CFAAR without a plan: a design-development framework for unplanned river restoration opportunities

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Abstract

The practice of river restoration is a growing field that seeks rejuvenation of river functionality. Restoration opportunities can range from prescriptive actions falling out of detailed planning efforts, to completely unplanned opportunities driven by extenuating circumstances. Unplanned opportunities have received relatively little attention within the literature, and as a result there is a lack of formal guidance on how to step through unplanned restoration opportunities in a holistic manner. To improve our collective abilities to address unplanned opportunities we have developed *CFAAR*, a design-development framework constructed and tested for applicable circumstances. *CFAAR* is short for Context, Feasibility, Alternatives, Analysis and Refinement. It is a simple framework in concept, which sequentially builds a restoration vision founded on a concrete understanding of the project site *context*, from physical to regulatory, coupled with a clear and honest appraisal of restoration *feasibility*, acknowledging that restoration can simply describe an enhanced or improved river condition. *CFAAR* offers a viable solution for unplanned actions and it can be utilized by trained and untrained scientists, engineers, or resource managers alike, who are supported by an appropriate team of restoration professionals. In developing and applying *CFAAR* it is clear that the framework works well with projects that are scheduled on compressed timelines, circumstances which heighten the risk of making mistakes and taking shortcuts. Under such circumstances, *CFAAR* compels restorationists to produce rational and transparent design concepts, effectively communicated via the *CFAAR* construct.

Keywords: river restoration; unplanned restoration; design framework; geomorphology

1. Introduction

Functional river ecosystems provide humans clean drinking water, a rich food supply, flood protection, a source of income, and recreation (World Water Assessment Programme, 2006). Unfortunately there are fewer and fewer rivers in the world that are functional (Wohl, 2010). Decades of dam building, over allocation of flow, and other myriad of stressors has resulted in the degradation of ecosystem services, aquatic and terrestrial habitat, and biodiversity (World Water Assessment Programme 2006; Palmer and Filoso, 2009). Predicted change to climate and associated phenomenon add to the seriousness of the observed trends (Fig. 1), and heightens the need for enhancement of rivers worldwide. River enhancement falls within the realm of *river restoration*, a somewhat controversial yet growing practice (Bernhardt et al., 2005).

River restoration – defined here as deliberate acts to measurably improve existing river conditions – benefits from a substantial and diverse literature base (e.g. Doll et al. 2003, Shields et al. 2003, FISWRG 2004, Saldi-Caromile et al. 2004, Palmer et al. 2005, Darby and Sear 2008, Beechie et al. 2010, Skidmore et al. 2010). A common theme within the literature provides that ideal(ly) restoration is supported by science-based planning that identifies specific actions. The wisdom of this theme is clear, and it is, in general, accepted as standard practice within the restoration community. In application however, science-based planning efforts do not account for all restoration actions. There exists a whole class of river restoration that is not envisioned or planned, but crops up due to unpredictable circumstances. This class of restoration opportunities can be thought of as non-ideal cases, as they commonly lack scientific basis with regards to their identification as a viable restorative or enhancement action. Despite this shortcoming, it is proposed that these opportunities can systematically and positively contribute to revitalization of river systems through use of a science-based design-development process, created specifically for the circumstances which characterize non-ideal opportunities. Restoration practitioners presently lack a science-based design framework for non-ideal cases, heightening its need.

Lack of a suitable design-development framework sets non-ideal opportunities at a disadvantage to their planned counterparts. This inequity is critical given that we find ourselves in an era defined by financial uncertainty, which raises the importance of unplanned opportunities. To respond effectively when non-ideal cases materialize, river restoration practice needs a simple yet effective framework that can successfully adapt the practice to unplanned opportunities. Beyond a basis in science, the framework needs to also serve as a useful communication and outreach vehicle (Jacobson and Berkely, 2011). Effective communication and outreach will foster efficiency, consensus building, and help to formalize an associated standard of practice for non-ideal circumstances.

We introduce *CFAAR*, short for <u>C</u>ontext, <u>F</u>easibility, <u>A</u>lternatives, <u>A</u>nalysis and <u>R</u>efinement, a design-development framework suitable for the circumstances of unplanned restorative opportunities, and usefully comparable to the defining framework of Adaptive Management (Smith, 2011). Experience suggests that diligent use of *CFAAR* as a science-based design framework will help us to realize the collective restorative successes that we seek and need. A brief review of the *CFAAR* framework follows and focuses on describing each component to a level sufficient for utilization.

2. **<u>CFAAR: Context, Feasibility, Alternatives, Analysis and Refinement (Fig. 2)</u>**

a. *Context* – spatial, temporal and cultural considerations. It is essential that restorative plans explicitly consider the contextual setting of each project (Montgomery 2004, Beechie et al. 2010, Skidmore et al. 2010; Jacobson and Berkeley, 2011), because context defines the scale at which river corridor processes, and impacts to those processes, are broadly manifest. Without context, it is not possible to explain the present river corridor's character, let alone begin to conceptualize design alternatives to affect the desired change. Consideration and characterization of context is challenging because it comprises the physical, ecological, cultural, and regulatory dimensions (Jacobson and Berkley, 2011). This necessitates that design teams include scientists and practitioners from a broad spectrum of disciplines (Montgomery 2004, Palmer 2008). Furthermore, design teams need to truly function as teams, drawing on the strengths of the various team members to develop the best concepts and plans possible. Clear deliberation of context at the start of the design process for unplanned opportunities defines the core precept of *CFAAR*. This supports scientists and practitioners to knowledgeably assess restorative feasibility, and ultimately enhances the probability of project success.

b. *Feasibility* – a distilled manifestation of goals, objectives and design criteria. The development of project feasibility is appropriately guided by establishing a concise and guiding restorative image (Palmer et al. 2005). Understanding context, focus of the restorative image is sharpened by weighing three attributes of contemporary river systems: perceived risk of restorative actions, land availability, and the hydrologic and sediment supply integrity of the basin (see *Feasibility* diagram of Fig. 2). The usefulness of these attributes stems from their representation of psychological (perceived risk), practical (land availability), and ecosystem (hydrologic and sediment supply integrity) circumstances, which together complements the "self-healing" suitability paradigm developed by Kondolf (2011), and the conceptual restoration model of Jacobson and Berkley (2011). Collectively, these circumstances will largely govern the trajectory of feasible restorative actions, which can be summarized as design approaches to: (a) control corridor process, (b) rejuvenate corridor process, and (c) achieve both control and rejuvenation of corridor process. For example, if working on a reach of river where the available land is low and the perceived risk is high, it is likely that it will be necessary to control corridor processes over the project lifetime, which is likely to extend 25 to 50 years. When project feasibility has been identified, it is detailed into goals, objectives, and design criteria. Goals are understood as the general or specific end states to achieve, comparable to hypotheses under Adaptive Management (Smith, 2011), objectives as the defined and measurable system attributes by which achievement of goals are judged, contributing to the learning process so key to Adaptive Management (Jacobson and Berkley, 2011; Smith, 2011), and design criteria the articulated performance metrics against which design analyses are compared. Notably, objectives are the cornerstone of the Adaptive Management approach to restoration (Smith, 2011). Likewise, objectives are one of two key outcomes to feasibility visioning within CFAAR, and therefore serve to guide development of suitable design alternatives. By front loading CFAAR with careful assessment of context and feasibility prior to development of specific design objectives, it is envisioned that the selected project design will be more likely to successfully drive the system to the desired and scientifically-appropriate outcome.

c. *Alternatives* – development of viable design concepts. Design alternatives are conceptualized once project context and feasibility are clearly established. In order to drive creativity, two alternatives at a minimum should be developed for each project. Design alternatives should address the physical and ecological circumstances, and potential of a site (Palmer et al. 2005), as established by studies, back-grounding and consensus building completed to characterize context and feasibility. For projects that seek to rejuvenate corridor processes, alternatives are first mocked up by sketching bird's-eye and section view layouts for the project reach, considering the target vegetative communities, range of channel bed slopes, and characteristic stream and corridor width which the constructed project will need to express. For projects which seek to control process, bird's-eye and section view layouts should focus, in part, on the general details of proposed structures, with careful thought given to the interface between proposed structures and infrastructure, or private property which control-centric projects generally aim to protect. The common goal at this point is to advance and illustrate alternatives in enough detail to understand design intent and facilitate analysis. Achieving this goal also aids outreach to project stakeholders and regulatory agencies in order to seek their constructive input at this critical stage in the design-development process.

d. *Analysis* – functional and technical evaluation of alternatives. Proposed alternatives should be fully evaluated technically (Wilcock 2004, Beechie et al. 2008, Darby and Sear 2008), including an assessment of potential impacts framed by applicable environmental regulations such as the National Environmental Policy Act (1969), and many others. Analysis generally involves hydraulic modeling, sediment transport and bed stability modeling, evaluation of fish passage and habitat conditions, and risk-based evaluations related to climate change and land use projections. Hydraulic modeling is used to evaluate and compare the predicted hydraulic performance of alternatives against the goals of the project, typically for a suite of flood events. Pertinent hydraulic performance elements include the predicted spatial patterns of flooding, and the spatial distribution and magnitude of hydraulic characteristics such as velocity. Sediment transport analysis relates to evaluation of the spatial patterns and magnitudes of streambed and floodplain erosion, as well as deposition, and how these patterns compare to the proposed stream morphology (Wilcock 2004, Beechie et al. 2008).

Fish passage evaluation is based on comparing hydraulic modeling results to established fish passage criteria (NOAA Fisheries 2001, CDFG 2009). Projects that seek to improve in-stream fish habitat are commonly evaluated with Habitat Suitability Index (HSI) curves (USFWS 1996). The use of HSI curves to evaluate design alternatives helps to maximize the potential benefit of constructed habitat to target fish species. Accordingly, HSI curves have been developed for a large number of freshwater fish species. Their use, along with the use of fish passage criteria expressly motivates design professionals to seek new levels of design ingenuity, and fosters a design culture that provides for methodical and careful evaluation of alternatives outside the typical stability-based paradigm (Shields et al. 2003).

e. *Refinement – final adjustment of design elements to address deficiencies revealed through* analysis and stakeholder review. Refinement represents the last critical step in the CFAAR process, and it is intended to provide all parties involved with an opportunity to express clear commitment to the project. The process of securing stakeholder commitment is facilitated through preparation of a design basis report. Design basis reports (DBRs) have a long tradition of application in architecture and engineering, and their use in ecological restoration design is a natural extension of this useful tool. CFAAR can be used as the organizing framework for DBRs because it provides the structure necessary to prepare a report that documents the design process in a clear and comprehensive fashion. It also facilitates more meaningful participation by project stakeholders who may lack the particular expertise related to ecological restoration because the components of CFAAR provide the cues necessary to ask appropriate and critical questions. All wrapped up, this should help to foster stakeholder confidence, minimize dramatic design overhauls, reduce restoration design costs and facilitate an enhanced probability of restorative success.

Once the scope of design refinement has been established through review of the DBR, the normal design progression provides for completion of the design package, suitable for regulatory permitting, and advertisement for implementation. It is important to note that unplanned restorative opportunities should not generally be viewed as experiments, as the Adaptive Management system demands, because regulatory agencies will typically require explicit project outcomes in order to successfully mitigate for impacts of associated actions. This underscores the practical logic framing the CFAAR progression, accentuated by design refinements that are informed by results of supporting technical or other analyses, and feedback by stakeholders and regulatory agencies. Experience suggests that practitioners should budget the refinement step carefully.

3. ***CFAAR*** **Case Study Application**

A brief case study application of *CFAAR* is provided. It represents a summary of the design development process for the Upper Penitencia Creek mitigation project (UPC Project) (Fig. 3) (Chartrand, 2011). Compensatory mitigation of Upper Penitencia Creek was associated with an approximately 2.3 billion dollar (U.S.) commuter rail expansion project spearheaded by The Santa Clara Valley Transportation Authority (VTA), a transportation agency servicing the South San Francisco Bay region. Mitigation was necessary in order to balance construction related impacts to freshwater resources, which in California are protected by numerous State and Federal (U.S.) regulations. The UPC Project was chosen as an example *CFAAR* application because it is characterized by competing interests, the watershed harbors an important regional steelhead population (*O. mykiss*) and it lacks a comprehensive planning document, identifying science-based and coordinated restoration actions. More importantly though, design of the UPC Project occurred under a very compressed timeline, without prior foresight, and as such it exemplifies an unplanned restorative opportunity.

Available technical studies useful to development of mitigation design alternatives included a (1) steelhead limiting factors analysis (Stillwater Sciences, 2006), (2) historical ecology assessment of the lower watershed (Grossinger et al., 2006), (3) geomorphic assessment (Jordan et al., 2009), (4) three seasons of streamflow and sediment transport measurements (unpublished data), and (5) geotechnical analysis. During preparation of UPC Project design documents, the U.S. Army Corps of Engineers (ACOE), in conjunction with the local flood control agency, the Santa Clara Valley Water District, was in the process of completing a new flood control study for UPC. The flood control project was developing along a trajectory to support a functional stream corridor environment. This was a benefit to the UPC Project design process as mitigation concepts were more aligned with the Flood Risk Management (Menke and Nijland, 2008), or Living River concepts of flood control, building from traditional flood control approaches.

a. *Context* – Surficial geologic maps (Helley and others, 1994) show that the UPC Project is located at the distal end of Upper Penitencia Creek's youngest alluvial fan, at the transition with floodplain or bank levee deposits from Coyote Creek. An historical map circa 1800 suggests that Upper Penitencia Creek at the project site did not in fact exist at that time (Fig. 3), and was instead an intermittent, distributary stream system. The distributary streams supported a freshwater marsh complex of thick willow groves, known locally as sausals

(Grossinger et al., 2006). The sausals were fed by seasonal surface flows generated during large, winter precipitation events, as well as by shallow ground-water flow, discharged during the spring and early summer months at the head of the alluvial fan.

In the early 1900's the sausals were destroyed and in their place a single thread channel was dug to drain Upper Penitencia Creek to Coyote Creek in order to support land conversion for agricultural purposes. Agriculture was abandoned beginning in the 1960s as the "Silicon Valley" technology center emerged, and with it substantial population growth and urbanization, leading way to neighborhoods and technology campuses. These land use shifts have brought significant change to the stream's hydrology, driving conversion of the lowermost reaches of the stream from an ephemeral, to a nearly perennial stream, despite a 29% reduction in the lowland watershed footprint (Jordan et al., 2009). Urbanization has also led to a shift in the flood flow hydrology, increasing the magnitude of flood flows and creating a new highly recurrent flood. Hydrological modeling shows that flows < 0.5 bankfull discharge occur more frequently under urbanized conditions (Jordan et al., 2009).

At the UPC Project site, the watershed drains approximately 62 km^2, 54 of which occur within the predominantly un-urbanized headwaters canyon of the Diablo Range. Upstream of the UPC Project, the contributing drainage area produces an approximate bankfull flow of 7.6 cubic meters per second (cms) (Jordan et al., 2009), which corresponds to roughly a 1.5-year recurrence interval flood. The 5-year flood is estimated as 45 cms. At the same location Jordan et al. (2009) also report a bankfull slope of about 0.68%, and an average bankfull width and depth of 8 m and 0.6 m, respectively.

The UPC Project streambed is composed of cobbles, gravels and sand. The sediment supply regime of the upper watershed is relatively intact, and sediment delivery from the upper watershed to the lower, urbanized portion of the watershed is for the most part unimpeded. As a result, the watershed sediment transport regime can be considered reasonably functional. At the UPC Project, the stream was confined by steep banks composed of natural substrate, and a variety of man-made materials. The lower one and a half kilometers or so of the channel lacks floodplain, and is characterized by weakly developed riffle, pool and bar morphology. The most apt description of the UPC Project reach is that akin to a drainage canal.

The Upper Penitencia Creek watershed is a primary producer of steelhead within the Coyote Creek basin (Stillwater Sciences, 2006), boasting one of the few steelhead runs in the South Bay of San Francisco (Buchanan et al, 1999) and offering what is considered to be the best steelhead habitat within the region (SCBWMI, 2003). The watershed also supports several other native fish species including Pacific Lamprey (*L. tridentate*), California Roach (*L. symmetricus*) and others (Stillwater Sciences, 2006).

Synthesis of UPC Project *Context* frames several tangible design development considerations. The historical alluvial fan setting coupled with the reasonably intact sediment supply regime suggests that enhancement design alternatives should account for periods of high sediment loading and deposition. Promotion of transient sediment storage will need to be balanced by flood conveyance standards given the urban nature of the UPC Project. Enhancement design alternatives should also address the altered watershed hydrologic regime, as accelerated rates of erosion are common within streams of altered hydrology.

b. *Feasibility* – The highly urbanized nature of the UPC Project suggests that the perceived risk of the project is *high*, as any significant failure of the project could have serious consequences. The perceived risk in this particular case is balanced by the generally *high* land available to the UPC Project. We also assume that the integrity of the hydrologic regime is relatively *low*, whereas the integrity of the sediment supply regime is *high*. These three site- and watershed-specific feasibility characteristics suggest that the UPC Project can likely achieve some level of process rejuvenation at a local scale, while also needing to control process where the perceived risk is most high, for example at a sharp meander bend bordered by a roadway. Long-term liabilities associated with efforts to control process must be communicated honestly to project owners, namely that control measures in particular have a finite lifetime, much like any engineering project, and as such long-term plans need to account for eventual repair, reconstruction, etc. of pertinent project components.

Determination of project *Feasibility* enabled development of rational goals, objectives and design criteria for the UPC Project. The primary goal of the UPC Project was to physically and ecologically enhance the existing and affected stream channel. To address this goal, four design objectives were envisioned:

1. Provide a constructed channel environment that will ultimately support enhanced geomorphic and ecologic functions of the creek corridor;
2. Provide a constructed channel environment that will provide for long-term stability and minimization of risk associated with large-scale channel migration, bank or slope failure, or damage to local infrastructure;
3. Provide a constructed channel environment that will maintain and improve fish passage conditions; and
4. Provide a constructed channel environment that will improve flood conveyance performance of the creek corridor consistent with preliminary planning of the new flood control project (Spinks et al., 2010).

The primary goal, and objectives were articulated into several design-specific criteria, pertinent to these being development of a mitigation approach that provides for (a) floodplain inundation during floods greater than bankfull; (b) opportunities to effectively store pulses of bedload sediment yet minimize risk of channel avulsion; and (c) high-flow refugia habitat for steelhead according to depth and velocity habitat suitability metrics.

c. *Alternatives* – From *Context* and *Feasibility* two mitigation design alternatives were developed, however here we present only the preferred one (Fig. 4).

The UPC Project alternative would re-locate the existing channel to the southwest, where it would generally occupy the middle portion of a stream corridor widened by some 50 meters. A riffle and pool channel architecture was proposed, coupled with a high-flow secondary or distributary channel consistent with distal alluvial fan environments. The distinguishing principal behind the primary/secondary channel approach is to provide defined flow paths to modulate sedimentation cycles, and minimize the risk of channel migration through floodplain areas. The proposed primary channel size was designed to convey the 1-year flood, above which the secondary channel is engaged. Combined, the channels will convey the approximate 2-year flood. Fringing the 2 active channels is a floodplain of varied width that would be inundated by floods > 2-year event. The UPC Project alternative would provide an estimated 1.05 acres of new floodplain, numerous large wood structures to provide bank protection and aquatic habitat, a backwater pool/wetland feature to provide high-flow refugia, and numerous bio-engineered measures, including a log crib wall, to protect the outside of meander bends, confluence zones, steep channel bank slopes and points of outfall discharge. Hydraulic roughness associated with planted vegetation (at full growth) was designed to be consistent with flood conveyance goals (Spinks and others, 2010).

d. *Analysis* – The UPC Project alternative was analyzed through several different means: (a) geomorphic analysis, (b) 1-, and 2-dimensional hydraulic and sediment transport modeling with the ACOE HEC-RAS (Army Corps of Engineers' Hydrologic Engineering Center River Analysis System) and CCHE2D (National Center for Computational Hydroscience and Engineering) platforms, respectively, (c) a proprietary log crib wall force balance model, and (d) a proprietary large wood elements force balance and structural model. The hydraulic and sediment transport modeling were conducted on two different platforms to bookend the likely range of hydraulic and sediment transport conditions, and assess comparability of results utilizing two different computational routines and associated simplifying assumptions. The HEC-RAS sediment transport model was utilized to establish general spatial patterns of sediment erosion and deposition, and to fine tune design geometries for the floodplains and the high-flow secondary channels. The CCHE2D sediment transport model supplemented the HEC-RAS modeling and was utilized to provide detailed information on spatial patterns of sediment erosion and deposition.

To address the altered, urbanized flow regime of Upper Penitencia Creek, a two-staged channel was proposed: a low-flow channel to convey the more frequent, low-magnitude floods inset within a larger active, secondary channel complex to convey the bankfull flood. This channel form was chosen in order to provide a constructed environment which more closely simulates channel pattern conditions of active alluvial fan surfaces. Site-specific data from Upper Penitencia Creek (Jordan, 2009) suggests that a constructed channel at the project site may evolve to a multi-threaded channel state (Fig 5). In this context it is hypothesized that the UPC Project design concept would provide for channel form stability over the foreseeable future given an absence of major shifts in land-use or climate. The multi-channel form approach also provides defined pathways for channel course shifting at susceptible locations which is assumed to reduce the avulsion risk.

Hydraulic analysis using CCHE2D was performed for bankfull, and 5-year flood conditions (Fig. 6). Notable results related specifically to UPC Project objectives and design criteria include the following observations. Bankfull is predicted to fully engage the high-flow secondary channels, and spill onto the adjacent floodplains at multiple locations. This suggests that the UPC Project alternative will flood in a manner consistent with design criteria, and bolster enhancement of channel-floodplain connectivity. Spatial patterns of flooding for the 5-year flood are consistent with the potential benefits observed for bankfull condition. Two-dimensional modeling also suggests that the 5-year flood will provide more complex hydraulics within the low-flow channel and at junctions between the low-flow channel and the high-flow secondary channels. We hypothesize that more complex hydraulics will help to create and maintain aquatic habitat in these locations as velocity gradients, etc. provide multiple types and scales of habitats for aquatic organisms.

HEC-RAS sediment transport analysis was carried out for two different hydrologic scenarios: a 3-day duration bankfull flood and a 12-day duration stacked flood hydrograph defined by the 1-year flood, followed by the 5-year, the bankfull and ending with the 1-year flood. We assembled the stacked flood event to evaluate the magnitude to which sediment transport pattern predictions are skewed towards the 5-year flood. The CCHE2D sediment transport model considered only one flow scenario, that being a bankfull hydrograph of 24-hour duration.

The HEC-RAS sediment transport results (Fig. 6) suggest that (a) the reach from sections 900 to 675 is likely to be depositional in the post-construction period-even if the predicted volumes are thought to be conservative; (b) the remainder of the project reach will likely function with relatively minor amounts of erosion and deposition, with the potential, however for enhanced pool scour along the upstream 90 degree meander bend, which is desired in order to maintain pool habitat for migrating steelhead; (c) minor amounts of sediment deposition could occur during frequent annual flows; and (d) larger floods will accentuate predicted patterns of sediment transport, deposition and erosion perhaps necessitating some level of corridor sediment maintenance at frequencies governed by the occurrence of larger floods. The need for sediment maintenance is dependent in this case on performance of the multi-channel design in relation to upstream sediment supply.

In relation to the HEC-RAS results, CCHE2D predicts a similar pattern of deposition and erosion along the project reach for the bankfull flood, with a clear focus of predicted sediment deposition within the upstream meander. The later result is consistent with the HEC-RAS results for both hydrologic scenarios, and thus increases confidence in the prediction. Importantly however, the refined spatial view provided by CCHE2D suggests that deposition through the upstream meander is focused along the outer bank of the channel rather than across the active channel width, and characterized by the suspended load fraction, which may drive development of a natural levee (Fig. 6). Possible levee development is associated with the specified high roughness for the meander, as well as non-erodible bank conditions, given proposal of fortifying log structures and wrapped fill lifts through the meander. Predicted zones of erosion are isolated to the upstream-most project segment where flows and sediment leave the incised, urban corridor and enter the UPC Project site. This segment is characterized by a gradual transition to the created floodplain environment, over which distance the sediment transport capacity outpaces the modeled sediment supply. The channel banks through this segment were also modeled as non-erodible due to the use of fortifying log structures and wrapped fill lifts. The predicted degree of bed erosion was deemed not critical as it occurs within a pool, and HEC-RAS suggests markedly less net erosion for broader hydrologic conditions (i.e. more than one hydrograph).

e. *Refinements* – The results presented in Figs. 4 and 6 reflect a design geometry selected as final based on numerous hydraulic and sediment transport model iterations completed in order to achieve predicted post-project conditions which are consistent with the mitigation project objectives and design criteria. In particular, preferred alternative channel and floodplain geometries were adjusted to minimize the predicted volume of sediment deposition within the upstream meander, while maintaining hydraulic performance goals such as full engagement of the secondary channel segments at the morphologic bankfull, and channel-floodplain connectivity above this flood condition. Of the approximate 8-month design development timeline, roughly 2 months were spent analyzing refined design geometries until a minimum of predicted depositional volumes was achieved through the upstream meander, balanced by secondary channel engagement condition at the morphologic bankfull. Pertinently for the present discussion, implementation of the first design geometry iteration for the preferred alternative was predicted to possibly drive channel avulsion to the south of the upstream meander under the morphologic bankfull. This scenario underscores the usefulness of the *CFAAR* framework and specifically honest use of the refinements when results are not consistent with the enhancement vision.

Concluding Remarks

CFAAR offers the river restoration community an opportunity-oriented design-development framework, which regulatory agencies can adopt as a standard to guide project visioning, communication, assessment and permitting under non-ideal circumstances. *CFAAR* provides the framework needed to realize new efficiencies and transparency in the stakeholder review, and regulatory permitting process for unplanned opportunities, and usefully complements the self-healing paradigm (Kondolf, 2011) and the Adaptive Management approach to river restoration (Jacobson and Berkley, 2011; Smith, 2011). This is turn may promote wider participation in river restoration by landowners and project proponents who have thus far chosen not to participate in such endeavors. Broader involvement in river restoration may provide the critical mass necessary to overcome the continued degradation of freshwater ecosystems. Perhaps most importantly though, use of *CFAAR* will further the call to conceptualize design approaches which respect the river system, not just a particular location (Kondolf 2006, Beechie et al. 2008, Beechie et al. 2010), and suitably improve the chance of restoring physical and ecological functionality to river systems.

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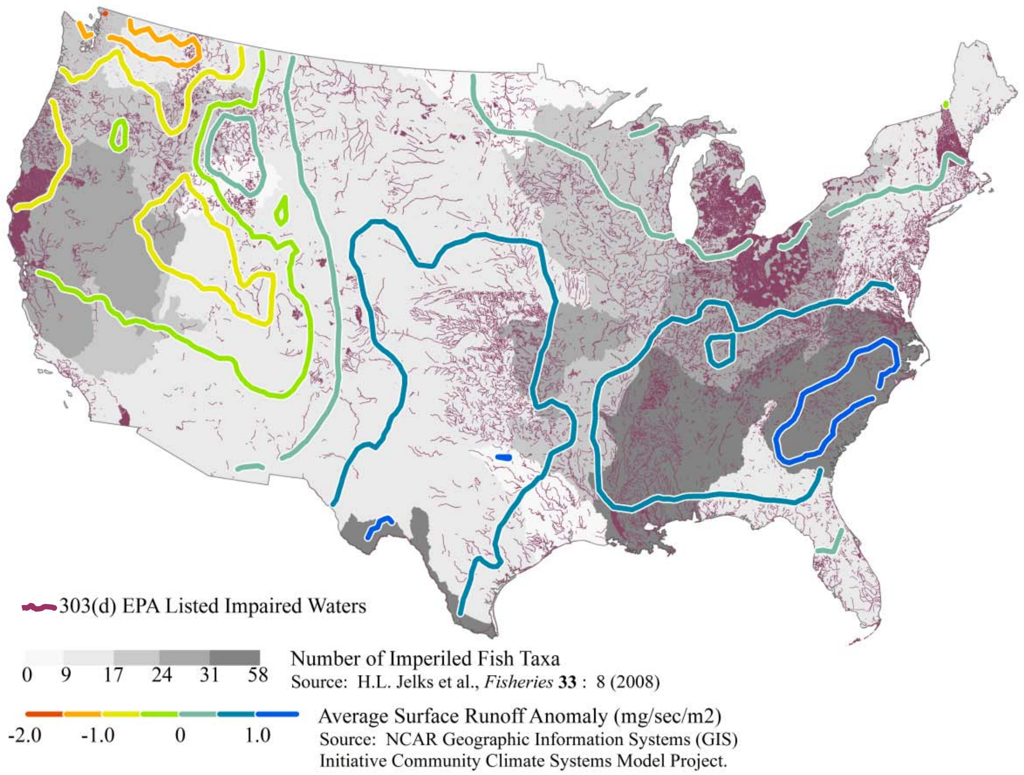
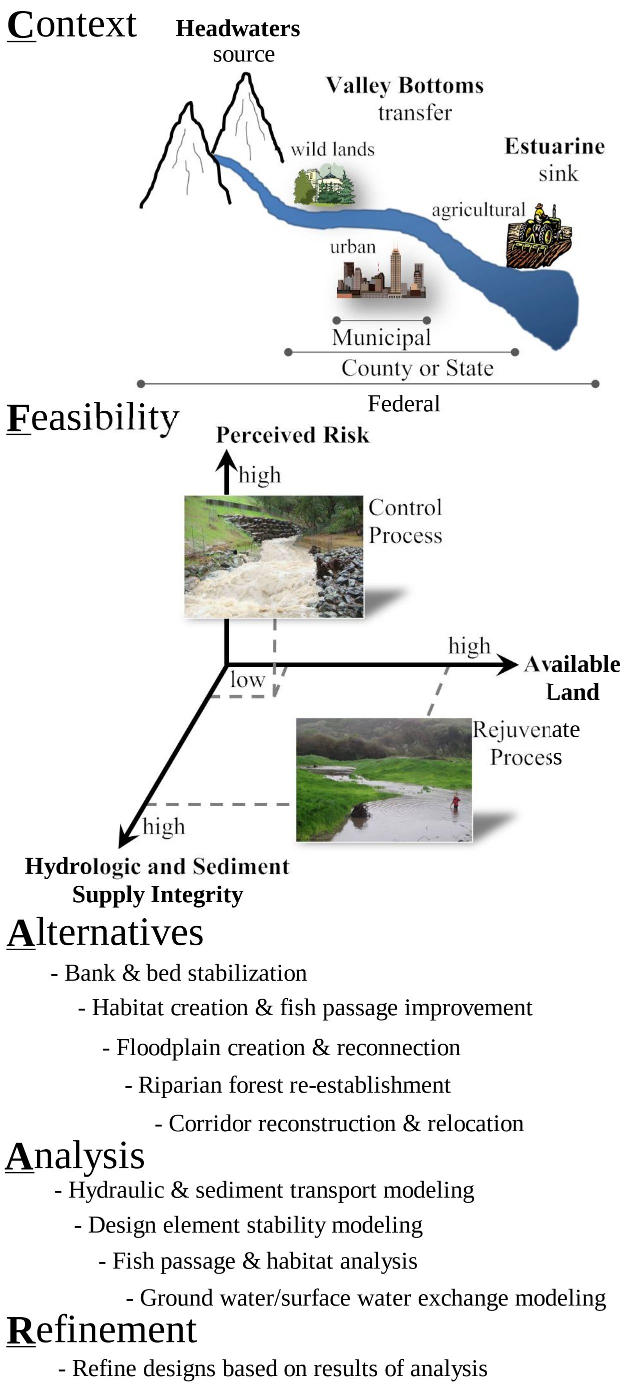


Source: H.L. Jelks et al., *Fisheries* **33** : 8 (2008)

Source: NCAR Geographic Information Systems (GIS) Initiative Community Climate Systems Model Project.

Fig. 1. State of freshwater ecosystems and an uncertain future. The combination of freshwater impairment due to a variety of pollutants and sediment and the narrowing of freshwater fish diversity highlights that freshwater ecosystems are in poor condition. Predicted changes in runoff volume due to climate change add uncertainty to how observed trends in freshwater ecosystems may unfold, and heightens the need for properly executed ecological restoration. Runoff anomaly represents the average annual difference of the 1979-1999 to 2079-2099 periods under the Intergovernmental Panel of Climate Change’s “SRES B1” emissions scenario. Annual averages were computed from monthly averages for each 20 year period. Imperiled fish taxa data source: Jelks et al. 2008. Climate change data source: NCAR Geographic Information Systems Initiative – Community Climate Systems Model Project.



Alternatives

- Bank & bed stabilization
- Habitat creation & fish passage improvement
- Floodplain creation & reconnection
- Riparian forest re-establishment
- Corridor reconstruction & relocation

Analysis

- Hydraulic & sediment transport modeling
- Design element stability modeling
- Fish passage & habitat analysis
- Ground water/surface water exchange modeling

Refinement

- Refine designs based on results of analysis

Fig. 2. The CFAAR framework

CFAAR is a sequential framework, providing a clear progression for design development from basis of understanding and intent, to final design completion. In this way, restoration design development can move forward in a coordinated and predictable fashion.

Map source: Microsoft, 2010

Map source: Grossinger et al., 2006

Fig. 3. Upper Penitencia Creek Mitigation project site at Berryessa Road, San Jose, CA, USA.
A and B. The modern day Upper Penitencia Creek at the UPC Project site consists of an artificial channel that extends to Coyote Creek. On its course to Coyote Creek UPC runs through a commercial/residential portion of North San Jose and is confined by existing infrastructure and property lines. B. The inset photo of the UPC Project reach illustrates deteriorated channel conditions. C. An historical ecology map prepared by Grossinger et al. (2006) suggests that UPC did not drain directly to Coyote Creek prior to land settlement, but instead drained to a large wetland complex.

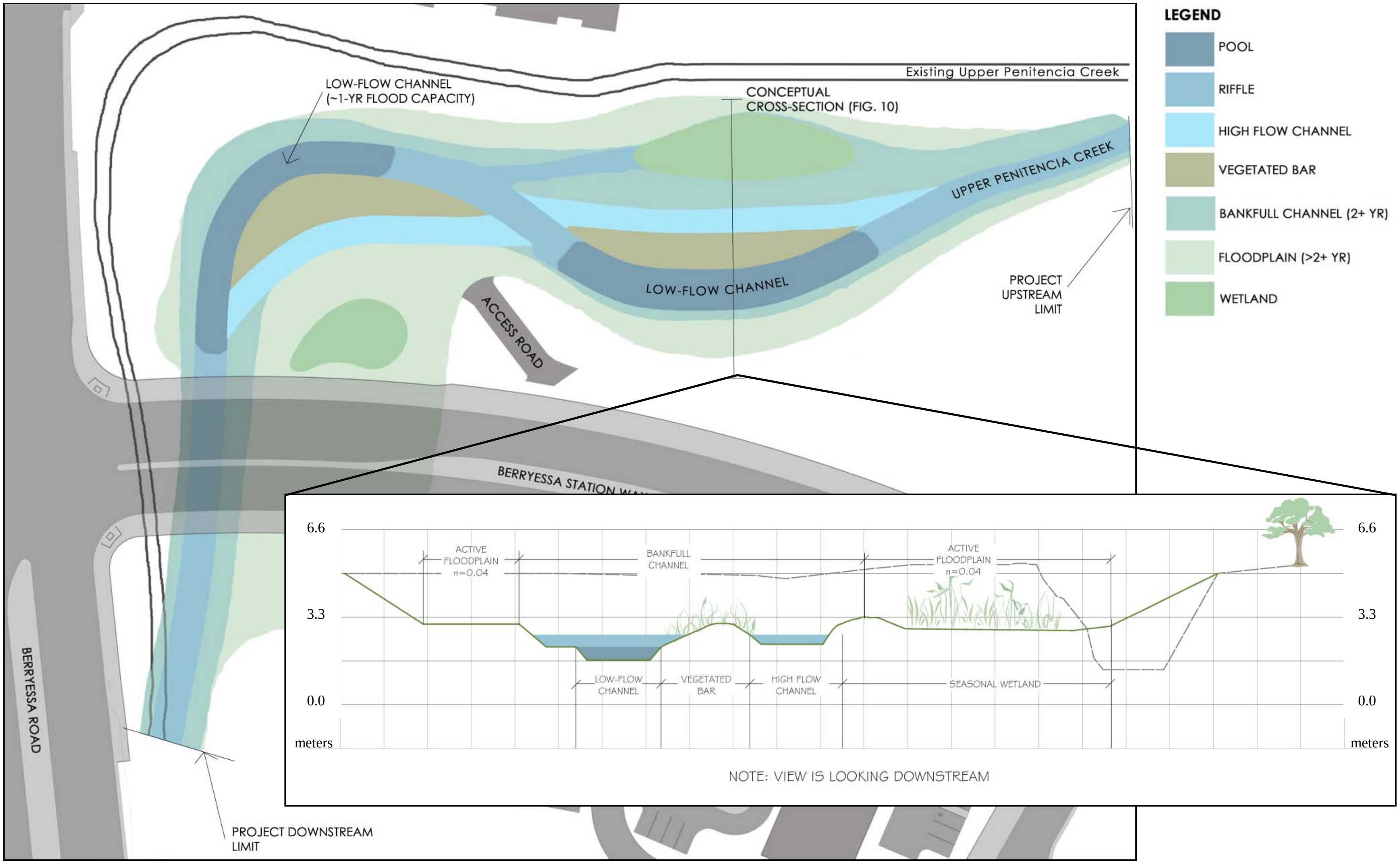


Fig. 4. Design Concepts for the Upper Penitencia Creek Mitigation project site at Berryessa Road, San Jose, CA, USA. The plan view map illustrates the preferred design concept for the UPC Project and the inset image shows the concept in cross-section at the indicated section location. The UPC Project preferred concept is characterized by a multi-channel concept reflective of the alluvial fan setting of the project location. Please note that the vertical and horizontal axes of the inset cross-section are equivalent.

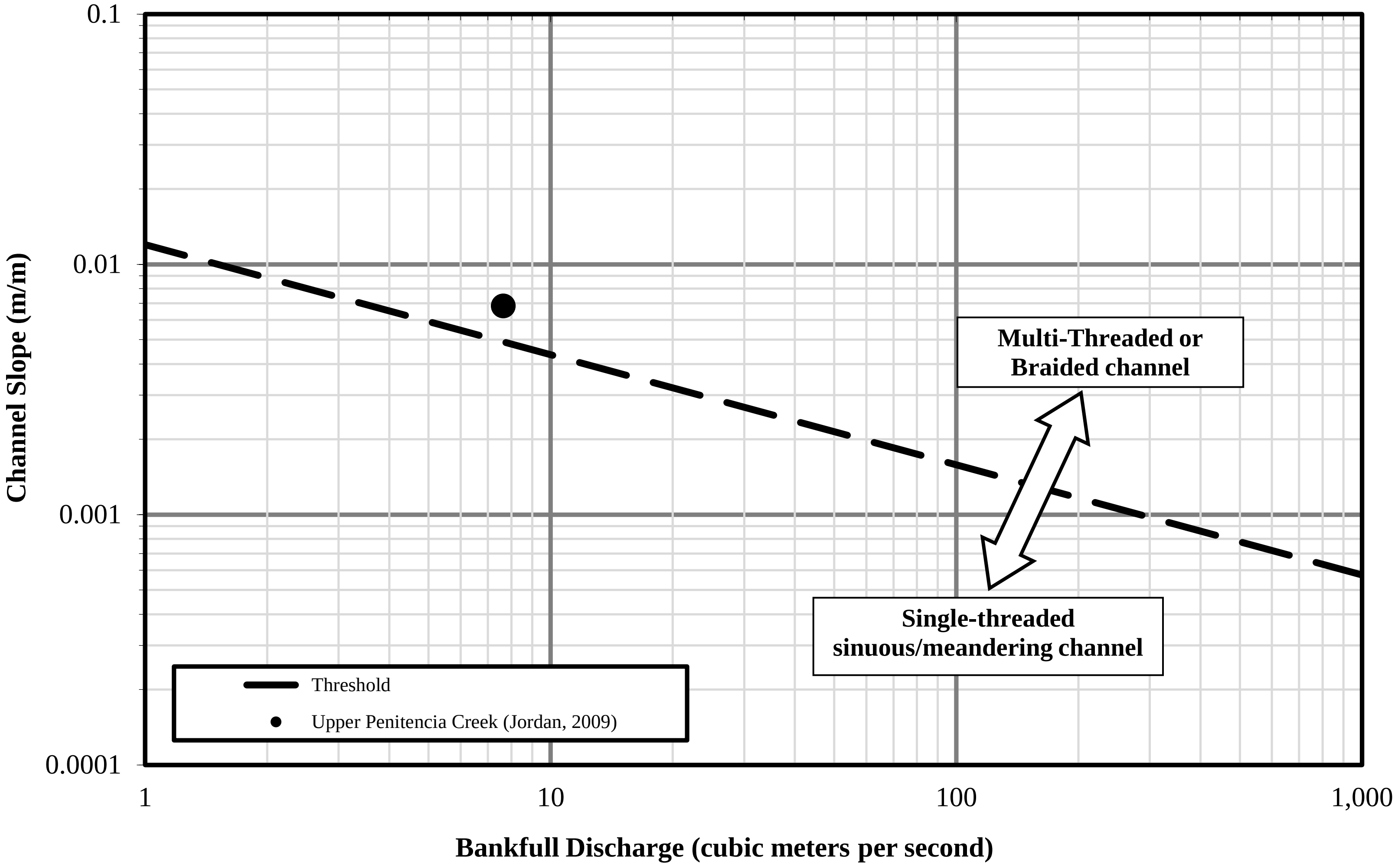


Fig. 5. Geomorphic metrics in relation to channel planform thresholds
Existing slope and bankfull discharge for the UPC Project compared to a threshold for geomorphic channel planforms in alluvial channels (Leopold and Wolman, 1957). The preferred alternative adopts a multi-channel concept, consistent with the single-thread/mult-channel threshold.

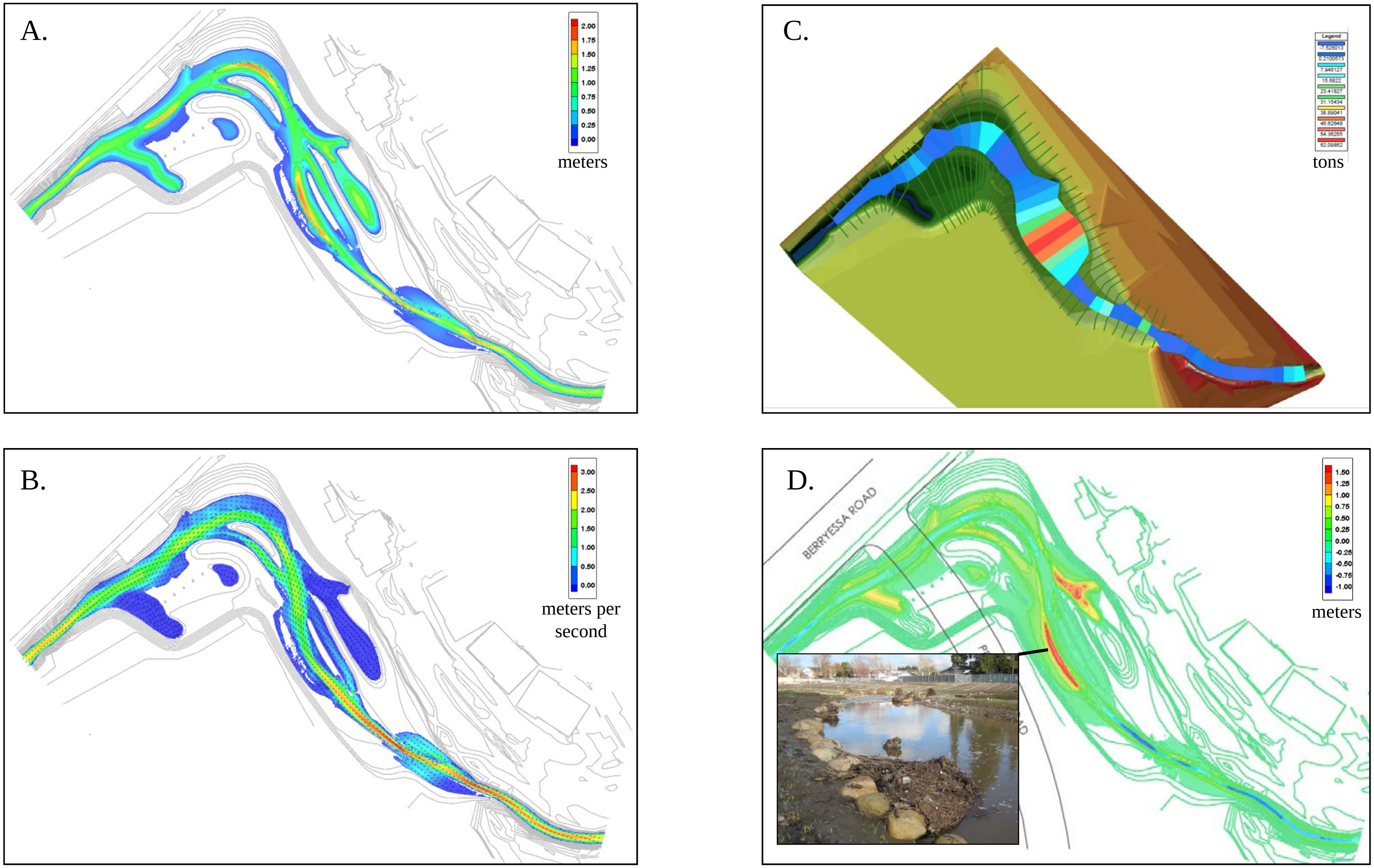


Fig. 6. Hydraulic and Sediment Transport Results, Upper Penitencia Creek at Berryessa Road, San Jose, CA.
A. and B. CCHE2D predicted water depths and flow velocities for the bankfull flood, respectively. C. HEC-RAS predicted sediment transport pattern of erosion and deposition for the bankfull flood. D. CCHE2D predicted sediment transport pattern of erosion and deposition for the bankfull flood; inset photograph shows fine sediment deposition 2 months after construction resulting from a bankfull flood. Please note that the numerical scales in A – D are not equivalent, and that cross-section lines in C vary from ~ 3 to 15 meters apart with cross-section lines ~ 8 meters apart within the zone of deposition.