SHASTA RIVER GEOMORPHOLOGY: INCIPIENT MOTION AND SEDIMENT TRANSPORT

1.0 Study Goals and Objectives

The primary goal of this study plan is to describe the methods by which recommendations for a subset of "channel maintenance" flows (based on the transport of bedload sediment) will be developed for the Dwinnell Reach on the Shasta River. Channel maintenance flows are typically defined as a range of flows that keep a stream in a condition of sediment equilibrium over time (years) by moving all sizes and amounts of bedload sediment, scouring vegetation, and maintaining riparian vegetation (Annear et al. 2004). This study is exclusive to characterizing the flow regime necessary to maintain the sediment equilibrium aspect of the definition. Characterizing the flow regime necessary to address the vegetation aspects of the definition is being accomplished with other studies. A secondary goal of this study plan is to describe the methods by which the volume and availability of spawning gravel will be quantified.

The study plan focus is the 6.8 mile reach of the Shasta River immediately downstream of Dwinnell Dam (referred to as the "Dwinnell Reach"). This reach was selected for the study because:

1. It is currently used by coho salmon for both spawning and rearing;
2. It includes Parks Creek that is an undammed tributary that also supports coho salmon;
3. Dwinnell Dam is the most acute hydrologic, hydraulic, and geomorphic impact of the Shasta River system;
4. It is considered to be the most geomorphically altered reach in terms of width, depth, and sediment conveyance (i.e., the downstream impacts of dams);
5. Having the dam immediately upstream provides the opportunity to test and control specific design flow releases;
6. Tributary inputs and agricultural diversions below Big Springs Creek represent additional and potentially significant confounding influences that will diminish the overall results of the study;
7. Conducting this type of study along the entire length of the river would be prohibitively expensive; and
8. Previous studies by the California Department of Fish and Game (1997) and Lestelle (2012) have recommended this reach for detailed sediment studies and restoration action respectively.

Specific objectives of the investigation are to:

1. Identify and quantify the sources and distribution of alluvial sediment, primarily spawning gravel sizes (5 mm – 152 mm), that are necessary for steelhead, chinook salmon, and coho salmon spawning;
2. Select two (2) 1,000-foot long reaches for incipient motion analyses;
3. Construct and calibrate one-dimensional (1D) hydraulic models for two selected subreaches; and
4. Conduct incipient motion and sediment transport analyses to identify the range of flows necessary to mobilize the spawning gravels and flush fine sediment and organics out of the gravel deposits.

2.0 Existing Information/Literature Review

Identification of spawning gravel sources and locations has been accomplished for much of the target reach by McBain and Trush (2010) and Chesney et al. (2011). Assessments of spawning habitat quality through local sediment sampling have also been accomplished by the California Department of Water Resources (Scott and Buer, 1981), Jong (1995 and 1997), and Ricker (1997). It appears that sediment transport has only been evaluated at one location in the Shasta River downstream of the Big Springs confluence (McBain and Trush, 2010). Incipient motion and sediment transport are multi-dimensional and multi-variable processes that are extremely difficult to measure accurately. A variety of hypotheses have been developed and tested over many decades of research (Buffington and Montgomery, 1997), but a single unifying theory has not yet emerged. Successful execution of this study plan requires the use of robust methodologies justifiable to a broad audience that includes subject-matter experts, legal professionals, and concerned stakeholders. Consequently, a proposal developed to implement this study plan must include a section which provides methodological specificity based on the literature, contemporary standards of practice, and personal experience.

3.0 Study Area

The Dwinnell Reach is the 6.8-mile section of the Shasta River located between Dwinnell Dam and the confluence with Big Springs Creek. Because Parks Creek represents a significant contribution of both sediment and streamflow into Shasta River, the Dwinnell Reach is divided into two Study Reaches: one upstream of the Parks Creek confluence (Reach 5) and one downstream of that confluence (Reach 6) (Figure 1).

4.0 Study Methods

The study approach will include collaboration with a Technical Advisory Committee, field assessments, hydraulic modeling, and incipient motion and sediment transport analyses. The investigation shall include the following steps (not necessarily in the order shown).

1. Establish a Technical Advisory Committee (TAC);
2. Obtain property access and design flow releases out of Dwinnell Dam;
3. Identify and quantify alluvial sediment deposits (i.e., spawning gravel);
4. Characterize subreaches selected for incipient motion analyses;
5. Construct and calibrate a one-dimensional HEC-RAS hydraulic model for two subreaches;
6. Conduct incipient motion and sediment transport analyses; and
7. Prepare a final report that summarizes the study results and presents recommendations for sediment transport specific channel maintenance flow regimes in the Dwinnell Reach.

4.1 Establish a Technical Advisory Committee (TAC)

In concert with the California Department of Fish and Wildlife (CDFW), a Technical Advisory Committee (TAC) shall be created to help guide development and monitor project progress. The TAC will include CDFW, NOAA Fisheries, the U.S. Fish and Wildlife Service (USFWS), the Montague Water Conservation District (MWCD), and other interested parties. Members of the TAC should have demonstrated experience in coho salmon fisheries management, hydraulic modeling, and fluvial geomorphology. The TAC will review methods and hydraulic models and provide quality control oversight. The TAC will be provided with regular project updates to ensure that the project remains on track and on schedule.

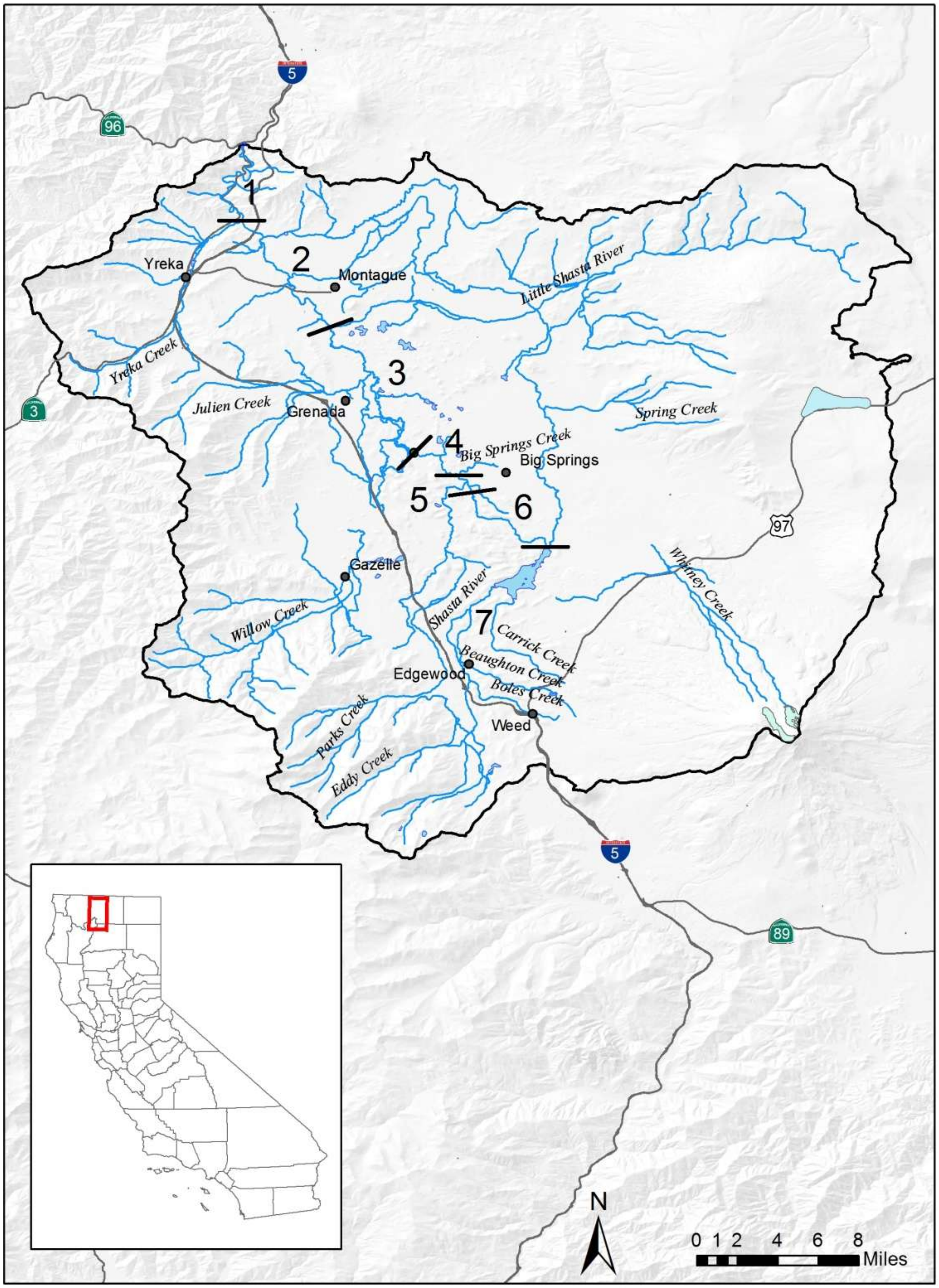

Figure 1. Shasta River Mainstem Reaches.

4.2 Obtain Property Access and Design Flow Releases out of Dwinnell Dam

The study plan described below requires access to the entire Dwinnell Reach and cooperation from MWCD to provide flow releases out of Dwinnell Dam to calibrate the hydraulic model. It will be up to the consultant and the TAC to collaboratively develop access and flow release plans. It is important to recognize that several previous studies have been criticized because of their reliance on extrapolations and inference to explain or estimate the conditions and characteristics of areas that were not physically accessed.

4.3 Identify and Quantify of Alluvial Sediment Deposits

The target alluvial deposits lie within the active stream channel and adjacent floodplain. A particular focus of this effort is on identifying, and quantifying, sources of spawning gravel that range in size from 5.0 mm to 152 mm in diameter. Included in this effort are the following tasks:

1. Map and quantify the volume of alluvial sediment deposits within the Dwinnell Reach
2. Identify and select subreaches for incipient motion analyses

4.3.1 Map & Quantify the Volume of Alluvial Sediment Deposits

The primary goal of this task is identify and inventory sources of spawning gravel that currently lie within the active channel or that can be recruited into the active channel within the reasonably foreseeable future (i.e., deposits that lie within the channel migration zone or meander belt width). For example, an avulsion is a reasonably foreseeable occurrence that could recruit floodplain gravel deposits. Review of aerial photography and LiDAR topographic data indicates that the meander belt width (or channel migration zone) of the Dwinnell Reach is approximately 300 feet with local variations up to plus-or-minus 100 feet. Thus, besides in-channel gravel bars, riffles, runs, and bank exposures, the mapping shall extend out onto the floodplain within the 300-foot meander belt width. Preliminary gravel mapping from aerial photographs as well as mapping data from McBain and Trush (2010) indicates the presence of over 100 in-channel gravel deposits. That estimate does not include any in-stream gravel deposits obscured beneath the riparian canopy. It is further recognized that significant gravel deposits are likely to be obscured from view by surficial deposits of fine sediment. All alluvial gravel mapping data will be tabulated within appropriate ArcMap GIS shapefiles and attribute tables.

At a minimum, the mapping effort shall recognize and characterize at least three types of gravel deposits:

1. Active (in-channel) gravel deposits that make-up the contemporary riffles (spawning gravel), runs, point bars, other types of unvegetated in-channel gravel bars, and exposed bank exposures;

2. Abandoned gravel deposits that were once part of the active channel during the pre-dam era, but are now inactive or “frozen in time” and vegetated due to dam closure 87 years ago. These gravel deposits are of particular interest because they are conceptually considered to be the most accessible source areas for future spawning gravel recruitment; and

3. Floodplain or terrace gravel deposits that exist within the channel migration zone.

More detail as to the specifics of these different deposits shall be provided to the TAC as mapping proceeds. Additionally, it will be necessary to characterize and/or quantify the relative availability or recruitment potential of those deposits that are either vegetated (Type 2) or lie outside the active channel (Type 3). Similarly, a method for estimating the relative percentage of Type 2 and Type 3 gravel deposits obscured by thin deposits of fine sediment shall be developed and implemented.

The mapping shall be conducted at a scale commensurate with the average redd size created by spawning coho salmon. More specifically, the USFWS (Laufle et al., 1986) reports that the average coho salmon redd is about 30 sq. ft. At a map scale of 1-inch equals 60 feet, a rectangle 3 feet by 10 feet (i.e., 30 sq.ft.) on the ground would be depicted on the map as 0.05 inches by 0.1 inches. In other words, such a rectangle (i.e., a coho salmon redd) could be accurately drawn on the map. High resolution aerial photography is available for the Dwinnell Reach that facilitates accurate desktop mapping at a scale of about 1-inch equals 20 feet. Thus, the first step in the mapping effort will be to map all gravel deposits visible on those aerial photographs. The primary value of this mapping effort is that it will help focus the field mapping component described below.

The second step will be to verify the desktop mapping in the field and fill in gaps (e.g., areas obscured in the aerial photographs beneath vegetation canopy). Included in this mapping effort will be the measurement, or estimation, of each deposit's thickness such that the volume of each mapped deposit can be determined. All thickness estimation methods shall be described in detail, validated with field data, and vetted by the CDFW prior to execution. Additionally, a Wolman-type pebble count shall be conducted for each mapped gravel deposit. In general, the pebble counts of the surface sediments will provide a first order estimate to quantify the deposit's particle size distribution. While it is recognized that the surficial particle size distribution is likely to be different than that of the subsurface, these pebble counts will provide the basis for initial estimates of gravel immediately available as spawning habitat (Kondolf and Wolman 1993), and the flows necessary to mobilize the surficial sediment layer. Additional details regarding the characterization of subsurface particle size distribution are discussed below under section 4.4.4. The field mapping effort will require access to the entire Dwinnell Reach

4.3.2 Identify and Select Subreaches for Incipient Motion Analyses

Using the map data described above, four (4) 1,000-foot long subreaches are to be identified for detailed incipient motion analyses. Two of the subreaches will be from Study Reach 5 (downstream of Parks Creek confluence), and two will be from Study Reach 6 (upstream of the Parks Creek confluence). The four subreaches will be presented to the TAC for review and consideration, and two of the four proposed subreaches will be selected for the incipient motion investigations. The subreaches will be selected on the basis of relevance to spawning gravel, juvenile rearing, and overall representativeness of the system. Selection shall also be based upon physical access, hydraulic efficiency, hydraulic simplicity, and similarity between the subreaches. Most importantly, the selected subreaches must contain Type 1 and Type 2 gravel deposits (described above).

4.4 Characterization of Subreaches Selected for Incipient Motion Investigations

Following selection of the subreaches, each shall be characterized in detail with regard to topography, bathymetry, geomorphology, and hydraulic roughness. Included in this effort are the following tasks:

1. Topographic surveying of subreaches and validation of LiDAR data;
2. Geomorphic mapping of the subreaches;
3. Selection of specific gravel deposits for incipient motion analyses; and
4. Characterization of size fractions within individual gravel deposits.

4.4.1 Topographic Surveying of Subreaches and Validation of LiDAR Data

The purpose of this task is to produce a detailed topographic map for each subreach that accurately depicts the spatial geometry and geomorphic complexity of the channel and floodplain within the entirety of the channel migration zone. This work will serve as the base map for the geomorphic characterization as well as the hydraulic modeling and 0.5-foot accuracy is expected. LiDAR data currently exists for the entire Dwinnell Reach and that data shall be validated as part of this effort. Additionally, the topographic surveying shall include longitudinal profiles and related water surface elevations as well as the monumenting and surveying of 20 cross-sections per subreach. In particular, cross-sections shall be established across prominent Type 1 and Type 2 gravel deposits, zones of hydraulic expansion and contraction, and sections that appear to have a high potential for adjustment. It is expected that these cross-sections will also be used in the 1D hydraulic model described below under section 4.4.

4.4.2 Geomorphic Mapping of the Subreaches

Using the topographic base maps described under 4.4.1, the geomorphology of each subreach shall be mapped. The primary purpose of the geomorphic mapping is to characterize channel roughness through the mapping of pools, riffles, runs, meanders, beaver dams, bars, bedrock exposures, large wood, bank vegetation, floodplain relief, and floodplain vegetation. Additionally, mapping the distribution of discrete sediment populations (i.e., facies mapping) across the prominent bars and riffles shall also be conducted.

4.4.3 Identify and Select Specific Gravel Deposits for Incipient Motion Analyses

The incipient motion analyses described below are designed to identify the flows (or flow regimes) necessary to mobilizing existing Type 1 spawning gravels and access and mobilize Type 2 gravel deposits. The first requires a focus on spawning areas that tend to be located in the tails of pools and heads of riffles where down-welling and upwelling flows are most likely to occur. The second requires a focus on reach-scale conditions. Using the detailed geomorphic map data described above, several sets of five (5) gravel deposits within each subreach will be identified for detailed incipient motion analyses specific to the dual purposes described above. These sets-of-five gravel deposits will be presented to the TAC for review and consideration, and one set for each subreach and purpose will be selected for the detailed incipient motion investigations.

4.4.4 Characterization of Particle Size Fractions within Individual Gravel Deposits

Accurately characterizing the size fractions of the Type 1 and Type 2 gravel deposits is an essential element of this study because it is the basis for: a) estimating the potential volume of available spawning size gravel (i.e., 5.0 mm to 152 mm in diameter); and b) conducting incipient motion and sediment transport analyses. Both Type 1 and Type 2 deposits are likely to exhibit several discrete populations of gravel across their surfaces. Moreover, such deposits are commonly paved to a depth of approximately twice the D_{84} value in response to winnowing, and may also be embedded with fine sediment. These attributes imply that the surficial particle size distribution may be different than that of the subsurface, and justifies the usefulness of the Wolman-type pebble counts as a first order characterization of either embedment or paving and whether or not the surficial gravels are suitable for spawning and/or fluvial transport. Such pebble counts will be undertaken during the mapping task of 4.2.1., and it is acknowledged that those particle size distributions may be skewed either by the pavement phenomenon and/or the fine sediment embedment. Consequently, careful notes regarding this skew potential shall be recorded as the characterization proceeds.

In order to quantify the potential skew, and/or evaluate the subsurface particle size distributions, bulk sampling will need to be conducted. Bulk sampling of many discrete gravel populations can be labor intensive. Alternatively, it may be more economical to collect bulk samples from all the discrete populations and create a single mega-sample. Based on the literature (e.g., Bunte and Abt, 2001 and American Society of Testing and Materials publications), the proposal to implement this study plan shall include in the methods section a definition of "discrete sediment populations" to be employed and the details of a proposed sediment sampling program.

4.5 Construct and Calibrate a One-Dimensional HEC-RAS Hydraulic Model

A 1D HEC-RAS hydraulic model shall be constructed for each of the 1,000-foot long subreaches with specificity at the sets-of-five gravel deposits. Surveyed cross sections to support the hydraulic modeling will need to include the hydraulic controls within the reaches (e.g., crest of the riffle, hydraulic contractions, and hydraulic expansions). Additionally, there are several culverts and bridges within the Dwinnell Reach that will need to be properly accounted for as hydraulic controls that may affect the model. It is estimated that each reach will require approximately 20 cross sections to develop an adequate 1-D HEC-RAS model with the necessary specificity at target gravel deposits. It is expected that the cross-sections surveyed as described above under section 4.3.1 will be planned in context with the hydraulic modeling effort. The HEC-RAS model shall be calibrated and validated in accordance with contemporary standards of practice. In particular, the model will be calibrated with measured discharge measurements for a range of flow events. Additionally, it is expected that as part of the calibration effort, basic hydrologic data sets such as synthetic hydrographs and flow duration curves will either be developed using the best available information, or acquired through the Shasta *River Hydrology and Integrated Surface Water/Ground Water* study plan.

There is no stream gaging data for the Dwinnell Reach so a range of discharge measurements at particular locations will be required to properly calibrate the hydraulic models for each subreach. In general, several measurements of the contemporary suite of flows that move gravel will be required, along with several measurements of flows equal to pre-dam bankfull discharge, which was estimated to be approximately 600 cfs by Nichols (2009)). Additional measurements above bankfull should also be captured, if possible. Moreover, in order to understand the full scale of system capabilities, discharge measurements associated with maximum dam releases out of Dwinnell Dam must also be undertaken. These flows to be measured are unlikely to occur naturally and predictably during the time frame of the study. Consequently, agreements for dam releases to provide such flows will need to be acquired from the MWCD. There are also reports of substantial dam releases being required in response to large spring runoff events circa 1998 (David Webb, personal communication). Consequently, the MWCD should be contacted with regard to acquiring any and all records of Dwinnell Dam releases.

Also included under this task is the initiation of simple sediment transport experiments to be executed during the experimental flow releases conducted to calibrate the hydraulic model. More specifically, painted rock and/or scour-chain type experiments will be established at a minimum of two locations within each subreach commensurate with the magnitude of anticipated flow releases. The intent of these experiments is to gain an empirical understanding of incipient motion and sediment transport across individual gravel deposits of particular interest as well as at the subreach scale. Having the empirical data will serve as calibration parameters for the computational modeling and analysis. While the experiments are to be initiated under this task, the post-flow data is to be collected and analyzed under Task 4.6 (Conduct Incipient Motion and Sediment Transport Analyses).

4.6 Conduct Incipient Motion and Sediment Transport Analyses

Incipient motion is referred to as the point where the bed material starts to become mobile. Because the objective of the overall study is to provide authoritative recommendations for a range of channel maintenance flows based on the transport of bedload transport and to also estimate the availability and recruitment potential of spawning gravel, several incipient motion analyses shall be conducted in a phased approach to first document existing patterns of sediment entrainment and transport, and then provide estimates of future desired conditions and potential sediment transport scenarios. Included under this task is the collection and analysis of the empirical sediment transport experiments that were initiated as part of Task 4.4.4 in anticipation of the experimental flow releases. Collectively, the proposed analyses are designed to:

1. Document the existing conditions of incipient motion and sediment transport specific to existing spawning gravels;
2. Identify flow regime alternatives necessary to increase the quality and quantity of existing spawning gravels;
3. Identify flow regime alternatives necessary to recruit Type 2 gravel deposits into the active system; and
4. Characterize the maximum “channel-maintenance” flows potential capable of being delivered by the existing outlet works of Dwinnell Dam.

4.6.1 Document Existing Conditions of Incipient Motion

This task is primarily a desktop effort in which the HEC-RAS model results for a representative range of flows are examined within a conventional Shields type analysis to determine the mobility of spawning gravel (5 mm – 152 mm in size). More specifically, the HEC-RAS model will be used to compute channel shear stress as a function of discharge at each cross-section across known spawning gravel areas. That characterization will then be followed with cross-section specific analyses that will identify discharges necessary to generate the critical shear stress necessary to initiate mobilization of each of six particle size categories that are: 4 mm, 8 mm, 16 mm, 32 mm, 64 mm, and 128 mm (Uden-Wentworth grain size scale). The analysis then advances to a comparison of the particle size distributions sampled at each cross section, and concludes with a discussion regarding the mobilization of spawning gravel at each cross section.

Incipient motion analysis is generally performed by evaluating the effective shear stress supplied by the flowing water on the channel bed in relation to the amount of shear stress that is required to move the sizes of sediment that are present. The shear stress required for bed mobilization is estimated using the Shields (1936) relation, given by:

$$\tau_c = \tau_{*c} (\gamma_s - \gamma) D_x$$

where τ_c = critical shear stress for particle motion,
τ_{*c} = dimensionless critical shear stress (often referred to as Shields parameter),
γ_s = unit weight of sediment (~165 lb/ft^3),
γ = unit weight of water (62.4 lb/ft^3), and
D_x = particle size of the bed material.

There exists considerable scientific discussion regarding what value should be used as the Shields parameter (τ_{*c}). Reported values range from 0.03 (Neill 1968; Andrews 1984; and Buffington and Montgomery, 1997) to 0.06 (Shields 1936), and a value of 0.047 is commonly used in engineering practice. Consequently, those values shall be evaluated as part of this analysis. Additionally, there are a number of different opinions as to how best estimate the shear stress supplied by the water to the bed. More specifically, many practitioners average shear stress through hydraulic radius, while others advocate grain resistance (Einstein, 1950) and the application of concepts such as skin friction. Therefore, the proposal to implement this study plan must include a methods section that describes a practical methodology for determining the bed shear stress necessary to accurately characterize streamflow in this application. The discussion shall include a critique and comparison of methods documented in the literature, and also describe differences between average bed shear stress, skin friction, and the grain resistance model of Einstein (1950).

4.6.2 Sediment Transport Analysis

The purpose of the sediment transport analysis is to quantify the volume of gravel-sized material transported by a range of flows in excess of those required for incipient motion. This is considered to be primarily a desktop effort in which the volume of transported sediment (tons per day) is computed by developing sediment rating curves based on an appropriate sediment transport equation integrated with the streamflow rating curve. In order to develop sediment rating curves, the 1D hydraulic output and sediment gradation data are integrated through a particular sediment transport equation. As discussed previously, there are several different sediment transport equations that could be used. For example, preliminary information on the bed material gradations for the Scott and Shasta Rivers, suggests that the Wilcock-Crowe sediment transport equation (Wilcock and Crowe, 2003) may be appropriate because it is able to incorporate sand–sized material. The proposal to implement this study plan shall include a specific sediment transport equation for this effort. The justification for such an equation shall include a discussion of contemporary literature as well a comparison to models proposed by Parker et al. (1982), Wilcock and Kenworthy (2002), and Wilcock and Crowe (2003). In addition to justifying a sediment transport equation, the discussion shall also include the methods that will be used to define the streamflow rating relation. More specifically, how are the realities of the existing regulated flow system best compared, contrasted, and/or represented with typical flow estimates based on either an event hydrograph or a flow duration curve?

4.6.3 Identify Flow Regime Alternatives to Improve Existing Conditions

Using the analysis described above in section 4.6.1, thresholds of stream discharge necessary to flush fine sediment from pools and out of gravel deposits shall be identified. This analysis will use the subreach results of the hydraulic modeling and Dwinnell Reach mapping data to make meaningful estimates of how a range of flows can improve the existing conditions (i.e., flush fine sediments from pools and gravel deposits). It will also be necessary to collect evidence regarding whether or not the fine sediment is chronic, episodic, or land-use related.

4.6.4 Identify Flow Regime Alternatives Necessary to Recruit Type 2 Gravel Deposits

As defined in section 4.3.1 above, Type 2 gravel deposits were part of the active channel during the pre-dam era, but are now inactive or “frozen in time” and vegetated due to dam closure 87 years ago. In other words, these gravel deposits lie outside the channel forming influences of the contemporary flow regime. These gravel deposits are of particular interest because they represent an additional source of spawning gravel that could be accessed by a new flow regime aimed at channel maintenance goals. Consequently, the primary focus to this task is to determine what flow discharges are necessary to mobilize these gravel deposits and incorporate them into the more active channel. A key outcome of this analysis will be an estimated annual rate of spawning gravel recruitment for the entire Dwinnell Reach.

This analysis will be closely patterned after those analyses described in sections 4.6.1 and 4.6.2, but will require an additional detail. In particular, because these deposits are likely paved (as described by Parker et al., 1982) and also embedded with fine sediment in the interstitial spaces, and perhaps vegetation as well; it will be necessary to consider those factors in any analysis of sediment mobilization and transport. There exists considerable scientific discussion regarding how to best evaluate the mobilization and transport of gravels within deposits that are paved and/or embedded with fine sediments. Therefore, the proposal to implement this study plan shall include a methods section that describes an accepted and practical methodology for partitioning and evaluating the shear stress necessary to overcome the resistance caused by the pavement and or embedded fine sediment and to then mobilize and transport gravel. This methodology shall include a critique and comparison of methods documented in the literature (e.g., Parker et al., 1982; and Wilcock and Kenworthy 2002). The discussion should also draw upon literature relevant to the transport and improvement of spawning gravel habitat for anadromous salmonids (e.g., Andrews 1984; Kondolf and Wolman 1983; Neil 1968; Wilcock and Crowe 2003; and Wilcock et al. 1995).

4.6.5 Characterize the Maximum Potential Channel Maintenance Flows

The analyses described above are aimed at identifying specific flows that will achieve channel maintenance objectives for the Dwinnell Reach. The purpose of this analysis is to evaluate whether or not the existing outlet works that regulate flow through Dwinnell Dam are capable of providing those identified flows. Because pre-dam bankfull discharge was in the range of approximately 600 cfs (Nichols 2008) and the maximum flow release out of Dwinnell Dam is reported to be 700 cfs (Watercourse Engineering 2005), it appears that sufficient capability may exist. As part of this characterization, records maintained by both the State Division of Dam Safety and MWCD regarding engineering details of the outlet works and flow releases shall be reviewed and incorporated into the characterization. Also included in this task will be the preparation of hypothetical outlet release hydrographs necessary to provide the range of channel maintenance flows identified through the previous analyses. Like similar dam release programs, it is envisioned that release hydrographs will be prepared for different water years (i.e., extremely dry, dry, normal, wet, and very wet).

5.0 Deliverables

The major deliverables from implementing this study plan include:

1. An ArcMap GIS-based map and inventory of gravel deposits that lie within 6.8 mile Dwinnell Reach;
2. Detailed topographic and geomorphic maps of two 1,000-foot long subreaches;
3. Calibrated and validated 1D HEC-RAS hydraulic models for two 1,000-foot long subreaches;
4. Technical memos prepared to document key decisions (described in this study plan) that are made by the TAC and the party implementing the study plan;
5. A detailed report documenting the methods and results of the incipient motion and sediment transport analyses;

6. A detailed characterization of the existing Dwinnell Dam outlet works and its maximum potential discharge capacity;
7. Recommendations for channel maintenance flow regimes that will improve the existing in-channel quality and quantity of spawning gravel habitat for anadromous salmonids; and,
8. Recommendations for a channel maintenance flow regime that will access, mobilize, and recruit into the active channel Type 2 gravel.

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