November 19, 2009

Ms. Melissa Jundt
NOAA Fisheries – Hydropower Division
1201 NE Lloyd Boulevard, Suite 1100
Portland, Oregon 97232

**RE: Engineered Riffle Concepts for Sodom Dam Removal Grade Control Elements**

Dear Ms. Jundt:

The following correspondence relates to River Design Group, Inc.'s (RDG) planned use of engineered riffles as part of the Sodom Dam Removal Project. Engineered riffles will be implemented as part of a channel stabilization, fish passage, and habitat enhancement strategy for the Sodom Ditch. Engineered riffles will be an element in the channel reconstruction effort that is planned to extend from the Bifurcation Point downstream 1,400 ft through the existing Sodom Dam site (project reach). The project reach is currently affected by the Sodom Dam backwater.

**Engineered Riffle Introduction**

Engineered riffles, similar to other techniques commonly referred to as Newbury riffles (Newbury and Gaboury 1993) and riffle grade controls (Hegberg et al. 2001), are rock structures that mimic natural riffle sections of streams. Engineered riffles are generally designed to stabilize eroding streambeds, provide fish passage over in-stream structures or knickpoints, and to reconnect channels with adjacent floodplains. Engineered riffles are actually comprised of four habitat units: an upstream glide section, a crest transition, a riffle section (riffle face), and a downstream run section. Glide sections transition flow from an upstream pool to the riffle crest. The riffle crest is provided to reduce stresses on the upstream end of the riffle and transition the channel cross-section shape. Riffle sections are designed to pass sediment and fish while providing long-term channel stability. Runs are the transitional feature from the riffle into an existing run or downstream pool and are designed to prevent knickpoint propagation from the pool into the upstream riffle (Hegberg et al. 2001). These morphologic features are designed to provide several critical functions including geomorphic stability, and diversity of water depth, substrate, and velocity. In streams that experience minimal baseflows, engineered riffles should be constructed to concentrate low flows for improved fish passage (Hegberg et al. 2001).

Newbury Hydraulics has been at the forefront of engineered riffle (Newbury riffle) design. Newbury riffles have been used for grade stabilization, reconnecting stream channels with adjacent floodplains and to achieve fish passage and habitat enhancement goals (Newbury and Gaboury 1993). RDG's proposed engineered riffles borrow on the Newbury riffle concept while also adding other elements intended to further improve redundancy, structural stability, habitat complexity and fish passage.

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Engineered riffles are designed to produce a hydraulic regime that promotes fish passage and provides habitat complexity. Depending on the location of these structures within a watershed and the targeted fish species, engineered riffles may trap spawning gravels in the upstream glide, provide benthic habitats for aquatic macroinvertebrate production and cover for sculpin and juvenile fish on the riffle face, and create diverse flow paths and feeding stations through the run for fish occupying the receiving pool.

Engineered riffle designs are methodically planned by assessing the watershed and site hydrology, developing hydraulic criteria for target fish species, and designing the structure in a suitable geomorphic context. The hydrologic analysis is necessary to estimate the flood return interval in order to determine the hydraulic conditions the project area is likely to experience. Essential components of the hydraulic criteria include determining the target fish species, their migratory behavior and swimming performance. This information is addressed during the engineered riffle design to ensure that water depths and velocities are sufficient for fish passage. Channel morphology and hydraulic design components for the engineered riffle include the channel size and bed material dimensions, discharge regime, and the water surface gradient coinciding with the design discharge.

For the Sodom Dam Removal Project, there are three goals for the engineered riffles. First, the riffles will serve as long-term, stable grade control structures. Currently, there is approximately 1,400 ft of gradient from the Bifurcation to downstream of the Sodom Dam apron. The dam removal would destabilize the upstream channel if grade stabilization is not addressed. Second, engineered riffles will increase the pool frequency in the reach. Preliminary plans suggest locating three pools through the project reach. Channel reconstruction will create a riffle-pool channel morphology, similar to that already found in the Calapooia River, with engineered riffles maintaining upstream pool water surface elevations. Third, engineered riffles will allow fish passage over all flows. Riffles will be built to promote at least four low flow paths through each structure. Low flow paths will be maintained by positioning larger channel bed material to focus streamflow. Because Calapooia River flows can decrease to less than 20 cfs during summer, providing low flow consolidation and passage routes for fish will be critical. Additionally, splitting base flows between the Calapooia River channel and Sodom Ditch will further the importance of focusing base flows.

**Engineered Riffle Calculations**

For each engineered riffle location, the channel cross sectional area and the adjacent floodplain elevation will be calculated from the HEC-RAS model. Because the Sodom Ditch is a human made structure, the ditch does not have a typical bankfull floodplain. We will calculate the channel hydraulics associated with the flow that accesses the land surface adjacent to the ditch. The riffles will be designed to have between a 40:1 and 20:1 facet slope. The tractive force at the design flow will be calculated to determine the minimum rock size needed for the framework boulders that will be placed in the riffle crest and riffle face. Tractive force is a measure of shear stress on the streambed, and is a factor of the depth of flow and the slope of the water surface (Newbury and Gaboury 1993). The framework rocks for the riffle crest and riffle face will be sized to resist the tractive force. A graded mix of smaller diameter cobbles and gravels will form the matrix of the structure. Sand and fine gravels will be jetted into the matrix in lifts as the matrix is constructed. The fines are jetted into the bed to fill voids around larger cobbles and boulders that protrude from the matrix. Additional boulders will be oriented on the riffle face to focus low flow threads for fish passage.

To determine the minimum size of framework boulders for the engineered riffles, we used the approximation relationship between tractive force and incipient diameter of bed material with the following formula:

$$\tau\ (kg/m^2) = \text{incipient diameter (cm)}$$

To find the tractive force we used the following equation:

$$T = 1000 \cdot d \cdot s$$

where d is depth of flow (m), s is slope of water surface, and T is tractive force of flow ($kg/m^2$). Depth, water surface slope, and discharge components will be determined during the design process. Using these parameters, an incipient particle diameter can be calculated. Appropriate safety factors are applied to the incipient particle diameter to finalize the rock size for the engineered riffle. Additional methodologies are also used to ensure further convergence of our final design rock sizes.

Figure 1 includes an example series of rock sizing gradation curves based on hydraulic modeling output. Similar curves will be used to check the minimum framework boulder diameter and to calculate the matrix gradation.

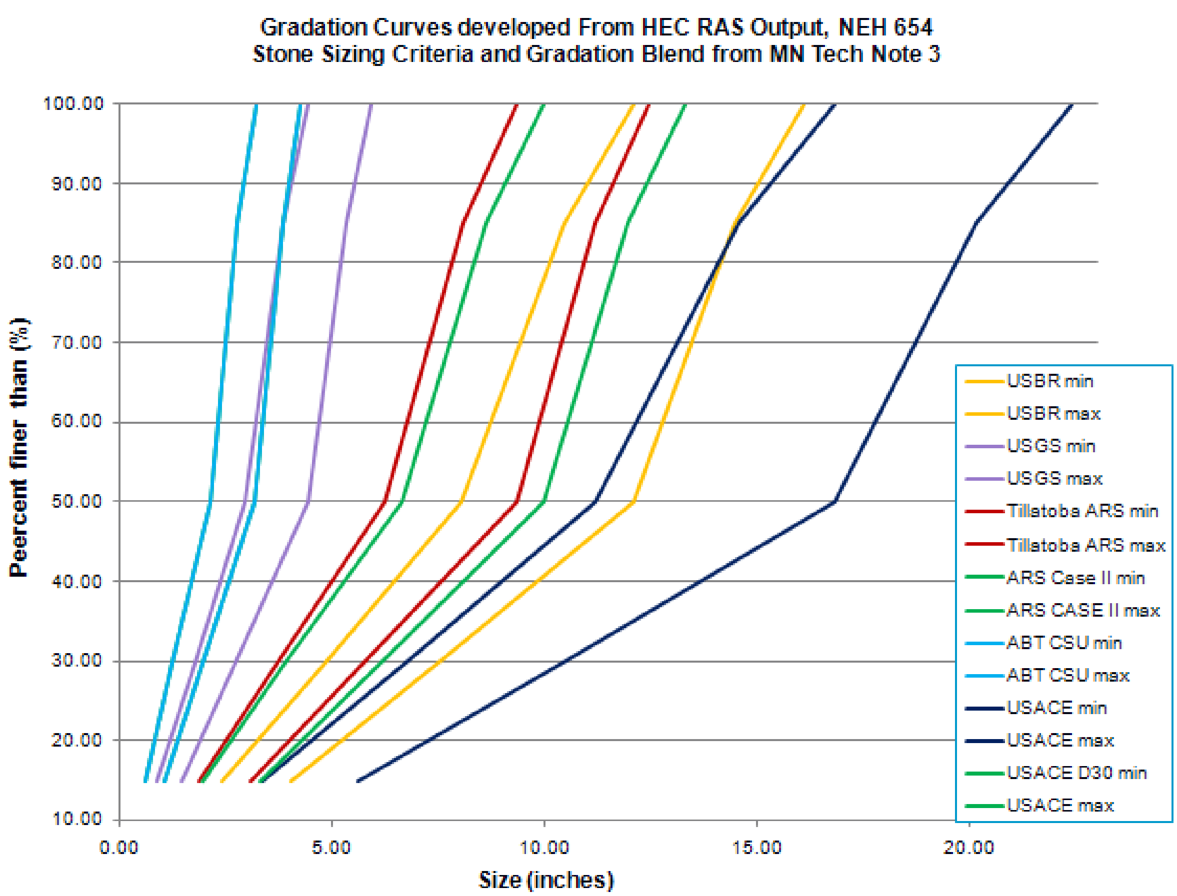



**Figure 1.** Example riffle gradation blends developed through hydraulic modeling and stone sizing methods.

**Engineered Riffle Construction Methods**

Channel excavation and imported bed sediment gradations vary by habitat unit within the engineered riffle. Construction of the glide will include the over-excavation of the channel feature below finished grade then backfilling with a well graded material to facilitate near term spawning production on the feature. The glide's wider cross section transitions at the riffle crest to the slightly narrower downstream riffle. Construction of the riffle will include the over-excavation of the channel below finished grade then backfilling with well graded material as developed through sediment gradation curves. The gradation will be augmented with the distributed placement of framework boulders to counteract scour of the finer gradation matrix. Boulder placement begins near the downstream end of the glide to provide large scale roughness during high flow and hydraulic variability under low flow conditions. Hydraulic effects of the boulder placement include spawning material retention and deposition along the glide face. Boulders placed along the riffle and run provide energy dissipation and serve a grade control function for the overall geomorphic unit. Boulders will be placed in random patterns that replicate natural stream conditions with particular attention to boulder placement to reinforce the run - pool transitional slip face and promotion of low flow fish passage routes.

This type of grade control structure also provides significant redundancy due to the unique boulder matrix. Rather than relying on a single element or a linear rock feature where failure can occur if on or two rocks move, this type of grade control feature incorporates the maximum redundancy possible for a natural looking structure. The large boulders in the matrix can have some movement and still serve their intended function and not compromise the integrity of the riffle feature.

**RDG Experience with Engineered Riffles**

RDG has constructed engineered riffles in streams and rivers in northwest Montana and eastern Oregon. Projects have been completed in moderate gradient, gravel bed systems that experience periodic rain-on-snow events, ice flows, and the capacity for substantial sediment and large wood loading. Engineered riffles have been constructed for similar purposes as the ones planned for the Sodom Dam Removal Project.

The following pages include ground photographs of engineered riffles completed by RDG personnel.

**Figure 2.** An engineered riffle constructed on Shitike Creek in the Deschutes River drainage. The engineered riffle was constructed to maintain channel stability and to appear as a natural feature (left). Protruding boulders dissipate energy and create diverse flow paths (right).


**Figure 3.** Engineered riffles constructed on the Jocko River in northwest Montana. The structures were built to provide grade control, to raise the channel bed, and to increase pool frequency. The project was completed in 2008.

**Figure 4.** An engineered riffle constructed on Grave Creek in northwest Montana. The structure was built to provide grade control at a pool tailout. The project was completed in 2005.

**Figure 5.** Constructed engineered riffles on Crow Creek in northwest Montana were designed to raise the channel invert and to maintain stability. The photos include paired as-built (left photos) and runoff views (right) from approximately the same photo points. The project was completed in 2007.

**Figure 6.** Additional example engineered riffles from Crow Creek, Montana. The project was completed in 2007.

**Figure 7.** Two constructed riffles on the Clark Fork River as part of the Clark Fork River Restoration Project associated with the removal of Milltown Dam near Missoula, Montana. Project completed in 2009. The upper two photos are looking downstream at the glide-riffle structure. The bottom two photos are looking back upstream at the constructed riffle.

Table 1 includes channel morphology, hydrology, and hydraulics descriptive statistics for the streams and rivers where RDG has completed engineered riffles.

**Table 1.** Channel morphology and hydraulics for streams and rivers where RDG has completed engineered riffles. Calapooia River metrics are included for comparison.

| Stream/River | Bankfull Discharge (cfs) | Bankfull Width (ft) | Bankfull Velocity (fps) | Bankfull Slope (ft/ft) | $D_{84}$ Particle (mm) |
|---|---|---|---|---|---|
| Clark Fork River | 3,200 | 150 | 5.8 | 0.003 | 180 |
| Jocko River | 650 | 60 | 5.2 | 0.011 | 116 |
| Crow Creek | 175 | 25 | 5.3 | 0.027 | 120 |
| Grave Creek | 660 | 54 | 5.7 | 0.009 | 146 |
| Shitike Creek | 615 | 51 | 4.8 | 0.008 | 95 |
| Calapooia River | 6,300* | 145 | 5.5 | 0.001 | 55 |

*: 2 year return interval discharge

We are confident that this type of grade control will provide the long-term stability and fisheries benefits for the Sodom Dam Removal project. Our experience, as well as the work of others such as Newbury Hydraulics, demonstrates that when engineered riffles are designed properly and placed in the right geomorphic context they can provide long-term stability. Likewise, this type of grade control structure at in the project area provides the most flexibility for future adjustments and modifications if necessary.

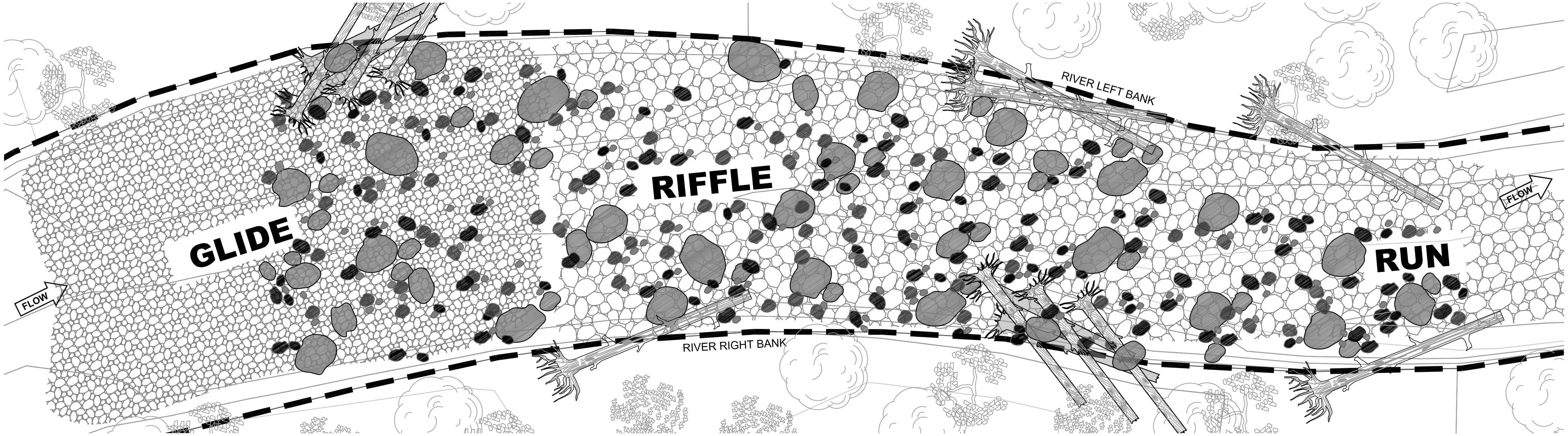
Respectfully yours,

Troy Brandt
Fisheries Biologist
Enclosures

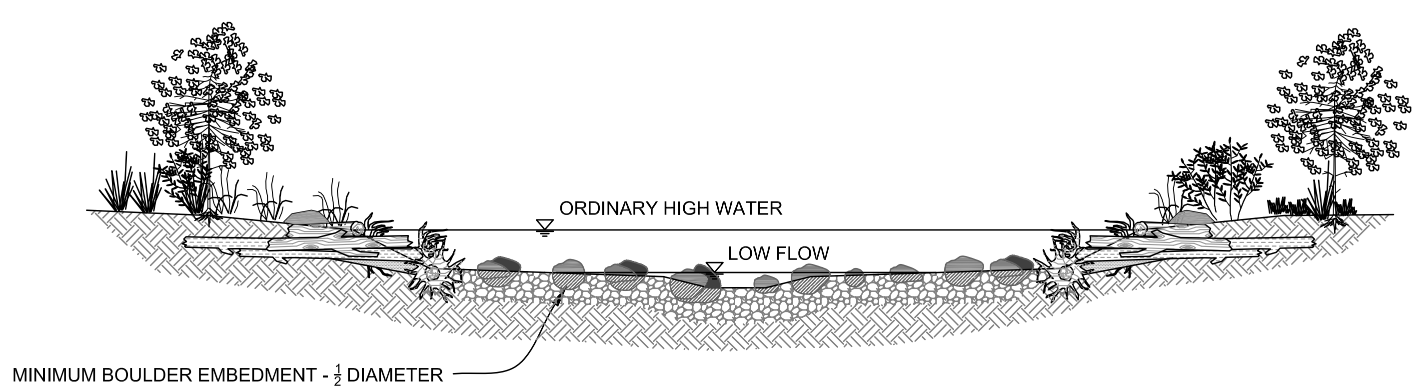
## Literature Cited

Hegberg, C.H., P.A. Schlindwein, S.J. Cohen, and S. Jacobs. 2001. Natural fish passage structures in urban streams (Part 2: Hydrologic design and analysis). 14 p.

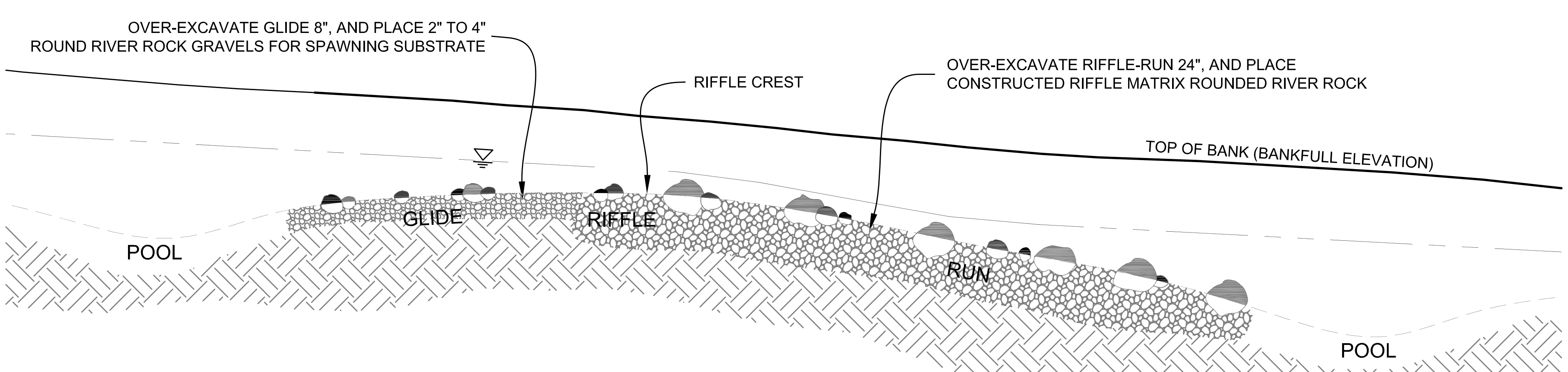
Newbury, R.W. and M.N. Gaboury. 1993. Stream analysis and fish habitat design. A field manual. Newbury Hydraulics, Gibsons, British Columbia. 256 p.




**1 PLAN VIEW**
NOT TO SCALE




**2 RIFFLE SECTION**
NOT TO SCALE




**3 RIFFLE-RUN PROFILE**
NOT TO SCALE

## CONSTRUCTION NOTES

BOULDER PLACEMENT BEGINS NEAR THE DOWNSTREAM END OF THE GLIDE TO PROVIDE LARGE SCALE ROUGHNESS DURING HIGH FLOW AND HYDRAULIC VARIABILITY UNDER LOW FLOW CONDITIONS. HYDRAULIC EFFECT INCLUDES SPAWNING MATERIAL RETENTION AND DEPOSITION ALONG GLIDE FACE. BOULDERS PLACED ALONG THE RIFFLE AND RUN PROVIDE DISRUPTION OF AVERAGE VELOCITY GRADIENTS AND SERVE A GRADE CONTROL FUNCTION FOR THE OVERALL GEOMORPHIC UNIT. PARTICULAR CARE SHOULD BE EMPLOYED WITH ELEMENT PLACEMENT TO REINFORCE THE RUN - POOL TRANSITIONAL SLIP FACE.

BOULDERS SHOULD BE PLACED IN RANDOM PATTERNS THAT REPLICATE NATURAL STREAM CONDITIONS AS DIRECTED BY THE PROJECT FISHERIES BIOLOGIST AND HYDRAULIC ENGINEER.

SEE GRADATION SCHEDULES ON THIS SHEET FOR CONSTRUCTED RIFFLE MATRIX GRADATION AND HABITAT BOULDER REQUIREMENTS. SUFFICIENT FINES (SAND FRACTION OR FINER) SHALL BE DEVELOPED FROM ON-SITE EXCAVATIONS AND PRESSURE WASHED INTO THE PLACED RIFFLE MATRIX BOULDER FEATURE.

ENGINEERED RIFFLE TO BE CONSTRUCTED IN ONE HALF FOOT VERTICAL LIFTS WITH FINES ADDED AND PRESSURE WASHED. SUCCESSFUL WASHING WILL BE DETERMINED BY MINIMIZATION OF VOIDS WITHIN PLACED MATRIX SUCH THAT PONDING OCCURS ON TOP OF LIFT WITH LITTLE TO NO PERCOLATION LOSSES OCCURRING THROUGH THE ENGINEERED RIFFLE.

## CONSTRUCTED RIFFLE HABITAT BOULDER SCHEDULE

| BOULDER ELEMENT SIZE (FT.) | RGCS #1 L=230' | RGCS #2 L=201' | RGCS #3 L=230' | RGCS #4 L=270' | RGCS #5 L=170' | RGCS #6 L=120' |
|---|---|---|---|---|---|---|
| 1.5' | 127 | 110 | 127 | 121 | 94 | 66 |
| 2.0' | 46 | 40 | 46 | 66 | 34 | 24 |
| 2.75' | 69 | 60 | 69 | 66 | 51 | 36 |
| 3.5' | 69 | 60 | 69 | 60 | 51 | 36 |

## CONSTRUCTED RIFFLE MATRIX GRADATION

| PERCENT PASSING | LOWER LIMIT (INCHES) | UPPER LIMIT (INCHES) |
|---|---|---|
| 100 | 17.0 | 22.5 |
| 85 | 14.5 | 20.0 |
| 50 | 11.0 | 17.0 |
| 30 | 6.5 | 10.5 |
| 15 | 3.5 | 5.5 |

MATRIX THICKNESS (T) = 24 INCHES

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# ENGINEERED RIFFLE

PROJECT NAME

CLIENT NAME

| NO. | DATE | BY | DESCRIPTION | CHK |
|---|---|---|---|---|
| 1 | 11/16/09 | | | |

PROJECT NUMBER RDG-0X-0XX

DRAWING NUMBER

3.X

Drawing X of Y