PLUNGE CREEK CONSERVATION PROJECT 30% DESIGN REPORT

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Project Objectives

The San Bernardino Valley Water Conservation District (SBVWCD) is leading a project along a 1.7 mi long reach of Plunge Creek with the primary goal of increasing the area of suitable habitat for the federally listed as endangered San Bernardino kangaroo rat (SBKR) and other sensitive species; and a secondary goal of increasing groundwater recharge opportunities without increasing the risk of flooding or erosion on non-SBVWCD owned or managed land. SBKR habitat is known to be associated with intermittent fluvial disturbance, and SBVWCD seeks to design a project that uses fluvial processes to create or enhance SBKR habitat in the same way that this process occurs in nature. This approach is expected to minimize implementation costs and disturbance to existing suitable habitat, and adopts an adaptive management approach to monitor and continue habitat development and protection over the long term. The approach is to some degree experimental, and the methods developed and results achieved could be used as guidance for further habitat restoration and water conservation projects in similar alluvial fan environments. The project goals are aligned with the broader goals of the Santa Ana Watershed One Water One Watershed program, including recharge of native surface water, enhancing groundwater quality, improving endangered species habitat, working in a collaborative setting, and achieving cost effectiveness by working on SBVWCD owned lands.

The total project area is approximately 110 acres located along a section of Plunge Creek wash where there currently is a substantial amount of degraded habitat in an historical overflow area. The degradation is largely due to human landscape alteration (mining, ditch construction) and artificial confinement of the Plunge Creek channel by bridge and pipeline crossings and levees. These conditions contribute to a less dynamic channel than historically existed, with reduced lateral movement and channel braiding, and incision of portions of the primary channel. As a result of the confinement and increase in the primary channel flow conveyance capacity, larger flood events are required to overtop the main channel banks onto the floodplain and to create new secondary channels through lateral erosion and braiding. Many remnant channel features exist in the project area that are hydrologically disconnected from the main channel flow and they rarely, if ever, receive flood flows. The reduction in secondary flow paths and lateral migration results in little opportunity for fluvial processes that support existing and new SBKR habitat. The project aims to create conditions that will enable natural fluvial processes to scour new channels and reoccupy old channel remnants. The hydraulic conditions must be sufficient to flush silt away from underlying sand, and to scour away non-native grasses, as well as deposit sand substrate suitable to enable growth and establishment of pioneer riversidean alluvial fan sage scrub (RAFSS) habitat. The result will be more complex channel morphology with a network of distributary channels that create new SBKR habitat while also increasing groundwater recharge.

Demonstrating project feasibility and successful implementation is important to SBVWCD and its collaborating partners—which include the US Fish and Wildlife Service (USFWS), Bureau of Land Management (BLM), California Department of Fish and Wildlife (CDFW), and a task force of more than 12 stakeholders—to initiate early implementation work under the Upper Santa Ana River Wash Land Management Habitat Conservation Plan (Wash Plan HCP). Close and continuous coordination with SBVWCD, regulatory agencies, and stakeholders will be critical to deliver a successful project.

A two-phase project approach is being implemented, with Phase 1 focusing on identification of a preliminary design to meet the goals stated above and initiating of the permitting process, and Phase 2 devoted to the engineering design development, obtaining necessary permits, and project implementation. This report describes the work performed to date for Phase 1 and Phase2.

Site Conditions

Plunge Creek drains 20.7 sq mi at the Metropolitan Water District (MWD) pipeline crossing located at the upstream limit of the project area (ICF 2015, Attachment 1). At the downstream end of the project area at the grade control structure located at the Orange Street Bridge, the total watershed area is 28 sq mi. This includes approximately 2.4 sq mi from Elder Creek and 1.2 sq mi from the Weaver Street Drain that empty into Plunge Creek within the project area, as well as additional land south of Plunge Creek that drains to the project site (see watershed sub-basins mapped in Figure 2 of Attachment 1). Watershed elevations range from a high of 6,537 ft along the ridgeline down to 1,418 ft at the MWD pipeline crossing and 1,273 ft at the downstream project boundary at the Orange Street Bridge. Plunge Creek is typically a dry channel during the months of June through October and only receives sustained runoff during the wet winter and early spring months. The hydrographs associated with peak flows typically rise and fall quickly (4 to 10 days) in response to storm events (see Attachment 1 for additional discussion of Plunge Creek hydrology).

Plunge Creek is located on an alluvial fan at the base of the San Bernardino Mountains. Its substrate is characterized by a poorly sorted mixture of sand to boulder sized material typical of stream deposits at the transition zone from steep and laterally confined upland areas to lower gradient and less confined land in which sediment transport capacity is greatly reduced and sediment deposition and accumulation occurs. Plunge Creek is channelized for 1.5 mi between where it emerges from the San Bernardino Mountains to the upstream limit of the project area at the MWD pipeline crossing.

Plunge Creek flows for 1.7 mi within the project area between the MWD pipeline and the Orange Street Bridge. These two boundaries define the fixed entrance and exit locations of the channel and limit natural channel movement and deviation from its existing alignment within the site, thus making it less probable that Plunge Creek will reactivate the remnant channel features separated from the active channel by terraces. This is discussed in more detail in the Chapter 2 Alternative Development section.

Plunge Creek exhibits patterns characteristic of a wandering channel morphology in which sinuosity and the braiding pattern are irregular. At some locations in the project area Plunge Creek flows in a single thread channel while in others flow may occupy two or more channels splitting around bars and vegetated islands similar to a braided channel morphology (Miall 2006). The channel pattern and number of flow paths can change rapidly during floods as sediment deposits and the creek avulses to occupy an inactive channel braid or erodes a new braid. The active channel zone, in which the creek has occupied a flow path in the relatively recent past as evidenced by the unvegetated substrate, is typically 200-300 ft wide. The wetted channel width during a 1.25-yr recurrence interval event is around 35-70 ft wide. The channel slope throughout the project area is quite uniform: in the upper reaches of the project area it is 1.8% and in the downstream portion it is 1.5% (see longitudinal bed profile in Exhibit 1). Bed material is a poorly sorted mixture of coarse sands to boulder size material, with recent floodplain deposits dominated by sands, and silty sand or sandy silt on the terraces.

Representative site photographs of the existing channel and design are included in Attachment 9.

Existing Condition Hydraulic Modeling

Model Setup

A previous memo (Attachment 1) presented analysis of hydrology studies performed to determine design flows to be used in the development and analysis of the project design. The recommended design flows are listed in Table 5 of Attachment 1. Hydraulic modeling was performed for the 6 design flows of the 1.25-yr, 2-yr, 5-yr, 10-yr, 50-yr and 100-yr recurrence interval events with the objectives of evaluating how inundation areas and floodplain connectivity, flow depths, flow velocities, and shear stresses vary both spatially across the site and with changing flow levels, and to compare hydraulic conditions with mapped species habitat.

The 2D hydraulic modeling was performed using SRH-2D software created by the U.S. Bureau of Reclamation at its Technical Service Center in Denver, Colorado. The model is a 2D depth-averaged velocity, finite element model well-suited for simulating the diverse hydraulic conditions along Plunge Creek, including split channel and floodplain flow and lateral flow. The model was run using a steady state flow condition. The modeling domain extended from upstream of the MWD crossing downstream to the Orange Street Bridge. Model topography is based on the 2013 San Bernardino County LiDAR elevations. All model set-up, including mesh generation and boundary condition establishment, was performed in Aquaveo's SMS software. The resolution of the modeling mesh in the main channel was set to 2 ft between nodes to provide greater detail amongst the large substrate elements that influence hydrodynamics at relatively low flow depths and discharges. The distance between nodes was increased in floodplain and terrace areas. Roughness values for the modeling mesh were based on inspection of air photos, a field visit, and guidance for correlating channel slope with predicted roughness based on research of flow resistance in high gradient channels (Yochum and Bledsoe 2010; Montgomery and Buffington 1997). A Manning's n value of 0.04 was used in the active channel areas and adjusted upward in floodplain and terrace areas depending upon vegetation density. The parabolic turbulence coefficient was set to 0.6 in the model. Monitoring lines and points were established throughout the model to monitor water surface elevations and continuity calculations during the model run. Each modeled flow was run for several hours or days at a time step of 1 second or less until an acceptable level of convergence was obtained in continuity, water surface elevations, and velocities.

The model has three inflow locations: 1) the Plunge Creek inflow to the project site at the MWD pipeline crossing; 2) the inflow from the Weaver Street Drain that enters the site from the north between the (MWD) pipeline crossing and Elder Creek; and 3) the inflow from Elder Creek. A 1D HEC-RAS model was created to establish the downstream water surface elevation boundary conditions for the 2D model. The HEC-RAS model accounts for the backwater effect of the Orange Street Bridge and utilizes bridge dimensions field surveyed by SBVWCD.

Model Results

Planview maps showing the 2D model results of flow depth and flow velocity for the 6 modeled flow events are shown in Attachment 2. At the 1.25-yr flood event, flow depths are less than 2 ft deep and less than 1 ft deep in many areas, and flow velocities are typically 3-4 ft/s. The key finding from the hydraulic modeling of existing conditions is that the 1.25-yr, 2-yr, and 5-yr flows are all mostly contained within the active channel visible on the aerial photography, which is the largely unvegetated area with coarse substrate. Flow does not overtop the channel's banks to inundate floodplain surfaces in these more frequent flood events. It is not until the 10-yr flow that any appreciable flow is observed outside of the active channel. Most of the floodplain flow occurs in a high flow flood channel that is the northern branch of the downstream remnant channel. All of the 10-yr flow is contained in channelized Plunge Creek upstream of the MWD pipeline. More appreciable floodplain flow occurs at the 50-yr and 100-yr events. Most of the floodplain flow is observed in the downstream remnant channels south of the primary channel, as well as along flow paths that parallel the road just south of the MWD pipeline and north of the primary channel and downstream of Weaver Street Drain. Importantly, even at these high magnitude flow events, floodplain flow is minimal for the upper two-thirds of the floodplain south of the primary channel. The water surface elevation in the main channel is not high enough for water to spill into the upper remnant channels. It is not until the 100-yr flow that water begins to overtop the right bank berm upstream of the MWD pipeline and flow spills into the existing channel features disconnected from Plunge Creek except under the rarest of events. The Orange Street road fill is a major flow obstruction and floodplain flow barrier that constricts the flow under the relatively narrow bridge.

Existing Species Habitat and Occurrence Mapping

Detailed species accounts of the three key species of concern within the project area are presented in Exhibit 2 for SBKR, Exhibit 3 for Santa Ana River wooly-star, and Exhibit 4 for Slender-horned spineflower. The species accounts include information on habitat affinities, threats, life history, seasonal phenology, and special management considerations.

SBKR primary habitat is Riversidean alluvial fan sage scrub within active alluvial floodplains. Each successional stage of this habitat (pioneer, intermediate, and mature) is used, but highest densities are often found in pioneer-intermediate, which tends to occur on the floodplains above the low flow channel because it is sandy and fairly open, and has low vegetation cover. A high density of non-native grass is the best negative predictor of occupancy. The density of vegetation is particularly important as it affects the species' burrowing, locomotion, and foraging ability. Experimental thinning of vegetation in the Santa Ana River resulted in an increase in use of the more open habitat. Mature-stage alluvial fan sage scrub is less suitable as primary habitat because of the typical dense vegetation cover, but is important as refugia in high flow events. Consequently, natural fluvial processes, whereby cycles of flooding and dry periods result in dynamic fluctuations of floodplains and habitat, are crucial (Exhibit 2).

A map showing SBKR critical habitat, habitat suitability, and trapping results within the project area is presented in Attachment 3. The mapping shows that the lowest SBKR habitat suitability occurs along the active Plunge Creek channel and the highest potential occurs along the large remnant channel feature located in the western portion of the floodplain south of Plunge Creek. A key project goal is to reactivate these remnant channels so natural fluvial processes of scour and sedimentation can create the substrate and vegetation conditions required for healthy SBKR habitat. Site observations indicate that these areas have retained the sandy soils and relatively sparse vegetation characteristic of recently flood-scoured areas, but the hydraulic models indicate that this does not presently occur. Thus, these areas can be considered vestigial or remnant habitat that is not currently supported by fluvial processes. The habitat potential in these remnant channels will become reduced the longer these features remain disconnected from the main channel as vegetation densities and non-native grasses will increase beyond suitable conditions for SBKR.

Santa Ana River woolly-star is found on the alluvial terraces of open floodplains with intermittent flooding, light surface disturbance, and relatively low cover of annuals or perennials. It occurs on nutrient-poor sands and is most competitive in early stage habitats with 97% or greater sand particles, but also competitive in moderate stage habitats with 90–97% sand particles. It is a pioneer plant that is outcompeted in more stable shrubby ecosystems. This habitat type is transient in nature and is an early-mid successional stage, which requires disturbance to maintain over a large scale. These scour events (light to heavy surface disturbance) are needed to keep >90% of soil substrate sand and to reduce cover of annuals and/or perennials. A map showing Woolly Star occurrences observed in 2008 within the project area is presented in Attachment 3. Wooly Star tends to be more abundant in the western portion of the study area and has been observed along both the active channel and floodplain and terrace features.

Slender-horned spineflower is typically found on alluvial terraces away from active channels in areas receiving little surface disturbance from flooding, but subject to sheet or overland flows. Populations occur in shallow depressions on relatively flat (0-2% slopes) surfaces. The association with older (100 year+) more stable alluvial terraces indicates the need for infrequent flood events to maintain suitable habitat conditions over the long-term. A few occurrences can be found on low alluvial benches or braids within active channels. Soil texture at occupied sites are silt, loamy sand, and sand, as well as slightly acid (pH 6.4) with low levels of nitrogen, phosphorus, and organic matter and low electrical conductivity and low cation exchange. These habitat features are most closely associated with the intermediate and intermediate-mature phases of Riversidean alluvial fan sage scrub. A map showing Slender-horned Spineflower occurrences observed within the project area pre-2000 and between 2000-2012, and occupied or potentially suitable habitat, is presented in Attachment 3. Most of the project area outside of the disturbed mining areas is mapped as potentially suitable habitat. Only three areas are mapped as occupied habitat in the project area: two are located upstream of the MWD pipeline and the third is on the terrace at the downstream boundary near Orange Street.

The alternatives development and 30% design described below seek to minimize construction activity in existing habitat and include the development of design elements intended to foster the physical processes necessary to complement or create new habitat area.

Chapter 2
Project Alternatives

Alternatives Development

ICF and its team member Northwest Hydraulic Consultants (NHC) were hired by SBVWCD to conduct Phases 1 and 2 of the study because of the team's experience constructing projects that are based on fluvial processes and are designed to reactivate former channel and floodplain surfaces that have become hydrologically disconnected. Initial work included development of conceptual design ideas that could be further developed and evaluated. Upon examination of the site's LiDAR topography and a site visit, excavation of pilot channels was selected as a central element of the design to enable flood flows in the existing active channel to be conveyed into the existing remnant channels separated from the main channel by high elevation terrace topography. The pilot channels are envisioned not to be heavily engineered features, and their dimensions would initially be much smaller than the existing active channel. They would only need to be dug deep enough to allow Plunge Creek's flood flow to naturally enlarge them through fluvial scour and provide a connection with the channel remnants.

Based on discussions with SBVWCD and feedback from the USFWS and CDFW, the ICF team used the conceptual designs to develop three alternative designs to consider for advancement to the 30% design level. The alternative maps are presented in Attachment 4. Each map shows key design elements and the modeled 1.25-yr recurrence interval existing condition inundation area to show existing hydraulic conditions and opportunities for enhancement.

ICF used the LiDAR to create a relative elevation map (also known as height above water surface, or HAWS) in which the low-flow channel invert sets the baseline elevation and all other elevations are shown as the height above the adjacent low-flow channel (Attachment 5). The changes in color show one-foot increment elevation differences. Displaying elevations in this manner clearly highlights geomorphic landforms, including the locations and dimensions of the active channel, remnant channels, floodplains, and terrace features. Several formerly active channel segments that formed during previous flood events, but have subsequently been disconnected from today's active channel, are apparent in Attachment 5. The remnant channel features are most pronounced in the downstream portion of the site south of the existing Plunge Creek channel, but channel remnants also exist in the upstream portion. Some of these channel remnants were likely formed by Plunge Creek and some, such as the upstream remnants without an obvious connection to Plunge Creek, were likely formed by the Santa Ana River during previous flood events when the river shifted northward through the wash. Hydrologic conditions on the Santa Ana River are modified by upstream regulation and potential for inundation of these remnants has been reduced in frequency. The elevations of the remnant channels are similar to the elevations of the active low-flow channel, but they are separated from the low-flow channel by a terrace up to 8 ft high. The mapping illustrates opportunities where pilot channels could be excavated through the terrace barrier to connect the active Plunge Creek channel with the channel remnants, thus diverting a percentage of the Plunge Creek flood flows to reactivate a large area south of the existing channel with the potential to create substantial new SBKR habitat. The HAWS mapping was a key resource for the alternatives development as each alternative includes different elements to divert water out of the existing Plunge Creek active channel to reactivate the remnant channel features readily observed on the HAWS map.

Alternative 1

The key elements of Alternative 1 include:

- Excavate a notch in the right bank (viewed looking downstream) berm on Plunge Creek upstream of the MWD pipeline crossing to allow high flow to spill into remnant channel features. Would have required implementation of stability measures where the remnant channel flow crosses the MWD pipeline downstream to protect against potential scour.
- Build a rock sill to raise the bed elevation and increase roughness in order to backwater the main channel flow downstream of the crossing and force flow into an existing channel path that is rarely active.
- Locally excavate new flow paths that tie into existing channel remnants to create a branching channel pattern with edge habitat.
- Construct rock sills in the active channel upstream of Elder Creek to raise bed elevations and increase roughness to force flow into a new pilot channel excavated to direct flood water onto the floodplain and reactivate existing channel remnants.

Alternative 2

The key elements of Alternative 2 include:

- Construct a buried rock grade control just downstream of the MWD pipeline to protect the pipeline from potential headcutting.
- Add large boulder flow deflectors in the main channel just downstream of the MWD pipeline to force flow into a pilot channel constructed in the floodplain.
- Build a hardened rock sill in the pilot channel entrance to create scour.
- Construct sections of pilot channel that would connect existing channel remnants on the floodplain and result in a long and continuous high flow flood channel that rejoins the main Plunge Creek channel upstream of Orange Street.
- Construct a berm along the northern boundary of the quarry made of material from the pilot channel excavation to prevent the pilot channel from entering the mine.
- Construct boulder deflectors in the western portion of the floodplain at the split of 2 remnant channels to force flow into the southern remnant channel branch.

Alternative 3

The key elements of Alternative 3 include:

- Construct a buried rock grade control just downstream of the MWD pipeline to protect the pipeline from potential headcutting.
- Add large boulder flow deflectors in the main channel just downstream of the MWD pipeline to force flow into a pilot channel constructed in the floodplain.

- Build a hardened rock sill in the pilot channel entrance to create scour.
- Construct a section of pilot channel that would direct Plunge Creek flow southwest across the existing terrace until it connects with connect existing channel remnants on the floodplain. The flood channel flow would re-join active Plunge Creek just downstream of the Weaver Street Drain.
- Construct a berm along the northern boundary of the quarry made of material from the pilot channel excavation to prevent the pilot channel from entering the mine.
- Construct boulder deflectors in the active Plunge Creek channel several hundred feet downstream of the Weaver Street Drain to divert high flow into another section of pilot channel.
- Construct a pilot channel that diverts flow southwest across the existing terrace until it reaches existing channel remnants. Flow would be allowed to flow down either the northern or southern branch of the remnant channel feature.

Preferred Alternative

A meeting was held with SBVWCD, USFWS, CDFW, and San Bernardino County Flood Control to review the alternatives. Some of the feedback on the alternatives included:

- USFWS preference for use of pilot channels to divert water onto the floodplain instead of sole reliance on hardened grade control and rock sill features constructed in the low-flow channel.
- Since SBVWCD does not have an agreement with MWD it cannot accept liability for the pipeline. Thus for the first phase of the project it was decided that no work should be proposed immediately adjacent to or upstream of the MWD pipeline.
- A reemphasis was placed on the level of existing constraint placed on Plunge Creek within the project area by the MWD pipeline and Orange Street Bridge. These constraints define the entrance and exit locations of the channel and limit natural channel movement and deviation from its existing alignment within the site, thus making it less probable that Plunge Creek will reactivate the remnant channel features on its own without direct action to divert water onto these surfaces. Restoring the site to a form of pre-disturbance condition is severely constrained by these artificial constraints.
- A key focus of the preferred alternative should be to create new habitat for SBKR and the other species of concern. In addition, the alternative must demonstrate the ability to significantly increase wetted channel area and groundwater recharge potential.
- The project should include elements that are adjustable and can be adaptively managed to change flow paths in future project phases to reactivate new channel and floodplain surfaces after the initial project phase.

Based on the alternatives review and comments Alternative 1 was not selected because it places emphasis on construction of hardened rock sills and grade control structures, includes work upstream of the MWD pipeline, and does not maximize wetted channel area compared to Alternatives 2 and 3. Alternative 2 is similar to Alternative 3, but it was not selected because it uses pilot channel construction to make one long and continuous flood channel. In order for Alternative 2 to succeed, the diversion point into the pilot channel downstream of the MWD pilot channel has to perform as intended since there are no other opportunities downstream designed for water to be diverted from the existing channel into remnant channels and floodplain surfaces. If the single point of diversion fails, then no water would leave the existing channel. Alternative 2 also constructs a pilot channel segment near the northwest boundary of the existing quarry. This increases the risk of the channel entering the quarry above the other alternatives.

It was decided that Alternative 3 best meets the project performance criteria of utilizing pilot channels to activate existing low elevations on the floodplain and terrace, does not include work upstream of the MWD pipeline, and maximizes remnant channel and floodplain activation areas necessary for creating the fluvial processes necessary for creating SBKR habitat and also creating new groundwater recharge. The preferred Alternative 3 formed the basis of the 30% design work described below.

Chapter 3
30% Design

Design Elements

The 30% design drawings are presented in Attachment 6. Key tasks for advancing the preferred Alternative 3 into a 30% level design included layout of the pilot channels on the detailed topography and adjustment to minimize excavation quantities, development of construction access and construction method concepts, and development of preliminary designs for flow split features at the heads of the pilot channels.

Pilot Channels

Consistent with the Alternative 3 concept, two pilot channel alignments were laid out in the project area. The Upper Pilot Channel takes off from the main channel downstream of the MWD pipeline near the upstream end of the project area, and cuts through terraces south of the main channel to intersect remnant channels that were likely created by Santa Ana River flows. The Upper Pilot Channel is approximately 3,600 ft long and rejoins the main channel downstream of the confluence with the Weaver Street Drain. The Lower Pilot Channel takes off from the main channel approximately 500 ft downstream of the point where the Upper Pilot Channel rejoins the main channel, and is approximately 4,200 ft long, with an additional 600 ft long south branch. The alignments are shown on Sheets C1 and C2 in Attachment 6.

The typical cross-section geometry developed for the pilot channels is shown in Sheet D2 in Attachment 6. The proposed pilot channel dimensions consider the need to convey flows at sufficient velocity to convey diverted sediment and to create scour and erosion along the pilot channel alignments. The fluvial disturbance associated with the pilot channels is intended to eventually result in complex natural topographic features typical of secondary channels, including a main flow path and floodplain surfaces suitable for RAFSS, Woolly Star, and SBKR habitat development. A relatively narrow geometry provides the flow energy necessary for sediment mobilization and transport, but the cross section must be sufficiently large to carry substantial flows and reduce the risk of plugging. The gradient of the pilot channels was developed using the valley slope and the existing channel slopes (1.5 to 1.8%) as guides. An average slope similar to the main channel slope is desirable for sediment continuity and to reduce potential for headcutting. Pilot channel slopes were varied to some degree from the average slope in order to minimize excavation quantities, but were generally held in the range of 1.2 to 1.8%.

Initial channel sizes and slopes were selected and simulated in the hydraulic model. Inlet geometry, size, and slope were then modified to achieve hydraulic conditions (see 30% Design Hydraulic Modeling below) considered adequate to create relatively frequent fluvial disturbance with sufficient velocities and shear stresses to promote development of secondary channel features.

The resulting channel sizes are sufficiently large to facilitate construction with typical earthmoving equipment. An excavator would be used to cut a channel with approximately 10 ft bottom width. The banks would be excavated at a nominal side slope of 1.5H:1V until they catch existing ground. The bank angle is approximate, and was used in quantity estimates to reflect the high end of the probable angle of repose for the material. Slightly steeper bank slopes might be allowed during construction as long as they do not result in safety hazards or potential for caving (and filling the pilot channel) during or shortly after construction. In particular, side slopes steeper than 1.5:1, but no steeper than 1:1, may be used where the cut depth is less than 3 ft and the cut slope is stable.

The height of the bank would vary depending on existing ground elevations, but are typically 2-3 ft tall through most of the pilot channel sections. Bank heights up to 7 ft would be constructed in the upper portion of the Upstream Pilot Channel since relatively deep excavation is needed to cut through the high terrace elevations to connect to the lower elevation remnant channel features. Variability in the depth of cut is illustrated on Sheets C3 through C6 in Attachment 6.

Channel Splits

Based on site observations and experience on other similar streams, the design team identified one process for braiding and erosion in the Plunge Creek channel that naturally occurs during flood events at points where large bed material or debris is deposited or gets stuck in the main channel. This flow resistance increases lateral pressure on the banks and results in flow splits into irregular braided channel patterns. Where flow resistance is low, the channel tends toward more of a single thread morphology and, depending on flow and sediment supply, may incise the main channel to contain relatively large floods. The alternatives showed placement of large boulders in the main channel to create flow resistance and produce a backwater effect that would divert flow into the pilot channels. After considering the process described above, the 30% design attempts to reproduce more closely the morphology of a natural flow split, with high roughness associated with large rock and wood in the main channel. The 30% design (see Sheet D1 in Attachment 6) utilizes splitter mounds constructed at the edge of the existing main channel to form the head of the pilot channels. The splitter mounds reflect the topography observed on site at the head of existing channel branches, with a low (3 to 5 ft high) elongate terrace separating the main channel from the secondary branch. In order to maintain the function of the splitter mound over time, large native rock will be used to create roughness on the main channel and to resist channel bed degradation in the main channel that would abandon or cause flow reduction in the pilot channel (native rock sill). In addition to the sill, rock will be used to stabilize the toe of the mound and to encourage scour at the head of the pilot channel to transport sediment and maintain the pilot channel opening, The native rock sill will be mostly buried and will be composed of coarse streambed fill material, rounded or sub-rounded in shape, 4 to 12 inches in size and intermixed with keystone boulders between 36 inches and 48 inches in size (1 to 3 tons) (see Type 1 detail on Sheet D1).

As shown on Sheet D1, a second variation on the splitter mound (Type 2) is similar to the Type 1 design except it incorporates wood into the rock. Logs with attached root wads would be buried in the keystone boulders and streambed fill material for ballast and lateral stability under high flows. The root wads would be oriented into the active flow to provide an opportunity for racking of additional woody debris transported down the Plunge Creek channel during high flows, thereby providing opportunity for creation of additional roughness and increased backwatering and diversion of flow into the pilot channel. The wood would also provide a natural aesthetic to balance the necessary use of large rock to provide stability at the feature.

The pilot channel entrance is 15 ft wide at the main channel and tapers down to 10 ft as flow is routed into the pilot channel. The invert elevation of the pilot channel entrance is set at approximately the same invert elevation as the rock sill in the low-flow channel to encourage flow to enter the pilot channel. The entrance angle of the pilot channel is designed to facilitate a smooth hydraulic transition between the active channel and pilot channel so that rapid changes in shear stress do not occur that could result in eddying, sedimentation or scour problems. The splitter mound designs can be field adapted for local topography for use in both pilot channels. The Upper Pilot Channel takes off from a point where the flow is channelized, and only one mound is shown on the plans to form the head of the pilot channel. In contrast, the Lower Pilot Channel takes off from a point on the main channel with a more braided planform, and multiple splits are required to increase the flow towards the southern braches, and then into the pilot channel.

Berm Protection at Quarry

The Upper Pilot Channel alignment is near the northerly edge of an existing quarry. An existing berm is present along the edge of the quarry for a portion of the area in the vicinity of the channel. Although modeling results do not show a tendency for flood flows to spill into the quarry, flow occurs along the edge of the berm in the highest floods. The excess material excavated from the pilot channels can be used to reinforce and extend the existing berm to provide increased protection from flows spilling into the quarry. The main objective for this protection is to prevent the potential for headcutting from the quarry back towards the pilot channel, and subsequent channel adjustment, if there was a spill. The berm design Sheet D2 shows a maximum 4 ft high by variable width berm, and the plan view on Sheet C1 shows the berm extending along the quarry edge in the vicinity of the pilot channel. The berm extends to the west to a point where an existing swale would guide flows back toward the main channel. The berm will be placed on scarified subgrade, and compacted to remove voids and prevent seepage. The top will be sloped slightly to drain back towards the Plunge Creek floodplain.

30% Design Hydraulic Modeling

The existing condition 2D hydraulic model previously described was re-run with the 30% design elevation surfaces generated in AutoCAD. The model was run for 4 design flows of the 1.25-yr, 2-yr, 5-yr, and 10-yr recurrence interval events. Several design iterations were made in which the modeling output from each run was used as a design tool to evaluate the design and specify necessary design changes to improve performance. Iterations included adjustments to the inlet angles, elevations and dimensions of points of diversion into the pilot channels to obtain the desired flow distribution splits between flow entering the pilot channel and flow continuing down the existing channel. Adjustments were also made to the configuration of the points of diversion to ensure hydraulic similarity in velocities and shear stresses are maintained between the transitions from the main channel into the pilot channel so that sediment transport continuity is attained and problems of excessive scour or deposition do not occur. Modeling output was also used to make adjustments to the invert elevations (grade lines) of the pilot channels so that a suitable balance could be obtained between matching grade lines with tie-ins to the existing channel and remnant channels, providing a sufficient pilot channel slope to encourage erosion and sediment transport to occur, and making the pilot channels shallow enough so that when conveying water they have the ability to overbank and inundate existing low topography on the floodplain rather than excavating them too deep and creating a scenario where the pilot channel flow is channelized with limited opportunities to spread out.

It is important to note that the shear stress results are based on a model that assumes the size of the pilot channels and remnant channels do not change in response to flood events. Because the model does not account for a changing morphology, it represents an as-constructed condition and over time erosion and deposition will occur and the actual hydraulics will differ from those modeled.

Planview maps showing the 2D model results for velocity, depth, and shear stress for the 4 modeled flow events of the 30% design are shown in Attachment 7. Each map has a table listing the discharge at 10 different cross-section locations throughout the project area. These cross-sections show the flow inputs into the reach (i.e., Plunge Creek upstream of the MWD pipeline, Weaver Street Drain, and Elder Creek) and the distribution of flow between the main channel and the pilot channels. The percentage of the main channel flow diverted into the pilot channels progressively decreases as the flow magnitude increases. At the 1.25-yr event, 43% (58 cfs) at the upstream point of diversion and 74% (63 cfs) at the downstream point of diversion is diverted into the pilot channels. At the 10-yr event, 12% (280 cfs) at the upstream point of diversion and 16% (371 cfs) at the downstream point of diversion is diverted into the pilot channels.

The key finding from the hydraulic modeling of the 30% design conditions is that the design meets the key objective of increasing inundation area by routing water through pilot channels into existing low-elevation topography located in remnant channels. Under the existing condition the 1.25-yr, 2-yr, and 5-yr flows are all mostly contained within the active channel and it is not until the 10-yr flow that any appreciable flow is observed outside of the active channel, and even then this is limited to floodplain flow in the north branch of the downstream remnant channel. The 30% design gets flood flows out onto the floodplain and reactivates remnant channels both upstream and downstream at the lowest flow modeled, the 1.25-yr recurrence interval event. By the 10-yr event under the 30% design, large portions of the floodplain are inundated. By excavating new channel segments through topographically high areas separating the existing main channel and low-lying elevations in channel remnants, new hydrologic connections are made that significantly increase total channel length, wetted area, and opportunities for the fluvial processes necessary to create and maintain SBKR habitat. Additional discussion of inundation area comparison of existing conditions and the 30% design is presented in the Recharge Analysis section below.

The shear stress output from the 2D model is classified in the map legends in Attachment 7 to show the particle size expected to be mobilized for a given flow event based on sediment transport incipient motion calculations. The 2D model results indicate that the flow diverted into the pilot channels will have enough energy to cause the intended erosion necessary for the channels to enlarge due to fluvial processes rather than relying solely on use of heavy earth moving equipment. At the 1.25-yr event, the upstream pilot channel is predicted to be capable of mobilizing sediment sizes up to a maximum of very coarse gravel. The results suggest that shear stress values are maintained high enough at the point of diversion into the pilot channel to keep gravel and sand sized material in transport through the entrance rather than it depositing and potentially plugging the entrance. Shear stress values decrease at the downstream end of the remnant channels associated with the upstream pilot channel since these features are wider than the pilot channels, and thus water spreads out and is shallower in depth in these areas of existing low-lying topography. Deposition of sediment will occur in these areas resulting in a dynamic situation where, depending on the location and size of the accumulation, the flow may shift into a different remnant channel branch in response to the interaction of flow, sediment transport, and existing topography. These fluvial processes of alternating areas of sediment scour and deposition will create the conditions necessary for SBKR habitat. Similar patterns of shear stress magnitudes and particle size transport are observed in the downstream pilot channel. At the 1.25-yr event, the downstream pilot channel is also predicted to be capable of mobilizing sediment sizes up to a maximum of very coarse gravel and high enough shear stress levels are maintained in relation to the existing channel to keep sediment in motion through the transition and prevent plugging of the pilot channel entrance. Shear stress levels decrease as flow enters the existing and wider remnant channels. Similar fluvial processes that will benefit SBKR habitat described for the upstream pilot channel are expected to occur. As flow levels increase so do the shear stress levels in the pilot and remnant channels. At the 5-yr and 10-yr events it is predicted that sediment sizes up to a maximum of small size cobble could be mobilized in the pilot channels. The results show that the shear stresses in the pilot channels are similar to the main channel, which indicates that sediment transport should be maintained through the pilot channel entrances.

Recharge Analysis

One of the key performance objectives of the project is to demonstrate that the design would increase wetted inundation area and groundwater recharge compared to the existing condition. A combination of field measurement and modeling analysis was performed to determine infiltration rates and inundation areas needed to estimate groundwater recharge for the existing and design conditions.

Infiltration Rates

In June 2015, NHC measured infiltration rates at four locations along Plunge Creek in the project area using a constant head permeameter (CHP). A memo describing the methods and results of the field testing is included as Attachment 8. NHC sampled at different elevation surfaces representative of channel, floodplain, and terrace features. The measured infiltration rate (18.0 ft/day) at location NHC 3b in the channel with coarse substrate and sparse vegetative cover was the greatest rate of all sampled locations. The measured infiltration rate was lower (11.1 ft/day) at location NHC 3a on a moderately high and relatively recently disturbed floodplain surface with fine to coarse sand with some gravel and sparse vegetation. The infiltration rate was lower yet (1.8 ft/day) at location NHC 3c on a higher elevation terrace surface with mostly fine sand substrate and shrub and grass cover vegetation. A fourth sample also on a moderately high floodplain location NHC 2 had a measured infiltration rate of 15.1 ft/day. The relatively large differences in infiltration rates between the terrace location compared to the lower elevation surfaces demonstrates how percolation rates are variable throughout the site and sensitive to local substrate and vegetation conditions.

Inundation Areas

Exhibit 5 is a table showing how inundation area changes between the existing condition and 30% design for the 1.25-yr through 10-yr recurrence interval events. The results are also plotted with best-fit curves in Exhibit 6. At the 1.25-yr event the 30% design results in an 80% increase in inundation area because construction of the pilot channels enables inundation of large floodplain areas that are dry during the existing condition. The gains in inundation area progressively decrease as flow magnitude increases because the existing condition begins to inundate some of the same floodplain areas inundated by the 30% design. At the 10-yr event the 30% design results in a 28% increase in inundation area compared to the existing condition.

The results of the field infiltration tests were used to assign an infiltration value to all locations throughout the study site. Air photography and LiDAR ground elevations were analyzed and polygons were digitized around areas with similar substrate/vegetation cover/elevation characteristics and an infiltration value was assigned to each polygon. These zones included active or channel remnant areas at low-lying elevations (similar to NHC 3b), sparsely vegetated flood channels and floodplain surfaces at moderate elevations (similar to NHC 3a), and more densely vegetated and higher elevation floodplain and terrace surfaces (similar to NHC 2).

Recharge Rate

The wetted inundation acreages predicted by the 2D hydraulic modeling for both the existing condition and 30% design were overlaid on the infiltration rate polygons to determine the average recharge rate in ac-ft/day for the project area for the 1.25-yr through 10-yr recurrence interval events (see Exhibit 5). The percent increases in recharge rate for the 30% design compared to the existing condition are similar to the trends in inundation area. At the 1.25-yr event the 30% design results in a 67% increase in recharge rate that progressively decreases to a 24% increase at the 10-yr event.

Recharge Calculation for a Storm Event

The analysis described above to determine recharge rates was used to estimate the recharge volume (ac-ft) at the project site for the existing condition and 30% design based on the hydrograph of an actual storm event. As presented in a previous memo (Attachment 1), precipitation gage records and the hydrographs from actual storm events at USGS gage 1055500 with peak flows that approximately equaled the flood recurrence interval values were analyzed to estimate the amount of precipitation required to produce different frequency Plunge Creek flood events. The analysis included a hydrograph (Exhibit 7) from March 1978 in which the peak instantaneous flow of 1,830 cfs approximately equals the 10-yr event of 2,010 cfs based on a log-Pearson Type III distribution. The precipitation event measured at the San Bernardino County Hospital Gage that corresponds to the rise and fall of the streamflow hydrograph lasted for 8 days with a total accumulation of 7.74 inches with a maximum daily rate of 2.23 inches. This storm was selected since its peak flow is quite similar to the largest flow modeled for the 30% design (i.e., 10-yr event). To determine the recharge associated with this particular storm hydrograph, best fit curves were fit to the recharge rates determined for the mean daily discharges that correspond to the 1.25-yr, 2-yr, 5-yr, and 10-yr recurrence interval flows so that recharge rates could be estimated for all discharges on the hydrograph with magnitudes between the recurrence interval data points.

The recharge calculations were started on February 27, 1978 and ended on March 18, 1978 (Exhibit 7). Under the existing condition, the estimated total recharge associated with the storm event is 8,637 ac-ft, while the 30% design results in 11,724 ac-ft, which is a 36% increase.

It should be noted that the recharge rates and recharge volumes reported herein are strictly estimates made to demonstrate the viability of the proposed design at increasing groundwater recharge in the project area compared to the existing condition. The values are based on interpolating infiltration measurements made at 4 sites across the entire project area. As discussed, the rate at which water infiltrates into the ground varies widely throughout the site. Furthermore, the inundation area values for each modeled flow are based on steady state conditions and do not account for any flow ponding and the rate at which flood waters would drain back into the channel as flows recede, or how infiltration rates would vary depending upon antecedent soil moisture and groundwater levels and changing conditions over the course of the hydrograph. Despite these limitations, it is clear that the 30% design will result in enhanced groundwater recharge opportunities since the inundated acreages and potential for recharge to occur for a given recurrence interval flow are appreciably higher under the proposed conditions compared to the existing condition.

30% Design Changes

On March 17, 2016, staff from SBVWCD, ICF, and NHC conducted a site visit of the project area to field verify elements in the 30% design and 2D model results. The locations of the proposed points of diversion, pilot channels, and berm around the quarry, as well as the existing remnant channels, were assessed for construction feasibility and potential design modifications to improve performance. The following changes to the 30% design are recommended for the final design. Additional changes may also arise upon review of the 30% design with the project partners and agencies.

Upstream Pilot Channel

Rather than excavate a pilot channel for the entire 3,700 ft as shown on the 30% drawings, the pilot channel excavation should extend from the point of diversion to station (STA) 21+00 (see Sheets C1, C3, and C4 in Attachment 6). At STA 21+00 the pilot channel intersects an existing low-lying remnant channel, and once water is delivered to this point it can flow freely and spread out in the existing channel as it makes its way back to the main channel. As the 2D modeling shows, there are two primary flow paths in the lower portion of the upstream pilot channel. The southern path traverses closer to the quarry and the other path (which is the path the 30% design pilot channel followed) has a more northerly alignment. Once the pilot channel delivers water to STA 21+00 it will have the opportunity to take either flow path. It is recommended that a short (approximately 200 ft long) section of pilot channel be excavated near STA 17+00 to remove a section of high ground and enable a continuous flow path in the northern channel. It is also recommended that the invert elevation of the pilot channel be raised between STA 21+00 and 27+50 to bring the bottom of the pilot channel closer to existing ground and allow more water to spread out into existing low-lying elevations in encounters in this section.

Downstream Pilot Channel

The splitter mound shown at STA 28+50 in Sheet C2 in Attachment 6 should be moved upstream to STA 26+00 to make the downstream point of diversion from the main channel further upstream than it is currently designed. This will enable the pilot channel to take a more direct route toward the existing remnant channels and avoid the sharp bend in the 30% design pilot channel at the point of diversion. The pilot channel from STA 17+00 to STA 22+00 will be removed in the final design since existing low-lying topography already exists in this location and a pilot channel is not needed. Similarly, nearly all (1,800 ft from STA 1+00 to 19+00) of the pilot channel excavation shown in the northern remnant channel branch will be removed in the final design. Field inspection showed that a well-defined remnant channel exists in the location and that a pilot channel is not needed to convey water through it and back to the main channel.

Removal and shallowing sections of pilot channel in both the upstream and downstream locations will enable the design to take better advantage of the existing low elevation topography and result in increased spreading of water with increased inundation and recharge potential. These changes will also substantially reduce the areas of disturbance and excavation quantities and cost.

Chapter 4
Construction Techniques

As shown in Atachment 6, the project involves excavation of approximately 8,900 cy of material to form the pilot channels. Note that the excavation quantity will be reduced in the final design based on the reduction in proposed pilot channel lengths described above in the 30% Design Changes section. The alignment of the channels, as observed in the field, includes a mixture of materials, dominated by sand and silt but including coarse alluvium and very large rock. This quantity of material is most efficiently handled by medium sized conventional excavation and hauling equipment such as track mounted hydraulic excavators, wheel mounted front end loaders, and conventional or off-highway trucks. This type of equipment has successfully been used in many stream and floodplain restoration projects, including sensitive wetland environments. Using medium sized equipment, it is feasible to complete the project in approximately one month, limiting the duration of temporary construction disturbance to wildlife and adjoining neighborhoods.

The main elements of work for the project are the excavation of pilot channels, placement of excess material in the berm along the quarry, and construction of the splitter mounds. Material excavated from the pilot channels can be transferred directly to the berm area to minimize handling and storage. Rock of suitable size that is excavated in the pilot channel alignments can be salvaged for use in the splitter mounds. Some additional transport of locally sourced rock and wood is anticipated for delivery of suitable materials for the splitter mounds. Significant trees near the pilot channel alignments were recorded during the March 17 site walk, and pilot channel alignments will be adjusted to miss tree locations. During construction, field adjustments are also possible to some extent to avoid impacts to desirable or sensitive species and habitat.

The main access point for the project will be via Abbey Way. A staging area is shown in the 30% design for storage of materials and equipment, and fueling and maintenance of equipment. This area will be protected with BMPs to be specified in a Stormwater Pollution Prevention Plan (SWPPP). Access routes from this point to the work areas are shown as four types in the 30% Design:

- Type 1 is along existing access routes;
- Type 2 is across floodplain areas;
- Type 3 is in the existing streambed; and
- Type 4 is along the pilot channel alignment.

By using the pilot channel alignments as access routes, additional disturbance for construction access is minimized. This would be accomplished by starting excavation at the end of the pilot channel furthest from the soil disposal berm at the quarry and working in one direction, such that no further disturbance is required after excavation. This method could be applied to most of the pilot channel alignments, such that Type 2 and 3 access routes would be used infrequently. Type 1, 2 and 3 access routes would be restored after construction, with restoration methods focused on removing ruts, obstructions to flow, and providing a naturally smoothed, irregular floodplain surface.

Chapter 5
Project Evolution

As previously described, the configurations of the splitter mounds and entrances to the pilot channels at the points of diversion are designed to be stable features that will withstand erosion during high flows. However, the pilot channel themselves are designed to erode and enlarge in response to high flow events. The rate at which the pilot channels enlarge, and the magnitude of the enlargement, depends on the frequency, duration, and magnitude of future flood events. Since the grade lines of the pilot channels are generally uniform, tie into existing channel invert elevations at the main channels and remnant channels, and have similar slopes as the existing and remnant channel features, it is likely that future pilot channel adjustment will include relatively more widening than deepening. Substantial headcutting of the pilot channels that would result in rapid channel downcutting is less probable than lateral erosion of the pilot channel's banks and overall channel widening.

Hydraulic geometry relationships that can be used to predict channel width based on inputs of discharge, slope, and flow resistance (channel roughness) were used to estimate how the pilot channels may evolve under future high flows. Hydraulic geometry relationships are not an exact predictor of channel morphology but the results can be used as an approximation of how the pilot channel will evolve. The selected equations are appropriate for the pilot channel substrate and bank resistance conditions and were used to predict channel widths for the 1.25-yr, 2-yr, 5-yr, and 10-yr events. The discharges used in the equations correspond to the modeled discharges entering the pilot channel. The results displayed in Exhibit 8 show that for a 10-year event the predicted channel width is around 35 ft and the widths decrease when the discharges associated with lower flood events are used as inputs into the equations. At the more frequently occurring events, such as the 1.25-yr flow, the predicted channel width of approximately 15 ft is similar to what the top width of the constructed pilot channel will be, thus appreciable bank widening is not expected at this relatively low flow. As higher flow events occur, however, the flows entering the pilot channels will have greater potential to erode and the channels will widen. The analysis indicates that the pilot channels may widen to 25-30 ft in response to flood events. This width is similar to widths found along the existing remnant channels.

The 30% design has elements that can be adaptively managed. The pilot channels are designed to route water into existing remnant channels. At several locations the flow can take multiple flow paths down different remnant channel branches. In the future, natural erosion and deposition processes may results in a preferential flow path emerging during a flood event so that only one of the branches is active. If after a period of time project monitoring shows that the project objectives of creating SBKR were successful in the preferential flow path, then the design could be modified to force water down a different flow path in a different remnant channel branch. For example, hypothetically the first flood event after construction may result in the northern remnant channel branch on Sheet C2 in Attachment 6 becoming the preferential flow path with flow not entering the southern branch. In this case the splitter mound constructed at STA 17+00 could be reconfigured to force flow during the next flood event into the southern remnant channel branch so new SBKR habitat can be created. Likewise, the geometry configuration of the points of diversion into the pilot channels can be adjusted in the future to alter how much of the main channel flow enters the pilot channels and how much remains in the existing channel.

Chapter 6
References

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Exhibit 1. Longitudinal Bed Elevation Profile of Plunge Creek's Low-Flow Channel in the Project Area based on 2013 LiDAR

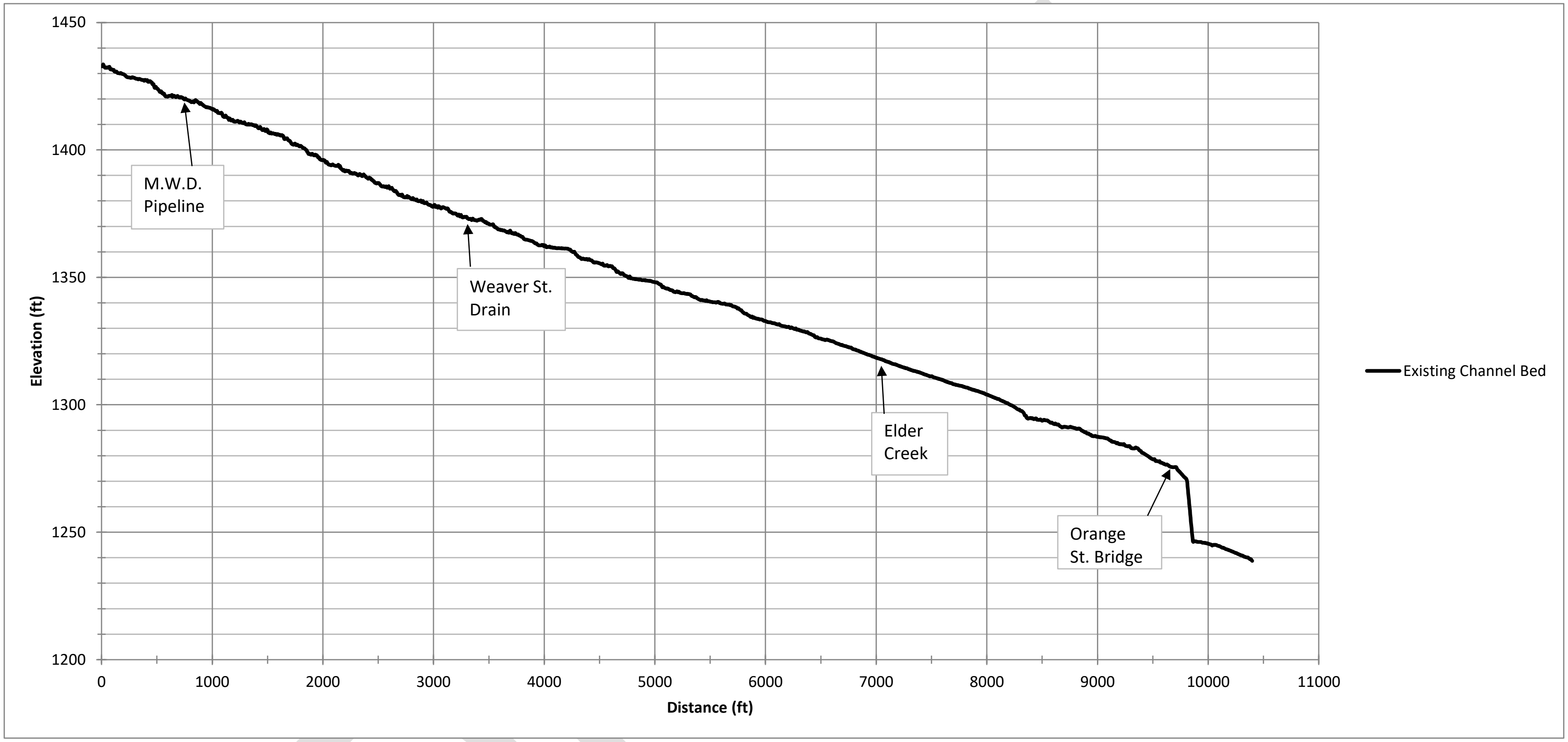

Exhibit 2. San Bernardino Kangaroo Rat (Dipodomys merriami parvus) Federally Listed as Endangered, California Species of Special Concern

Current Distribution: Range-wide/Plan Area	Habitat Requirements	Reproduction	Dispersal	Threats
Range-wide distribution includes Santa Ana River, Mill Creek, Plunge Creek, City Creek, Lytle Creek, Cajon Wash, Cable Creek, and the Etiwanda Fan, as well as the San Jacinto River and Bautista Creek.	Primary habitat is Riversidean alluvial fan sage scrub within active alluvial floodplains (1). Each successional stage of this habitat (pioneer, intermediate, and mature) is used, but highest densities are often found in pioneer-intermediate. Mature habitat is the greatest elevation from the low flow channel and provides the most protection from inundation during storm events (3). A high density of non-native grass is the best negative predictor of occupancy (4).	Reproductive activities peak in June and July (2), but pregnant or lactating females can be present January to November (1). Capable of more than one litter per year and typical size is 2–3 individuals (16). Breeding varies in relation to ecological conditions, with individuals not breeding when plant productivity is poor (7).	Philopatric so tends to establish home ranges close to natal range (12). Movements of 40–60 m are common (1), and long-distance events can be over 240 m (14). However, more than 85% of individuals disperse less than 125 m (13). Dispersal is slightly male-biased (13).	Loss of habitat and habitat fragmentation. Flood control, dams, and water conservation projects that change the hydrology of a system are indirect long-term threats to fluvial process required for habitat.
Daily/Seasonal Activity	Diet and Foraging	Systematics	Territoriality/Home Range	
Unable to enter a state of torpor (7), and therefore can be active at the surface year-round. Crepuscular (emerging from burrows at dusk to forage and returning before dawn). Occupies burrows during daylight hours for shelter and to avoid high temperatures. Reproductive males travel farther than females or males with regressed testes (8). Surface activity reduced during full moon periods (9).	Primarily granivores (seed eaters), but consume herbaceous material and insects when available (10). Collects seeds in cheek pouches and stores them in surface caches (11) or in burrow. Water requirements satisfied by seeds and herbaceous material consumed (12).	One of three subspecies of Merriam's kangaroo rat (*Dipodomys merriami*) in California (2). No genetic studies conducted (2). However, is the most highly differentiated subspecies of *Dipodomys merriami* (6).	Individuals are primarily solitary but have overlapping home ranges (15). Tend to tolerate familiar neighbors more than strangers and may have long-term associations with the same individuals (15). Actively defend small core areas near burrows (16). Sand baths may be important to establish familiarity between individuals (17). Average male home ranges may be slightly larger than that of females (0.74 ha versus 0.26 ha) (13).	

Special Management Considerations

Because existing flood control structures, roads, and dams have altered fluvial processes, long-term maintenance of high-quality habitat through vegetation management and fluvial processes will be important for conservation in the Plan area. Pioneer- and intermediate-stage alluvial fan sage scrub, which tends to occur on the terraces above the low flow channel, provide the highest quality habitat because it is sandy and fairly open, and has low vegetation cover. The density of vegetation is particularly important as it affects the species' burrowing, locomotion, and foraging ability. Experimental thinning of vegetation in the Santa Ana River resulted in an increase in use of the more open habitat. Mature-stage alluvial fan sage scrub is less suitable as primary habitat because of the typical dense vegetation cover, but is important as refugia in high flow events. Consequently, natural fluvial processes, whereby cycles of flooding and dry periods result in dynamic fluctuations of terraces and habitat, are crucial.

Other Relevant Information

Currently, the suitable habitat connection between City Creek and the Santa Ana River is constrained at Alabama Street with a very narrow swath of habitat. The suitable habitat connection between City Creek and Plunge Creek is constrained at Interstate 210 and Plunge Creek where only a very narrow swath of habitat is present. The suitable habitat connection between Plunge Creek and the Santa Ana River is constrained by maturing vegetation characteristics and the presence of non-native grasses.

Phenology

Life Stage/Activity Period	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Breeding (1, 2)												

Sources: USFWS 1998, USFWS 2009, USFWS 2002, USFWS 2010, Williams and Braun 1993, Lidicker 1960, Brown and Harney 1993, Behrends and Wilson 1986a, Daly et al 1992a, Reichman and Price 1993, Daly et al 1992b, French 1993, Jones 1989, Zeng and Brown 1987, Randall 1993, Jones 1993, Randall 1991

Exhibit 3. Santa Ana River Woolly-Star (*Eriastrum densifolium* ssp. *sanctorum*); Federally Listed as Endangered, California Listed as Endangered, California Rare Plant Rank 1B.1

Current Distribution: Range-wide/Plan Area	Habitat Affinities	Taxonomy and Genetics	Pollination/Seed Dispersal	Threats
Range-wide, occurs along the Santa Ana River, Mill Creek, Lytle Creek, and Cajon Creek.	Found on the alluvial terraces of open floodplains with intermittent flooding, light surface disturbance, and relatively low cover of annuals or perennials. Occurs on nutrient-poor sands. Most competitive in early stage habitats with 97% or greater sand particles, but also competitive in moderate stage habitats with 90–97% sand particles. A pioneer plant that is outcompeted in more stable shrubby ecosystems (2). This habitat type is transient in nature and is an early-mid successional stage, which requires disturbance to maintain over a large scale.	Taxon was originally described as *Hugelia densiflorum* and changed to *Eriastrum* in 1945. Currently five total subspecies are described for this species (4). Also thought to intergrade with other subspecies, namely subspecies *elongatum* around Cajon Creek and Lytle Creek and subspecies *austromontanum* in Lytle Creek and La Cadeña Drive (2).	Self-incompatible and an obligate outcrosser (2). Primary pollinators vary with location and include the sphinx moth *Hyles lineata*, two bees, *Micranthophora flavocincta* and *Bombus californicus*, and two hummingbirds, black-chinned hummingbird (*Archilochus alexandri*) and Anna's hummingbird (*Calypte anna*) (2). Seeds have a smooth surface morphology with a coating that becomes mucilaginous on contact with water and attaches the seed to the soil. Most seeds drop within a foot of the plant (2), but some stay in the capsule that can remain on the plant for several years (2). Seeds and capsules can be transported longer distances by floodwater (2).	The primary threat is habitat alteration from development, mining, flood control, off-highway vehicle activity, and hydrology changes. USFWS cites inadequacy of state and local plans to fully protect this species, specifically in that discretionary impacts are allowed by state and local laws and that most occurrences are not on conserved lands. More broadly, climate change and hybridization at ⅓ of the known locations could threaten this species (2).

Life History/ Demography	Seasonal Phenology
Perennial subshrub. Typically living 5 years but some individuals known to	Blooming is typically from April to September (3), but most heavily in June.

live to 10 years (2). Each head typically produces 4–30 flowers, each flower 1 fruit (a capsule), each with 6–33 seeds (1). Seeds germinate with the first major fall rainfall (2).	Fruiting typically occurs from mid-July to mid-October (2).

Special Management Considerations

Requires maintenance of alluvial terraces that have some intermittent flooding that would create suitable conditions for this species. These scour events (light to heavy surface disturbance) are needed to keep >90% of soil substrate sand and to reduce cover of annuals and/or perennials.

Other Relevant Information

The building of the Seven Oaks Dam has reduced the Plan Areas natural flooding pattern that would create scour and suitable habitat for this species. Active management practices of redirecting flows to mature terraces can be an effective management technique, as can creating new sand lenses.

Phenology

Life Stage/Activity Period	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Blooming (3)												
Fruiting (2)												
Status	CRPR 1B.1, FE, SE											

Sources: De Groot 2014, USFWS 2010, CNPS 2014, IPNI 2014, CDFW 2014

Exhibit 4. Slender-Horned Spineflower (*Dodecahema leptoceras*); Federally Listed as Endangered, California Listed as Endangered, California Rare Plant Rank 1B.1

Current Distribution: Range-wide/Plan Area	Habitat Affinities	Taxonomy and Genetics	Pollination/Seed Dispersal	Threats
Occurs in 22 known extant occurrences throughout coastal foothill drainages of Riverside, San Bernardino, and Los Angeles Counties.	Typically found on alluvial terraces away from active channels in areas receiving little surface disturbance from flooding, but subject to sheet or overland flows (Wood and Wells 1996). Populations occur in shallow depressions on relatively flat (0-2% slopes) surfaces (Wood and Wells 1996). The association with older (100 year+) more stable alluvial terraces indicates the need for infrequent flood events to maintain suitable habitat conditions over the long-term. A few occurrences can be found on low alluvial benches or braids within active channels (as summarized in 3). Soil texture at occupied sites are silt, loamy sand, and sand, as well as slightly acid (pH 6.4) with low levels of nitrogen, phosphorus, and organic matter and low electrical conductivity and low cation exchange (Allen 1996). These habitat features are most closely associated with the intermediate and intermediate-mature phases of Riversidean alluvial fan sage scrub.	Was first described as *Centrostegia leptoceras* in 1870 and then published as *Chorizanthe leptoceras* in 1877. The original name is the name under which the species was listed by state and federal agencies. It was changed to its current name in 1989 (6) based on its morphological and phylogenetic distinctiveness (3). Genetic diversity is high for the entire population; however, this is due to the populations in Los Angeles County being genetically different than populations in Riverside and San Bernardino Counties (3). Plants are mostly outcrossing but also self-fertile (7). Seed bank enhances genetic diversity because germinating plants in a single season lack the full gene diversity of the population (Ferguson and Ellstrand 1999).	Demographic and genetic diversity studies indicate seed bank is long-lived (Ferguson and Ellstrand 1999). Pollination information is limited. Thought to be pollinated by various small insects (3). The single-seeded fruits are located in involucres with hooked spines that may attach to wildlife for dispersal. Seeds are glabrous with no dispersal mechanisms of their own (1). Although not well understood, seed dispersal may occur by local overland flow during rain events (USFWS 2010). Some level of surface disturbance (e.g., sheet flows or soil disturbances during and following fire) may enhance germination in years following the disturbance (USFWS 2010).	Primary threat is habitat modification or destruction from development, mining, proposed flood control measures and other hydrology alteration, off-highway vehicles, illegal dumping, and invasive non-native species. Other general threats include climate change and the small population size present at each occurrence location (3).

Life History/Demography	Seasonal Phenology
Annual herb. Involucre number per individual varies and	Typically germinates with a 6–52 percent survival rate in February (3, 7). Blooming period is typically from

depends on climatic and genetic factors but has been observed to range from 1–169 involucres (3). Three flowers per involucre; one fruit per flower; one seed per fruit (1).	April to June (2). Seed banks are long-lasting, which helps maintain the species in dry years (3). Within each population, wide fluctuations in population size occur due to seasonal rainfall (3).

Special Management Considerations

With very few occurrences of this species within the Plan Are, each location has conservation value. This species has very particular micro-habitat requirements, which also adds value to the current extant occurrences. A management approach that can propagate the species in new areas and also allow the successful transplant will be required to secure future populations and allow development in currently occupied areas.

Other Relevant Information

Can be difficult to identify with certainty, especially in the field and outside of flowering and fruiting. As such, occurrences reported without voucher collections can be unreliable and unverifiable (3). Future discovered occurrences should always be vouchered to ensure certainty. It is also difficult to detect because they are small and occur in relatively small, isolated patches across often extensive floodplain habitat. Additionally, plant densities may be low during drought conditions.

Phenology

	Month											
Life Stage/Activity Period	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Blooming period (2)												
Germination (3)												
Status	CRPR 1B.1, FE, SE											

Sources: Reveal 2005, CNPS 2014, USFWS 2010, CDFW 2014, CCH 2014, IPNI 2014, Ferguson & Ellstrand 1999

Exhibit 5. Comparison of Flood Inundation Areas and Estimated Recharge Rates for Existing Condition and 30% Design at the 1.25-yr through 10-yr Recurrence Interval Flows

		Recurrence Interval			
		1.25-yr	2-yr	5-yr	10-yr
Existing Condition	Inundation Area (ac)	14.6	26.7	47.1	63.6
	Recharge Rate (ac-ft/day)	260	471	803	1041
30% Design	Inundation Area (ac)	26.3	40.4	63.6	81.7
	Recharge Rate (ac-ft/day)	435	665	1,034	1,286
% Increase	Inundation Area (ac)	80%	51%	35%	28%
	Recharge Rate (ac-ft/day)	67%	41%	29%	24%

Exhibit 6. Modeled Inundation Area versus Discharge Recurrence Interval Curves for Existing Condition and the 30% Design

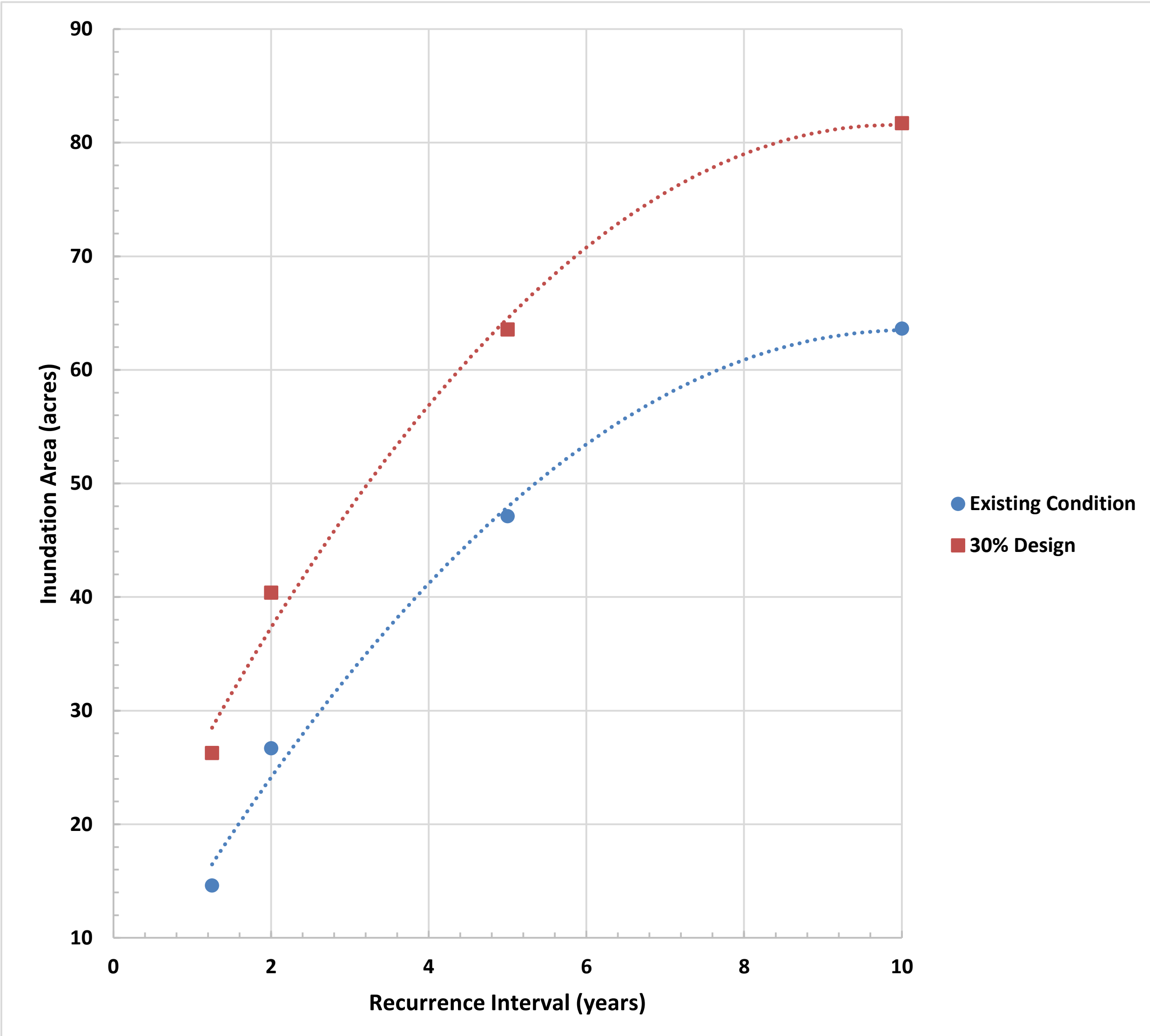

Exhibit 7. San Bernardino County Hospital Gage Daily Precipitation and Plunge Creek Daily Flow Hydrograph with a Peak Instantaneous Flow Similar to the Log Pearson Type III Value for the 10-Year Flood Event at USGS Gage 11055500

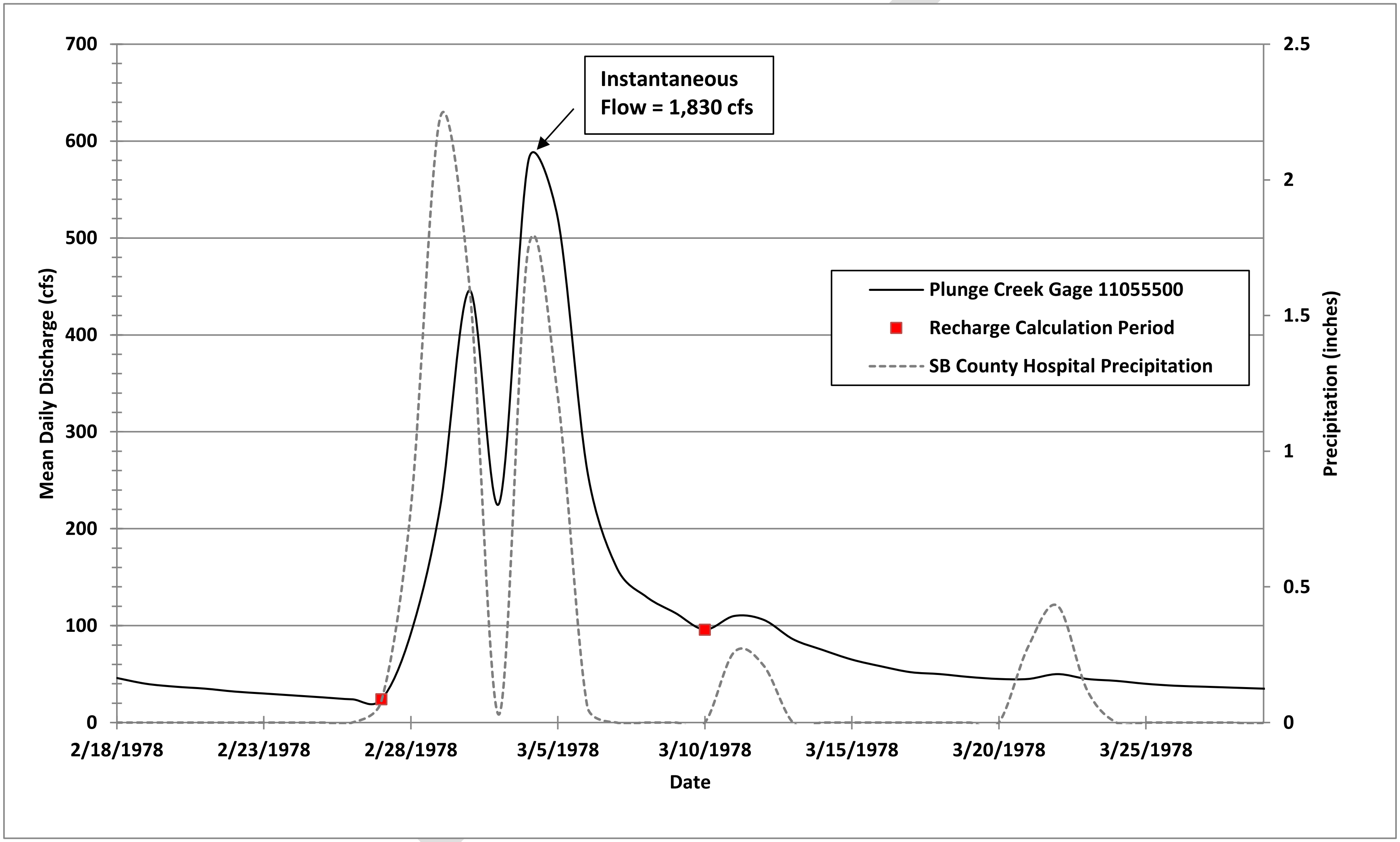

Exhibit 8. Estimates of Evolution of Pilot Channel Width based on Hydraulic Geometry Equations

Hydraulic Geometry Equation	Flow into Pilot Channel 1.25-yr Event 58 cfs	2-yr Event 145 cfs	5-yr Event 239 cfs	10-yr Event 280 cfs
Huang and Nanson (1998)[1]				
Non-Cohesive Sand Banks	16.5 ft	26.1 ft	33.5 ft	36.2 ft
Gravel Banks	14.1 ft	22.3 ft	28.7 ft	31.1 ft
Soar (2001)[2]				
Average of all Sand and Gravel Channels without Resistant Banks	15.5 ft	24.8 ft	32.0 ft	34.7 ft

[1] Based on a Manning's n of 0.045 and channel slope of 1.3%

[2] Average of several equations presented in Soar (2001)

Attachments