide for flows to satisfy immediate habitat needs for fish (spawning, rearing and migration), using determination tools such as the Oregon Method or the Physical Habitat Simulation Model (PHABSIM) as part of an Instream Flow Incremental Methodology (IFIM) investigation (OAR 635-400-0015). These determinations are for minimum or optimum flows that provide suitable velocity and depths over suitable cover and substrates for fish life stages such as spawning and rearing. However, in addition to these base flow needs, elevated or peak flows are also necessary. The ecological needs for elevated streamflows can be divided into ecological triggering flows that cue critical fish or aquatic organism behaviors and channel habitat maintenance flows that maintain long-term habitat forming processes or attributes. Ecological triggering flows are applied to direct habitat needs of fish or other aquatic organisms while channel maintenance flows represent an indirect need that over the long term creates and maintains channel conditions such that they are conducive to aquatic life.

Because of the diversity and complexity of geomorphic/ecologic processes and interactions, some authors have suggested simply mimicking the natural flow regime within some constraint (Arthington et al 2006 or see Washington states recent approach for the Skagit basin, Appendix A) or creating extremely complex ecological models (Anderson et al. 2006). A challenge with mimicking the flow pattern is it allows for little or no storage or off stream allocation of water. It offers little empirical justification for those specific flows other than the argument that aquatic organisms are genetically adapted to the current flow regime and any change to the regime will damage the ecosystem. Creating complex ecological models requires the acquisition of very detailed long-term ecological data and the application of many poorly tested hypotheses to make the models work. Considering management decisions must be made now with often incomplete data, these approaches have serious limitations. The alternative presented here is to prescribe flows to be left instream based on known ecological triggers and to calculate channel maintenance needs based on established methods.

Ecological Triggering flows

Fish and other aquatic organisms are known to key certain activities such as migration or spawning to changes in environmental conditions such as water temperature, turbidity, daily sunlight, or flows (Poff et al. 1997). Usually these conditions need to occur on a regular basis and need to be provided to enable the survival of a species. Some known scenarios where variability in streamflow or elevated flows cause aquatic organisms to initiate important phases of their life cycle include:

1. Increases in flows that initiate fish upstream or downstream migration (Montgomery et al. 1983 and Trepanier et al. 1996);
2. Elevated flows to initiate spawning activity (Nessler et al. 1988);
3. Elevated flow periods to allow for the use of off channel, floodplain, or side channel habitat on large rivers (Sommer et al. 2001 and Morley et al. 2005); or
4. Changes in flow and the initiation of different life stage activity in aquatic insects (Merritt and Cummins, 1984).

The potential combinations of life stage (spawning, rearing, and migration) versus flow change interactions for even just fish are numerous. Adding in potential life stage/streamflow interactions for aquatic insects presents even more possibilities. Because there are so many possibilities, these flows are best defined through biological investigation and observation, and typically the expertise and knowledge of the local fish/aquatic biologists provides specific information about fish and other aquatic organism's behavior and how fish and other aquatic life respond to differing stream flows.

In deciding the significance of an ecological triggering flow, criteria should be used including:

1. Is an elevated streamflow actually triggering a life stage or activity that would otherwise likely not occur without the increased streamflow or is elevated streamflow merely enhancing it;
2. Is the life stage activity crucial for survival of a target species such as game fish or sensitive species; and/or
3. Is the effect of the ecological trigger flow documented by indicating correlation in species abundance with the occurrence of the triggering flow or by studies showing population decline when elevated streamflows are reduced?

When evaluating documentation, species and locations closer to the stream in question carry more weight than studies done in other states or countries. Triggering mechanisms that have been shown in several studies would carry more weight than a single observation from a single study. Because methods for determining needed ecological trigger flows are sometimes not as well established, they may be more open to negotiation than the channel maintenance flows.

Channel Maintenance Flows

Why flows are needed

In contrast to ecological trigger flows, the objective of channel maintenance or flushing flows is to provide conditions conducive to creating or maintaining stream morphology and habitat where the concern is more long term and intermittent in nature. Within this objective, elevated channel forming streamflows serve many purposes including:

1. Moving existing streambeds and gravels allowing for "cleaning" of gravels intruded with fines which improves spawning habitat and foods sources in the medium and long-term by providing higher quality macro invertebrate habitat (Schmidt and Potyondy, 2004);
2. Souring and filling the stream channel against encroaching riparian vegetation which allows the stream to retain its bed form rather than loosing conveyance capacity and stream habitat;
3. Retaining bed configurations including the formation of riffles and pools and other channel unit habitats (Knighton, 1998);
4. Creating conditions for the replenishment of streamside vegetation such as cottonwoods (*Populus sp.*) to maintain long-term riparian functions (Richter and Richter, 2000); and/or

5. Maintaining large wood movement and function by providing elevated flows to allow wood to reconfigure and be recruited via mechanisms such as bank scour.

While there are many purposes for elevated streamflows in maintaining channel form and function, the focus of this guidance is on methods for determining streamflows in which bed movement occurs. The reason for this emphasis is channel movement underlies many of these formative processes. The number and sophistication of methods to find appropriate flow levels varies for each purpose. Of these purposes there are more numerous and refined methods for determining the needed flows for moving the streambed (Gordon et al. 2004). Methods to determine flows for other purposes are site specific and only apply to certain channel types. For instance, the method given by Richter and Richter (2000) to create conditions for streamside vegetation replenishment applies only to meandering streams with fine grains. The methods for determining flows needed to create channel configuration (Knighton, 1998) are strongly tied to sediment inputs as well as the prevalence of large woody debris and other factors, but the requirement of bed movement is a large factor. Flows needed to remove encroaching vegetation are going to vary based on vegetation type and stream type but are also integrally related to bed movement flows.
In the literature, there are many approaches to determining channel maintenance flows with no clear consensus on a single given method (Schmidt and Potyondy, 2004).

Most methods attempt to customize the flow prescription based on the stream type or where it fits in a channel classification. These methods distinguish fine or sand bed stream reaches in which the bed moves even during the smallest events to course bed streams that require higher flows to initiate bed movement (Texas Water Quality Commission, 2006). The channel maintenance flow needs for different stream types can be radically different; therefore, stream channel classification and/or a stream bed composition analysis is necessary in any channel maintenance flow study.

Determination of Sediment bed types

The major determinant of the maintenance streamflow regime will be its bed composition with a) sand bed streams b) gravel bed streams and c) course bed streams needing different flow prescriptions. This is because the discharge level that can move the streambed is directly related to substrate size and characteristics (Knighton, 1998). Almost all methods on how to determine channel maintenance discharge requirements determine the prevalent streambed composition as the first step in the analysis (Reiser et al. 1990; Gordon et al. 2004). How to delineate what the streambed composition will be for the reach or segment of concern best comes from a field investigation of the streambed substrate using methods ranging from a surface pebble count to subsurface sieving of bed materials (Wolman, 1954; Bunte and Abt, 2001). In some analyses that involve bed shear stress or velocity vs. bed sediment size, a specific bed size gradation will need to be determined. With other more cursory methods, a more general classing of the reach into one of the three types will suffice.

Sand bed streams have a high percentage of fines and sands in the bed. Gravel bed streams have a prevalence of gravels along with fine and course material. Course bed streams have mostly cobbles, boulders and/or bed rock as the prominent streambed material. Rosgen (2004) distinguishes bed type by what is the “D 50” (median particle size) or the dominant particle size (i.e. the statistical “mode”) from a Wolman (1954) pebble count method in which 100 surface bed particles are randomly measured. If the median or mode particle size (intermediate axis; Wolman, 1954) is less than about 1/10 of an inch then it is a sand or fine bed stream, if particle size is between 0.1 to about 2.5 inches then it is a gravel bed stream, if greater than 2.5 inches then a coarse bed stream type.

General “reach scale” stream channel classification schemes can be used to estimate what type of bed composition will be present. A “reach” is a length of stream that has similar morphology characteristics like width and streamflow that can be anywhere from 100 feet to over a mile long. Stream bed composition in a reach is largely determined by five factors that include the streams discharge regime, valley slope leading to overall stream slope, how constrained the stream is by its hill slope, sediment supply and characteristics, and the prevalence of large roughness in the stream such as wood or boulders (Robison, 1998). These factors in turn are determined by climate, topography, geology, and the position of the reach in the stream channel watershed network. There are many ways to classify streams that will give an indication of the substrate type that may be available including Rosgen (1994) and Montgomery and Buffington (1997). Channel classification systems differ in their objectives with some being used for restoration while others are used for specific regulatory or management goals (Kondolf et al. 2003). In using a classification system for the purpose of determining the bed substrate composition, the one chosen must be focused on reach scale and be able to differentiate the prevalent bed substrate based on what type they are classed into. Both the Rosgen and the Montgomery and Buffington classification schemes can do this in certain situations. As an alternative to these schemes, Oregon has developed its own stream channel classification scheme as part of the Oregon Watershed Assessment Manual (Watershed Professionals Network, 1999). The Oregon scheme is reach focused and the different channel types generally can be classed into different bed sediment types.

Using the Oregon Watershed Assessment manual as a means to initially classify streams has key advantages in Oregon because the method is already known to the natural resources community and many of the streams have already been classified. In many cases, published information about stream classification is available from watershed councils or from Oregon Watershed Enhancement Board (see http://www.oregon.gov/OWEB/WSHEDS/index.shtml for sources of information). The Oregon Watershed Assessment Manual has 15 stream types that are delineated based on stream size, slope, confinement, and position in the watershed (Figure 1 and Table 1; Watershed Professionals Network, 1999). A reach is normally delineated from topographic maps and air photo coverage based on these characteristics. For a first cut determination, channel types with lower gradient and unconfined floodplains ES EL and FP1 would generally fall into the sand bed stream category. Streams with low to moderate slope and confinement would be either gravel or sandbed streams in most cases (i.e., FP2, FP3, AF). Stream reaches with moderate gradient and low to moderate confinement would be categorized into gravel bed streams (i.e., LM, LC, MM, MC, and MH). Stream reaches with steep gradient and moderate to tight confinement MV, BC, SV, and BH types would fall most often into the coarse bed category (see Figure 1 and Table 1 below). Understand that these are generalizations. There are many cases where a stream class could legitimately have different stream bed compositions. For instance, the moderate gradient headwater type (MH) could have almost any bed type depending on sediment supply and stream slope.

Also at times the streambed will already be altered due to pre-existing diversions and regulation, so it will be important to discern this when taking field data or applying a general classification to a stream reach. For this reason, site specific bed substrate size data sometimes may need to be overruled by general classification results.

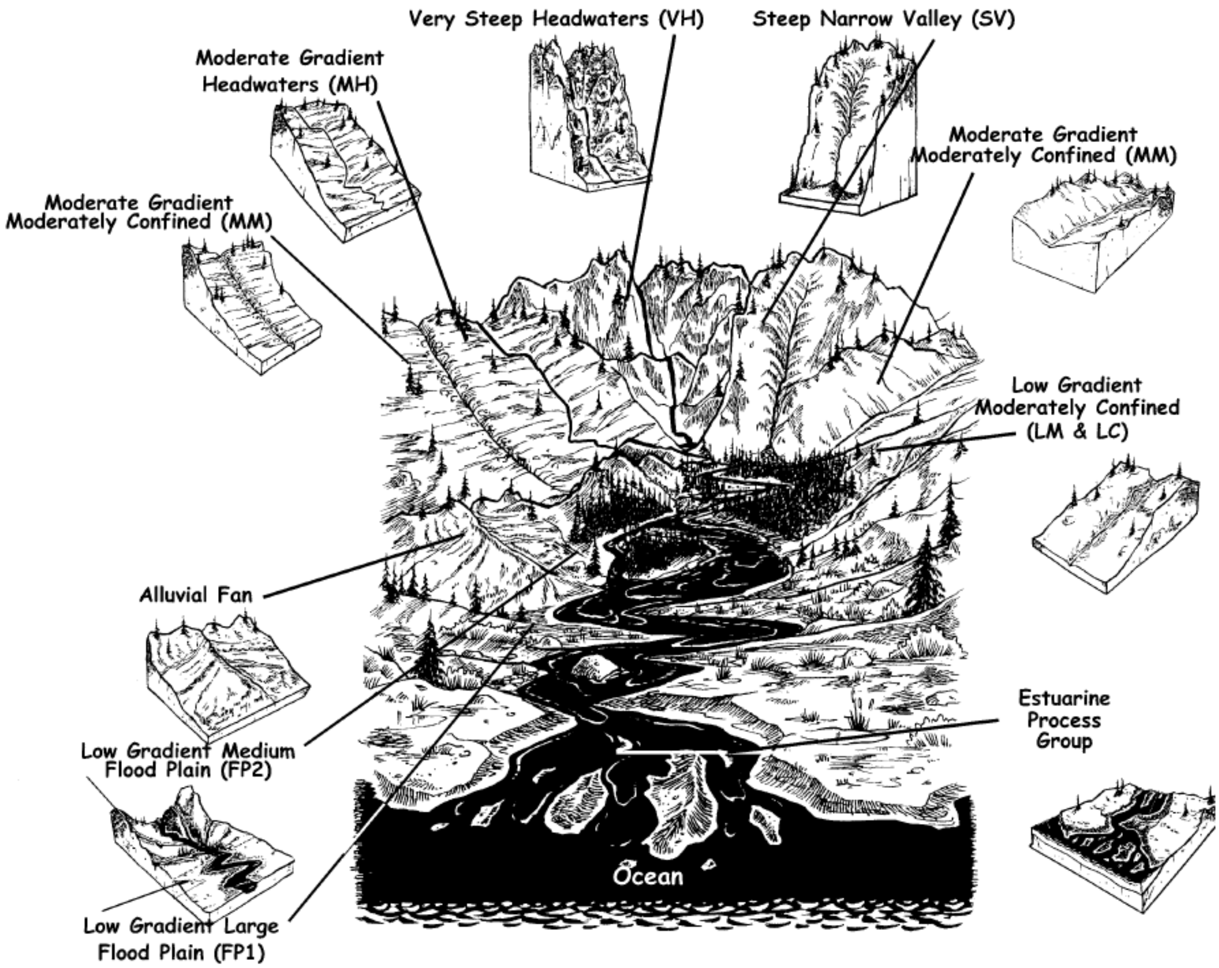


Figure 1. Channel habitat types from the Oregon Watershed Assessment Manual (Watershed Professionals Network, 1999)

In most cases any findings done using a general classification scheme should be verified with field information. In addition to general classification there is existing data from habitat surveys (Moore et al. 1999) and databases available for many stream reaches that have visual characterizations of sediment. There is also existing data from the Department of Environmental Quality, Forest Service and other agencies that have for various reasons characterized the sediment at the reach scale. These sources can be used to help verify the sediment composition of the reaches. Two clearing houses for this information include the Stream Net database (http://www.streamnet.org/online-data/ids.cfm?keywords) and the Oregon Natural Resources Information Program database (http://nrimp.dfw.state.or.us/nrimp/default.aspx?p=259).

In deciding the streambed type, it is also important to locate the target stream reach that is affected by the diversion. Generally, this will be the stream reach that is immediately downstream. However, in some cases, the target reach may be located further downstream. An example would be the diversion is at the upstream end of a constrained canyon which would be a course bed stream reach but five miles downstream the channel gradient decreases and the valley broadens out and now the stream is a sand bed stream. The resulting prescription would have to factor in the channel maintenance needs of the canyon but also of the sand bed stream downstream of the canyon. Since prescriptions for sand bed streams are more inclusive of different flow needs the analysis would probably be for a sand bed stream.

Table 1. Channel Unit types as used in the Oregon Watershed Assessment Manual (Watershed Professionals Network 1999) (probable substrate types added to right).

Code	CHT Name	Gradient	Channel Confinement	Size	Bed
ES	Small Estuary	<1%	Unconfined to moderately confined	Small to medium	Sand
EL	Large Estuary	<1%	Unconfined to moderately confined	Large	Sand
FP1	Low Gradient Large Floodplain	<1%	Unconfined	Large	Sand
FP2	Low Gradient Medium Floodplain	<2%	Unconfined	Medium to large	GR/SA
FP3	Low Gradient Small Floodplain	<2%	Unconfined	Small to medium	GR/SA
AF	Alluvial Fan	1-5%	Variable	Small to medium	GR/SA
LM	Low Gradient Moderately Confined	<2%	Moderately confined	Variable	Gravel
LC	Low Gradient Confined	<2%	Confined	Variable	Gravel
MM	Moderate Gradient Moderately Confined	2-4%	Moderately confined	Variable	Gravel
MC	Moderate Gradient Confined	2-4%	Confined	Variable	Gravel
MH	Moderate Gradient Headwater	1-6%	Confined	Small	Gravel
MV	Moderately Steep Narrow Valley	3-10%	Confined	Small to medium	Coarse
BC	Bedrock Canyon	1->20%	Confined	Variable	Coarse
SV	Steep Narrow Valley	8-16%	Confined	Small	Coarse
VH	Very Steep Headwater	>16%	Confined	Small	Coarse

Note: Stream size refers to the ODF designations based on average annual streamflow. Small streams possess flows less than or equal to 2 cubic feet per second (cfs). Medium streams possess flows greater than 2 but less than 10 cfs. Large streams possess flows of 10 cfs or greater. Stream sizes are mapped at 1:24,000 for the entire state, with the exception of the southeast quarter of the state.

Instream flow need variation with streambed type

Sand Bed Streams

Sand bed streams require a longer duration of elevated flows but not necessarily the very highest flows for channel maintenance because the bed moves at even the smallest elevation of flow. Therefore, protection of lower elevated flows between baseflow and bankfull flow are necessary with less protection required for the higher flows at or beyond bankfull stage in many cases. Methods for determining threshold flows are given in Reiser et al. (1989) but almost any elevated flow will induce bed transport on a sand bed stream.

On a sand bed stream, instream flow allocations should include streamflows from the whole spectrum of discharges because different discharges fulfill different roles in terms of channel maintenance. Baseflow levels based on direct physical habitat needs can be determined with tools such as PHABSIM (Bovee et al. 1998) or the Oregon Method (Thompson, 1972). Lower elevated flows will allow for bed movement and create small scale bed forms, small peak flows will reform the channel and clean out fines from gravel bed spawning areas where they occur. The very highest peak flows will provide for riparian and flood plain connection and maintenance which may be an important habitat factor (Hill et al. 1991, Richter and Richter, 2000 and Chapin et al. 2002). In addition, many of these sand bed/fine bed streams have broad floodplains and numerous side channels and fish may use these areas for extended periods during times of elevated streamflow (Sommer et al. 2001 and Morley et al. 2005). Because of this potential use, maintenance of vegetation and habitat conditions related to areas inundated in floodplains becomes more significant.

A prescription may be to allow for an extended time period where a portion or all of the elevated flow is bypassed during the high flow season for these types of streams. This may be coupled with a time period where there is a known ecological trigger flow timing component to meet two needs at once. Specifically the approaches can take the following forms.

1. A percentage of flow in which 70-90 percent of the elevated flows are retained instream and the hydrograph follows the same pattern as a natural hydrograph with the flows reduced as a percentage.
2. A critical time period (such as a month or six week period) in which all flows are bypassed in order to allow channel maintenance functions to occur while there are other time periods where water can be allocated down to a minimum streamflow associated with direct fish or aquatic habitat (see Appendix A for an example).
3. A percentage 10-20% of a specified flow such as the storage season median or mean flow is given as allocation for out of stream or storage uses with the rest going instream (see Appendix D from Skagit River rule in Washington for this type of prescription).
4. A trigger flow is set at a one or two year instantaneous peak flow depending on specific bed composition and stream characteristics. All flows greater than that amount are bypassed instream until flow reaches a high flow trigger in which the diversion/storage can begin again. In addition, when the stream is less than the trigger and greater than the minimum flow level water will be retained instream for a given time period or percentage of streamflow. This option requires real time gaging and the ability to change the diversion/storage rate relatively quickly.

Examples of flow regime prescriptions for a sand bed stream are given in Appendix D (Washington State) and Appendix A (a hypothetical stream in Oregon using these guidelines). The choice of which approach is best for a sand bed stream will be based on site specific conditions taking into consideration possible ecological trigger flows in order to try to get maximum function out of the elevated streamflow. Another consideration is the ability and ease of implementation. Option number 2 is relatively easy to implement and regulate while option number 4 requires more gaging and active management.

Gravel Bed Streams

Gravel bed streams have courser materials. For only slightly elevated flows there may be little reason to retain these flows for channel maintenance purposes. However, streamflow will need to be maintained for the baseflows that are necessary to maintain habitat functions that were determined using a tool such as PHABSIM or the Oregon Method. At some point, around the bankfull flow, all flows should be bypassed to allow for channel maintenance functions to occur (Schmidt and Potyondy, 2004; Figure 2 below). Figure 2 illustrates the theory of dominant or effective discharge in which there is a streamflow level that does most of the geomorphic work (i.e. transports most of the sediment and sets in place most of the channel bedforms). This effective discharge is the level at which there is sufficient streamflow to move sediment coupled with it occurs often enough and long enough to do significant work. Larger events can carry and move more sediment but they occur less frequently so they do less work. Smaller events occur more often but have such low transport capability that they do little work. The point at which streamflow is high enough to move a significant portion of the streambed is the level at which bypass of streamflow to instream use should be triggered. In Figure 2 this is a flow that is greater than smaller flows that only transport fine material but less than the "effective discharge" so that this dominant streamflow that does the most geomorphic work is bypassed.

Schmidt and Potyondy (2004) have a solid outline of how to determine channel maintenance flows for gravel bed streams particularly in areas dominated by snowmelt runoff. Unfortunately there is not a comprehensive "how to" manual for gravel bed streams in other hydrologic regimes nor is there such a tool for sand bed streams as yet.

The actual trigger flow point where the channel is mobile usually corresponds to a level at or near bankfull flow (Schmidt and Potyondy (2004). Schmidt and Potyondy suggest using 80% of the "bankfull flow" as the trigger in Rocky Mountain systems. In the literature, the actual recurrence of bankfull flow can vary from 1-32 years with an average of 1.5 years (see Williams, 1978 as an example). For a dataset of mostly larger Pacific Northwest Rivers (Castro and Jackson, 2001) recurrence intervals were found to vary between 1-3 years with a mean of 1.4 years with somewhat smaller recurrence for wetter coastal streams (1.2 years) than drier interior streams (1.5 years). A factor that seems to make "bankfull" flow recur less often is higher overall flow variability (Knighton, 1998). Oregon has high variability about the annual mean peak flow (i.e. more flashy streams compared to most places). Schmidt and Potyondy also suggest 80% of bankfull is the best overall value for when the streambed begins to move but flows for bed movement can be as high as a 75 year recurrence for streams with beds and banks that are highly resistant to erosion (Grant and Wolf, 1991). The events that can move the bed are also rarer for "supply limited" streams (streams that have more capacity to move sediment than they have sediment supply). Oregon gravel bed streams tend to be supply limited, in most cases exhibiting indicators such as streambed armoring as well as a lack of depositional features.

Because Oregon streams are considered generally "supply limited," tend to be armored, and most have high flow variability, a reasonable approach would be to have a rarer event for a "trigger flow" than one that occurs every 1.4 years or more (i.e. Castro and Jackson's bankfull flow recurrence values). For Oregon gravel bed streams, a two year recurrence flood event represents a likely place where significant sediment transport and bed movement is occurring and would be a reasonable streamflow level for a trigger flow. If stream characteristics indicate a stream has abundant sediment supply (by having features such as numerous bars and braiding) or has lower flow variation, a trigger flow that occurs more often such as a one year recurrence flow or 80% of a bankfull flow should be advocated.

Course Bed Streams

Course bed streams are those that have cobble, boulder or bedrock substrate. In this case, only the most extreme flows need to be bypassed to help reform the stream because it is only the very high flows that have a channel forming feature (Knighton, 1998). A starting place would be to prescribe the two year recurrence peak flow and/or the calculated bankfull flow as the trigger flow to bypass to allow channel maintenance functions. It is possible that flows need only be reserved and bypassed once every several years during an extreme event to allow the water to provide essential maintenance functions such as clearing away encroaching vegetation in the limited areas where they occur. Some justification regarding the streams overall resistance to bed transport events would have to be provided in order to justify prescribing a less frequently occurring streamflow as the initial trigger.

As with sand bed and gravel bed streams, course bed streams require baseflow levels to maintain direct instream habitat. These are determined using tools such as PHABSIM (Bovee et al. 1998) and the Oregon Method (Thompson et al. 1972).

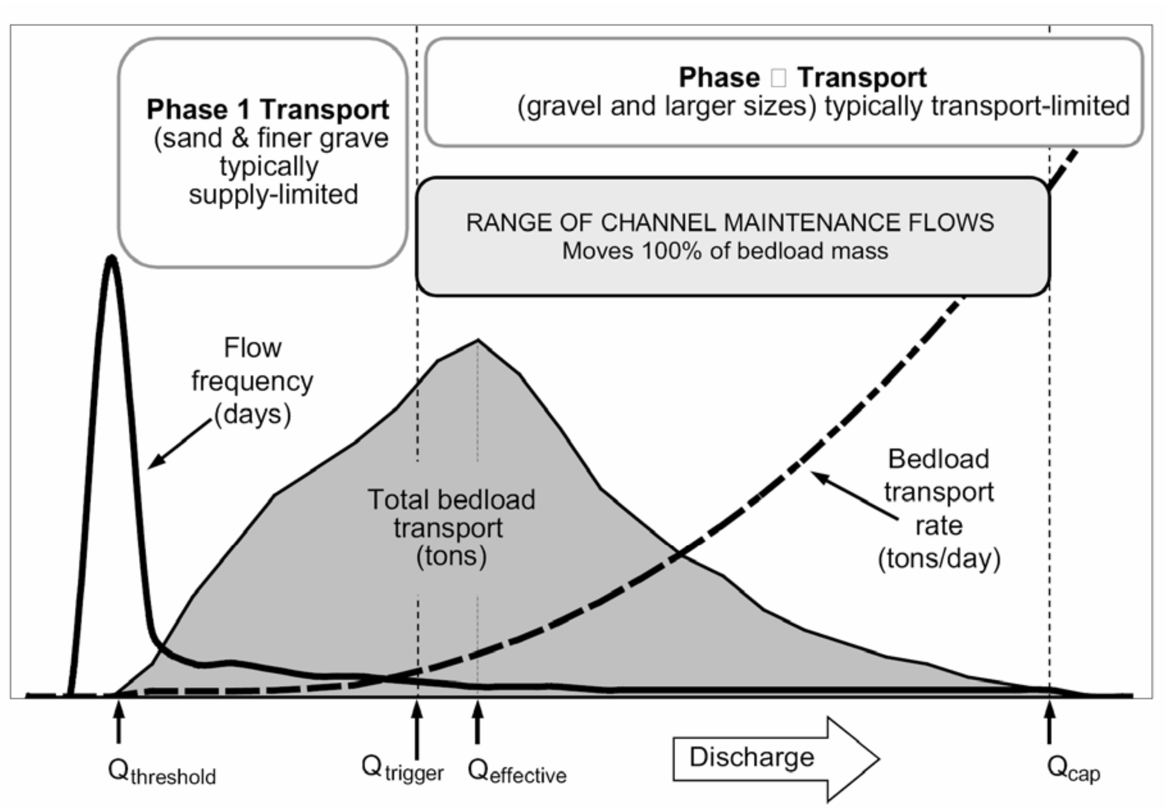


Figure 2. Schematic of long-term total bedload transport model for gravel-bed rivers based on Wolman and Miller's magnitude-frequency concepts.
(Bedload movement begins at Q threshold, flows between Qthreshold and Qtrigger are Phase 1 transport, Qtrigger is the beginning of Phase 2 transport, flows exceeding Qtrigger are Phase 2 and move the majority of the coarse sizes, and Qcap is the upper limit of the required channel maintenance flow regime. Flows from Qtrigger to Qcap constitute the range of flows necessary to maintain the channel. (Schmidt and Potyondy, 2004)).

Proposed Steps in Determining Channel Maintenance Flows

The steps for determining a channel maintenance flow are:

1. Determine the channel type:

The bed type (sand bed, gravel bed or course bed) needs to be determined using channel measurements and/or channel habit unit types. See references and discussion given previously for more information on this step. For cursory analysis or to determine which general prescription will be appropriate for a reach downstream of a diversion or storage project a channel classification determination of dominant sediment type (i.e. Table 1) may be all that is necessary. However, if a more advanced method is warranted because a project is proposing to take a large percentage of streamflow or because the reach has high fish values or concerns, it may be necessary to conduct a sediment bed composition assessment in which the dominant substrate is determined using Wolman Pebble Count (Wolman, 1954) or other techniques (Bunte and Abt, 2001).

2. Prescribe instream flow reservation regime based on stream bed type

Sand bed Streams

For sand bed stream types, the streamflows reserved for channel maintenance will be over the full range of flows. Not all flows need be protected to retain the character of the stream but a portion of each of the flow types should be protected. Hydrologic and/or geomorphic analysis is needed to understand the flow regime of the stream over time to decide on which flows need to be reserved for various functions. One of these functions is a time period of elevated flows for general movement of bed substrate and peak flow periods to connect the floodplain and reset riparian vegetation (Hill et al. 1991). A time period of elevated flows should be reserved along with some component of very high peak flows. It may be preferable to coincide the reservation of the elevated flow with a known or suspected ecological trigger flow need such as downstream flushing of juvenile anadromous fish. Some considerations in doing this analysis include the following.

- The best way to do a hydrologic analysis is to use gaged data. The 2 year and possibly the 5 year and 10 year peak flow should be determined to provide context for the flow regime.
- If no gage data is available for use, peak flow estimates for ungaged and gaged sites can be obtained from Cooper (2005; Western Oregon) and Cooper (2006; Eastern Oregon). Information on using these tools from the Water Resources Department's website can be found at: http://www.wrd.state.or.us/OWRD/SW/peak_flow.shtml. Tools that can be used to get peak flow information include 1) regional regression models developed by Cooper, 2) basin area ratios to apply flow information form a nearby gage to the stream, or 3) a combination of both. Using a basin ratio approach vs. a regional model is sometimes a difficult decision with models being preferred in areas with a relatively dense network of gages and basin ratios preferred in areas with significant model error and closer matching/pairing between the watershed being studied and the nearby gaged watershed for comparison. Information on discerning which method to use can be found in Robison (1991) and Cooper (2005 and 2006). When interpreting output from Water Resources Department tools, remember that gage data is preferable to data based on empirical models because it represents actual measured values at the site.
- If a continuous record is desired, stream flow can be modeled using precipitation and watershed data (Fedora, 1987 or other methods). These are often called rainfall runoff models and the best ones to use are based on site conditions, available data, and the analysts comfort with the various techniques.
- Another way to determine the bankfull flow, if you are dealing with an ungaged basin and have little confidence in the modeled flows (or want to have a second check against the modeled flows), is to estimate the bankfull discharge. This method would be useful in areas where streamflow records are lacking and the variation in bed type makes a beginning of bed movement problematic. Methods to determine the bankfull water line include Gordon et al. (2004). Gordon et al. also instructs on how to use the slope area method to estimate the discharge. Training videos are available that can be used to train personnel on determining bankfull water levels especially for streams that have easily discernable depositional surfaces (USFS, 2003 and 2005). Hardy et al. (2006) also provides a tool (WinXSPro) for quickly determining flows from cross-sectional data, roughness and slope once the bankfull water level has been determined. As stated above, these geomorphic/hydrological interaction calculations are complex. Contact the instream flow specialist if needed.

- Flow reservation for instream should include streamflows at all levels including the largest peaks. A strategy may be to allow all water to go through for a longer time period when flows are normally high and then allocate down to the minimum streamflow during other time periods (see list of various flow regime types on page 9).
- It would be desirable to allocate a leading and trailing edge to a flood flow regime and provide for minimum down ramping rates because ramping can be a major factor in the decline of fishery species in and around storage and diversion facilities (Harby et al. 2001 and many others).

With a sand bed or fine bed stream, almost any elevated flow will initiate bed movement so the calculation of a channel bed movement trigger flow is not as important. Perhaps more important is understanding where bankfull and overbank flows occur that connect streams with their flood plains and provide events to reset riparian vegetation. The level at which overbank flows would occur usually requires a geomorphic analysis.

Some considerations in doing a geomorphic analysis include:

- Tools such as "WinXSPro" (Hardy et al. 2006) can be used along with representative stream cross-sections to estimate at what streamflow level bankfull and overbank flows occur and perhaps a trigger flow can be prescribed to allow for bypass of streamflows higher than that trigger. Also critical is determining the actual bankfull flow or active channel flow stage level for the cross section(s). Training for determining bankfull active channel flow are given in Forest Service videos (USFS, 2003 and 2005) along with textbooks Rosgen (1996), Knighton, (1998) and Gordon et al. (2004).
- If there is "backwatering" from channel constrictions or channel feature such as debris dams a more in depth investigation may need to occur using tools such as HEC RAS (Brunner, 2002)
- Calculations regarding hydrological/geomorphic interactions are among the most complicated encountered in natural resources and require specialized knowledge. Contact the instream flow specialist as needed.

Gravel Bed Streams

For gravel bed stream types, several representative cross-sections should be measured and/or a hydrologic analysis should be done to determine the trigger flows. Once the trigger flows are determined then all or most flows above the trigger should be protected. Some considerations regarding the determination of the trigger flow and subsequent calculations include:

- Trigger flows can be estimated from a known recurrence of a gaged or modeled peak flow. See section above regarding methods for determining recurrence interval flows for gaged and ungaged streams. As discussed earlier a 2 year reccurence flow will be a good candidate for the trigger flow level unless there is low flow variation or ample sediment which will lead to a more frequent reccurence such as a 1 year flood flow.
- The bankfull flow (or a percentage of it) can be considered the "trigger flow" in which bed movement occurs. Methods for calculating bankfull flow are given above.
- An analysis can be done with cross-sectional and substrate data to estimate at what critical velocity or shear stress the stream will likely have the initiation of bed movement. Methods for conducting this kind of study are in Gordon et al. (2004) and Knighton (1998). An example of this type of analysis is given by Wilcock et al. 1996. WinXSPro (Hardy et al.

(2006) also provides a tool to determine this if substrate, morphological and flow data are applied. As the gravel size becomes larger, generally a greater peak flow event is necessary to initiate bedload movement so perhaps a longer recurrence interval can be used (Gordon et al. 2004).

In most prescriptions, all or most discharges greater than the trigger flow will be reserved. An example of how a flow prescription can be done for a gravel bed or coarse bed stream using only hydrologic records and channel classification is given in Appendix B. Examples on how to do a more in depth analysis of when bed movement flows begin to occur and what level to set flows at include some of the references given above along with Reiser et al. (1989) and Wilcock et al (1996).

Coarse Bed Streams

For course bed and bed rock controlled streams conduct a hydrologic and/or fluvial geomorphic analysis to determine trigger flows for this stream type. Most of these flows should be only floods that occur once every two to three years or less frequently on average. For very bedrock dominated streams, it is also possible that channel maintenance flows would not be required because the bed is insensitive to reworking by discharge. The methods to determine the "trigger flow" are almost identical to that of gravel bed streams but may involve larger recurrence intervals (i.e. a 3 year peak flow vs. a 2 year peak flow). An example of analysis for elevated flows for a course bed stream is given in Appendix C.

Multiple streambed types

Often times the reach that will be most directly impacted will consist of two or more streambed types. Often times the transition for a gravel bed to a sand bed stream is abrupt – marked by a discontinuity in overall streambed slope, sediment supply or another factor (Parker and Cui, 1998). If a reach has both sandbed and gravel bed characteristics, independent analyses of flow needs for both may need to be done and the one that needs the most flow will be the determinative factor in providing instream flow recommendations.

3. Hydrologic Analysis

In stream basins with a high degree of off stream water use, a first step would be to evaluate the level of out of stream and storage use there is during the non-irrigation season. In some cases there is very little use even when there is high irrigation use, in other cases there is high storage and out of stream allocation even during the winter months. Streams that already have considerable storage and flow modification during the non-irrigation season (generally November – March or April) warrant more concern because of the degree of past flow modification. If there is little or no water available and already significant diversion and storage, a hydrologic analysis should also be done to determine how often these flows occur to evaluate if the proposed water right is still feasible with peak flow and base flow conditions applied. This analysis will require an actual or synthesized hydrologic record. The analysis should be over a longer time frame (such as 10 years or more), include the daily flows versus the different trigger flows where water will be left in the stream and also the baseflow instream water right. Spreadsheet functions are useful in figuring how much water would be allocated in these analyses. Oregon Department of Fish and Wildlife has some example calculations on spreadsheet if interested in understanding how to do this analysis. Some examples of hydrologic analysis are given in Appendixes A-C).

<u>Conclusions</u>

The above steps represent only an outline of what would be done and how analysis would vary based on channel type. There should also be consultation with local biologists regarding any ecological trigger flows that may initiate migration, shift behavior, or that may be used to help flush migrating fish downstream. Many of the channel maintenance flow calculations are complex and specialized. Please contact the instream flow specialist if needed when reviewing calculations or conducting a study. Any diversion or storage project that has the ability to impact elevated flows that may provide these functions should have some analysis of the possible impacts if there is stream habitat involved. The degree of analysis and concern should be proportional to the size of the project vs. the stream size, the degree of impact the stream has already sustained due to other storage or off channel diversion projects, and the importance of the habitat or fishery involved. It should also be recognized that once these conditions or prescriptions are determined, that stream gaging with the ability to be evaluated in real time may be necessary to determine when to initiate bypass of streamflow into streams if a trigger flow mechanism is used for conditioning the new water permit.

References

(note: most of these can be provided by request except for textbook references)

Anderson, K.E., A.J. Paul, E. McCauley, L.J. Jackson, J.R. Post, and R.M. Nisbet. 2006. Instream flow needs in streams and rivers: the importance of understanding ecological dynamics. Front. Ecol. Environ. 4(6) 309-318.

Arthington, A.H., S.E. Bunn, N.L. Poff, and R.J. Naiman. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications 16(4) p. 1311-1318.

Bovee, K.D., B.L. Lamb, J.M. Barholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Res. Div. Information and Tech. Report USGS/BRD-1998-004, viii = 131 pp.

Brunner, G.W. 2002. HEC-RAS River System Analysis Users Manual. U.S. Army Corp of Engineers. Software downloads along with user manual are available at: http://www.hec.usace.army.mil/software/hec-ras/

Castro, J. and P. L. Jackson. 2001. Bankfull discharge recurrence intervals and regional hydraulic geometry relationships: Patterns in the Pacific Northwest, USA. Jour. Wat. Res. Assoc. 37(5): 1249-1262.

Chapin, D.M, R.L. Beschta, H.W. Shen. 2002. Relationships between flood frequencies and riparian plant communities in the Upper Klamath Basin, Oregon. Jour. Water Res. Assoc. 38(3): 603-617.

Cooper, R.M. 2005. Estimation of peak discharges for rural, unregulated streams in Western Oregon: U.S. Geological Survey Scientific Investigations Report 2005–5116, 134 p. Program available at (http://www.wrd.state.or.us/OWRD/SW/peak_flow.shtml)

Cooper, R.M. 2006. Estimation of peak discharges for rural, unregulated streams in Eastern Oregon: U.S. Geological Survey Scientific Investigations Draft Report 2006. 152 p. Program available at (http://www.wrd.state.or.us/OWRD/SW/peak_flow.shtml)

Bunte, K., and S.R. Abt. 2001, Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and stream-bed monitoring: U.S. Department of Agriculture Forest Service Rocky Mountain Research Station General Technical Report RMRS-GTR-74, 428 p.

Fedora, M. A. 1987. Simulation of storm runoff in the Oregon Coast Range. U.S. Department of Interior Bureau of Land Management, Technical Note 378, Denver, Colorado.

Gordon, N.D., T.A. McMahon, B.L. Finlayson, C.J. Gippel, and R.J. Nathan. 2004. Stream Hydrology: An Introduction for Ecologists, 2nd Ed. Wiley and Sons N.Y. 444 p.

Grant, G.E. and Wolff, A.L. 1991. Long-term patterns of sediment transport after timber harvest, western Cascade Mountains, Oregon, USA. In: Walling, D.E. and Peters, N. (eds) Sediment and Stream Water Quality in a Changing Environment, Proceedings of the Vienna IAHS Symposium, International Association of Hydrological Sciences Publ. No. 203, Oxfordshire, U.K. p. 31-40.

Harby, A, K.T. Alfredson and 11 other authors. 2001. Ecological impacts of hydropeaking in rivers. 8 p. In: Hydropower in the New Millennium: Proceedings of the 4th International Conference on Hydropower Development Hydropower '01/Bergen/Norway/20-22 June 2001 Bjorn Honningsvag (Ed.)

Hardy, T.; P. Panja; and D. Mathias. 2005 WinXSPRO, A Channel Cross Section Analyzer, User's Manual, Version 3.0. Gen. Tech. Rep. RMRS-GTR-147. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 94 p.

Hill, M.T., W.S. Platts, and R.L. Beschta. 1991. Ecological and gemorphological concepts for instream and out-of-channel flow requirements. Rivers 2(3) p. 198-210.

Interagency Advisory Committee on Water Data. 1982. Guidelines for determining flood flow frequency. Bulletin 17b. USGS. Office of Water Data Coordination. Reston, Virginia, 22092. http://water.usgs.gov/osw/bulletin17b/bulletin_17B.html

Knighton, D. 1998. Fluvial Forms and Processes: A New Perspective. Oxford University Press N.Y. N.Y. 383p.

Kondolf, G. M., D.R. Montgomery, H. Piégay, and L. Schmitt. 2003.Geomorphic classification of rivers and streams, in Tools in Fluvial Geomorphology, edited by G. M. Kondolf and H. Piégay, John Wiley & Sons, Inc., p. 171-204.

Merritt, R.W. and K.W. Cummins (eds). 1984. An introduction to the aquatic insects of North America 2nd Edition. Kendall Hunt Publishing Co. Dubuque Iowa. 722 p.

Montgomery, D. R. and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin, 109(5), 596-611.

Montgomery W.L., S.D. McCormick, R.J. Naiman, F.G.Whoriskey, and G.A. Black. 1983. Spring migratory synchrony of salmonid, cato-stomid, and cyprinid fishes in RiviSre la Truite, Quebec. Canadian Journal of Zoology 61: 2495-2502.

Moore, K.M.S., K.K. Jones, and J.M. Dambacher. 1999. Methods for stream habitat surveys. Oregon Department of Fish and Wildlife. Corvallis, Oregon.

Morley, S.A., P.S. Garcia, T.R. Bennett, and P. Roni. 2005. Juvenile salmonid (Oncorhynchus spp.) use of constructed and natural side channel in Pacific Northwest rivers. Can. Jour. Fish. Aquat. Sci. 62:2811-2821.

Nesler T.P., R.T. Muth, A.F. Wasowicz. 1988. Evidence for baseline flow spikes as spawning cues for Colorado Squawfish in the Yampa River, Colorado. American Fisheries Society Symposium 5: 68-79.

Parker, G. and Y. Cui. 1998. The arrested gravel front: Stable gravel-sand transitions in Rivers Part 1: Simplified analytical solution. Jour. of Hydraul. Res., 36(1) 75-100.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. Richter, R. Sparks, and J. Stromberg. 1997. The natural flow regime: a new paradigm for riverine conservation and restoration. BioScience 47:769-784.

Richter, B.D. and H.E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. Conservation Biology 14:1467-1478.

Reiser, D.W., M.P. Ramey, and T.A. Wesche. 1989. Flushing flows. Pp. 91-135 in: J.A. Gore and G.E. Petts, editors. Alternatives in regulated river management. CRC Press, Boca Raton, Florida.

Robison, E.G. 1991. Methods for determining streamflow and water availability for Oregon Rivers and Streams. Hydrology Report #2. Oregon Water Resources Department, Salem Oregon.

Robison, E.G. 1998. Reach scale sampling metrics and longitudinal pattern adjustments of small streams. Ph.D. Dissertation. Oregon State University Forest Engineering and Civil, Construction and Environmental Engineering Departments. Corvallis OR. 254 p.

Rosgen, D. L. 1994. A Classification of Natural Rivers. Catena, 22(3), 169-199.

Rosgen, D. L. 1996. Applied river morphology 2nd Edition. Wildland Hydrology. Pagosa Springs Colorado.

Schmidt, L.J. and J.P. Potyondy, 2004, Quantifying channel maintenance instream flows: An approach for gravel-bed streams in the western United States, General Technical Report RMRS-GTR-128, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 33 pp.

Sommer, T.R., M.L. Nobriga, W.C. Harrell, W. Batham, and W.J. Kimmerer. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Can. Jour. Fish. Aquat. Sci. 58: 325-333.

Texas Water Quality Commission and others. 2006. Texas Instream Flow Studies: Technical Overview. Texas Commision on Environmental Quality P.O. Box 13087 Mail Code 160 Austin, TX 78711-3087. Draft Dated May 22, 2006. 150p.

Thompson, K.E., 1972, Determining stream flows for fish life: Proceedings of the Instream Flow Requirement Workshop, March 15-16, 1972, Portland, Oreg.: Pacific Northwest River Basins Commission, p. 31-50.

Trepanier S, M.A. Rodriguez, P. Magnan. 1996. Spawning migrations in landlocked Atlantic salmon: time series modeling of river discharge and water temperature effects. Journal of Fish Biology 48: 925-936.

U.S. Department of Agriculture, Forest Service (USFS). 2003. Identifying bankfull stage in forested streams in the Western United States: Rocky Mountain Research Station, Stream Systems Technology Center, video. 1 DVD.

U.S. Department of Agriculture, Forest Service (USFS). 2005. Guide to identification of bankfull stage in the northeastern United States: Rocky Mountain Research Station, Stream Systems Technology Center, General Technical Report RMRS-GTR-133-CD, 4 CDs.

Watershed Professionals Network. 1999. Oregon Watershed Assessment Manual. June 1999. Prepared for the Oregon Watershed Enhancement Board, Salem, Oregon. 440 p. http://www.oregon.gov/OWEB/docs/pubs/ws_assess_manual.shtml

Wilcock, P.R., G.M. Kondolf, W.V.G. Matthews, and A.F. Barta. 1996. Specification of sediment maintenance flows for a large gravel river. Water Res. Res. 32(9): 2911-2921.

Williams, G.P. 1978. Bankfull discharge of rivers. Water Resources Research 14: 1141-1158.

Wolman, M.G. 1954. A method of sampling coarse river-bed material: Transactions of the American Geophysical Union, 35: 951-956.

Appendixes

Appendix A. Flow Prescriptions for a sand bed stream – Long Tom River downstream from Noti

Summary:

In this hypothetical application, up to 100 cfs is to be diverted from the Long Tom River during the storage season (November 1 – April 31st) into a 10,000 acre foot constructed off channel reservoir in a near flood plain terrace. Based on map and air photo based analysis, the stream is low gradient (less than 1%) with some incision. Based on analysis of slope and confinement using Oregon Watershed Assessment Manual criteria, the stream reach of interest is determined to be a FP2 (a low gradient – medium flood plain). The expected substrate is a sand bed type consistent with low gradient medium flood plain watersheds. In reviewing the water availability information there is no water availability basin above the reservoir, but based on data below the reservoir, there is water available during the storage season. Because it is upstream of the reservoir there are not high fishery values in this reach, mainly resident cutthroat trout and warm water species that move into the river from Fern Ridge Reservoir.

Downstream from Noti there is a streamflow gage available. From peak discharge evaluation available from Water Resources Department, the two year peak flow is 3010 cfs. Because this is a sandbed stream the flow prescription needs to encompass something that considers both high flows and low flows. Also because fishery values are low and this is a low cost operation with an expected low tech headgate, a prescription was chosen that simply stops diversion during an extended time period to provide for channel maintenance. A minimum flow (75 cfs) is also prescribed during the other time periods to provide for instream habitat. In order to capture channel maintenance flows, the diversion was prescribed to be shut off from December 15 – January 31 when many of the highest flows occur. Streamflows greater than 75cfs are allowed to be diverted for the months of November , December 1-14, February, March and April. Hydrologic analysis found that this prescription allowed for the complete filling of the reservoir at 10,000 acre feet 67/70 years from 1936-2005 and partial filling for all 70 years.

Analysis of Long Tom Diversion

Step 1 - Determine streambed type

Based on air photo and map analysis the reach downstream from Noti is a sand bed stream. The stream reach is less than 1% in gradient (based on map analysis) and does have the ability to move about a valley though it is somewhat incised. Based on confinement and slope (using Oregon Watershed Assessment Manual criteria; Watershed Professional Network, 1999), it would be considered a FP2 (a low gradient – medium flood plain) and the call could be either gravel or sand bed type. Map and photo based coverage was obtained using ODFW GIS coverage on an internal server. However, the same data is available from: http://nrimp.dfw.state.or.us/odfw/viewer.htm

Because the gradient is so low (less than 1%) the stream was designated as the sand bed type.*

**Please note: If this were an actual application, field measurements would have probably been used to determine type because it is quite possible this could be a gravel bed stream.*

Step 2 – Develop Prescription

On page 8 of the white paper, the following prescription types were given for flow needs for a sand bed type stream.

1. A percentage of flow in which 70-90 percent of the elevated flows are retained instream and the hydrograph follows the same pattern as a natural hydrograph with the flows reduced as a percentage.
2. A critical time period (such as a month or six week period) in which all flows are bypassed in order to allow channel maintenance functions to occur while there are other time periods where water can be allocated down to a minimum streamflow associated with direct fish or aquatic habitat.
3. A percentage 10-20% of a specified flow such as the storage season median or mean flow is given as allocation for out of stream or storage uses with the rest going instream (see Appendix A from Skagit River rule in Washington for this type of prescription).
4. A trigger flow is set at a one or two year instantaneous peak flow depending on specific bed composition and stream characteristics. All flows greater than that amount are bypassed instream until flow reaches a high flow trigger in which the diversion/storage can begin again. In addition, when the stream is less than the trigger and greater than the minimum flow level water will be retained instream for a given time period or percentage of streamflow. This option requires real time gaging and the ability to change the diversion/storage rate relatively quickly.

Evaluation of Prescription Options:

- Option number 1 is eliminated, in this case because there is no real information about what percentage of the natural stream flows should be retained for channel maintenance. Because this stream borders on being a gravel bed stream there should be a time period when “all’’ the remaining flow (not a percentage of it) is allowed to remain instream to provide for channel maintenance functions.

- Option number 3 is eliminated because it is overly restrictive for this reach as there is no justification that only a percentage of the storage season median flow can be allocated to allow for instream flows that provide channel maintenance or ecological triggers.

- This leaves options 2 or 4. Because the reach is above a reservoir and has limited resident fishery values, a simple low technology option such as leaving all water in stream for a given time period may be appropriate, but we need information on what time period would have a high likelihood of annually capturing the channel maintenance flows. There is a stream gage in the reach and the record can be examined to understand when is a time period when flood flows occur and there is a reliable range of flows to enable other channel maintenance functions. If no time period has a clear distinction in terms of having peak flow and flow variability, then option 4 may need to be selected which would require gaging, remote access, and the ability to quickly manipulate the diversion in reaction to given flow events.

In examining peak flow data from the USGS website for gage number 14166500 (Long Tom River near Noti, OR), 16 of the top 35 years of flood peaks occurred in the month of January. The other 19 were spread among December (11), February (5), November (2) and March (1). Because the record is for 70 years 1936-2005, these 35 values correspond to 2 year recurrence interval and greater flood events. In fact all 35 values are greater than the calculated 2 year flood recurrence interval of 3010 cfs determined from peak flow analysis application from the Oregon water Resources Department (see http://www.wrd.state.or.us/OWRD/SW/peak_flow.shtml also Cooper, 2005 in main references). In viewing Figure 3, the greatest flow variability on a daily basis occurs in late December and throughout January. Because January has the most larger peakflows and has greater variability than other months, January (and perhaps last half of December) should be the time set aside for channel maintenance flows. January also has a near majority of peaks and adequate variability to be set aside as the only month for elevated flows. If the peaks were more spread out and variability was more even throughout the storage season perhaps option 4 would merit more consideration. According to the Basin Report (Hutchinson et al. 1966), the minimum streamflow for this time period is for 75 cfs. Therefore, a plausible diversion condition or flow prescription is to set the diversion to only take water for streamflows over 75 cfs and to be closed during the second half of December and the month of January.

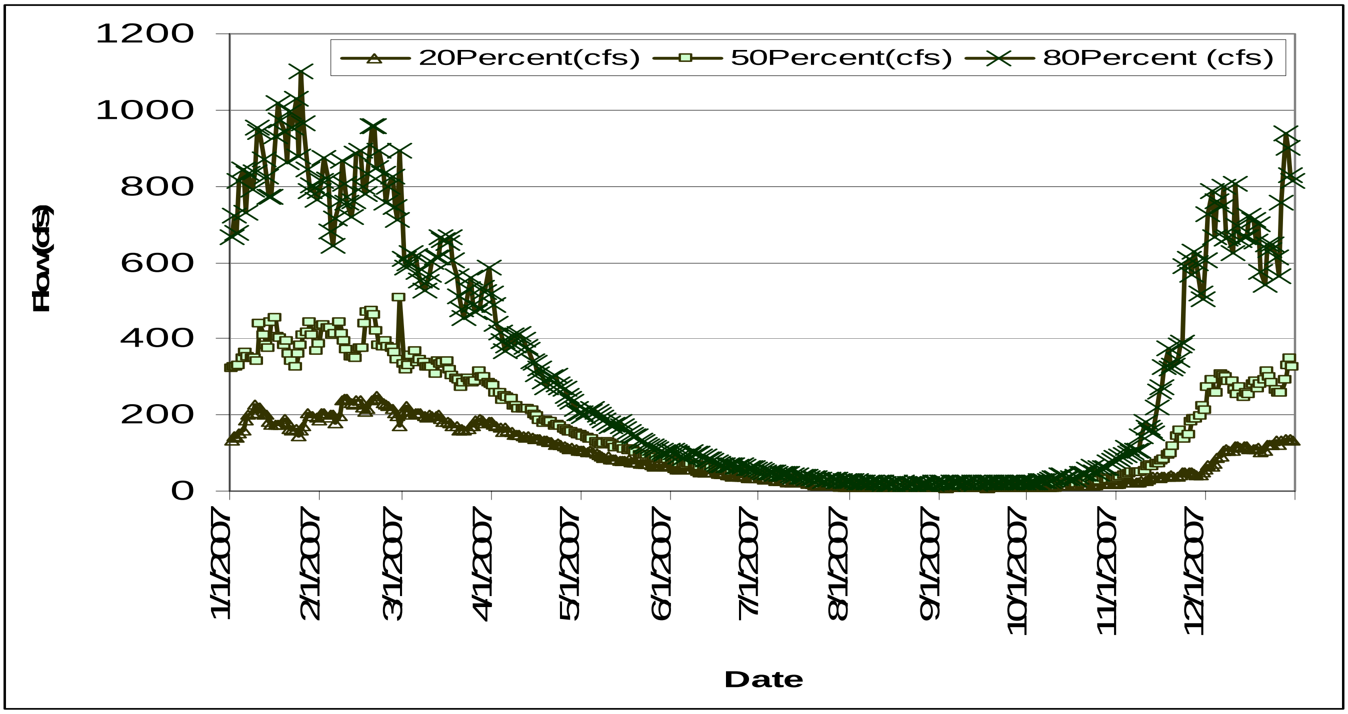


Figure 3. The 20%, 50% (median) and 80% percentile streamflows. The percentile corresponds to the percentage of flows smaller than streamflow for 70 years of record for given day.

Step 3 – Hydrological Analysis

Another key step is to examine how much water could be diverted if the diversion is capped to 100 cfs and 10,000 acre feet over a season. Based on an analysis of 70 years of data in which only water greater than 75 cfs can be diverted in November, December, February, March and April, the diversion reservoir would attain 10,000 acre feet every year except two (1977 and 2001) over a 70 year period of record from 1936-2005 water years. Even if the last half of December is included for channel maintenance, every year the reservoir would fill except for 1977, 2001 and 2005 (in 2005 it would almost fill with over 9,800 acre feet. It should be noted that there is little or no current storage activity in this basin which simplifies the analysis. If there were other storage facilities an analysis of their storage schedules and their effects on gaged flows along with estimates of natural flow would need to be calculated. The degree of diversion and ability for the storage facility to fill in a given year would be reduced with each successive storage project because eventually enough flow would be allocated that the stream would be taken down to near baseflow levels outside of the December-January time period.

Conclusion

Based on this analysis, with the setting aside all flows in the last half of December and all of January along with a low flow minimum of 75 cfs this recommendation would still allow the applicant to fill their reservoir almost every year. The inclusion of the last half of December and all of January allows for ample channel maintenance opportunities with 27/35 of the two year peak flows and greater and maintains flow variability for channel maintenance functions.

Reference

Hutchinson, J.M., K.E. Thompson, and J.D. Fortune Jr. 1966. The fish and wildlife resources of the Upper Willamette Basin, Oregon and their water requirements. A report with recommendations to the Oregon State Water Resources Board. Fisheries Stream Flow RequirementsProject F-69-R-3 Job No. 1 June 1966.

Appendix B. Example of Peak flow / Channel Maintenance analysis for a hypothetical diversion on a coastal stream in Southwest Oregon: Mussel Creek north of Gold Beach

Summary

Mussel Creek is a small coastal stream with a hypothetical diversion approximately 2 miles upstream form tidal influence. The location of the point of diversion is where the stream begins to transition into a wider valley and the reach has areas with significant habitat and spawning gravels. In this example, an empirical model was used to estimate 2 year peak flows and was compared to a flow estimate of bankfull flow using cross-sectional data where the high flow stage was estimated. The bankfull flow was used as the channel maintenance trigger flow so all flows greater than this would be reserved instream. In addition there was an instream water right for 34 cfs as a minimum flow that was also adhered to. This allowed for diversion of water when the streamflow was greater than 34 cfs and less than 540 cfs during the storage season from November through April.

Analysis of Mussel Creek Diversion

Mussel Creek is a stream that enters the Pacific Ocean north of Gold Beach at Arizona Beach. The hypothetical project would divert 50 cfs of water during the irrigation season into a 2000 acre foot off channel storage reservoir. The hypothetical diversion would occur as the stream opens up into a valley about 2 miles upstream from tidal influence.

Step 1 – Determine Streambed Type

The target reach for evaluation is near the diversion area. This immediate area was chosen because of its superior habitat and spawning areas available. From channel habitat survey data provided by the Oregon Department of Fish and Wildlife just upstream of the diversion at (http://nrimp.dfw.state.or.us/crl/default.aspx?pn=AIgisData), the stream is about 2% channel gradient and its bankfull width is approximately 18 feet wide. There is no stream gage on the stream but the watershed area at the point of diversion is 5.6 square miles. A map based evaluation (i.e. dividing elevation gain by stream distance) at the point of diversion estimates a 1.8% stream gradient. From evaluating topographic maps and air photos it appears that this stream could be classed as "low gradient moderately confined; LM" or "medium gradient moderately confined; MM" (from OWEB classification; Watershed Professional Network, 1999). Both of these channel types have gravel as a primary substrate type.*

**Because the channel is transitioning from moderate to low gradient and lower down from moderate confinement to low confinement, a field investigation of the channel bed substrate would be conducted if this were an actual diversion application.*

Step 2 – Develop Prescription

The key flows in this analysis were the minimum or optimum fishery flows often expressed in Basin Investigations or codified as Instream Water Rights and the channel maintenance trigger flow. Another consideration may be special elevated streamflow needs to flush down juvenile fish or to induce upstream migration. This stream is ungaged. The 2 year peak flow is estimated using an empirical model from the Oregon Water Resources Department (see http://www.wrd.state.or.us/OWRD/SW/peak_flow.shtml for more information on this tool; also see Cooper 2005 in main paper references). The 2 year peak flow estimate is 663 cfs. Because of the uncertainty of the hydrologic model (for instance the upper and lower confidence intervals vary from 390-1130 cfs), cross-sections would also need to be taken along this reach and the bankfull flow estimated using geomorphic techniques and tools such as WinXSPro (see Hardy et al. 2006 in main paper references). Because this is a hypothetical application, I created cross-sections that have dimensions similar to the channel habitat survey data for the reach upstream and used them to compare with the peak flow. I found that an average of three of these cross-sections was 540 cfs. When locating sites for cross-sectional measurements it is important to find places where the bankfull flow can be identified and the channel is relatively straight and free from immediate obstructions. Because I would have more certainty in the cross-sectional measurements (if they were actually measured in the field), the bankfull flow of 540 cfs is considered the trigger flow in which all flow greater should be reserved instream to allow for channel maintenance and formation functions. A streamflow stage recorder with a data logger that can send signals via cell phone or telemetry would need to be installed to know when a high flow event that is approaching bankfull would occur and the stream diversion would be closed during these time periods which would probably occur for short periods of time approximately every other year on average.

Recommended habitat based streamflow using the Oregon Method (Thompson et al. 1972) range from 20-25 cfs minimum flows during the storage season to 34 cfs optimum flows. The instream water right is set at 34 cfs. The conditioning for the diversion could create the diversion to only take streamflow once the stream reaches 34 cfs by positioning the diversion point at a higher elevation than the streambed. Another alternative is to accurately gage the streamflow using discharge rating curves and use the telemetry/cell phone information to manage the head gate and keep it closed unless the flow is greater than 34 cfs.

Step 3 – Hydrologic Analysis

According to the streamflow model used by Oregon Water Resources Department to estimate monthly flows, median streamflows for the storage season are:

Month	Streamflow (cfs)	Comments
November	43.5	Limited storage opportunities
December	96	High flow month many opportunities for diversion
January	87	High flow month many opportunities for diversion
February	97.2	Highest flow month
March	85.9	Still good opportunities for storage
April	45	Limited storage opportunities

There is no gage data so daily or continuous streamflow values would have to be extrapolated from a nearby gage such as USGS #14325000, South Fork Coquille River at Powers Oregon or by creating a continuous model such as API and creating flow statistics from the output.

Conclusion

In this example an empirical model was used to estimate 2 year peak flows and this was compared to a flow estimate of bankfull flow using cross-sectional data where the high flow stage was estimated. The bankfull flow was used as the channel maintenance trigger flow so all flows greater than this would be reserved instream. In addition there was an instream water right for 34 cfs as a minimum flow that was also adhered to. This allowed for diversion of water when the streamflow was greater than 34 cfs and less than 540 cfs during the storage season from November through April.

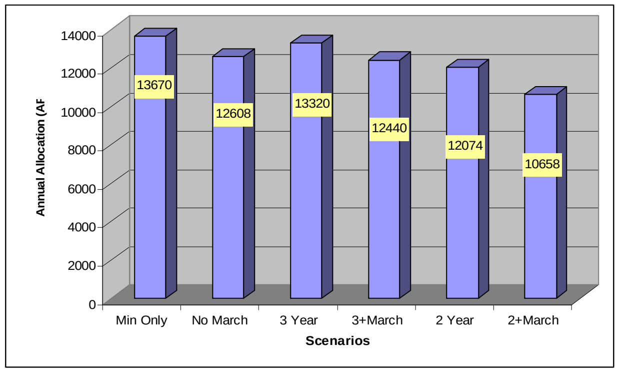
References

Thompson, K.E., A.K. Smith, and J.E. Lauman. 1972. Fish and wildlife resources of the south coast basin, Oregon and their water requirements (revised). A report with recommendations to the Oregon State Water Resources Board. Federal Aid to Fish Restoration, Completion Report Fisheries Streamflow requirements Project F-69-R-7, Job Number 11. April 1972.

Appendix C: Coarse Bed stream example: Elevated flow evaluation of Application R-84628 which would divert winter streamflow from the Deschutes River at Bend for aquifer storage

Summary

Application R-84628 is a proposed winter time water withdrawl for aquifer storage at a rate of 200 cubic feet per second (cfs) up to 25,000 acre feet (AF). The stream reach impacted the most is the Deschuttes River from Bend to Lake Billy Chinook. This stream reach has already been severely impacted by summer water withdrawls and winter water storage. The removal of up to 200 cfs may impact the channel's ability to perform alluvial maintenance especially streambed flushing of fines as well as removal of encroaching vegetation. The loss of 200 cfs may also impact downstream smolt migration especially in March. To prevent these effects, conditioning to require the instream bypass of all March flows and peakflows capable of performing channel maintenance is proposed. Streamflows greater than a "trigger flow" would be reserved from out of stream appropriation. There is already an instream water right and recreation based streamflow reservation to protect minimum flows (660 cfs). Since this is a preliminary analysis, no geomorphic evaluation of stream flows needed for channel maintenance was conducted. The stream was assumed to be gravel or a course bed stream.



An analysis of long-term hydrologic records was conducted to determine the 2 year (1250 cfs) and 3 year (1500 cfs) mean daily peak flows at the Benham Falls gage upstream of the diversions. The 2 year and 3 year mean peak daily flows were used because in literature a peak flow event of about 2-3 years is when channel maintenance functions begin to occur on gravel bed streams. Scenarios were evaluated in which flow greater than the 2 year or 3 year mean daily peaks as well as March flows were reserved instream and compared with only the minimum flow reservation (Figure above). If peak flows/March flows are not reserved instream, approximately 13,670 AF can be diverted on average per winter (record November-March 1950-51 to November-March 2004-2005). If March flows are reserved then the average drops to 12,608 AF/winter. If both 2 year peak flows and March flows are reserved then the average drops to 10,658 AF/winter. The average yearly storage amount can be increased to 12,440 AF/winter if a 3 year peak flow is used rather than a 2 year. Because no geomorphic study was done, we proposed using a 2 year peak flow (1250 cfs) trigger along with a March instream bypass that will still allow the allocation of 10,658 AF per average winter (average over the 55 years of record).

Peak Flow Analysis of Application R-84628

Having a water availability calculation that deems no water is available at 50 or 80% exceedence provides some important safeguards in terms of the ability to do efficient regulation of the water resource as well as leaving behind enough water for issues such as channel maintenance. If in the future, water storage/diversion applications receive the ability to pick off any elevated flow even when no water is available under current criteria, then a satisfactory examination should be done on the effects of the loss of peak flows on channel maintenance. Another consideration is there would also need to be an examination on whether the water right can be properly regulated considering the fact that the junior water right will be appropriating during times when water is not available and must turn on and turn off the diversion within minutes or hours because of the dynamic nature of a peak flow event. These considerations would be consistent with OAR 690-410-0070(2)(a).

For the case in question, Application R-84628, the Deschutes River has regulation from several upstream reservoirs already (Figure 4) and is dewatered in the reaches immediately below Crane Prairie and Wickiup Reservoirs during the winter (compare Figure 5b to 5a). Because of the pre-existing storage projects, an analysis of the hydrology and its alterations is done (before the actual peakflow analysis of this proposed diversion) to ascertain if there is even water available to skim from peak flows.

The channel reaches just below the reservoirs historically had a relatively even annual hydrograph with fairly high flows sustained in the winter and spring, however, with storage reservoirs in the head waters the river now has very low winter discharges with higher flows in the summer (Figure 5). Still for some high flow events, excess water that can't be stored escapes downstream and is joined by flows from other tributaries such as the Little Deschutes River.

The water right application is to take excess streamflows and divert them into the diversion system to let the water seep into the ground and provide groundwater recharge, then use this seepage as a way to allow for greater groundwater pumping during other times of the year. Water is diverted at or near Bend from six irrigation canals (Figure 4) during the irrigation season (April to October) until the river is nearly dewatered downstream in the summer. Currently, in the winter, there is good variation in streamflow and considerable streamflow downstream from Bend because the canals are not diverting (Figure 6a and 6b). This application asks for the diversion of up to 200 cfs until 25,000 acre feet are diverted. The canal system will be used for re-charging the groundwater aquifer to generate mitigation credits for additional groundwater pumping. It is apparent that approximately 500-700 cfs is being stored or used in the winter already (Figure 7). The 200 cfs would be a cumulative impact in addition to the current water being stored.

In evaluating the water availability, there is no water available at the 80% exceedence level based on water availability analysis for Watershed ID #197 conducted on August 16th 2006. At the 50% level, only two months have availability. The reach has an instream flow requirement that is a constant 250 cfs throughout the year (Figure 7). There are also scenic water way requirements that vary up to 500 cfs in the winter. Since some of the canal diversions are upstream, the instream flow requirement there (660 cfs) applies as well as a scenic waterway flow that varies up to 1660 cfs in the summer months.

Currently, there is still flow variation in the winter downstream of Bend (Figure 5a) with many years where streamflows get over 1500 cfs for short periods of time. If this application were approved, 200 cfs of these flows would be taken off the peak which is a significant percentage of existing streamflow during these peak flow periods. The loss of high flows for channel maintenance has not be studied or dealt with in any of the previous correspondences regarding this application. Considering approximately 500-700 cfs is already being taken out of the system daily during the winter months by storage and winter stream flow uses (Figure 7) what added cumulative effect would this application have on these important channel maintenance flows? Furthermore, if this application were granted and another application was proposed when would the Water Resources Department decide that there was a need to protect some of these peak flows for channel maintenance?

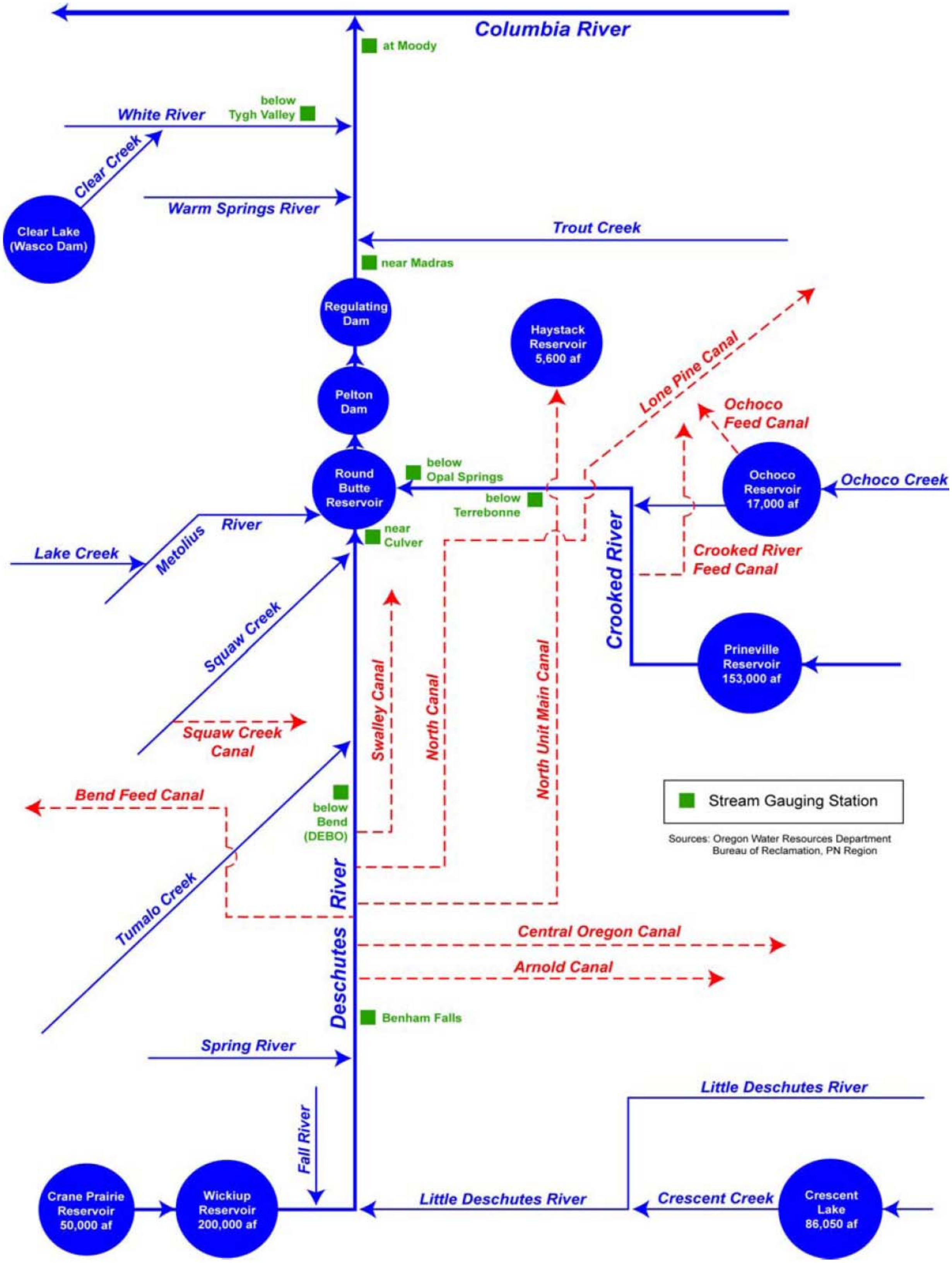
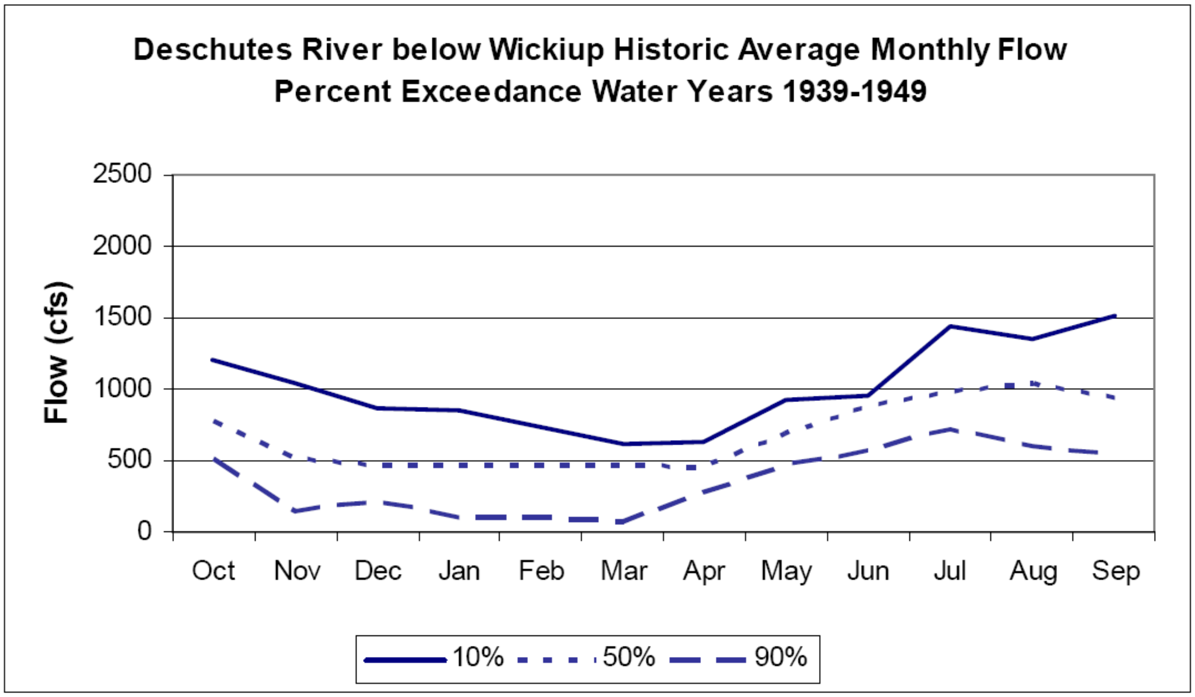


Figure 4. Hydrologic system for the Deschutes River basin in reference to reservoirs and diversions from BOR, 2003.

a.



b.

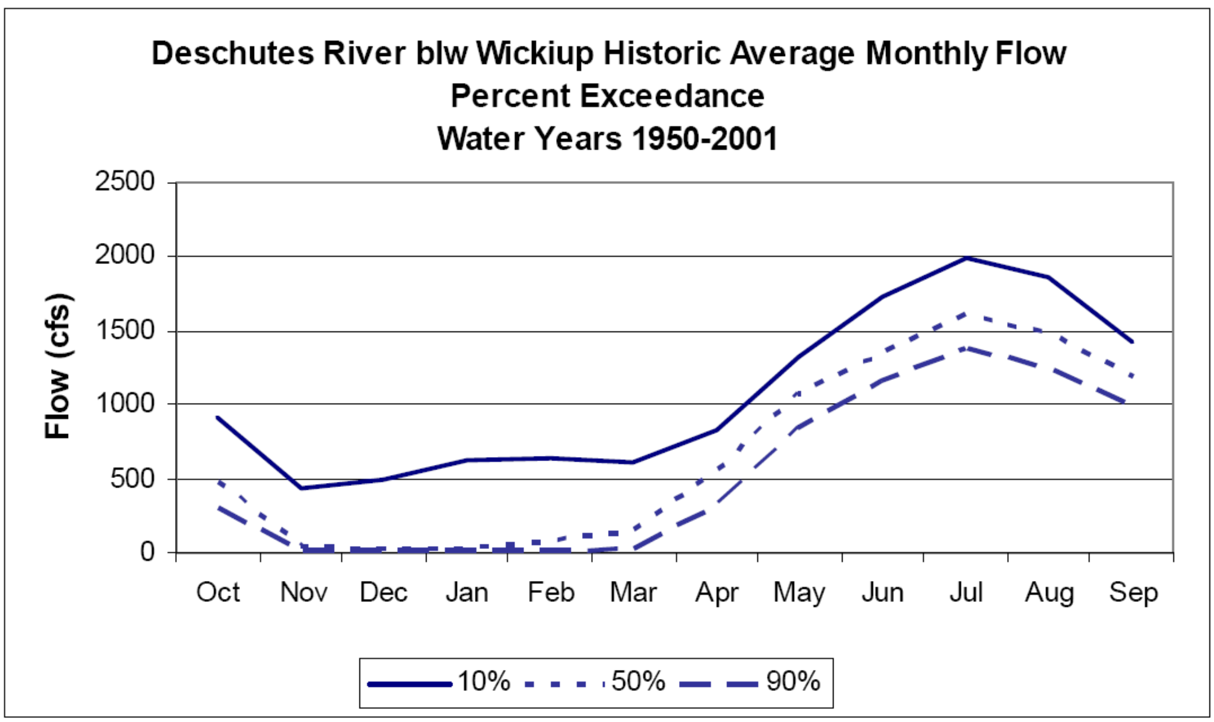
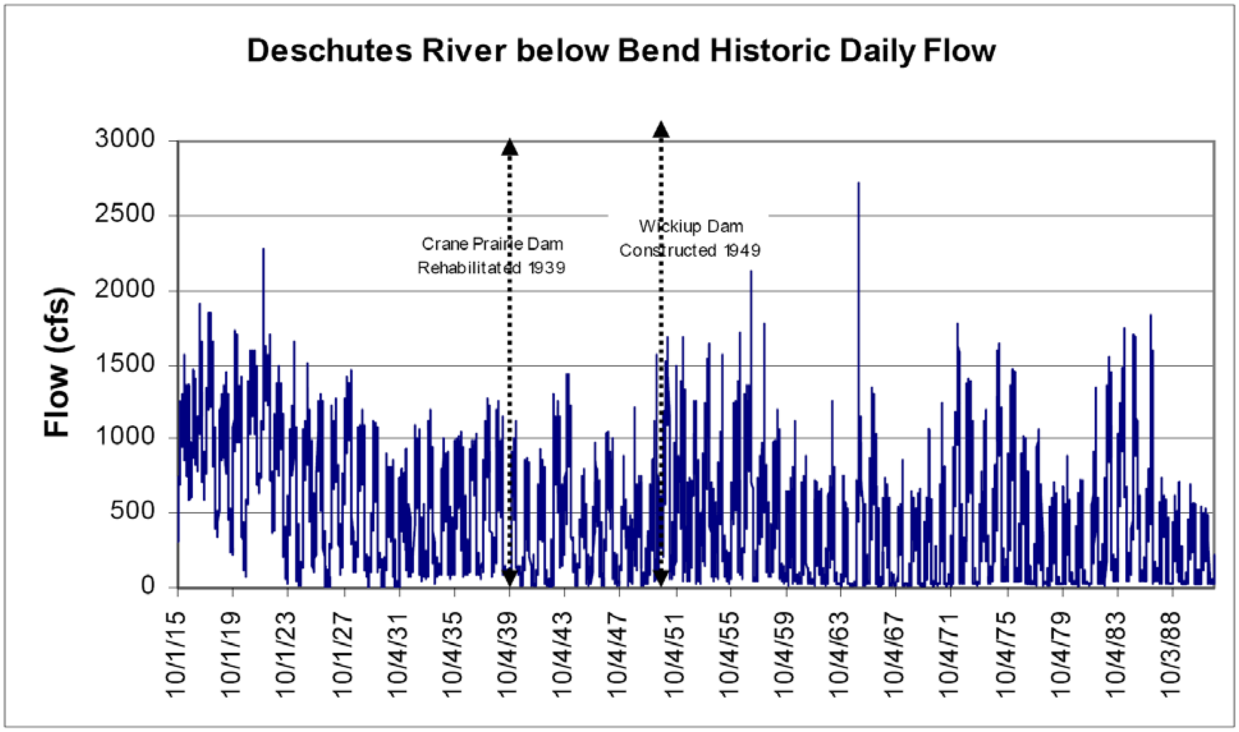


Figure 5. Deschutes River below Wickiup Dam before and after dam construction. Please note that even before 1949 there was already significant storage and regulation from Crane Prairie Reservoir that was lowering winter flows and increasing summer flows (from BOR 2003).

a.



b.

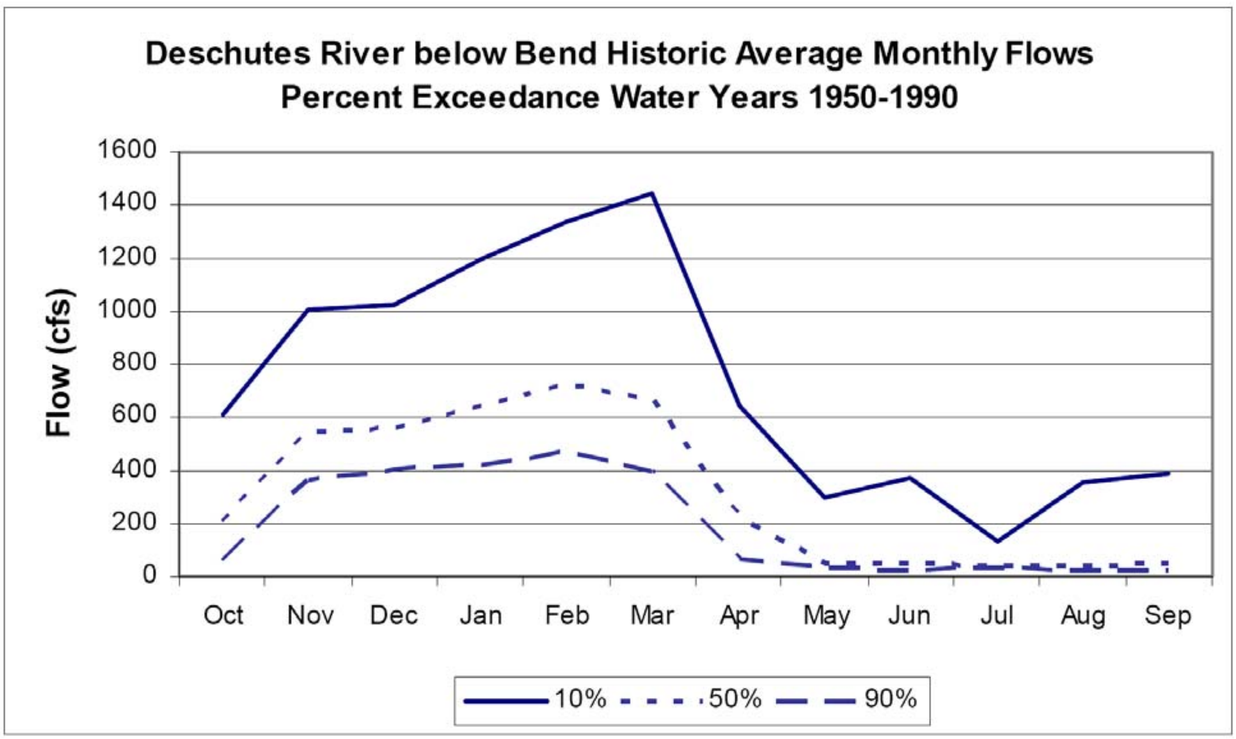


Figure 6. Daily and monthly flows for the Deschutes River below Bend located downstream from all the major diversion canals. The top figure represents the daily values from 1915 forward and the bottom graph is the percent monthly exceedences since both Crane Prairie and Wichiup Reserviors have been in existence.

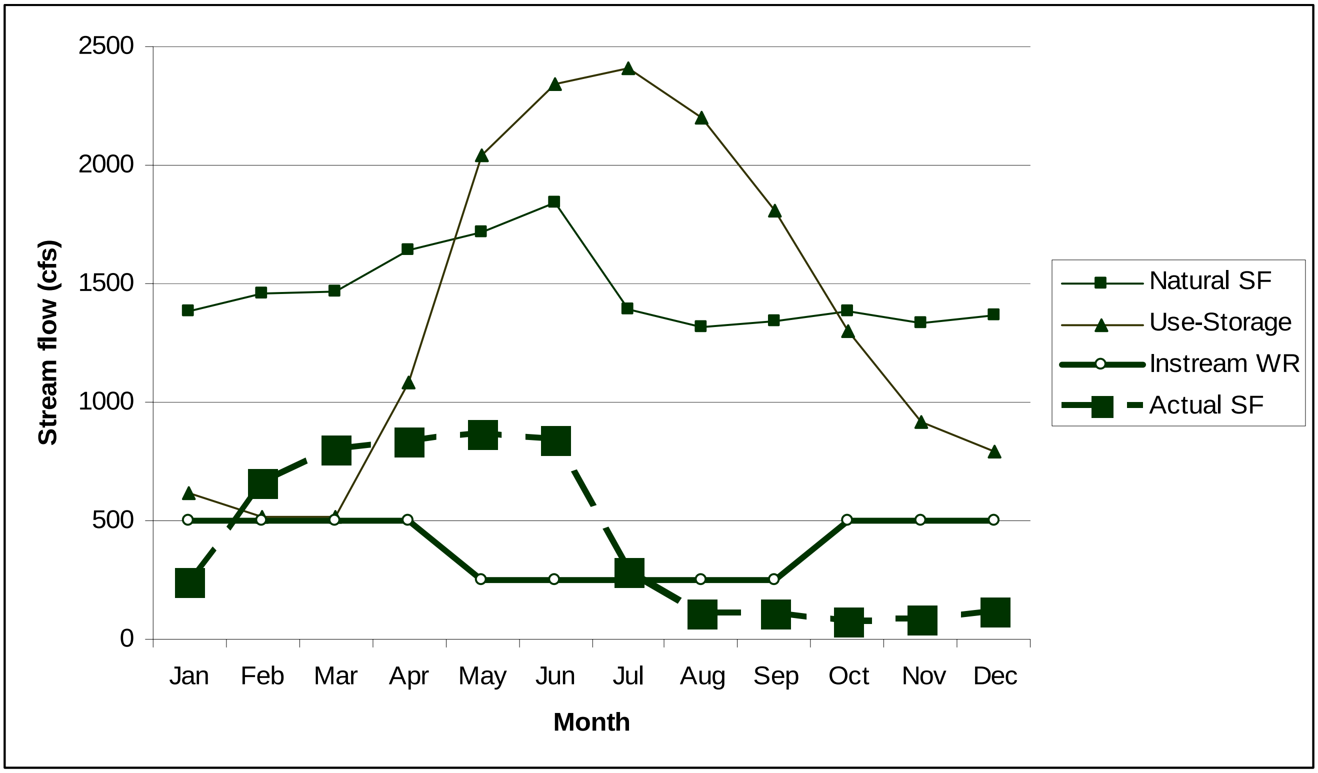


Figure 7. Monthly natural streamflow, estimated stream flow use and storage and instream water right for the Deschutes River downstream of Bend at Gage # 14070500 based on Water Availability Report for Watershed #197 August 16, 2006. Instream flows account for scenic water flows as well as a protested instream water right application IS-70695. All streamflows are the median monthly flows (50% exceedence mean monthly flows). The actual streamflows are from BOR, 2003 for period of record since Wickiup Dam was completed.

To consider applications requesting elevated or peak flows ODFW would need an examination of the stream needs for channel maintenance flows. The examination would consist of the following steps:

1. Classify the stream reach being impacted by the withdrawal (using classification scheme in the Oregon Watershed Assessment manual (Watershed Professionals Network, 1999)). In the Redmond/Avion proposal this would mean the reach downstream from Bend.

2. Evaluate needed “trigger flow” levels from representative cross-sections especially in gravel dominated areas and compare that with flood recurrence hydrology. Examine the bed composition and do an analysis of the flows likely to initiate full scale bedload transport.

3. Propose keeping some of the peaks (or perhaps all or none of the peaks depending on conditions) in the stream especially those near, at, or above the determined “trigger flow” level.

4. Conduct a hydrologic analysis of the historical record to see if it is really feasible to have a recharge diversion considering the peaks that would need to be retained along with other times when water is not available.

Step 1 – Channel Classification

After reviewing orthophotos, other photos (especially Watershed Sciences, 2002), and topographic map coverage, the reach is a course bed stream reach with some gravel dominated areas. However, if basin this on classification using the Oregon Watershed Assessment Manual (Watershed Professionals Network, 1999), the stream type is moderate gradient – moderate confinement "MM." This would normally be associated with a gravel bed stream type but because the stream is so large it is more of a course bed stream. Subsequent analysis is based on gravel to course bed stream type.

Step 2 – Trigger Flow

Since we do not have any field cross-sectional data, the determination of the trigger flow is based solely on the hydrologic record. An example where cross-sectional data is used is given in Appendix B. Literature indicates that the point of bed substrate transport initiation is somewhere around bankfull flow for gravel bed streams which have a recurrence interval of about every 2 years (with a range from 1-7 years) (Knighton, 1998). As the streambed becomes courser, the trigger flow necessary to mobilize the bed becomes greater thus the recurrence interval of the effective discharge to move the sediment becomes greater. In order to evaluate the effect of differing trigger flows both the 2 year and 3 year daily peak flow was used in scenarios below. Peak flow analysis was done for gage #14064500 Deschutes River at Benham falls. This gage was used because it is located at the upstream end of the reach and has a long period of record and will be used by the applicant to control flow allocations if the application is eventually accepted. If this was more than a precursory evaluation, there would need to be some field work to better evaluate the trigger flow based on bed grain size and the cross-section of the channel rather than simply using the 2 and 3 year recurrence intervals. Based on 55 years of record (1950- 2004) (since both Crane Prairie was improved and Wickiup Dam constructed) the 3 year mean daily peak flow is 1500 cfs and the 2 year mean daily flow peak is 1250 cfs at gage #14064500 using plotting position formula for frequency analysis from Brooks et al. (2003, p.35). These values are lower and more conservative than natural instaneous peak flows and will allow for more water to be reserved instream for channel maintenance.

Step 3 – Flow management analysis

For this example, low streamflows were evaluated at the Benham Falls gage upstream from Bend that is upstream from all diversions. The high trigger flows were also analyzed directly at Benham Falls. The instream water rights are for 660 cfs and because there are water losses between Benham falls and the diversion point in Bend, and for a general factor of safety, the trigger flow to begin diversion will be set at 760 cfs. At an informal meeting, the applicants agreed to this level. The Benham Falls gage will be used for day to day management of this diversion because it is upstream of the diversions. The amount of diversion was as follows:

Less than 760 cfs at Benham falls no diversion
760-810 cfs at Benham Falls – Divert 50 cfs
810-860 cfs at Benham Falls – Divert 100 cfs
860-910 cfs at Benham Falls – Divert 150 cfs
> 910 cfs at Benham Falls – Divert 200 cfs

Because streamflow diversion did not initiate until 760 cfs, a full 50 cfs was allowed once the flow reached that level. Likewise the flow skips up to 100, 150 and 200 cfs once a trigger level is reached rather than subtract the exact flow amount from 660 or 710 cfs. The reduction of diversion rates to the five listed immediately above is because there are multiple canals with multiple gates and the applicant wants to minimize the number of times the diversion head gates would have to be adjusted.

Six scenarios related to ecological and channel maintenance flows were examined.

1. Streamflow diverted only limited by instream water right flows – 760 cfs minimum for triggering diversion with diversion rates as above.
2. Streamflow limited by minimum trigger flow as outlined above and no March flow
3. Streamflow diverted limited by minimum flow and then shut off at the high trigger flow determined above 1500 cfs (3 year peak)
4. Streamflow diverted limited by minimum flow and then shut off at the high trigger flow determined above 1500 cfs (3 year peak) and also no March flows
5. Streamflow diverted limited by minimum flow and then shut off at the high trigger flow determined above 1250 cfs (2 year peak)
6. Streamflow diverted limited by minimum flow and then shut off at the high trigger flow determined above 1250 cfs (2 year peak) and also no March flows.

March flows were proposed for reservation to provide a downstream migration trigger and flushing flow for anadromous salmonid smolts that are planned to be re-introduced to this reach in the near future. <u>This is an example of an ecological trigger flow.</u>

The ramping rates associated with opening and shutting the gates are considered negligible and canceling on the rising and falling side of the hydrograph for this analysis. However, the conditioning should include down ramping rates to minimize stranding. Another important consideration is this analysis only evaluated impacts on the stream reach upstream from Lake Billy Chinook to Bend. It was assumed that flow rates below the lake are controlled by reservoir flow releases not pulses upstream. If the lower Deschutes gage and instream water right levels are considered the amount of flow that can be diverted may be lower.

Step 4 - Hydrologic Analysis

The six scenarios given above were simulated at the Benham Falls gage for 55 years of record and the following average allocations were calculated (Figure 8). The reason for this analysis is to evaluate the feasibility of the application in light of the proposed conditioning. A typical year is plotted (Figure 9) to better understand the time periods in which diversion can occur. These times are when flows are greater than the water right associated flows and less than the channel maintenance trigger flow.

The results of this analysis yield the following:

1) If only the minimum flow is reserved instream, an average of 13,670 AF per year is available for groundwater recharge based on 55 years of record.

2) This reduces to 12,608 AF if March flows are reserved instream for downstream smolt migration.

3) To retain the three year peak alone reduces the average annual diversion down to 13,320 AF (a loss for allocation of only 350 acre feet). The reason the differences are so minimal

is because the allocation is limited to 25,000 AF and also limited to an instantaneous rate of 200 cfs. Because flood events are short lived minimal losses occur by reserving flood waters. Also, in big water years when floods occur there are also ample days to divert water to fulfill the allocation without needing these peaks.

4) As the return interval is reduced from 3 years to 2 years, more events will be reserved and there is a decrease in the water stored (over 3000 AF), especially when coupled with a March reservation of instream flow. The more conservative 2 year daily peak should be used in this case because there has been no analysis of what flows will cause movement of the streambed.

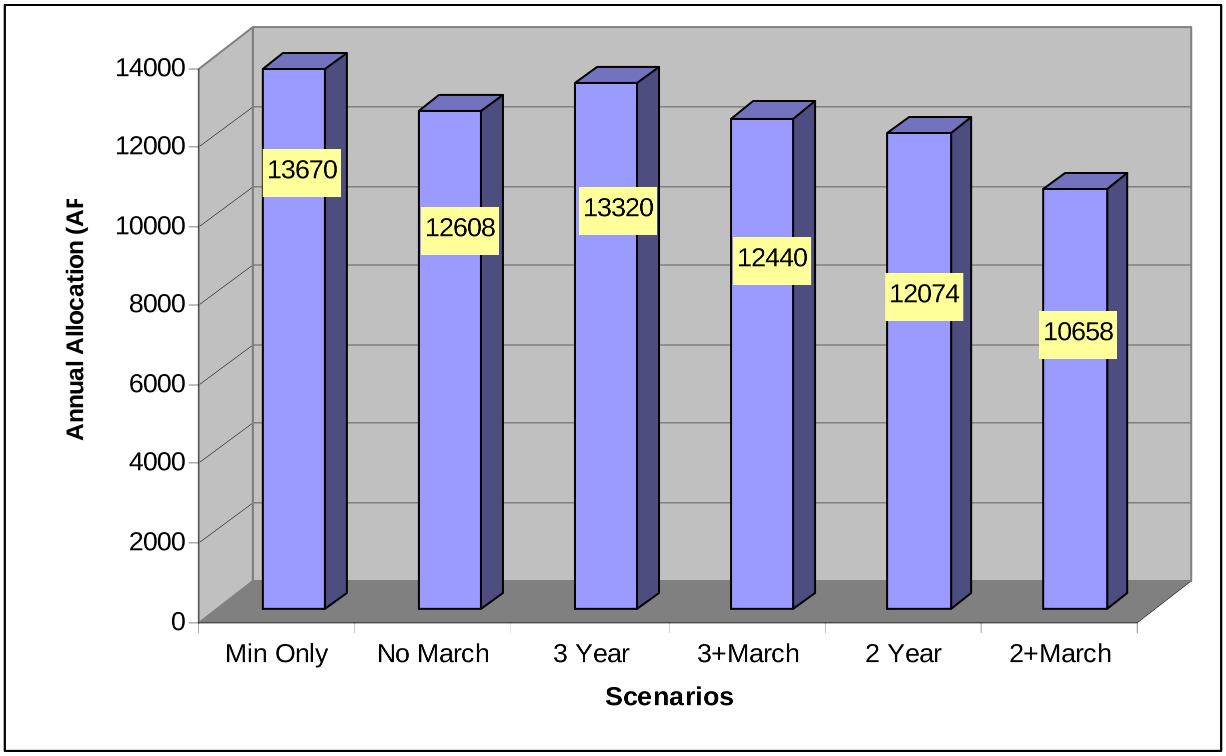


Figure 8. Average annual allocations for the six scenarios in acre feet (AF)

5) If the applicant did a geomorphic analysis and it was found that the 3 year peaks were when bed movement was initiated, it is possible that they could get nearly 1,800 more AF per year. Having better information can be beneficial to the applicant, but since we do not have this, a conservative option should be employed.

It should be noted that in the draft guidance if this stream was a sand bed or fine bed stream, a different flow regime would be required with more flows being retained because bed movement begins at lower flows and perhaps some of the very highest flows would be allowed to pass.

How this allocation would look for an "average year" (winter of 1995-1996) of an actual hydrograph is given in Figure 9. Note the times and triggers causing water to be reserved during different portions of the storage period. For 1995-96, the 3 year peak was not reached so it would not be a factor. The 2 year daily peak was reached but only in March so it did not have an effect for this year because water was already being released instream for downstream migration.

Conclusion

It appears that a consideration of peak flows for instream use still allows for considerable allocation for storage water while setting aside water for channel maintenance needs, even for a stream that does not have water available at the 80% or 50% exceedence level. This memo has given some ideas on how to do a channel maintenance calculation for a real life application. Missing from the analysis are field measurements of substrate and cross-sections to determine channel bed movement trigger flow. The consequences of reserving instream peak flows in this case appear to be minor but could be more significant in situations such as an in channel reservoir that would store greater amounts of water during a peak (i.e. no 200 cfs diversion limitation).

To summarize we reviewed the level of hydrologic modification already in the basin, evaluated stream substrate type, assigned a trigger flow based on hydrologic record, and conducted a hydrologic analysis to examine the plausibility of the diversion in light of all the flow needs. It was found that considerable water would still be able to be diverted even with March flow, peak flow, and minimum flow being reserved for instream use. The March flows represent a known ecological trigger flow to aid fish out migration while peak flows would be used for channel maintenance, and the minimum flows are needed for direct fish habitat.

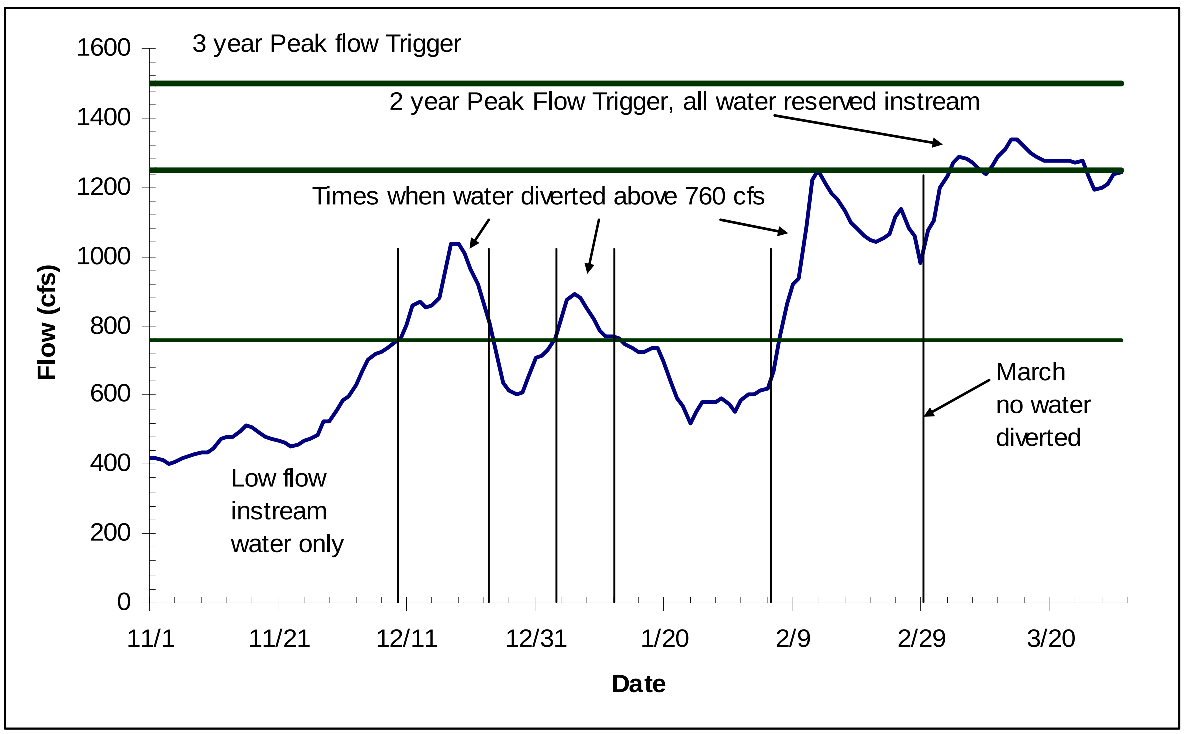


Figure 9. Streamflow and allocation trigger flows for Deschutes River at Benham falls for winter of 1995-1996.

References Appendix C (note: these can be provided by request except for textbook references)

Brooks K.N., P. F. Ffolliott, H. M. Gregersen, L. F. DeBano. 2003. Hydrology and the Management of Watersheds, 3rd Edition. Blackwell Publishing. 574 p.

Bureau of Reclamation. 2003. Biological Assessment on Continued Operation and Maintenance of the Deschutes River Basin Projects and Effects on Essential Fish Habitat under the Magnuson Stevens Act U.S. Department of the Interior. Bureau of Reclamation Pacific Northwest Region Boise, Idaho, September 2003: Deschutes, Crooked River, and Wapinitia Projects. 316 p.

Knighton, D. 1998. Fluvial Forms and Processes: A New Perspective. Oxford University Press N.Y. N.Y. 383p.

Watershed Professionals Network. 1999. Oregon Watershed Assessment Manual. June 1999. Prepared for the Oregon Watershed Enhancement Board, Salem, Oregon. 440 p.

Watershed Sciences. 2002. Aerial Surveys in the Deschutes River Basin. Report to: Oregon Dept. of Environmental Quality. 811 SW 6th Avenue Portland, OR 97204. Feb. 11, 2002. 37 p.

Appendix D: An example of elevated flow reservation from Washington State

The state of Washington has recently prescribed in rule for a specific basin that a streamflow percentage (90% of median winter streamflow) be retained at all times (Jeff Caldwell Per. Com., 2006). The approach that the state of Washington used is illustrated with the following example: given a stream with a winter median streamflow of 500 cfs and a winter required minimum flow or water right of 200 cfs. In this case 10% of the median winter flow is allocated to off stream uses as long as the minimum streamflow level is maintained. If the median streamflow for the winter is 500 cfs then 50 cfs can be allocated to off stream storage as long as the minimum flow is maintained. If there is a peak flow of 2000 cfs, 1950 cfs would be retained in the stream. If there is a minimum flow of 200 cfs and the winter base flow drops to below 200 cfs the storage would have to stop. If this formula was applied to many of the Basins in Oregon with existing storage projects there would be no water allocated because the storage of existing reservoirs is already in excess of 10% of the median flow.