Gravel/Cobble Augmentation Implementation Plan (GAIP) for the Englebright Dam Reach of the Lower Yuba River, CA

(photo of proposed gravel augmentation location)

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OVERVIEW

The purpose of this report is to thoroughly document a plan for implementing a gravel/cobble augmentation program below Englebright Dam and to address its biogeomorphic impact on the lower Yuba River. As described below, Englebright Dam plays a crucial role in protecting the downstream region from being overwhelmed by sedimentary mining waste debris still being eroded off hillsides and stored in long sections of the channel network upstream. Most of the active lower Yuba River also still has tens of millions of cubic yards of sedimentary mining waste debris in it that pre-date Englebright Dam and are still being re-worked as part of a highly dynamic, meandering gravel-bed river. However, the reach between Englebright Dam and the confluence with Deer Creek is now almost devoid of river-rounded gravel and cobble necessary for salmon spawning. In particular, spring-run Chinook salmon that historically went far upstream would substantially benefit from a gravel/cobble augmentation program below Englebright Dam. Yet the critical reach is in a narrow canyon that is difficult to access and manage, let alone place thousands of tons of coarse sediment into. Numerous issues have to be considered and addressed. That effort is facilitated by the existence of many studies of the river in recent years that form the basis for understanding the status and challenges ahead for the river.

This report covers topics related to preliminary planning efforts, pre-project characterization of the reach in question, design development for the specific 2010 next-phase pilot project, and long-term planning. Section 1 is an overview of the literature that describes what is already known about the river leading to a geomorphic and biological nexus for the action necessary to rehabilitate the river with respect to the impact of Englebright Dam. Section 2 explains what gravel/cobble augmentation is and how it may be implemented. Specific constraints and opportunities associated with the possible use of each method below Englebright Dam are described, including how specific methods affect site selection and project goals. Section 3 presents the pre-project characterization of the Englebright Dam Reach. That includes a summary of available data and information, a new estimation of the gravel/cobble deficit for the reach, 2D hydrodynamic modeling and analysis of results, and a conception of how the reach works in its baseline condition. Section 4 presents the details of the concept for how to get gravel to the river bed in the remote canyon. The recommended method involves sluicing gravel and cobble to the river. Section 5 explains and tests design concepts, objectives, and methods for the opportunity to place gravel in 2010 to yield immediate, preferred salmon spawning physical habitat. Section 6 describes a long-term plan for monitoring the outcome of the 2010 pilot project and then what actions should be taken thereafter to continue to rehabilitate gravel/cobble storage and enhance salmonid spawning habitat in the reach with additional augmentations over time.

1. LOWER YUBA RIVER BACKGROUND

The 3,490-km^2 Yuba River basin has hot, dry summers and cool, wet winters. Relative to other Sierra basins, the Yuba has among the highest mean annual precipitation (>1,500 mm), so it has been used for hydropower, water supply, flood regulation, gold mining and sediment control (James 2005). During the Gold Rush (mid- to late 1800's), hillsides were hydraulically mined until several court decisions first outlawed the practice, then reinstated it with restrictions and taxes instituted to construct and pay for dams such as Daguerre Point Dam and Englebright Dam. These dams were designed to prevent the transport of hydraulic mining debris to the valley, thus lowering the risk of flooding. However, hydraulic mining never returned to the levels of the 1800's (Gilbert, 1917). Englebright Dam is located at 39°14'23.37"N, 121°16'8.75"W (Yuba River mile 23.9 upstream from confluence with the Feather River) in a narrow bedrock canyon on the Yuba River in northern California. Streamflow is recorded at the United States Geological Survey Smartville gage (#11418000) 0.5 km downstream of Englebright Dam. The gage's statistical bankful discharge 1971-2004 was 5620 cfs (159.2 m^3 s^{-1}), which matches field indicators (tops of active medial bars and positioning of bank vegetation) for the bankful discharge in Timbuctoo Bend. Given that the Middle and South Yuba tributaries lack large reservoirs, winter storms and spring snowmelt produce floods that overtop Englebright Dam. The Lower Yuba River (LYR) is ~38 km (24 mi) long from Englebright to the junction with the Feather. The Englebright Dam Reach (EDR) extends from Englebright down to the confluence with Deer Creek (Fig. 1.1).

1.1. LYR Geomorphic History

No records are known to exist describing river conditions in the canyon that Englebright sits in prior to placer gold mining in the mid-Nineteenth century. During the era of placer gold mining, Malay Camp on the northern bank of the Yuba close to the confluence of Deer Creek served as a base of operations for miners working Landers Bar, an alluvial deposit in the canyon nearby. The historical records of the existence of this camp and placer-mining site proves that coarse sediment was stored in the canyon prior to hydraulic mining in a large enough quantity to produce emergent alluvial bars.

During the period of hydraulic gold mining, vast quantities of sand, gravel, and cobble entered the Yuba River (Gilbert, 1917) and deposited throughout the system (Fig. 1.2). This human impact completely transformed the river. Historical photos from 1909 and 1937 document that the canyon was filled with alluvial sediment with an assemblage of river features including riffles (Pasternack et al., 2010). Conditions downstream of the canyon during that period were described by James et al., (2009). Even though Daguerre Point Dam was built on the valley floor in 1906 (at Yuba River mile 11.4 upstream from confluence with the Feather River) to prevent the transport of hydraulic mining debris, it is too small to block sediment migration during floods.

Englebright Dam (capacity of just 82.6 million m^3) was constructed in 1941 to serve as an additional, highly effective barrier to the hydraulic-mining waste material continuing to move down to the Central Valley. Thereafter, photos show that the amount of alluvium in the entire lower Yuba River, including the canyon, decreased (Pasternack et al., 2010). At the Marysville gaging station, the river incised ~20’ from 1905-1979, while 0.5 mi downstream of the Highway 20 bridge it incised ~35’ over the same period (Beak Consultants, Inc., 1989). These landform adjustments are still on-going. For example, Pasternack (2008) estimated that ~605,000 yds^3 of sediment (primarily gravel and cobble) were exported out of Timbuctoo Bend from 1999 to 2006. Further investigations of landform and sediment-storage changes are on-going, and the early indications are that they will show significant dynamism well beyond what was presumed by Beak Consultants, Inc (1989).

The reported changes conform with the expected, natural response of a river to blockage of downstream sediment passage (e.g. Williams and Wolman, 1984). For most rivers, such geomorphic changes represent a harmful human impact on a river, but in this case of pre-existing, unnatural snuffing of the river corridor by mining debris, the dam is actually *restoring* the river toward its historical geomorphic condition, in the truest meaning of the term- to go back to the pre-existing state prior to hydraulic gold mining. Hydraulic mining is the primary disturbance to the Yuba River. Going back in this case means evacuating much of the waste debris associated with that historic practice. Abatement of the downstream effects of sediment derived from uplands through the use of dams is an accepted practice for watershed rehabilitation (Shields, in press). On the LYR, there is strong evidence that Englebright Dam has helped to evacuate sediment without hurting important channel processes. For example, despite the evidence that Timbuctoo Bend is undergoing significant sediment export and river-corridor incision, White et al. (2010) reported that eight riffles persisted in the same locations over the last 26 years (likely back much further). Most of these persistent riffles are positioned in the locally wide areas in the valley, while intervening pools are located at valley constrictions. Thus, incision and sediment export do not necessary translate into harmful degradation of fluvial landforms. In Timbuctoo Bend, the existence of undular valley walls preserves riffle-pool morphology in the face of on-going geomorphic change. Given the vast quantity of waste material still present in the upper system and the ability of many unhealed hillsides to generate more, Englebright Dam continues to serve as an important protection for the environment of the LYR.

Confounding the natural response of the river to the restorative impact of Englebright, the Yuba River has been subjected to harmful in-channel human activities that further altered it. The greatest impact came from dredgers processing and re-processing most of the alluvium in the river valley in the search for residual gold and to control the river (James et al., 2009). First, there was the formation of the ~10,000 acre Yuba Goldfields in the ancestral migration belt. Then there was the relocation of the river to the valley's northern edge and its isolation from the Goldfields by large "training berms" of piled-up dredger spoils. Dredger-spoil training berms also exist further upstream in Timbuctoo Bend away from the Goldfields (Fig. 1.3); these berms provide no flood-control benefit.

Although no training berms exist in the canyon downstream of Englebright Dam, mechanized gold mining facilitated by a bulldozer beginning ~1960 (Fig. 1.4) completely reworked the alluvial deposits in the vicinity of the confluence with Deer Creek, changing the river's form there (Pasternack et al., 2010). Prior to mechanized mining, glide-riffle transitions were gradual, enabling fish to select among a diverse range of local hydraulic conditions. Bulldozer debris constricted the channel significantly, induced abrupt hydraulic transitioning, and caused the main riffle at the apex of the bar to degrade into a chute. In addition, mining operations evacuated the majority of alluvium at the mouth of Deer Creek. On top of these impacts, the 1997 flood caused angular hillside rocks and "shot rock" debris from the canyon bottom to be deposited on top of the hydraulic-mining alluvium in the canyon.

At present, the Yuba River downstream of Englebright Dam continues to change in response to the complex assemblage of natural processes and human impacts. The legacy of hydraulic mining is the first and foremost impact to the system, relative to the pre-existing condition. Englebright Dam blocks further impacts from upstream mining waste and is directing the river on a trajectory toward restoration of the pre-existing landform. Daguerre Point Dam serves as a stabilizer in the system, providing a base level for how far incision can go between it and Englebright Dam. Mechanized re-working of alluvium and associated channelization have dictated the lateral bounds of what the river can do now and also impact the diversity and distribution of river-corridor landforms.

In summary, the fluvial geomorphology of the Yuba River is so unique that it is crucial to evaluate it on its own terms and not apply simple generations and concepts from other rivers with dams. Hydraulic mining, dredger re-processing of the valley floor, mechanized in-channel mining, upstream watershed management choices, and dams all combine to yield a system that requires careful investigation before making conclusions about how the fluvial geomorphology works and what restoration opportunities exist. Recent studies have helped clarify the current status of the river and more investigations are on-going.

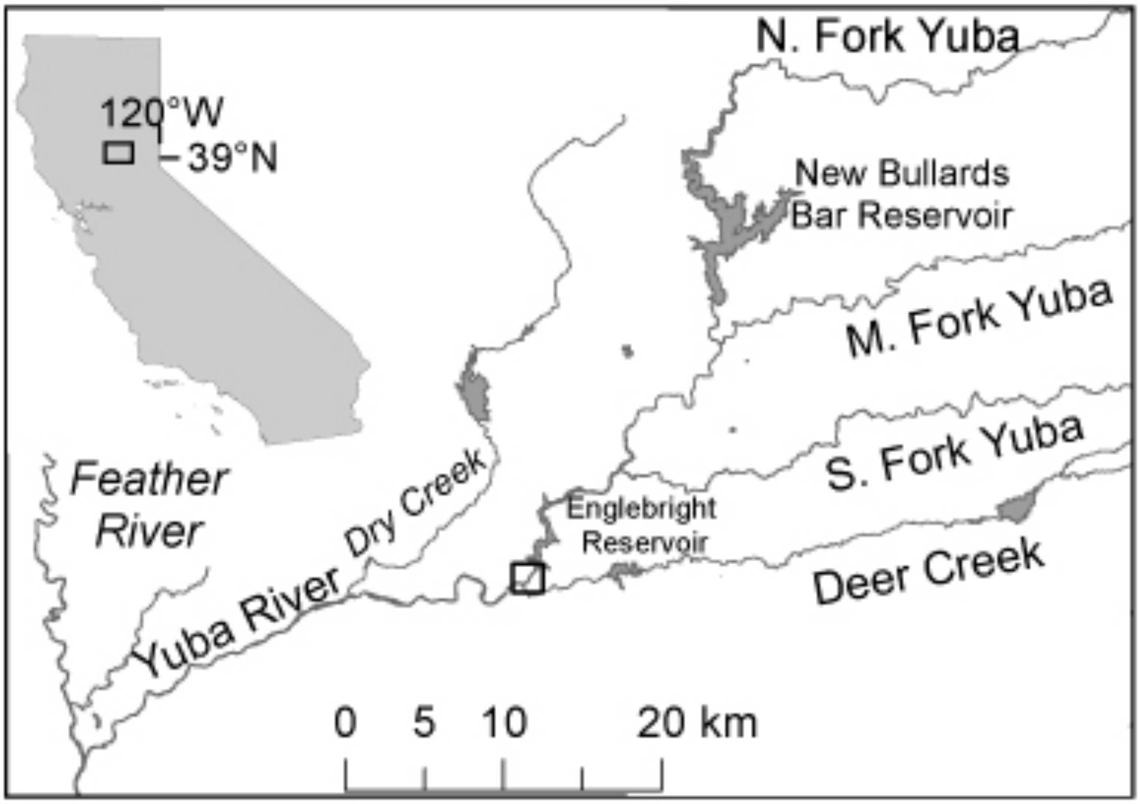


Figure 1.1. Location map of the Englebright Dam Reach (black box) in the Yuba catchment.

Figure 1.2. 1905 photo of the LYR near Parks Bar taken by G.K. Bilbert (http://libraryphoto.cr.usgs.gov/photo_all.htm).

Figure 1.3. Dredger forming high tailings berm out of a mining-waste point bar at Rose Bar on 10/21/1937. (Photo from the California Transportation State Archive).

Figure 1.4. Photo of a gold mining operation on Sinoro Bar circa 1960. (Photo courtest of Ralph Mullican).

1.2. LYR Salmonids History

1.2.1. Historical Population Accounts

The spring run of Chinook salmon (SRCS) is a federally threatened species that is differentiated by the time at which adults migrate from the ocean to freshwater systems (Yoshiyama et al. 1996). There are no quantitative estimates for pristine, historic salmonid populations on the Yuba River prior to hydraulic gold mining, let alone isolating just SRCS, but Yoshiyama et al. (1996) reported historic accounts suggesting a large population, possibly in the hundreds of thousands. For example, they cite Chamberlain and Wells (1879) as stating that the Yuba was so full of salmon that Indians speared them "by the hundred". However, during hydraulic gold mining much water was diverted away and the river valley was allowed to fill 20-80' high with mine tailings. A first-hand account of a miner at Long Bar in the valley stated that the miner's diet primarily consisted of pancakes and there is no mention of fish at all (Lecouvreur, 1906). Yoshiyama et al. (1996) reported accounts of the construction of Bullards Bar Dam in 1921-1924 in which it was stated that so many salmon were blocked at the construction location that their carcasses had to be burned. SRCS and steelhead both were known to migrate far up into the North and Middle Yuba Rivers and several miles up into the South Yuba before reaching potentially impassable waterfalls. However, much of the spawning habitat in the upper watershed was badly degraded by mining debris, sand, and turbidity. If the SRCS population was in the hundreds of thousands of fish, then the riffles in the canyon where Englebright Dam is located would likely have been used by part of that large population during the mining era and early 20th century. However, relative to the total abundance, this number of fish spawning in the canyon may not have drawn the attention of naturalists at the time, especially given the difficulty of getting to that area.

During the latter half of the 20th century, Yuba River salmonid populations were estimated quantitatively (Fig. 1.5), but it is still difficult to isolate SRCS numbers. Yoshiyama et al. (1996) cite several estimates of the fall-run Chinook salmon population, but provide no enumeration of SRCS. They cite John Nelson as reporting that fall- and spring-run populations are mixed and that these mixed fish are now present in "minimal numbers". CDFG (1991) enumerates the annual estimate of fall-run Chinook salmon, with a range of 1000 in 1957 to 39,000 in 1982. For SRCS, CDFG (1991) states that a remnant population exists and that it is composed of some in-river natural reproduction, strays from the Feather River, and restocked, hatchery-reared fish. Restocking of fingerlings and yearlings was done in 1980. CDFG (1991) reported that 20 pairs of Chinook salmon were observed to spawn at the Narrows powerhouse in autumn 1986 and due to passage barriers in the autumn, it was decided that these were SRCS that migrated during high spring flows. CDFG stopped conducting annual escapement surveys in 1989. No survey was done in 1990. The Yuba County Water Agency (YCWA) sponsored Jones and Stokes, Inc. to perform escapement surveys using the CDFG methodology for 1991-2004.

For 2005-2007 CDFG took over the effort again, but beginning in 2008 the responsibility shifted to the Yuba Accord River Management Team (RMT) as part of its new Monitoring and Evaluation Plan. The RMT's 2008 escapement and redd reports used temporal modalities associated with fresh carcass observations and frequencies of redd observations to try to differentiate spring- and fall-run Chinook salmon. However, it was not possible to obtain a clear distinction and all data were analyzed together. In all of these modern enumerations, abundance estimates did not isolate SRCS or the subpopulation of all Chinook in the EDR; carcass counts were not made in the EDR due to challenging accessibility.

For March 2007 through February 2008, the RMT operated a Vaki RiverWatcher video monitoring system on both fish ladders at Daguerre Point Dam (~12 miles downstream of the EDR). This system scans the side-view projected area of each fish and takes a color photo of each fish. From these data, staff counts the number of fish that pass and use characteristic morphometrics to identify the species of each fish (for ~70% of individuals). Of the 1,324 Chinook that were observed, 336 (25%) passed in March-August, which is the period that SRCS likely migrate.

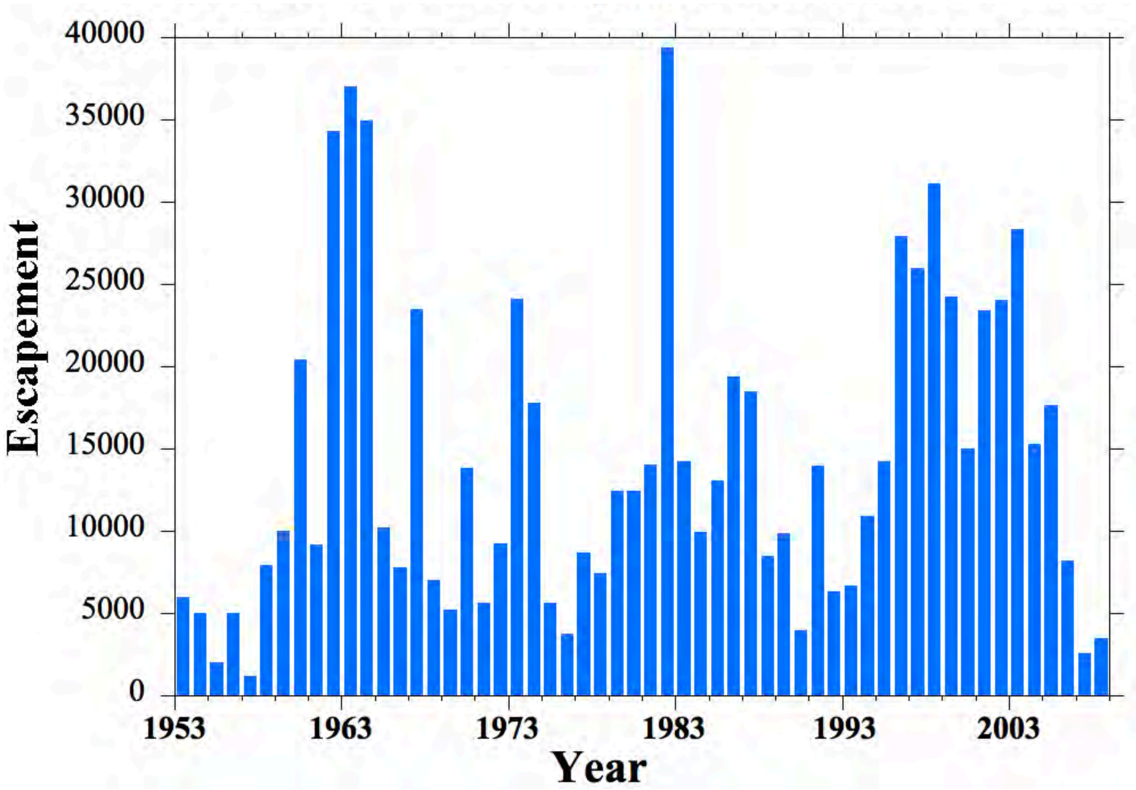


Figure 1.5. Adult Chinook salmon abundance for the LYR based on carcass surveys and coded-wire tagging.

1.2.2. Physical Habitat Conditions

Physical habitat units in rivers are defined as zones with characteristic attributes where organisms perform ecological functions, which are the ways in which organisms interact with each other and their surroundings. Common attributes of physical habitat include substrate type, water depth, water velocity, water temperature, cover objects, and shading. The quantity and quality of physical habitat are critical factors that can limit the size of fish populations. The assemblage of these attributes stem from the interaction among hydrologic, hydraulic, and geomorphic processes. As a result, when processes are altered or degraded by human intervention, then physical habitat will likely be degraded too. In turn, that decreases the size of fish populations.

Physical habitat conditions related to salmonids downstream of Englebright Dam have been studied over the years. With respect to the spawning life stage, Fulton (2008) investigated salmon spawning habitat conditions in the canyon below Englebright Dam and found the conditions to be very poor to nonexistent. No rounded river gravels/cobbles are present in the canyon between Englebright Dam and Sinoro Bar by the confluence with Deer Creek other than a small amount injected artificially in November 2007. For the whole lower Yuba River, Beak Consultants, Inc (1989) states:

> "The spawning gravel resources in the river are considered to be excellent based on the abundance of suitable gravels, particularly in the Garcia Gravel Pit and Daguerre Point Dam reaches. The tremendous volumes of gravel remaining in the river as a result of hydraulic mining make it unlikely that spawning gravel will be in short supply in the foreseeable future. Armoring of the channel bed is possible, but has not developed to date, probably due to periodic flushing by floods comparable to the 1986 event."

Similarly, Pasternack (2008) reported that:

> In Timbuctoo Bend "…there is adequate physical habitat to support spawning of Chinook salmon and steelhead trout in their present population size. Furthermore, all of the preferred morphological units in the *[Timbuctoo Bend Reach]* TBR have a lot of unutilized area and adequate substrates to serve larger populations."

With respect to rearing life stages, Beak Consultants, Inc (1989) states that:

> "The Daguerre Point Dam and Garcia Gravel Pit reaches contribute most of the *[Weighted Usable Area]* WUA, and substantially more than the Simpson Lane Reach; The Narrows Reach contributes little fry habitat… Total WUA for juveniles is highest in the Daguerre Point Darn and Garcia Gravel Pit reaches… The Simpson Lane Reach contributes a small amount of WUA, while The Narrows Reach provides virtually no juvenile habitat."

Adult migration is presently under study by the RMT, but there are some pre-existing observations. Adult SRCS are commonly observed holding in pools in the canyon below Englebright Dam, in the pools in Timbuctoo Bend, and in the pool below Daguerre Point Dam. In September 2007, UC Davis graduate student Aaron Fulton observed SRCS attempting to dig redds and spawn on bedrock covered with a thin veneer of angular gravel, causing them injury. Acoustic tracking of adult SRCS in 2009 by the RMT showed that some individuals migrate into and out of the canyon until September at which point they stop migrating and attempt to spawn between Englebright Dam and the highway 20 bridge.

1.3. LYR Geomorphology-Salmonids Nexus

Two key conclusions from this review of previous knowledge are that most of the lower Yuba River is still geomorphically dynamic and that the river possesses a diversity of in-channel physical habitats, even if some types are not as abundant as would be optimal for restoring the size of fish populations that likely existed in the Yuba River prior to the onset of hydraulic gold mining. Hydraulic mining snuffed the river and its floodplain with a vast, homogenous mix of mining waste. Since Englebright Dam blocked that, channel complexity and habitat diversity has been re-emerging, and that process continues. The extent to which it can continue is impacted by the role of the training berms and the degraded state of the entire Yuba Goldfields, both of which are beyond the scope of actions related specifically to the impact of Englebright Dam, which is the focus of this report. The glaring problem in the system associated with this dam is the status of SRCS spawning in the EDR.

The dramatic decline in SRCS in California has been attributed to dams, as they block up to ~80% of historic spawning habitat. Based on life history, impassable high dams have hurt the spawning life stage of adult SRCS the most, because spawning is the purpose behind the migration of SRCS to Sierran headwaters. Under a regulated flow regime, SRCS migrate to bedrock reaches at the base of large dams and hold in pools supplied with cold sub-thermocline water releases. On the Yuba holding occurs below Daguerre Point Dam and to a lesser extent below Englebright Dam (Fig. 1.6), but once it is time to spawn, SRCS move upstream into the canyon. Therefore, whether they provided historically preferred physical spawning habitat or not (and for the Yuba the evidence is that they did), bedrock reaches at the base of large dams play a key role in SRCS viability under the current regime of impassable dams.

If SRCS cannot spawn in sufficient numbers, then physical habitats supporting their subsequent life stages downstream are irrelevant. There is no question that Englebright Dam is a complete barrier to fish migration upstream and gravel/cobble transport downstream. Any effort to reinstate SRCS presence upstream of Englebright Dam would take significant time to figure out, implement, and evaluate its effectiveness. If such an effort were undertaken, it would still be critical to sustain existing populations below the dam using well-proven methods until passage efforts were equally well demonstrated in the watershed. To achieve usable, preferred SRCS spawning habitat in the canyon, it is necessary to resolve the lack of river-rounded gravels/cobbles there. At this time and for the foreseeable future, only the canyon is in need of a gravel/cobble supply to offset the impact of Englebright Dam.

Figure 1.6. Photo of SRCS holding in bedrock/boulder section of the LYR near the mouth of Deer Creek (photo courtesy of Ralph Mullican).

2. GRAVEL/COBBLE AUGMENTATION

The key negative impact of Englebright Dam on the lower Yuba River is the loss of a mixture of gravel- and cobble-sized river-rounded rocks in the canyon between Englebright Dam and the confluence with Deer Creek, which is necessary to support SRCS spawning there. This reach is known as the Englebright Dam Reach (EDR). Fulton (2008) investigated physical habitat in the uppermost third of the EDR and found that suitable hydraulics for salmon spawning were present there, but needed substrates were absent (Fig. 2.1). Subsequent modeling of the entire EDR showed that the same holds true for the entire reach- there are areas of good hydraulics, but they lack the needed river-rounded gravel and cobble mixture (Pasternack, 2008a). Thus, the solution to this problem is to implement a procedure known as gravel/cobble augmentation (Wheaton et al. 2004a; Pasternack, 2008b).

Figure 2.1. Photo of the EDR below Narrows 1 showing the dominance of shot rock on the banks. The wetted channel is devoid of river-rounded gravel and cobble in this area.

2.1. Gravel/Cobble Augmentation Defined

Gravel/cobble augmentation (aka gravel/cobble injection) is defined as the piling up of coarse sediment (usually a mixture of gravel and cobble ranging in size from 0.3-4 inches (8-100 mm) in diameter) within or along a river (Wheaton et al., 2004a).

The ***geomorphic goal*** *of gravel/cobble augmentation is to reinstate interdecadal, sustainable sediment transport downstream of a dam during floods, which is necessary to support and maintain diverse morphological units, such as riffles, pools, point bars, and backwaters* (Pasternack, 2008b).

The ***ecological goal*** *of gravel/cobble augmentation that yields self-sustainable morphological units is to have the associated assemblages of physical attributes that are preferred for each of the freshwater life stages of salmonids* (Pasternack, 2008b).

Pasternack (2008b) explains the pros and cons of gravel/cobble augmentation relative to other methods of river rehabilitation in support of salmon spawning. It is important to understand that achieving the geomorphic goal does not mean that the ecological goal will be achieved too. It has frequently been observed that when gravel is injected into a river, it just settles into the bottom of a deep in-channel pit or pool, never to be re-entrained. Unless a reach is investigated for its hydrogeomorphic mechanisms of fluvial landform maintenance, then there is no basis to an assumption that ecological benefits will necessary be achieved from successful redistribution of injected coarse sediment. This is the concept of “process-based” river restoration (Beechie et al., 2010). Any action may or may not work, depending on whether its usage has been placed into the context of the fluvial mechanisms at work in the system. Augmentation of flow or gravel/cobble in the absence of an understanding of processes and impacts is a gamble of unknown value or harm (Pasternack, 2008b).

When performing gravel/cobble augmentation it is often possible to place the material into the wetted channel according a specific design capable of yielding immediate salmon spawning habitat (Wheaton et al., 2004b; Elkins et al., 2007). It can be beneficial to add large wood and boulders during construction to form hydraulic structures in symphony with the gravel/cobble placement (Wheaton et al., 2004c). Together, these diverse elements are shaped (but not hard-wired) to provide adult holding habitat proximal to high-quality spawning habitat, further enhance spawning habitat with complex gravel oxygenation and shading conditions, and furnish early rearing habitat before fish migrate or are flushed downstream. Depending on site history and the specific goals and methods of such efforts, this approach of blending gravel/cobble placement and hydraulic structure construction can dramatically enhance or rehabilitate morphological units and sub-unit hydraulic complexity for a reach below a dam (Elkins et al., 2007). By coupling that with a long-term gravel/cobble injection program at the base of a dam and evaluation of the flow regime, a comprehensive framework for rehabilitating and managing a regulated river can be achieved (Pasternack 2008b). Such a framework for river rehabilitation is hierarchical, because it incorporates a) microhabitat diversity to provide preferred local conditions to support different life stages of existing populations, b) geomorphically sound mesohabitats that provides more and larger organized areas to grow populations, and c) flow variability and injections of gravel to provide the physical inputs necessary for geomorphic dynamics that renew and sustain a gravel-bed river.

2.2. LYR Pilot Gravel/Cobble Augmentation

The United States Army Corps of Engineers (The Corps), UC Davis, and USFWS collaborated on an experimental gravel/cobble injection below Englebright Dam (in the pool below the Narrows II powerhouse) in November 2007. The purpose of this experiment was to find out if and where gravel/cobble would deposit in the EDR and thus gain insight into the efficacy of gravel/cobble injection as a habitat enhancement tool for spring-run Chinook salmon in the EDR. The basic study design involved injecting gravel/cobble during low flow in autumn of 2007 and then waiting for high flows in subsequent water years to move it. Then it would be possible to track where those materials went.

Five hundred short tons of triple washed river gravel/cobble was purchased from a nearby quarry downstream. Based on bucket tests in a quarry, Merz et al. (2006) reported a dry bulk density of gravel/cobble to be ~0.722 yds^3 per short ton for a Mokelumne River quarry. Using this estimate, a total of 361 yds^3 of gravel/cobble was available to be injected in the EDR. The material was trucked in ahead of time and piled on top of the gravel parking lot at the Narrows II powerhouse (Fig. 2.2). Gravel/cobble injection took place on November 29, 2007 beginning at 9:30 am and finishing by 3:00 pm (Fig. 2.3). A TB 135 truck-mounted gravel conveyor was used to reach out over the river and inject gravel into the Narrows II pool. A single small loader was used to transfer piled gravel/cobble into the hopper, but it turned out that not all the gravel/cobble could be fully injected during the single allotted day using that one loader. Consequently, a small amount ended up being incorporated into the parking lot, instead of going into the river (Fig. 2.4). Using a tape measure, the volume of gravel/cobble left behind on the parking lot, in between boulders on the edge of the lot, and spilled over the side was estimated to be ~34 yds^3. Thus, ~327 yds^3 of gravel and cobble was placed into the river.

As the material was being placed into the river, ~400 painted, magnetized tracer stones were put into the hopper with the gravel/cobble to facilitate tracking. Those tracers are thus integrated all throughout the in-river gravel/cobble pile. Those stones are traceable using a magnetic locator, but any rounded gravel that is found downstream in the EDR must be coming from this source, because there is virtually no other such material in this reach.

Pasternack (2009) investigated the status of the injected gravel/cobble after two winters, and some interesting lessons were evident. Although the two intervening winters were relatively dry (Fig. 2.5), some transport did take place. Of the 327 yds^3 that was successfully injected to the river, only ~3 yds^3 moved during the period when flow was ≤ 8014 cfs. After a flood with a peak flow of 15381 cfs, a total of ~75 yds^3 moved. That amount includes the ~3 yds^3 that was moved prior to that, so that means that ~252 yds^3 remained in the gravel/cobble injection pile in the Narrows II pool as of July 1, 2009. For the 2010 water year, the peak discharge occurred in June 5, 2010 and it was only 6928 cfs.

Preliminary observations of Chinook salmon redds in 2009-2010 by the RMT found that 120 redds were located in the EDR between September 7, 2009 and February

22, 2010. This response to limited gravel injection indicates that if more gravel was present, a population of SRCS could be accommodated.

Figure 2.2. 500 short tons of gravel/cobble prior to injection into the Narrows II pool.

Figure 2.3. Gravel injection on November 29, 2007. Gravel pile is located in zone of aeration downstream of the Narrows II powerhouse.

Figure 2.4. Photo of stockpiled gravel/cobble left on the parking area and hillside after the 2007 pilot injection.

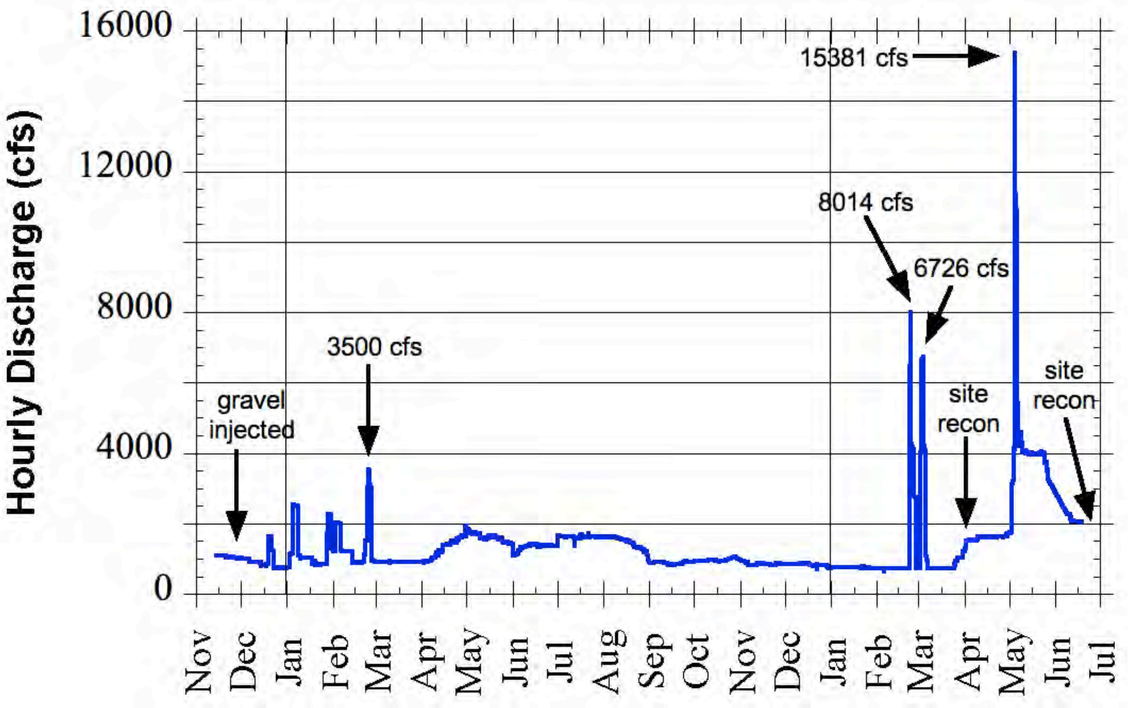


Figure 2.5. EDR Hydrograph of 2008-2009 water years showing flow peaks and the timing of key activities.

2.3. Methods for Gravel/Cobble Augmentation

Once a decision is made to perform gravel/cobble augmentation relative to other possible actions (Pasternack, 2008b), then it is necessary to determine how to implement it. Several reports have analyzed different methods for implementing gravel/cobble augmentation downstream of dams on rivers. Kimball (2003) described methods, limitations, horizontal placement distance, discharge rate, and the price per ton for 1,000 tons of gravel/cobble placed using helicopters, cable ways, and various conveyor belt systems (portable, truck-mounted, crane mounted and attached to dump truck). Bunte (2004) took a different approach and focused on the diverse river forms made with gravel/cobble-augmentation deposits through active construction and "passive" injection. Those included hydraulic structures, big flat plateaus of gravel, supplementation and lengthening of existing riffles (either upstream or downstream of crest), long riffles with 1-3 crests, artificial spawning channels, complex river patterns, filling of pools, bar shaping, spot fixing. She also covered placement of emergent deposits for future flood redistribution, including dumping along the streambank and construction of ephemeral wing dams directing flow into irrigation diversion canals (Bunte, 2004). Sawyer et al. (2009) reported a thorough analysis of the opportunities and constraints of using front loaders to place gravel/cobble according to a detailed design.

The environmental assessment report for the 2007 pilot gravel/cobble injection analyzed three methods of gravel/cobble augmentation (USACE, 2007). For the remote canyon downstream of Englebright Dam, there is a tremendous challenge to get down to the water's edge in the section where gravel is needed most. The alternatives considered were road construction, helicopter, and truck-mounted conveyor belt.

2.3.1. Road Construction and Gravel Placement

The first method assessed by USACE (2007) was gravel/cobble placement by hauling material in 10-ton and 20-ton trucks down to the river's edge, pouring it along the edge, and distributing it with front loaders. However, the EDR has not had a road down to the water's edge since the 1997 flood destroyed the previous one there. The elevation of the river's water surface at 855 cfs is ~292' (NAVD88 datum), whereas the elevation of the end of the existing road at the Narrows II facility is ~353'. The vertical drop of 61' takes place over a horizontal distance of just ~100', so the slope is 0.5 (50%). As a result, the road would have to be steep with switchbacks. It would be unlikely for 20-ton trucks to negotiate the switchbacks, so delivery would be limited to 10-ton trucks or front loaders. Moreover, to construct a new road would require importing a large quantity of road fill materials. USACE (2007) raised a serious concern about the risk of these materials eroding by rain, landslide, or flood, which would cause harmful mud, sand, and angular crushed rock to enter the river and integrate into the bed material. USACE (2007) also indicated that it would be extremely costly and environmentally harmful to remove a temporary road after gravel/cobble augmentation. It is not possible to remove a road off a steep rocky hillside without causing debris to be left behind risking water quality and river-substrate problems. Further considerations in 2010 raised the concern over possibly having to excavate the end of the road in the channel, which could cause water quality problems. Also, the permitting process for road construction would take a long time, precluding gravel/cobble augmentation in 2010 and possibly 2011.

Assuming that a road was constructed and gravel/cobble were to be placed by front loaders, then a suite of concerns related to these machines come into consideration (Sawyer et al., 2009). Extra care would be necessary to avoid oil or gas leaks out of the machinery (a problem known from other efforts). There is also a limitation in matching grading plans in that front loaders cannot go into water deeper than ~2-2.5' or else the transmission can be flooded, ruining the machine (another problem known to have happened in the past on another river). Finally, front loaders cause a high level of turbidity as they drive over the river bed, which can be a water quality problem. For all the above reasons, the method of direct gravel/cobble placement commonly used on the American, Mokelumne, and Trinity Rivers in California is not preferable.

2.3.2. Helicopter Delivery

The second method assessed by USACE (2007) was helicopter delivery. This can be the only means possible for extremely remote locations. However, this approach is the most expensive method, it has a slow delivery rate (depending on how far the stockpile is from the placement site), and it involves highly risky helicopter flying in the presence of power lines and in a narrow canyon with variable winds.

2.3.3. Truck-Mounted Conveyor Belt

The third method assessed by USACE (2007), which was ultimately used in the 2007 pilot project, was a truck-mounted conveyor belt. For this approach, a 135' long conveyor belt mounted onto a truck is fully extended and rotated perpendicular to the truck so that its end is over the river. With a ~100-120' bank width, this length is just sufficient to get material into the Narrows II pool. Material is fed into a hopper using a small 0.5- to 1-ton front loader, and then a feeder with a conveyor belt lifts the material up and onto the truck-mounted belt that delivers it out over the water. By pouring the gravel/cobble into a deep pool, particle breakage is avoided. The experience with using this method in 2007 was highly positive. The only lesson learned from the 2007 pilot project that would enhance future usage of this method was that gravel/cobble injection would have been faster if two loaders had been used instead of one.

Unfortunately, there are two serious problems with using the truck-mounted conveyor belt approach in 2010 and beyond below Englebright Dam. First, given the geometry of the road, hillside, channel, and Narrows II powerhouse, the area of the wetted channel suitable for injection that is within the 135' length of the conveyor belt is very limited. Gravel/cobble is not permitted to be injected up against the powerhouse and any pile cannot interfere with the immediate outflow jet issuing from the powerhouse. The Narrows II pool is ~15' deep, but much of it is not reachable with the conveyor belt. Based on visual appearance at the end of the injection in 2007, the gravel/cobble pile was ~ 11' high off the bed. Given some more rotation capability and making the water even shallower, it looked like a total amount of <1000 tons could be stored in the pool by this method. The gravel/cobble deficit for the EDR (to be enumerated below in section 3) is one to two orders of magnitude higher than that, making this approach inadequate for the need.

Second, there is a proven concern of gravel/cobble injected into the Narrow II pool depositing into the shallow area between the Narrows II and Narrows I powerhouses (Pasternack, 2009). The gravel/cobble injected in 2007 fractionated by size during transport in 2008-2010, such that coarser material deposited on the first bedrock plateau and finer material deposited further downstream. Spawning has been observed on the shallow coarser material on the bedrock plateau. A potential exists in emergency situations where gravel may be de-watered.

When Fulton (2008) and Pasternack (2008a) evaluated the scour potential in the Narrows II pool for different sized floods, they assumed that the gravel/cobble would be in a blanket at the bottom of the pool, not standing ~11' high in a loose conical pile. They had no knowledge at the time of their efforts in 2005-2006 how gravel/cobble augmentation might be done at remote Englebright Dam, so they made a basic assumption about it. As a result, they studied a very different situation from what ended up happening. For the case of a blanket fill on the bed, they predicted that any flood capable of scouring the bottom of this deep pool would easily transport the material beyond the Narrows I powerhouse. The reason is that the intervening channel area consists of a bedrock plateau that is narrower and shallower over the whole flow range, so that focuses flow into the fastest, most scouring jet of water possible for the EDR. Based on 2D modeling, it was demonstrated that any flow that could scour gravel/cobble off the bed of the deep pool would definitely be able to transport it beyond the Narrows I facility.

In fact, the actual conditions associated with the 2007 pilot (and any such gravel/cobble augmentation using the truck-mounted conveyor belt) as well as the flow regime that occurred in 2009 were quite different from what had been investigated. Not only was the gravel/cobble piled high unlike in the model simulations, but another important factor not considered was that the Narrows I powerhouse was releasing 500 cfs perpendicular to the channel during the 2009 peak flow overtopping Englebright Dam. Fulton (2008) did not have a topographic map all the way down to Narrows I for his model study and did not investigate the impact of a flow jetting across the riverbed at that location. Conceptually, such a jet would be expected to dramatically reduce bedload transport past that location.

Thanks to the use of a real-world pilot experiment, Pasternack (2009) observed that the 2009 flood of 15381 cfs scoured off the top ~23% of the 2007 pile. None of the eroded material made it past the Narrows I powerhouse. Instead, it deposited in the nooks in bedrock fractures and behind boulders and bedrock outcrops in a narrow band down the length of the area between the two powerhouses. In autumn 2009 Chinook salmonids were observed by RMT staff to be spawning on that material.

Pasternack (2009) provides a thorough evaluation of what happened and the consequence is that injection of a large amount of gravel/cobble into the Narrows II pool would certainly yield deposits in the area between the powerhouses that is at risk for annual dewatering in September-November. Given that the entire EDR is lacking in gravel/cobble, there are other areas where gravel could be introduced downstream of Narrows I, thereby avoiding the problem if channel dewatering. At a later time it might be worthwhile to revisit the issues related to gravel augmentation upstream of the Narrows I powerhouse to determine any conditions under which gravel/cobble could be added there to expand total habitat capacity and gravel/cobble storage in the reach.

2.3.4. Dumping Gravel/Cobble off Roadside

Although not discussed in USACE (2007), another option is that gravel/cobble may be added to a stream by dumping it off a truck down a hillside to the stream bank or into a stream (Bunte, 2004). This approach has been used on Clear Creek, Trinity River, and the upper Sacramento River. It is very inexpensive and fast. However, this approach only serves geomorphic and ecologic goals if the material avoids breakage and actually becomes entrained into the river. Normally that requires a flood to achieve, which could be years to decades before it happens, precluding ecological benefits. For the hillside below Englebright Dam, the only section accessible by truck is between Narrows I and II powerhouses raising the potential problem of material depositing on the bed at risk of dewatering. Also, the hillside is composed of large boulders, shot rock, and bedrock, so dumping material there would cause a lot of breakage. Angular gravel/cobble harms adult spawners. Finally, there are so many nooks in the material on the hillside that it is most likely that the material would be absorbed into those recesses and locked away. Dramatically more material would have to be placed to offset that problem, and even then it is unclear that the material would ever deposit where desired. A thorough, process-based analysis would be required, but the technical challenges of such an assessment yield high uncertainty.

2.3.5. Cableway Delivery

For steep canyons it is possible to build a cableway high across the canyon and drop gravel down into the river. By having one end of the cableway at a higher elevation than the other, it is possible for the weight of gravel/cobble to carry the load down over the river. After dumping to out, then one winches the container back up. Kimball (2003) reported details and costs. For the canyon below Englebright Dam, the problem is that the only place to stockpile gravel and install/operate a cable way would be in the area between Narrows I and II facilities. As discussed before, this area has a risk of gravel/cobble dewatering in September and October making it unsuitable for gravel/cobble augmentation at this time. Also, gravel/cobble placement is limited to a single cross-section, and for that cross-section there is little control over how and where gravel is place in the river. These factors make this method unsuitable for the EDR for 2010 and likely beyond.

2.3.6. Gravel/Cobble Sluicing

According to Pittman and Matthews (2007) and Kimball (2003), gravel/cobble sluicing involves drawing water up from a source and into an 8" diameter "Yelomine" flexible pipe where gravel/cobble is added from the top to produce a water-sediment slurry that is then piped down to a site for directed placement by 1-2 operators. The amount of water used to do the sluicing depends on the pipe and pump configuration, and is typically 1000-1500 gallons per minutes, which is 2.23-3.34 cfs. The best way to get the water is to locate the water pump(s) at the source-water's edge and then push the water uphill in a 6-8" pipe. The pump cannot draw water vertically up to it more than 30', but if the pump is placed at the water's edge it can push the water vertically much farther as needed to get to the top of the a hill where the gravel/cobble is added.

Normally, it takes five people to operate the system- one person operating the water pump at the water source, one person in a loader bringing gravel to the feeder, one person operating the feeder to prevent clogs and coordinate communications, and two people at the nozzle directing gravel placement and adding pipe as needed to move downstream periodically. This approach is particularly notable for its minimal construction footprint. The main cost is in the upfront purchase of expensive piping, so it largely depends on how far water and the water/sediment slurry has to be pumped. Once the pipes are purchased, they may be used for several years, and the more sediment that is injected, the lower the cost per ton. Also, it may be possible to permanently fix the pipes for annual injections, thereby reducing the labor cost of setting up and taking down the system each year.

Using the sluicing method, the rate of gravel/cobble injection is ~100-300 tons per day, all depending on how frequently the system clogs. This is slow relative to gravel placement by truck-mounted conveyor (~500 tons per day) or truck/front loaders (~1000 tons per day). Indeed, clogs at pipe joints are a likely occurrence and are factored into operations. The primary factors that cause them are 1) low local head, 2) dense packing of 4-6" clasts, and 3) long, flat "finger" shaped rocks that fit through 5-6" sieve openings, but are much longer than that. Once in the pipe finger rocks can turn perpendicular and jam in a coupling. When a jam happens, operations stop, the location of the jam is determined (usually in a coupling), the coupling is broken to release the jam, a new coupling installed, and then operations continue. The steeper the descent (speeding flux), the more continuous the slurry flow (preventing deposition in the pipe), and the finer the sediment mixture (reducing the size of finger rocks), the less clogging will occur. Grain breakage in the pipe has not been evident in any noticeable amount, but the sediment does abrade the pipe, especially at bends. The typical lifetime of a pipe section at a bend has not been reported. Having extra pipe segments on hand is important for long-duration sluicing operations.

In terms of the gravel/cobble placement into the river, the approach with sluicing is to start at the water's edge, build across the river, and then work downstream. At the outlet of the system, gravel/cobble goes into a rigid pipe supported by floating, air-filled barrels. The outlet is manually directed to the placement spot with the aid of ropes as needed. Using this approach, it is possible to place gravel/cobble according to a sophisticated design with a few constraints. As the operators work their way out into the channel, they must add additional pipe to reach new areas. Pipe in the river lies on the bed. Given the weight of the pipe sections and the need to manually couple them, the pipes have to be placed in shallow water. That limits the depth of water that pipes may be placed into to depths of < ~2-2.5'. As a result, front slopes up to the riffle crest have to be relatively steep. Back slopes can be lower, because ambient river velocity aids distribution of the sediment slurry in a blanket downstream. This approach has been used on the lower Stanislaus River and Clear Creek, with favorable reports in both cases. Given its remoteness and steepness, the canyon below Englebright Dam is a strong candidate for gravel/cobble sluicing.

3. PRE-PROJECT CHARACTERIZATION OF THE EDR

The spatial focus of this gravel/cobble augmentation implementation plan is the Englebright Dam Reach (EDR) of the lower Yuba River, which has been identified to be the area of the river below Englebright Dam that has been impacted by the dam requiring action (Beak Consultants, 1989; Pasternack, 2008a; Pasternack et al., 2010). The next step is to perform a pre-project characterization that documents the baseline conditions of the EDR. This involves reviewing the available data and information for the reach to yield a conceptual model that captures the processes playing central roles in shaping fluvial landforms in the EDR. Broad based information related to the entire watershed helps guide an understanding of the processes relevant to the focal reach, but ultimately what is needed is an understanding of the mechanistic physical process active in the reach today and potentially active through rehabilitation actions. Thus, the effort involves a process-based approach to the problem by nesting different spatial and temporal scales of investigation.

3.1. EDR Literature Summary

Because the EDR is remote, it has not been nearly as well studied as the rest of the lower Yuba River, but it has received some investigation. As described earlier, Beak Consultants, Inc (1989) performed studies in the EDR, including fish habitat mapping, fish community characterization, and implementation of the Instream Flow Incremental Methodology (IFIM) for evaluating stage-dependent physical habitat (using 6 cross-sections in "The Narrows", which includes the EDR and the subsequent 1.8-km long gorge). In 1999, the terrestrial land in the EDR was topographically mapped by contractors working for The Corps by aerial photogrammetry, but the river's bathymetry in the reach was not mapped. From 2003-2008 the U.S. Fish and Wildlife Service collaborated with the Watershed Hydrology and Geomorphology Lab at UC Davis to compare and contrast conditions in the EDR and those in Timbuctoo Bend. The reports that presented data and information on EDR were Fulton (2008), Pasternack (2008a), and Pasternack et al. (2010).

3.2. EDR Existing Data and Analyses

There does exist some data for the EDR. Key data include a bathymetric survey and digital elevation model of the reach (Fig. 3.1), substrate pebble counts, water surface elevation observations for flows ranging from 800-91400 cfs, georeferenced historical aerial photos, and observations of Chinook salmon attempting to spawn on bedrock. At the time that Fulton (2008) performed his 2D modeling analysis in 2005-2006 to assess flow-habitat relations, sediment entrainment, and geomorphic processes, available data were limited to just the reach between the Narrows II pool and the Narrows I powerhouse. Subsequently, Pasternack (2008a) did do a few 2D model simulations of the EDR using a newer software program suitable for that length of canyon. Pasternack et al. (2010) reported a detailed historical aerial photo analysis of the EDR focusing on the history and status of Sinoro Bar in the vicinity of the confluence with Deer Creek. Finally, Pasternack (2009) did reconnaissance of the EDR to map the movement of injected gravel and cobble out of the Narrows II pool and quantify a sediment budget for that material.

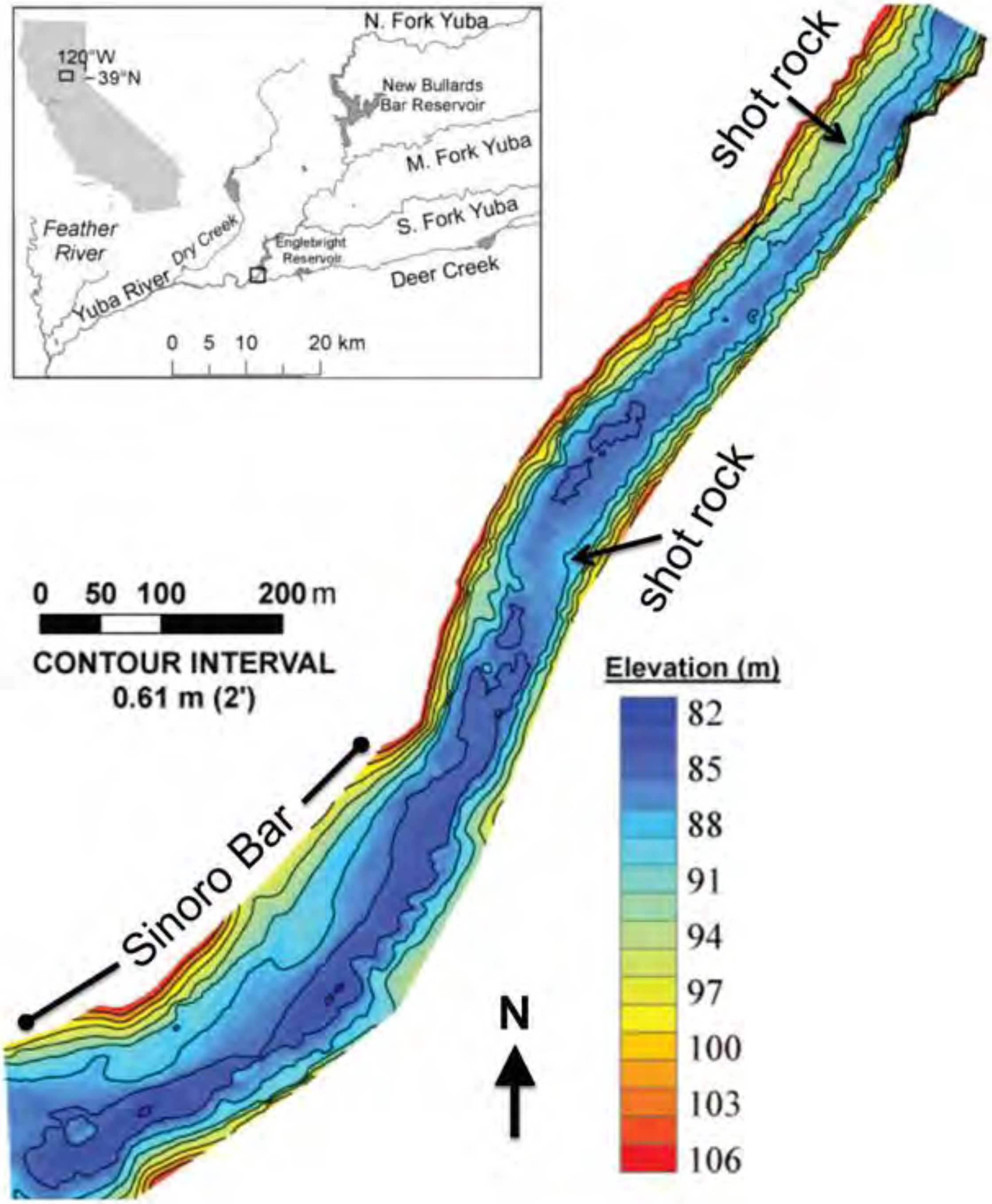


Figure 3.1. EDR topographic map showing locations of existing shot rock deposits. Inset map shows location of study site within the Yuba River basin and within California.

3.3. EDR Gravel/Cobble Deficit

The EDR is mostly devoid of any river-rounded gravel/cobble. This material is the basic building block of alluvial morphological units for the LYR. It is the necessary substrate for SRCS spawning. That leads to the following question:

How much gravel/cobble is needed in the EDR to rehabilitate ecological functionality?

To answer this question it needs to be recognized that different volumes of material would be required to achieve different combinations of geomorphic and ecologic functions. Let us define a placement volume (PV) as

$$PV = \alpha \bullet A \bullet D$$

where A is the plan-view wetted channel area (m^2), D is average depth (m) at spawning flow, and α is a non-dimensional depth scaling factor. A simple approach would be to fill in the entire wetted channel for a typical low autumnal spawning discharge to form one large, flat spawning riffle. Completely filling in the wetted channel in this way would involve assigning $\alpha=1$, so $PV=A \bullet D$. This amount would displace the water up, making it shallower and faster, due to a significant decrease in cross-sectional area. However, past studies have all concluded that large, flat spawning riffles do not work. Adult SRCS spawners need deep holding habitat for over-summer holding, local holding refugia proximal to red locations for rest during spawning activity, and locations with hydraulic complexity (presumably because it promotes better hyporheic flow).

Based on many years of experience with designing diverse spawning habitat rehabilitation projects, Pasternack (2008b) reported that for rehabilitating a small riffle of ~50-500’ length, a value of $\alpha=0.8$ is appropriate. At this scale the focus is just on a single riffle crest and the presumption is that morphological unit diversity exists at a larger scale outside of this one riffle site. For a long reach for which a diversity of morphological units would need to be created, a value of $\alpha=0.5$ is more appropriate. This value is lower, because riffle crests are the highest points by definition, so constructing a reach with other morphological unit types involves using less volume than that for a riffle crest. As a result, for an intermediate length scale between a site and a reach, an intermediate value of $0.5<\alpha<0.8$ would be appropriate. Although there is no formal scientific proof of these values, they provide a simple, low-cost method of estimating gravel/cobble needs. This provides a reasonable starting point for thorough analysis and design development.

To apply the above method for use in the EDR, the variables A and D were estimated using the SRH-2D model simulation for 855 cfs for three separate sub-reaches and the amount was totaled (Table 3.1). The volume-to-tonnage conversion of Merz et al. (2006) was applied (see section 2.2 above). The total amount of material to eliminate the deficit for the EDR is estimated to be 63,077 short tons (45,510 yds^3). To account for uncertainty, a higher estimate using $\alpha = 0.8$ was also generated, which yielded an estimate of 100,923 short tons (72,816 yds^3). These numbers bound the likely intermediate amount of storage that would be appropriate for the EDR.

Because the reach widens downstream, the largest component is associated with the area downstream of the gaging station rapid. However, that area has been heavily impacted by mechanized gold mining and would greatly benefit from an independent river rehabilitation effort to take advantage of the opportunity to fix Sinoro Bar, which is beyond the scope of the gravel/cobble augmentation plan required to account for the impacts of Englebright Dam. Also, material placed upstream in the narrower part of the canyon is expected to migrate downstream anyway, addressing the gravel deficit in the vicinity of Sinoro Bar over time. Recognizing that the section between the Narrows II and Narrows I facilities has other uncertainties with operations, the relevant area of gravel addition is therefore the area between the Narrows I facility and the top of the rapid downstream of the gaging station.

The recommended long-term gravel storage volume for the section between the Narrows I powerhouse and the rapid downstream of the gaging station is 15,949 to 25,518 short tons.

The exact value may be determined in future design development and evaluation. The idea would be to augment gravel into the appropriate area of the EDR until this amount of gravel storage is achieved. Then, as floods transport material out of the area, more additions would return the storage amount to the total level.

Table 3.1. Estimated gravel/cobble deficit for the EDR to have a diverse assemblage of morphological units (excludes any independent action related to rehabilitating Sinoro Bar). Assumes α = 0.5.

subreach	A (ft^2)	D (ft)	volume (ft^3)	volume (yds^3)	short tons
Narrows II to I	61107	4.313	131777	4881	6765
Narrows I to top of rapid	117373	5.294	310686	11507	**15949**
bottom of rapid to end	306193	5.136	786304	29122	40364
total			1228767	45510	63077

Table 3.2. Maximum estimated gravel/cobble fill associated with α = 0.8.

subreach	A (ft^2)	D (ft)	volume (ft^3)	volume (yds^3)	short tons
Narrows II to I	61107	4.313	210844	7809	10823
Narrows I to top of rapid	117373	5.294	497098	18411	**25518**
bottom of rapid to end	306193	5.136	1258086	46596	64582

3.4. EDR SRH 2D Model

Two-dimensional (depth-averaged) hydrodynamic models have existed for decades and are used to study a variety of hydrogeomorphic processes. Recently, their use in regulated river rehabilitation emphasizing spawning habitat rehabilitation by gravel placement has been evaluated (Pasternack et al., 2004, 2006; Wheaton et al., 2004a; Elkins et al., 2007). Two-dimensional models have also been applied to better understand the relative benefits of active river rehabilitation versus flow regime modification on regulated rivers.

The U.S. Bureau of Reclamation created and maintains a 2D model called Sedimentation and River Hydraulics 2D (SRH) that is freely available to the public. SRH is highly efficient in its computations and is also highly stable in performing wetting and drying, which is a common problem of other 2D models. The way it has been programmed, it is highly automated. Thus, it is now possible to make 2D models of dramatically larger river segments than before, while retaining the same high resolution desired for characterizing microhabitat.

Apart from characterizing the spatial pattern of hydraulics in the EDR, SRH 2D was to answer two specific questions:

1) *what the spatial pattern of hydraulic habitat for Chinook spawning at 855 and 4500 cfs?*
2) *what is the spatial pattern of gravel/cobble erosion potential for flows ranging from 855 to 96100 cfs?*

The former question addresses the need to determine the extent to which the inadequacy of spawning habitat is due solely to the lack of spawning substrate or whether it is a combination of more microhabitat factors. The latter question seeks to understand the stage-dependent hydrogeomorphic processes responsible for scour and deposition in the EDR, given its unique pattern of channel nonuniformity.

3.4.1. EDR 2D Model Setup

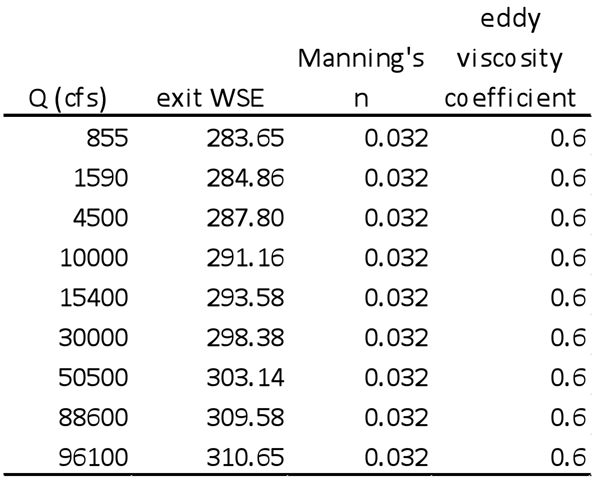
As part of this planning effort, the SRH 2D model of the EDR reported by Pasternack (2008a) was updated to the latest software version and used again. To maintain computational efficiency, three different computational meshes were used, each with an intermodal spacing of ~3' in the wetted area. For low-flow conditions, the original mesh from Pasternack (2008a) was used for flows <5000 cfs. This mesh covered the whole canyon width with ~3' internodal spacing in the channel and up to 6' internodal spacing along the edge. The wetted area for the low flow runs were all within the mesh elements with ~3' internodal spacing. A mid-flow mesh was made for flows 5000-30000 cfs. A high-flow mesh was made for flows 30000-96100 cfs. A higher flow mesh may always be used to run a lower flow, but it takes longer to run than using the appropriate lower flow mesh. Creating a new EDR mesh takes only ~1-2 hours compared with models running for 3-7 days, so making a mesh that is optimal for a given flow is worth the small time and effort.

Table 3.1 reports the stage-discharge relation estimated for the exit cross-section of the model reach as well as the constant Manning's n roughness parameter used and the constant eddy viscosity coefficient used for turbulence closure. For all simulations, 500 cfs was pushed into the river from the bank at the location of Narrows I and all remaining flow came from the upstream boundary in the Narrows II pool. Unfortunately, the stage-discharge relation for the end of the reach was not directly observed, but was estimated by linear slope interpolation based on the water surface elevation (WSE) values at the exit and at the Smartville gaging station observed at 855 cfs. The one test of the accuracy of this approach was obtained by surveying the photo-based evidence of the water line for the 88600 cfs flow occurring on 12/31/2005 (photo and land access for surveying graciously donated by local landowner Ralph Mullican). The two observed WSE's for that flood were 309.71' and 310.77', so the predicted value of 309.58' is reasonable, given the uncertainty in the field observations (especially the higher value, which was measured at a spot up on the side of a large boulder). Ideally, a water level recorder ought to be installed and maintained at the confluence with Deer Creek in support of future investigations.

The chosen constant Manning's n value is more certain as it was based on 2D model calibrations performed by Fulton (2008) for the same wide range of flows. Manning's n does not decrease with increasing stage in the EDR or Timbuctoo Bend, which is consistent with the concept that as flow increases, large roughness elements become active and maintain the overall roughness of the reach, even as grain-scale roughness and riffle-undulation form roughness become less important.

No velocity validation data exists for the EDR at this time, but WSE data is available over the full range of flows from Fulton (2008). Analysis of model performance with WSE indicated that it was within the normal range typical of 2D models. Extensive velocity validation has been performed for this model for the LYR between Hammon Grove Park and Hallwood Road, with the resulting metrics equaling or exceeding the performance of 2D models of other rivers (Barker et al., 2010). Velocity validation has also been done for Timbuctoo Bend (Moir and Pasternack, 2008; Pasternack, 2008) as well as for bedrock and boulder/cobble reaches of the upper South Yuba between Spaulding Dam and Washington, CA (Pasternack, unpublished data). All evidence indicates that the model is suitable and valid for the EDR.

Table 3.3. SRH 2D model inputs and parameters for the discharges simulated.



Q (cfs)	exit WSE	Manning's n	eddy viscosity coefficient
855	283.65	0.032	0.6
1590	284.86	0.032	0.6
4500	287.80	0.032	0.6
10000	291.16	0.032	0.6
15400	293.58	0.032	0.6
30000	298.38	0.032	0.6
50500	303.14	0.032	0.6
88600	309.58	0.032	0.6
96100	310.65	0.032	0.6

3.4.2. Microhabitat Prediction Method

Hydraulic habitat quality predictions for Chinook spawning were made by extrapolating 2D model depth and velocity results through independent habitat suitability curves. No bioverified habitat suitability curves (HSC) for depth, velocity, substrate, or cover for salmonid life stages are accepted by stakeholders on the LYR. Beak Consultants, Inc (1989) collected observations of depths and velocities for a typically small number of redds for that era and generated "utilization-based" curves. They compared their curves to those for the lower Mokelumne River available at that time and found a lot of similarities. CDFG (1991) published utilization-based curves for the lower Mokelumne River and in recent years these curves have been shown to perform very well at predicting Chinook spawning preference and avoidance for baseline and post-rehabilitation conditions (Pasternack, 2008b; Elkins et al., 2007). These Mokelumne curves were tested for use in Timbuctoo Bend on the LYR by Pasternack (2008a) and found to pass all bioverification tests. Other curves based on logistic regression proposed by the USFWS in recent years have not passed the same rigorous tests and remain controversial. Consequently, the bioverified curves used by Pasternack (2008a) were applied in this study.

A global habitat suitability index (GHSI) was calculated as the geometric mean of the depth and velocity indices (Pasternack et al., 2004). To account for uncertainty SRH-2D model predictions, GHSI values were lumped into broad classes, with GHSI = 0 as non-habitat, 0 < GHSI < 0.2 as very poor quality, 0.2 < GHSI < 0.4 as low quality, 0.4 < GHSI < 0.6 as medium quality, and 0.6 < GHSI < 1.0 as high quality hydraulic habitat (pasternack, 2008a). In bioverificaiton, it turned out that only the medium and high quality habitat classes proved to be preferred in terms of being utilized by spawners more than their percent availability, while the remaining classes were all avoided. Therefore, an even further simplification may be made by lumping GHSI into classes of 0-0.4 and 0.4-1.0. This reduces the possibility of error down to just misclassifications across this threshold.

3.4.3. Sediment Transport Regime Prediction Method

To evaluate gravel/cobble sediment scour risk across the widest possible range of flows, nondimensional Shields stress was calculated at each node in the model as described in Pasternack et al. [2006]. The reference grain size used to characterize the mixture of a gravel/cobble bed was 64 mm, which is close to the median size reported for Timbuctoo Bend (Pasternack, 2008a) and is in the range of common values used for assessing spawning habitat rehabilitation materials. Shields-stress values were categorized based on sediment transport regimes defined by Lisle et al. [2000] where values of $\tau^*<0.01$ correspond to no transport, $0.01< \tau^*<0.03$ correspond to intermittent entrainment, $0.03< \tau^*<0.06$ corresponds to "partial transport", and $\tau^*>0.06$ corresponds to full transport.

3.4.4. EDR 2D Model Results

Depth and velocity results are depicted in Figures 3.2-3.5 below. For flows <5000 cfs there are distinct areas of high and low velocity longitudinally down the river. As discharge increases, the longitudinal variation in velocity decreases and lateral variation increases. This is a common pattern previously reported for other constricted reaches (Brown and Pasternack, 2008). It is characteristic of the stage-dependent role of multiple scales of channel nonuniformity in controlling flow-habitat relations and fluvial geomorphology.

The GHSI pattern for Chinook spawning hydraulic habitat (Fig. 3.6) shows that regardless of gravel/cobble presence, the canyon presently has almost no suitable microhabitat (GHSI>0.4) capability to support SRCS spawning. At 855 cfs there is a small area of suitable hydraulics on the bedrock plateau just downstream of the Narrows II pool, a little upstream of the rapid by the gaging station, and a little habitat on the edge of the Sinoro Bar point bar. At 4500 cfs there is significantly less hydraulic habitat present.

The pattern of the sediment transport regime for the EDR (Fig. 3.7-3.8) is highly stage dependent. For flows below 15,400 cfs, the primary area of scour risk is in the narrowest part of the canyon between narrows I and II powerhouses, which is the area studied by Fulton (2007). The only other area of high scour potential is in the rapid below the gaging station. At 30,000 cfs, large area experience full bedload mobility, but there is a small area of lower Shield stress in the pool adjacent to the gaging station. Also, the widest part of the canyon around Sinoro Bar does not experience full mobility at this flow, so it is highly unlikely that a gravel/cobble mixture would move past that area. Note that the model does not include the perpendicular influx from Deer Creek, which would further reduce velocities and block transport. At 50,500 cfs there is full mobility through the upper 2/3 of the reach, but still no full mobility around Sinoro Bar. At 96,100 cfs, there is full mobility through the reach; again, not considering any influx from Deer Creek to block that.

In summary, detailed 2D hydraulic modeling of the EDR found that the river is too deep to provide Chinook spawning habitat right now, necessitating gravel augmentation to fill in the channel and provide opportunities for creating morphological unit complexity. Geomorphically, the river does not exhibit stage-dependent flow convergence, with routing of sediment through pools and deposition on high "riffles" at high discharges. Instead, as discharge increases, depth and velocity simply increase almost everywhere, so the area of scour increases down the river. The widest part of the canyon would be the ideal location for a diverse assemblage of morphological units, but it was degraded by mechanized mining in the 1960s. In terms of a gravel augmentation program, the indication is that the area in the upper half of the EDR where gravel might be augmented into the river is susceptible to full mobility at 10,000 cfs (except for the Narrows II pool, which is deep enough to require much higher discharge to scour the bottom of it). Meanwhile, augmented gravel would be unlikely to move out of the EDR until a flood of >95,000 cfs associated with minimal flow out of Deer Creek, such as during a snowmelt period or the later stages of a rain-on-snow event. The reason Deer Creek flow needs to be minimal (not maximal), is that at high flow the tributary enters the Yuba nearly perpendicular to it. This creates a barrier to sediment transport. Maximum export of sediment out of the EDR is thus expected to occur during the lowest Deer Creek outflow. The timing of flows out of the Yuba and Deer Creek catchments differs, based on their differing watershed hydrology.

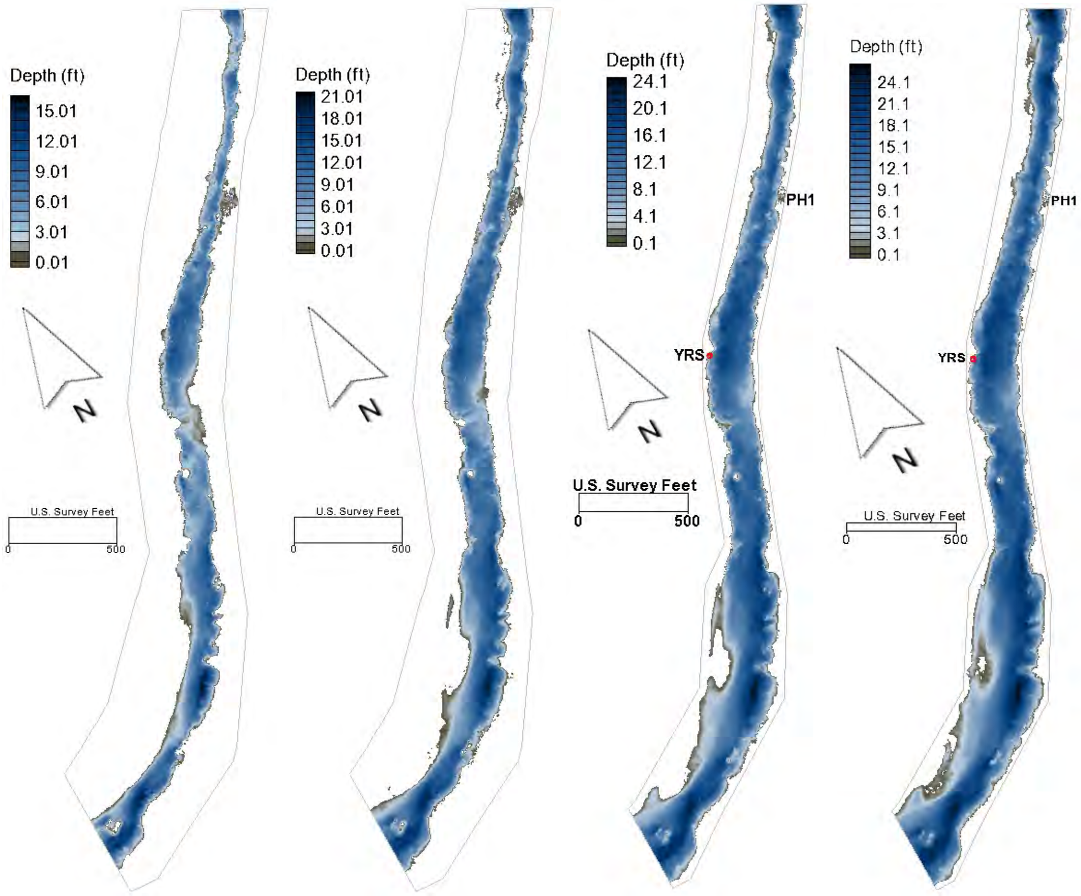


Figure 3.2. EDR water depth for increasing discharge from left to right (855, 4500, 10000, 15400 cfs). Color scale is different for each image.

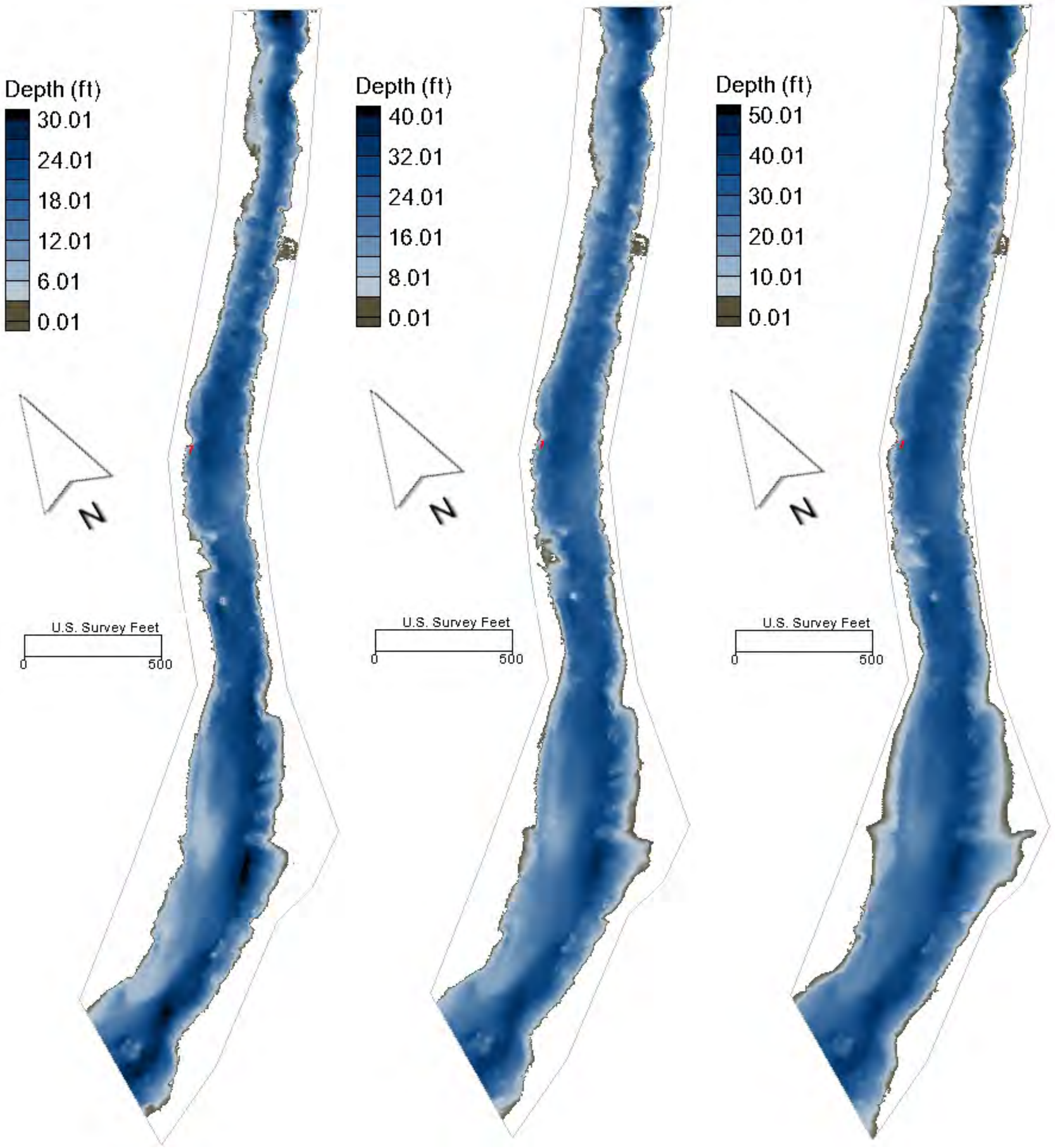


Figure 3.3. EDR water depth for increasing discharge from left to right (30000, 50500, 96100 cfs). Color scale is different for each image.

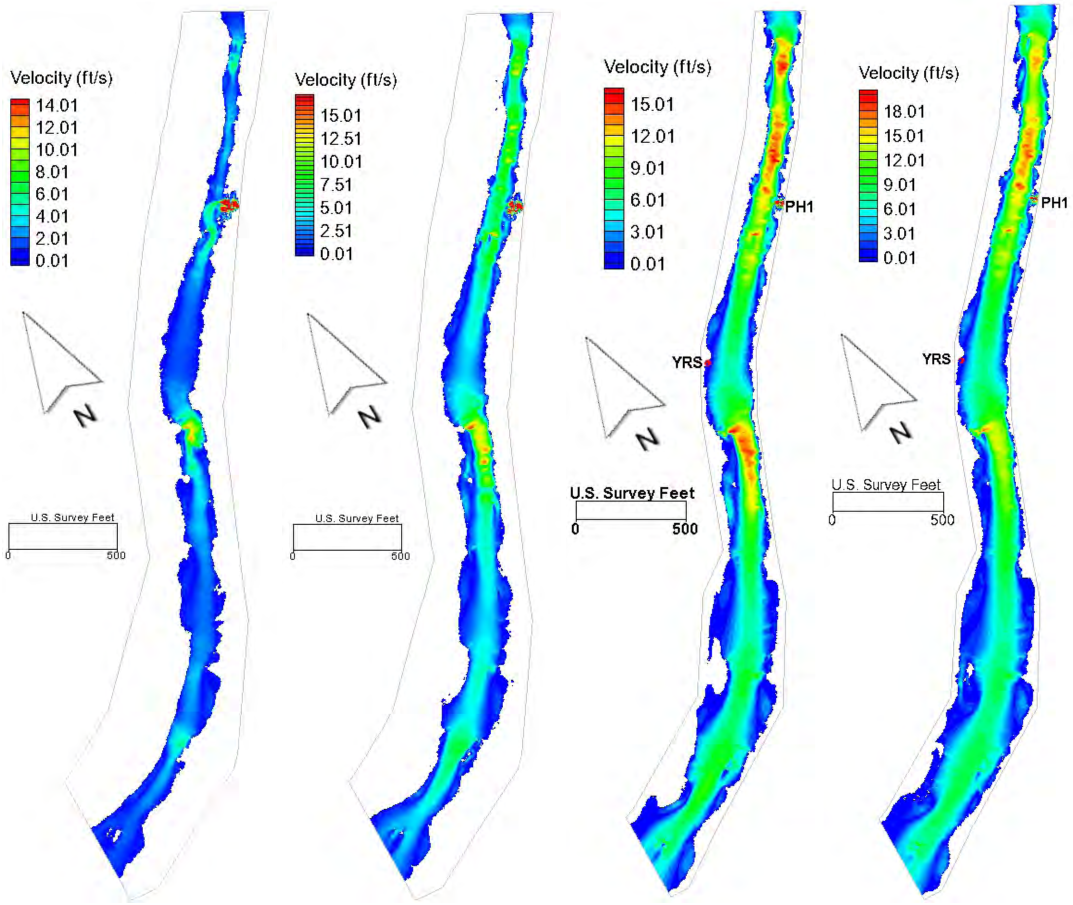


Figure 3.4. EDR water velocity for increasing discharge from left to right (855, 4500, 10000, 15400 cfs). Color scale is different for each image.

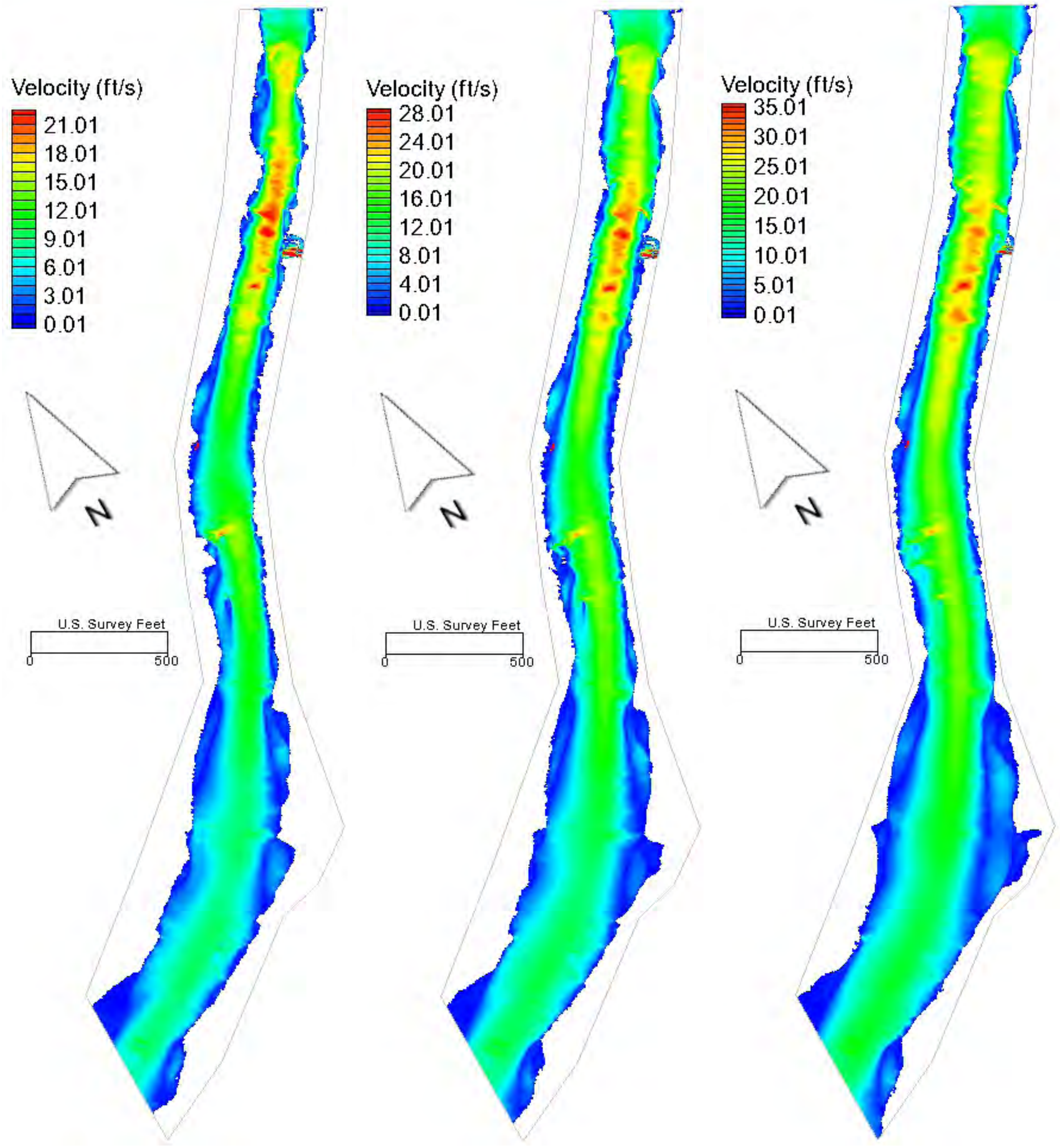


Figure 3.5. EDR water velocity for increasing discharge from left to right (30000, 50500, 96100 cfs). Color scale is different for each image.

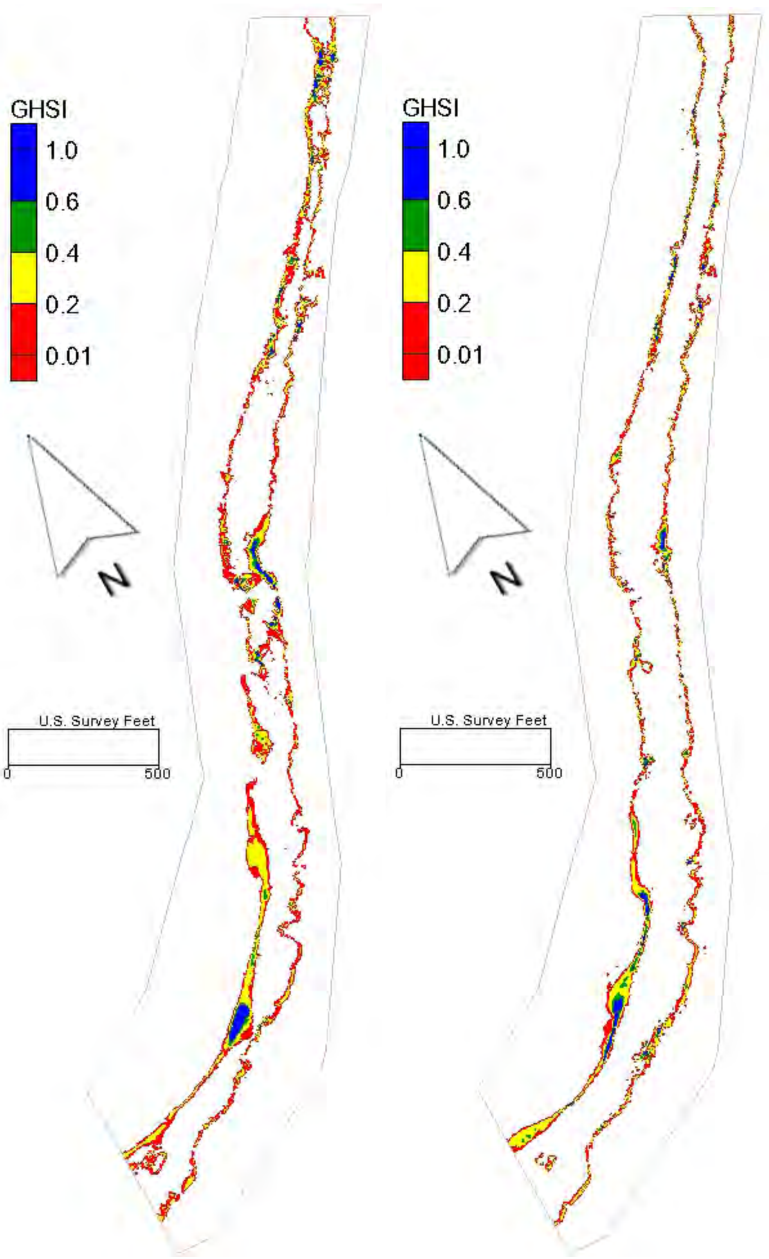


Figure 3.6. EDR Chinook spawning hydraulic habitat quality (GHSI) for 855 (left) and 4500 cfs (right). Color scale is identical for both images

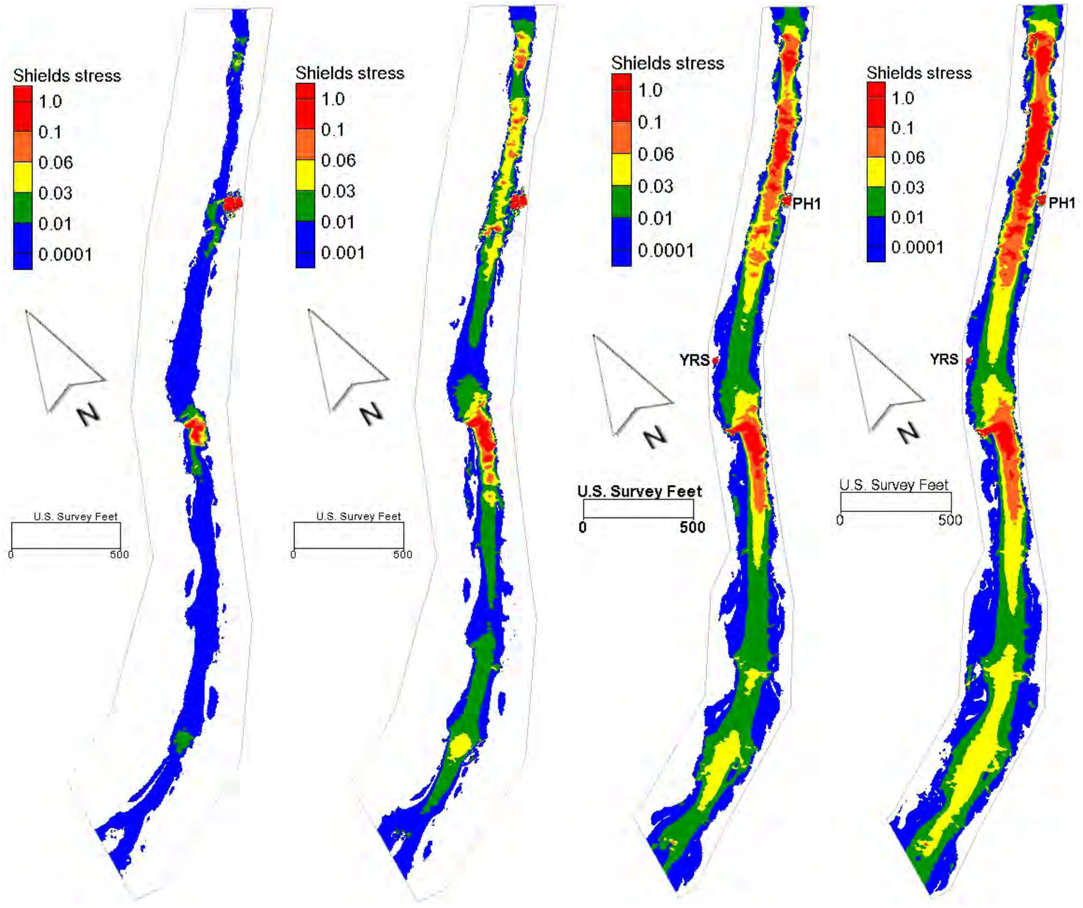


Figure 3.7. EDR Shields stress for increasing discharge from left to right (855, 4500, 10000, 15400 cfs). Color scale is identical for each image.

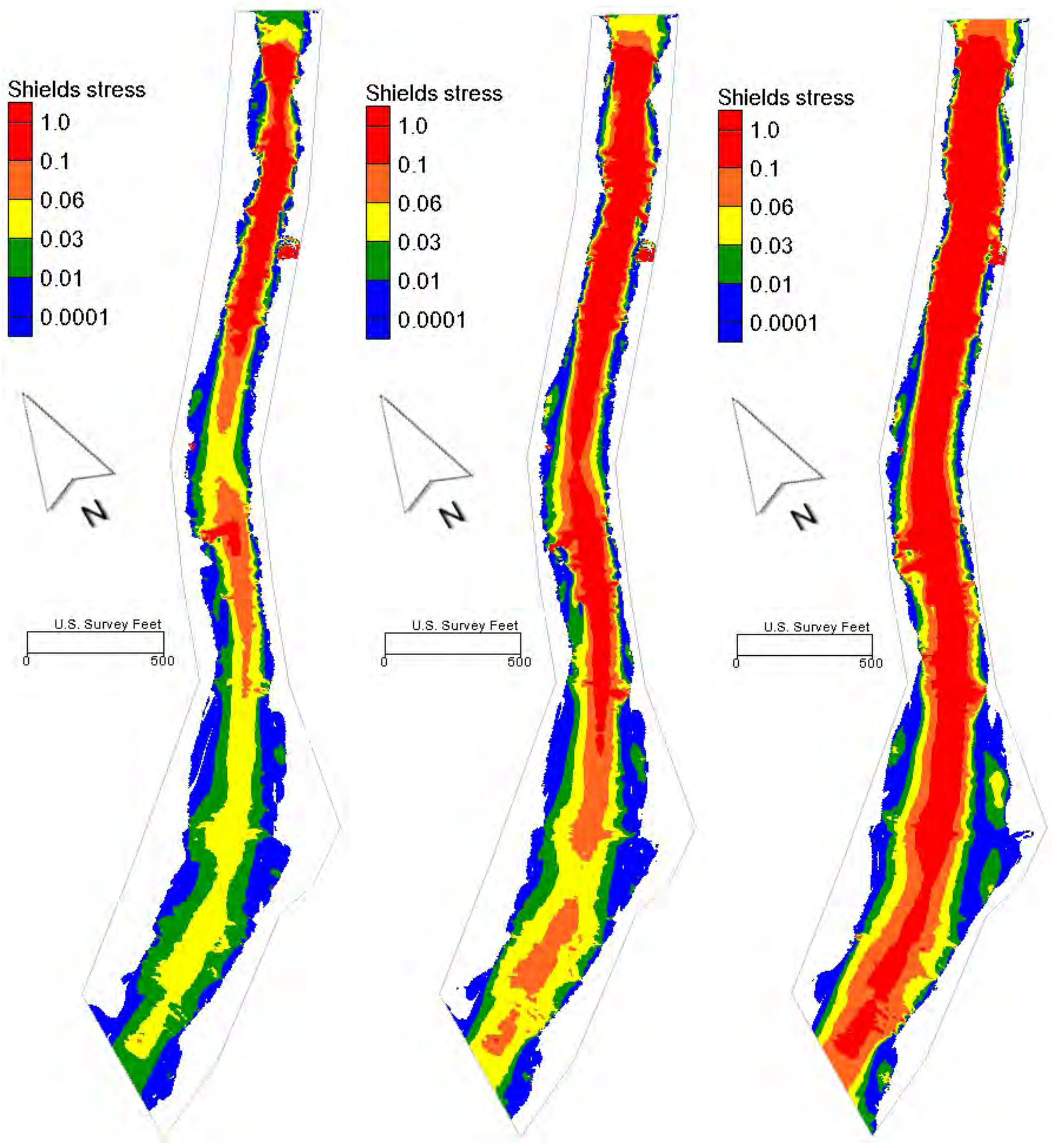


Figure 3.8. EDR Shields stress for increasing discharge from left to right (30000, 50500, 96100 cfs). Color scale is identical for each image.

4. RECOMMENDED METHOD FOR GRAVEL/COBBLE AUGMENTATION

Discussion of how to implement gravel/cobble augmentation below Englebright Dam has been on-going for years. Every idea that has been thought up by diverse stakeholders has been thoroughly discussed and vetted. The Lower Yuba River Technical Working Group and the Yuba Accord River Management Team have provided forums for discussion about this topic over the years. The 2007 pilot gravel injection with a truck-mounted conveyor belt demonstrated that gravel/cobble augmentation is not only technically feasible, but institutionally and politically possible. Observations of Chinook spawning in 2009 prove that salmon will use what is injected.

4.1. Elimination of Inadequate Methods

For the canyon below Englebright Dam, gravel is needed throughout the reach, but most especially in the longer and wider sections downstream of the Narrows I facility, as reflected in the estimates provided in Tables 3.1 and 3.2. This is a key constraint on augmentation methods. The truck-mounted conveyor belt method, roadside-dumping method, and (short of heroic measures) cableway delivery method are simply unable to get gravel into the river downstream of the Narrows I facility. A helicopter theoretically could dump gravel into the river, but the U.S. civil helicopter accident rate per 100,000 flight hours is 8.09 (IHSS, 2005), which is high. Operating in a narrow canyon with uncertain winds is even riskier than normal. Taking such a risk with human life is not necessary. That leaves road construction with front-loader placement and gravel/cobble sluicing.

Part of the reason why there is so much undesirable debris down at Sinoro Bar at the confluence of the Yuba and Deer Creek is that the pre-existing road down to the river at Englebright Dam washed away and deposited down there. Building a road requires a large amount of crushed aggregate, and in this case it has to be placed on a landslide-prone hillside where it will be attacked by large floods (Fig. 4.1). The 1997 flood was not a fluke. Floods of close to the same size or bigger occurred in 1955, 1963, 1964, and 1997 (Pasternack et al., 2010). That is four times in the last 55 years, or roughly once every ~14 years (foregoing detailed flood frequency analysis). If the road went all the way to the baseflow channel, then the lower part of the road would be submerged almost annually and seriously scoured every 3-5 years. The potential environmental harm from this is serious. Together with the long duration for permitting, the difficulty of getting big trucks down the steep road with switchbacks, and water quality impacts, the risk of aggregate entering the river makes road construction an unsatisfactory alternative.

Figure 4.1. Photo of the New Year's 2006 flood drowning the area where a road would have to be built to use trucks and front loaders as the delivery method for gravel/cobble augmentation. Aggressive velocities were evident all along the north bank.

4.2. Best Method for The EDR

By the process of elimination, the only remaining option is gravel/cobble sluicing. To my knowledge, no one has ever attempted to do gravel/cobble augmentation by as long of a sluice pipe as would be necessary for this plan. The long distance that water has to be pumped up and then slurry pumped down make the method much more expensive than for past projects using this method. Also, this method is relatively slow and potentially subjected to regular clogs. At an average rate of 150 tons per day, it would take 33 days to inject 5,000 tons. Front loaders typically place that much into a roadside river in ~4-6 days. On the other hand, the elevation drop for the EDR is so great that clogs may be relatively infrequent; a record speed of injection is possible. Once pipes are purchased in the first year, they can be stockpiled and used again in future years, reducing the overall cost of the system to a normal level. After thorough scrutiny, discussion, and on-site visit with the inventor of the method, no major impediment to the approach is evident at this time.

4.3. Detailed Concept for Sluicing Gravel Mix Down to EDR

Despite the fact that sluicing will have to be done over a long distance, the EDR has excellent attributes that promote the idea of attempting this method. The overall schematic for the application of sluicing to get gravel/cobble into the EDR is shown in Figure 4.2. Prior to the start of sluicing operations, 2000 short tons of gravel would be stockpiled in the three parking/turnaround areas at the overlook on the north side of the dam. This location is behind a locked gate and is inaccessible to the public. Englebright Reservoir is close by and easily accessible. Only ~2.3 cfs is needed for the sluicing operation, in comparison to the typical autumnal release of ~750 cfs- that's just 0.3%. A gravel road on the north side of the reservoir close to the dam (Fig. 4.3, right) goes right to the water's edge (Fig. 4.3, left), so that the water intake pump system (including fish screening custom built by Morrill Industries) can be safely positioned and easily operated. From there, water would be pumped in one or two 6-8" diameter pipes ~1070' up the side of the road (Fig. 4.3, right) to the crest. Where needed, the pipe would cross 1-2 roads in Rain-For-Rent Entrance/Exit Ramps, enabling vehicles to pass over the pipe with no interference to anyone's normal activities. The water pipe(s) would go over the crest of the hill and down the side of the paved road ~300' toward the Narrows II powerhouse until a point at which there is a noticeable slope break especially favorable to beginning gravel/cobble addition to the pipe. At that location a screened hopper on the north side of the road would receive sediment from a front loader bringing the material the short distance from the stockpile. The loader operator would gently bounce the bucket to trickle the sediment into the hopper as the primary control on the flow rate. A hopper operator would be standing there to ensure no blockages, clean out finger rocks as needed, and communicate conditions with other operations participants by radio. Under the hopper the gravel and water would join in a metal pipe that would then connect to the beginning of the 8" diameter, semi-flexible "Yelomine" pipe. This pipe would then go ~1270' down the ditch on the north side of the road to the switchback. From that point, the best option would be to go 264' straight down the grassy hillside (Fig. 4.4, left) to a terrace level where an old roadbed and foot trail is located. From there, the pipe would make a straight line 130' down to the water's edge near the upstream end of the gravel placement area for 2010 (Fig. 4.4, right). Overall, this approach would use roughly 2000' of Yelomine pipe to drop a vertical height of roughly 360', yielding an overall slope of 0.18 (18%).

Figure 4.2. Schematic of the gravel/cobble delivery system using a sluice method.

Figure 4.3. Landing area at the water's edge of Englebright reservoir (left) and gravel road leading up to the hillcrest (right).

Figure 4.4. Hillslope from road down to low terrace (left) and view from low terrace down to the Area A gravel placement location (right).

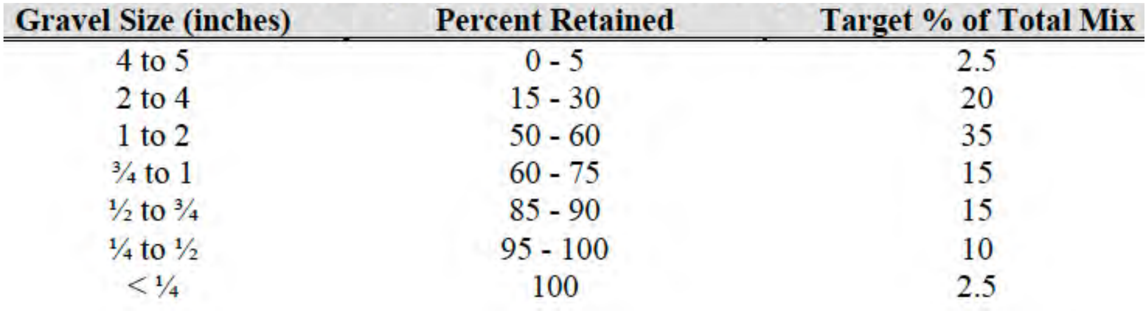
4.4. Gravel/Cobble Placement Location

The selection of the specific location within the EDR for focusing gravel/cobble placement was guided by constraints in powerhouse operations, potential benefits to the river, and feasible delivery methods. Powerhouse operations presently make gravel/cobble augmentation between Englebright Dam and the Narrows I powerhouse uncertain for the reasons described in section 2.3.3. To get the most benefit and longevity from adding gravel to the river, the further upstream it is introduced, the better. Thus, gravel/cobble augmentation could begin in the scour pool adjacent to the Narrows I facility. This pool is up to 8’ deep at 855 cfs. To avoid having to fill in that scour hole and yield riffle habitat for immediate spawning use with the least amount of initial gravel injection during a pilot gravel sluicing operation, it would be advantageous to begin placement ~115’ downstream of the end of the Narrows 1 powerhouse where the maximum depth is under 5’ at 855 cfs. If the sluicing operation is successful, the Narrows 1 pool could be partially filled in a future year. Accessing this placement location with the gravel/cobble sluicing method is highly feasible according to the pipe pathway described in section 4.3. From this point, additional sluice pipe could be added to reach across the river or shift placement downstream in future years.

4.5. Gravel Cobble Mixture Design

Table 4.1 below provides the design of the gravel mixture to be used at the site. This mixture is consistent with the scientific literature on what is preferred for salmon spawning, embryo incubation, and fry emergence. Because the mix only specifies 2.5% of the material to be 4-5” in its B-axis dimension, that helps reduce the likelihood of having large finger rocks that can clog the sluice pipe.

Table 4.1. EDR gravel and cobble specifications (from USACE, 2007).



Gravel Size (inches)	Percent Retained	Target % of Total Mix
4 to 5	0 - 5	2.5
2 to 4	15 - 30	20
1 to 2	50 - 60	35
¾ to 1	60 - 75	15
½ to ¾	85 - 90	15
¼ to ½	95 - 100	10
< ¼	100	2.5

5. 2010 EDR SPAWNING RIFFLE DESIGN DEVELOPMENT

The Watershed Hydrology and Geomorphology Lab at UC Davis has been designing spawning habitat rehabilitation projects since 1999 using the Spawning Habitat Integrated Rehabilitation Approach (SHIRA) (Fig. 5.1). Over the years, testing of numerous gravel-contouring schemes in 2D models and in actual construction has yielded a conceptual understanding of expected hydraulic attributes, geomorphic processes, and ecologic benefits. Numerous specific design examples are illustrated on the SHIRA website at http://shira.lawr.ucdavis.edu/casestudies.htm.

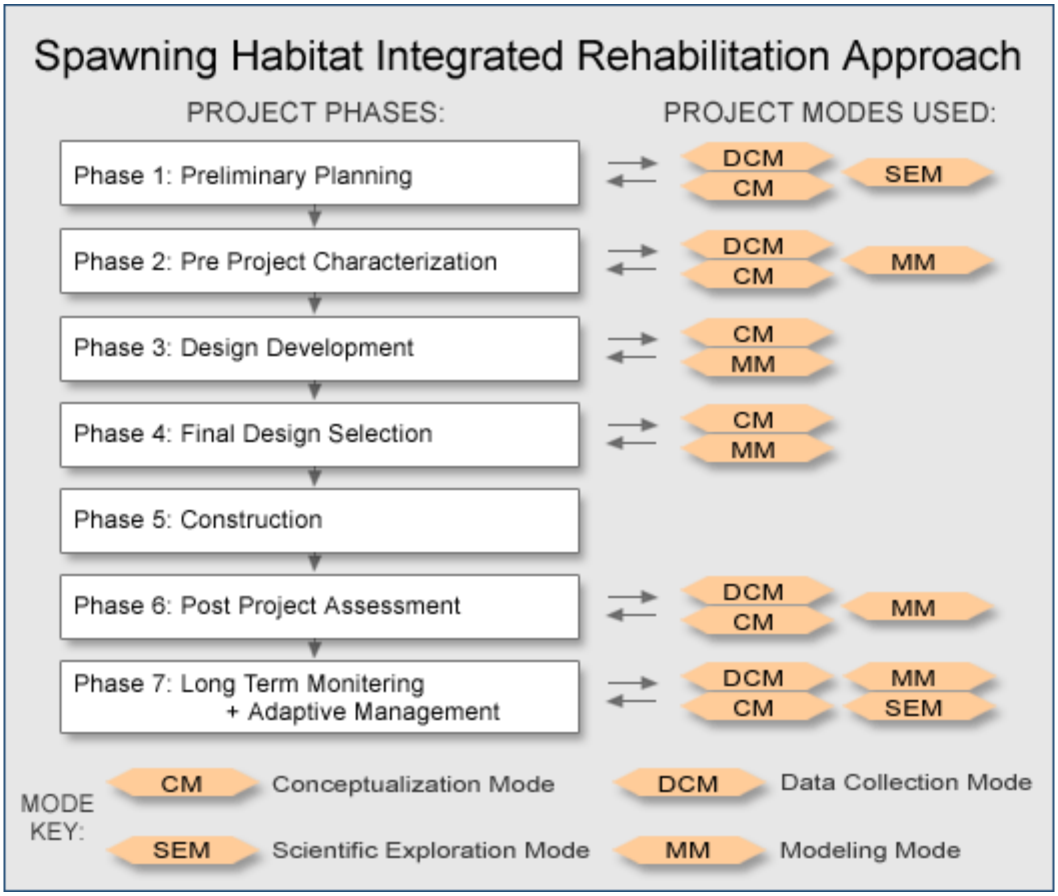


Figure 5.1. General schematic illustrating what is involved in the SHIRA framework.

5.1. Project Constraints

Based on past experience and site-specific constraints, it is possible to reduce the number of possible alternatives down considerably. An enumeration of key constraints helps put the options into focus. First, the amount of gravel to be added in the 2010 pilot trial of the gravel/cobble sluicing method has to be relatively small compared to the total deficit in the EDR given the uncertainty over how the method will work out. A lot of lessons may be learned from this trial in support of improvement to facilitate larger placements in future years. The consequence of placing a small amount of gravel is that there may not be enough material to form a resilient landform at the injection location in the face of a range of flow releases. Second, even at the typical low discharge of ~500-950 cfs in the EDR in September and October, baseline 2D modeling shows that the flow in the placement area is deep and fast (Figs. 3.1-3.4). This location is in a narrow part of the canyon that focuses flow over a range of discharges (Figs. 3.3-3.4). Several placement configurations (e.g. diagonal bar and chevron) would be at risk to scour away quickly under such focused scour. Third, the rate of gravel sluicing may be to low relative to the ambient velocity to control placement pattern at all. As sediment settles out of the water column, it will be pushed downstream in a way that is not easy to control.

One element excluded from consideration for this plan was the addition of large wood to the wetted channel in support of habitat heterogeneity, refugia, and cover. Presently there is large wood stored in the EDR (Fig. 5.2), which is ultimately derived from the small tributaries of the Middle and South Yuba Rivers. These two high-order tributaries have long stretches of unblocked channel network leading into Englebright Dam. The dam itself passes streamwood over its top during floods (wood floats, gravel/cobble does not), as evidenced by the available large wood stored in the EDR and the debris clogging Daguerre Point Dam and its fish ladders during and after floods. Historical photos 1909-2006 do not show wood jams or smaller wood accumulations in the wetted channel of the EDR. Given the width of the channel in the EDR and the power of the flow during floods, there is no reason to expect that large wood was ever stored in the channel there, in contrast to gravel/cobble, which was stored there and is now absent. Finally, because wood floats, any placement of large wood as part of the gravel/cobble augmentation plan would be highly likely to wash downstream. Use of engineered cables and fasteners to force wood to stay in place is problematic, because the underlying sediment is not expected to stay in place. Hard-wiring objects in place is also inconsistent with the approach of rehabilitating naturalized dynamic processes.

Figure 5.2. Example of large wood stored in the EDR.

5.2. Project Goals

Regardless of these constraints, the primary project goal of injecting river-rounded gravel/cobble is not at risk in the choice of placement design. If the sluice method gets the sediment into the wetted channel, then it is a success with regard to the primary goal of the project. *Creating a placement design is a bonus opportunity enabled by the ability of the sluicing method to have moderate control over where gravel is laid down on the river bed.* The extent to which the bonus can be achieved hinges on the amount of gravel added and ambient flow conditions. It is impossible to predict in advance how that will turn out. Nevertheless, it is sensible to be prepared for a successful outcome in which it is possible to control gravel placement on the bed. In that case the extra effort of controlling placement can yield physical habitat immediately available for Chinook salmon spawners to use (Elkins et al., 2007).

5.3. Design Objectives And Hypotheses

A design objective is a specific goal that is aimed for when a project plan is implemented. To achieve the objective, it has to be translated into a design hypothesis. According to Wheaton et al. (2004b), a design hypothesis is a mechanistic inference, formulated on the basis of scientific literature review and available site-specific data, and thus is assumed true as a general scientific principle. Once a design hypothesis is stated, then specific morphological features are designed to work with the flow regime to yield the mechanism in the design hypothesis. Finally, a test is formulated to determine after implementation whether the design hypothesis was appropriate for the project and the degree to which the design objective was achieved. Through this sequence, a process-oriented rehabilitation is achieved. From the mathematics of differential equations, it is evident that processes derive from the physics of motion, input conditions, and boundary conditions. Changes to either of input or boundary conditions impact processes, so it is possible and appropriate to design the shape of the river bed to yield specific fluvial mechanism associated with desired ecological functions.

The design objectives and associated information for the EDR gravel/cobble augmentation plan are enumerated in Table 5.1. This table provides a transparent accounting of the objectives, hypotheses, approaches, and tests for the gravel/cobble augmentation effort.

The last column in the table lists specific measures for monitoring the success of gravel/cobble augmentation.

Table 5.1. Design objectives and hypothesis for EDR gravel/cobble augmentation.

Design objective	Design hypothesis	Approach	Test
1. Restore gravel/cobble storage	1A. Total sediment storage should be at least half of the volume of the wetted channel at a typical base flow under a heavily degraded state (Pasternack, 2008b).	Inject gravel into the river to fill up recommended volume of sediment storage space.	Use DEM differencing of bed topography over time to track changes in storage
2. Provide higher quantity of preferred-quality Chinook spawning habitat	2A. SRCS require deep, loose, river-rounded gravel/cobble for spawning (Kondolf, 2000).	Add river-rounded gravel/cobble.	Perform Wolman pebble counts of the delivered sediment stockpile and in the river after each gravel injection to insure that the mixture's distribution is in the required range.
	2B. Spawning habitat should be provided that is as close to GHSI-defined high-quality habitat as possible (Wheaton et al., 2004b)	Place and contour gravel to yield depths and velocities consistent with salmon spawning microhabitat suitability curves.	Measure and/or simulate the spatial pattern of GHSI after project construction to determine quantity of preferred-quality (GHSI>0.4) habitat present.
3. Provide adult and juvenile refugia in close proximity to spawning habitat.	3A. Structural refugia in close proximity to spawning habitat should provide resting zones for adult spawners and protection from predation and holding areas for juveniles.	Create spawning habitat in close (<10 m) proximity to pools, overhanging cover, bedrock outcrops, boulder complexes, and/or streamwood.	Measure distance from medium and high GHSI quality habitats to structural refugia and check to see that most spawning habitat is within reasonable proximity.
4. Provide morphological diversity to support ecological diversity, including behavoral choice by individuals.	4A. Designs should promote habitat heterogeneity to provide a mix of habitat patches that serve multiple species and lifestages.	Avoid GHSI optimization of excessively large contiguous areas of habitat; design for functional mosaic of geomorphic forms and habitat.	Large (>2 channel widths) patches of homogenized flow conditions in hydrodynamic model and homogenized habitat quality in GHSI model results should not be present at spawning flows.
5. Allow gravel/cobble to wash downstream	5A.Suitable mechanisms of riffle-pool maintenance are not present or realistically achievable in the upper section of the EDR	no specific action required	Conduct annual recon of EDR to track where injected gravel/cobble goes.
	5B. Flows that overtop Englebright Dam erode sediment off the placement area	no specific action required	Measure and/or simulate the spatial pattern of Shields stress and identify areas with values >0.06

5.4. Design Concept

Given the array of site and project constraints described earlier, there is a limited range of concepts possible for implementing spawning habitat rehabilitation. To facilitate a larger, longer term vision, a staged design concept was developed that can be aimed for over time. The design concept for the plan is illustrated in Figure 5.3. Area A is the focus of the effort for 2010. The design for Area A involves filling in the channel to a depth of ~2' for the primary spawning area at 855 cfs and then having a 3' deep thalweg going up to the crest. The thalweg is in the 2D model-predicted location of the pre-existing thalweg for 855 cfs. A deeper thalweg is required to cope with the total volume of flow focusing through the gravel-placement site. The thalweg ends at the riffle crest allowing water to diverge laterally across the crest. By design the thalweg does not go all the way through riffle, because that would increase the rate and likelihood of the flow cutting the gravel deposit into two lateral benches, which is not desirable (Pasternack et al., 2004). However, given the strength of the flow, it may be unavoidable, even without the thalweg going through the whole riffle by design. If fully built, Area A would use up an estimated 4673 short tons of gravel. The conversion of gravel amount from a design volume to a tonnage is based on the density measurements of Merz et al. (2006) reported earlier in section 2.2, noting that with the sluicing method there is no heavy machinery to compact the bed, in contrast to the effect of front loaders reported by Sawyer et al. (2009). A key reason to aim for 2' water depth at 855 cfs is that flows can drop to 700 cfs in a schedule A year and 500 cfs in a schedule B year. This depth provides a hydrologic buffer so that the riffle does not dewater. This is consistent with design objective #4. Another factor is that the design has to be constructible using the gravel sluicing method, and this simple design meets construction criteria based on past experience.

Figure 5.3 also illustrates design concepts for adding coarse sediment in future years to continue to meet the design objectives (Areas B and C). Because the channel deepens downstream, Area B uses more gravel than Area A, but is about half as long. Area B divides the flow and refocuses it into two 3'-deep thalwegs. Between them is a medial bar. This channel pattern is known to promote habitat diversity as well as resiliency against interannual flow differences during the spawning season. Area B requires an estimated 4870 short tons. Area C terminates the medial bar and joins the two thalwegs along the right bank, before beginning to shift it back toward the center. Area C requires an estimated 3192 short tons. Thus, the overall design concept would use 12735 short tons of gravel if it were possible to build it out over a period of a few years. This accounts for 56% of the estimated gravel/cobble storage deficit for the area from Narrows II to the rapid below the gaging station (Table 3.1). For the sake of comparison, a “blanket fill” design that would involve filling half of the pre-existing mean water depth at 855 cfs with coarse sediment between Narrows I and the rapid downstream of the gaging station would require an estimated 15850 short tons. Such a blanket installation is not feasible by gravel sluicing as it is currently practiced. Nevertheless, this value is helpful to appreciate that the creation of a heterogeneous spawning riffle in a relatively small area can achieve the same gravel/cobble storage goal, while also yielding the benefit of providing preferred SRCS spawning habitat.

If the gravel introduced in the first year washes downstream consistent with design objective #5, then that is fine, as the eroded material would still be serving the primary plan goal (design objective 1). Future injections would use the next amount of material purchased to rebuild as much of Area A, then Area B, and then Area C as possible. It is possible that frequent floods could preclude the complete design concept from ever being achieved, and that is an acceptable outcome consistent with the overall goals of the plan and the specific design objectives.

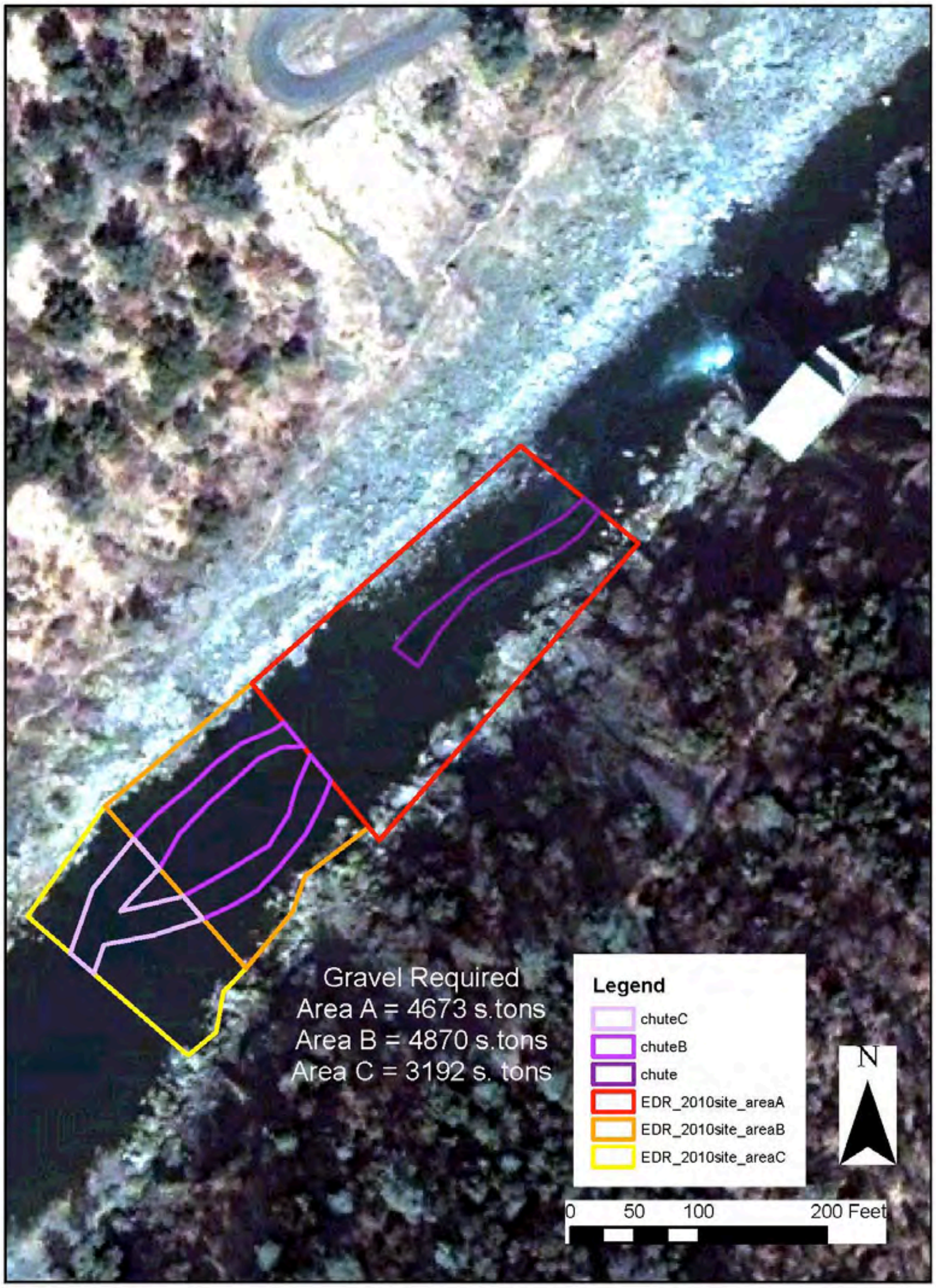


Figure 5.3. Design concept for using gravel augmentation in the EDR to possibly obtain a salmon-spawning riffle with diverse microhabitat features.

5.5. 2D Model Testing of Design Hypotheses

The likely ability of the design concept to achieve design objectives 2 and 5 is testable by performing spatially distributed, mechanistic numerical modeling of the design. Objective 2 and hypothesis 2B require that the design yield areas with GHSI>0.4 at a typical autumnal discharge of ~500-950 cfs. Objective 5 and hypothesis 5B require that the design yield areas with Shield stress values > 0.06 at flows overtopping Englebright Dam, which is Q>4500 cfs. The abilities of the design for Area A, Areas A+B, and Areas A+B+C to achieve these requirements were tested by incorporating their respective topographic features into SRH-2D models of the EDR and putting these models through the same paces as the models reported in section 3. The computational meshes used were the same as for the baseline simulations, with only the bed topography changed.

The SRH-2D model simulation for 855 cfs revealed that the design concept for Area A successfully achieves substantial area of spawning habitat with GHSI>0.4 (Fig. 5.4). Because excessive depth appears to be the limiting variable, lower discharges would have lower depths, higher GHSI values, and thus a larger total area of preferred Chinook spawning habitat.

The SRH-2D model simulation for 855 cfs revealed that the design concept for Area A yields a stable bed with a Shields stress of 0.01-0.03 during this spawning discharge (Fig. 5.5). Depending on how loosely the gravel/cobble settles onto the bed and whether any grain size fractionation occurs during settling, it is unclear whether this range of Shields stress values would be associated with partial transport. However, if that happened, the bed can be expected to adjust very quickly to yield a stable configuration prior to the autumn 2011 spawning season.

The SRH-2D model simulation for 10,000 and 15,400 cfs revealed that the design concept for Area A successfully provides a condition of full bedload mobility over the majority of the project area at these discharges (Fig. 5.6). That means that at these high discharges and any higher ones, the project site will scour significantly. Beginning with the 1991 water year, flows of >10,000 cfs have occurred in 12 out of 20 years, or once every 1.67 years. Therefore, there is a high likelihood that the placed grave/cobble will transport downstream in accordance with design objective #5. Results shown in Figures 3.6-3.7 indicate that the placed material is unlikely to leave the EDR. Considering that those analyses do not account for the impeding effects of flow out of Deer Creek, then the likelihood is even stronger that the material will stay in the EDR.

One other consideration related to any riffle design is the fact that a riffle is a partial barrier to flow. Water backs up behind a riffle and accelerated over it. When a riffle is added artificially or degraded riffle-pool relief is rehabilitated, then an increased backwater effect will result (Wheaton et al., 2004a). The Area A 2D model simulations show that effect for that design. In the EDR, there is no negative environmental impact of this upstream backwater effect, because it serves to decrease velocity and increase depth in an area that is already mostly devoid of spawning habitat anyway. In terms of powerhouse operations, both powerhouses operate normally with a wide range of tailwater depths, so an increase in water surface elevation in the Narrow I pool and Narrows II pool should not impact their operations.

Overall, there do not appear to be any impediments for the use of the Area A design. The design uses a reasonable amount of gravel to pilot the gravel sluicing method in 2010. If the material survives in its placement location through winter and spring 2011, the design is predicted to yield preferred Chinook spawning habitat and is predicted to yield a stable riffle during spawning and embryo incubation in 2011 prior to winter storms in 2012. The designed riffle is predicted to be erodible during floods overtopping Englebright Dam roughly every other year, but when moved the material is expected to stay within the EDR. This means that the tonnage still counts toward achieving the geomorphic goal of eliminating the gravel/cobble deficit for the reach over the long term. Further gravel additions to re-build Area A in future years would yield short-term habitat benefits and add up toward the longer term geomorphic goal. The last column of Table 5.1 lists specific measures than can be used to test the efficacy of gravel augmentation toward meeting each specific design objective.

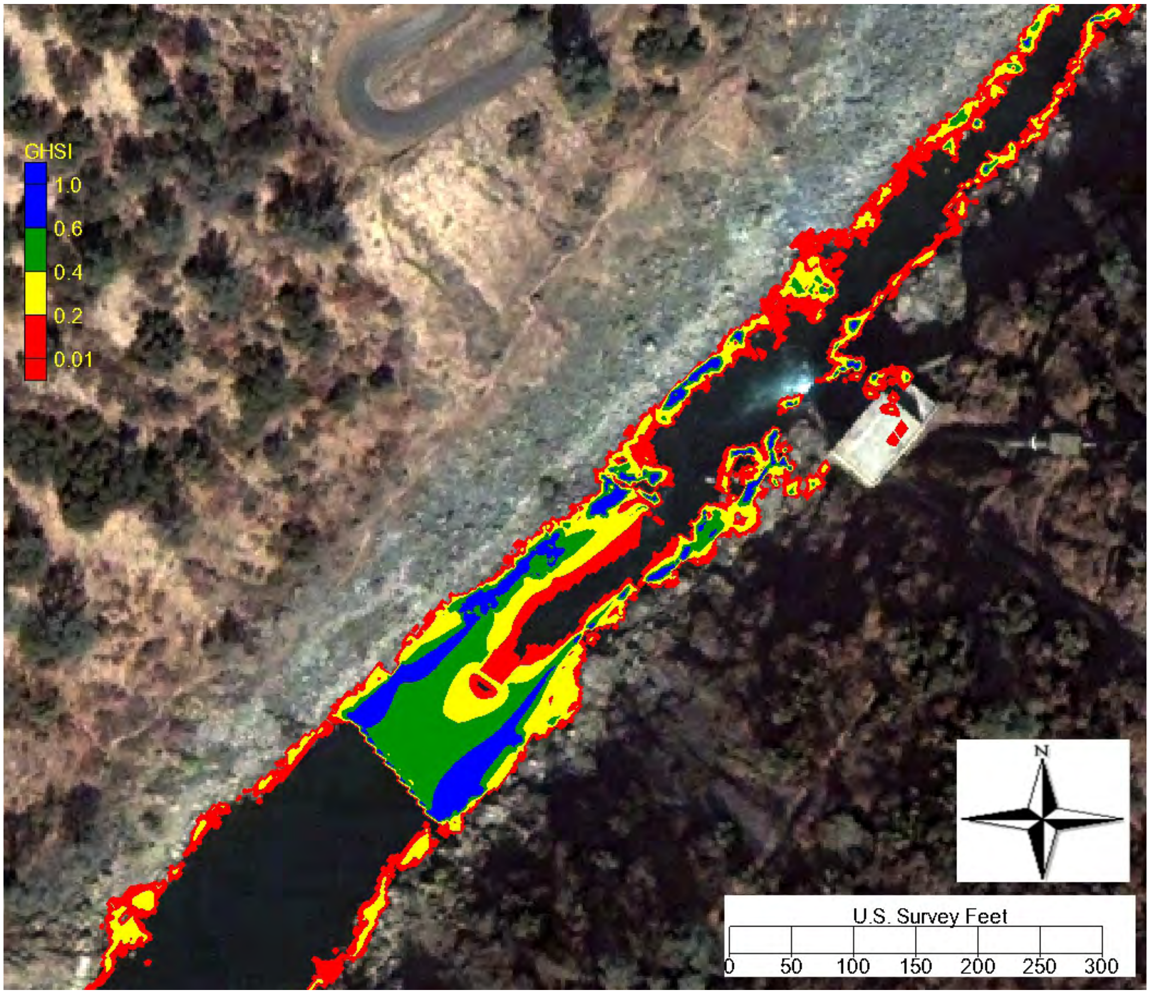


Figure 5.4. GHSI prediction for Area A at 855 cfs. Areas of green and blue are predicted to be preferred Chinook spawning habitat.

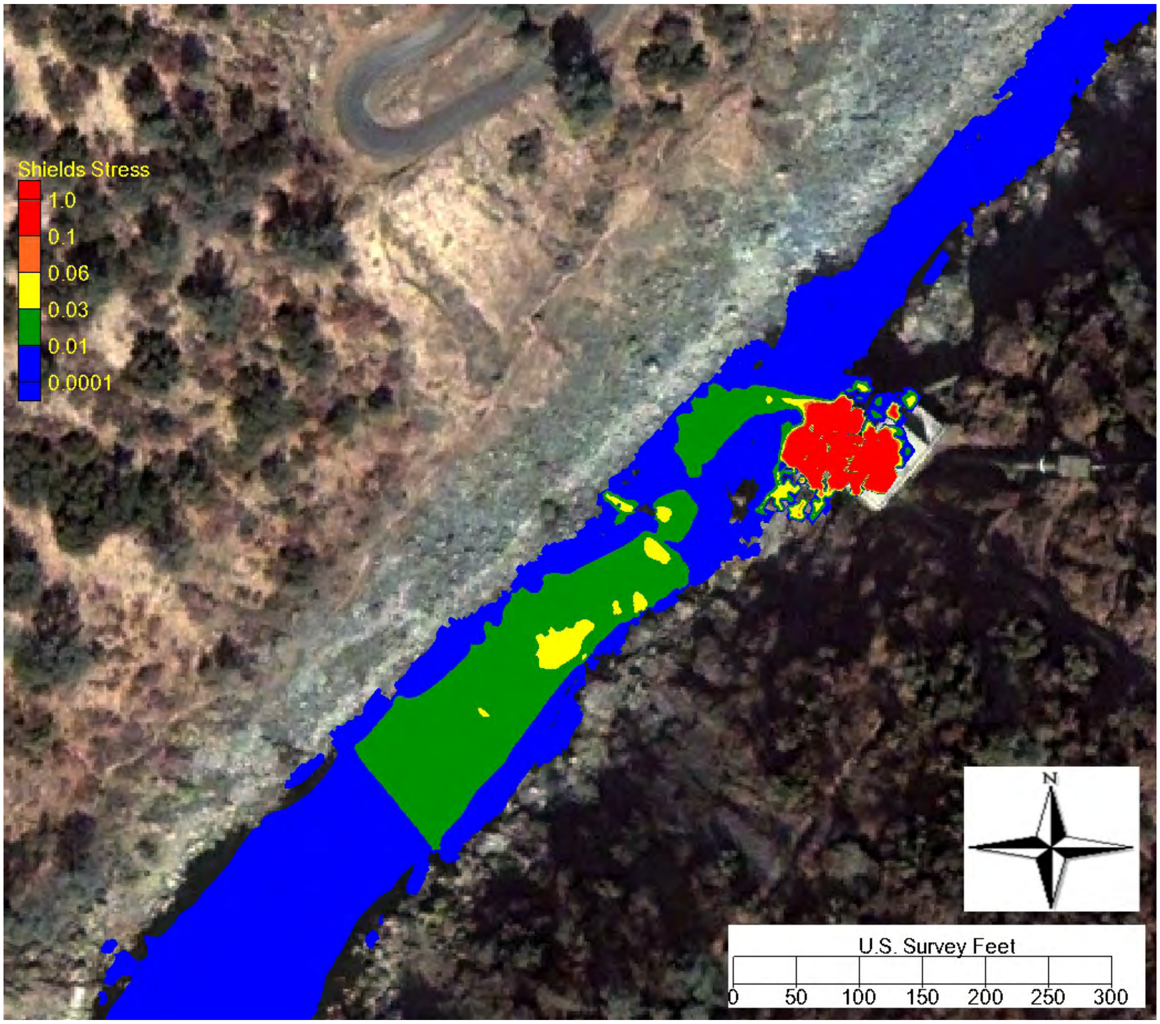


Figure 5.5. Shields stress prediction for Area A at 855 cfs.

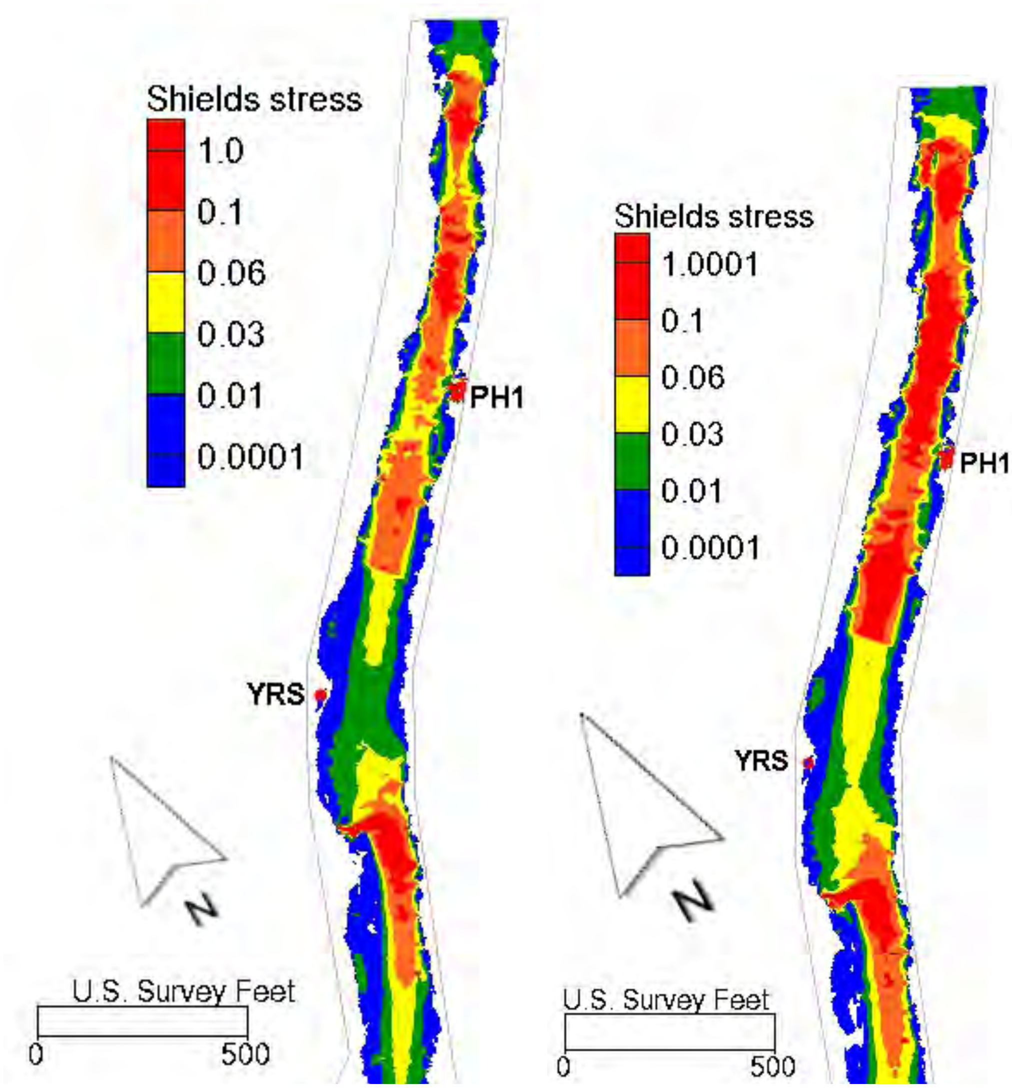


Figure 5.6. 2D model predictions of Shields stress for flows of 10,000 cfs (left) and 15,400 cfs (right), focusing on the location of gravel placement below the Narrows I powerhouse (PH1). In both scenarios, Shields stress > 0.06 over the majority of Area A.

6. LONG-TERM GRAVEL AUGMENTATION PLAN

The estimated gravel/cobble deficit for the EDR is 63,077 to 100,923 in the current condition. Considering just the area from the Narrows I powerhouse to the rapid downstream of the gaging station, the amount is 15,949 to 25,518 short tons. The lower value for each domain is consistent with the idea of having a diversity of complex morphological units in the reach, while the higher value for each domain is consistent with the idea of having a fully alluvial reach with a lot of riffle area and low morphological diversity. The former conception involving a balanced role of alluvial and bedrock influences is interpreted to be the best match for what was likely present prior to hydraulic mining. The latter conception of a fully alluvial river within the canyon would more resemble the state of the river during severe alluviation with hydraulic mining debris, and therefore is deemed less appropriate.

Strategically, different approaches are feasible for the sequencing of placing gravel and cobble. It is not feasible to erase the entire gravel/cobble deficit in one year. It is very important to use an incremental approach in this type of project, because it yields a more resilient and better-tested outcome (Elkins et al., 2007). The area of the river that is presently appropriate for gravel augmentation is the domain from the Narrows I pool to the top of the rapid downstream of the gaging station. The recommendation for the 2010 pilot project is to use the sluicing method to place 2000 to 5000 short tons of gravel/cobble to build up an Area A riffle. This project is a "pilot", because the gravel/cobble sluicing method has never been attempted for salmon habitat rehabilitation over such a long distance and with such a high height drop.

During and after the 2010 pilot gravel/cobble placement, a monitoring program should be instituted to evaluate what happened. Baseline data exists for the pre-project characterization (see section 3). Observation, description, and photo-documentation of the gravel/cobble sluicing operation would help assess its logistical effectiveness to get gravel/cobble into the river. After construction, an as-built topographic survey should be performed to enable 2D hydrodynamic modeling for mapping of physical habitat and sediment transport potential for the site. The as-built survey is also required for DEM differencing to track volumetric change over time. Thereafter, the seven tests listed in

Table 5.1 should be carried out. These tests will ascertain the veracity of the design hypotheses and the suitability of the design objectives. Based on the outcome of a thorough evaluation, future projects may be designed differently to yield improved outcomes.

Assuming the gravel-sluicing method of doing gravel/cobble augmentation is judged successful after evaluation of the 2010 pilot project, then a long-term plan that continues to use this approach would be recommended. The concept would be to add gravel and cobble to Areas A, B, and C until the EDR deficit is erased. Building out the design concept for Areas A, B, and C would come close to achieving the total deficit for this section, and it would be easy to add an Area D to finish it off when and if that is needed. Thereafter, as floods relocate the sediment into the lowermost section of the EDR, further additions would be made to the placement area to keep up with the flux into the lowermost section plus any outflux leaving the EDR. Eventually, the gravel deficit for the whole reach would be erased. Once the overall deficit is erased, then further additions would only be appropriate after material is observed leaving the EDR, and then the amount would match the estimated loss.

For the section between the Narrows II and I powerhouses, it may or may not be feasible to ever erase the gravel/cobble deficit. Further evaluation of options in light of existing and possible future powerhouse operations is required.

Overall, the evidence shows that the EDR has the potential to accommodate thousands of Chinook spawners. Erasing the gravel/cobble deficit for the reach would be beneficial toward achieving that potential. Gravel sluicing is the recommended method for augmenting gravel into the EDR. Going further to build diverse morphological units in the reach would yield a sufficient amount of preferred holding, spawning, and embryo-incubation habitat for the population. Such actions would account for the most significant and evident geomorphic impacts of Englebright Dam on the lower Yuba River.

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