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Managing Water in the West

Ecosystem Features in Urban Channels: Scoping Report

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Final Report ST-2016-1582-1

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Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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14. ABSTRACT ***(Maximum 200 words)***

Many rivers and streams have been severely impacted during the last century by human development and urbanization. Degraded ecological conditions have resulted from alterations to watershed hydrology, sediment yield, and imposed constraints that currently limit natural channel adjustment and floodplain access. In some urban corridors, rivers have been completely channelized and lined with concrete to efficiently convey floods and minimize risk of erosion. However, reliable base flows in many urban streams have led to opportunities for recreation and habitat features to revitalize ecosystem services. This scoping research included a site visit to the Los Angeles River, literature review, and stakeholder outreach. Future research proposes to develop and evaluate methods that can be implemented within confined urban channels to improve ecosystem function at low flows without raising flood stage at high flows.

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Executive Summary

As watersheds throughout the western United States have become increasingly urbanized over the last century, Reclamation facilities and lands such as reservoirs, canals, and rivers have been impacted. Urban streams have perhaps suffered the greatest decline in biological habitat values and species diversity as rivers have been channelized and confined. Threats to native aquatic species may jeopardize the ability of Reclamation and its stakeholders to continue to deliver water and manage these degraded river systems. Urban rivers have been extensively channelized to meet flood control needs, thereby resulting in homogenous conditions at low to medium flows that provide minimal ecosystem services.

This scoping research considered how to rework the channel bed and banks, or add features such as flow deflectors and pools/riffles, to provide increased flow complexity and habitat heterogeneity. The primary constraints are the existing channel top width and flood stage at high flows. Ideally, increasing channel width, floodplain area, and stormwater detention would all be aspects of a comprehensive urban stream restoration project. However, these elements are often cost prohibitive or not feasible to implement in highly confined urban environments. Therefore, the scoping review focused on designing ecosystem features within the existing channel footprint.

The primary accomplishments of the scoping phase were completing a literature review, selecting a pilot site for the research, conducting a site visit, and identifying partners. The literature review identified the important considerations, challenges, and benefits for restoring urban streams, as well as a framework for diagnosing urban streams and selecting restoration targets. It appears that most urban stream restoration projects have only been evaluated with a one-dimensional hydraulics model, and there have been minimal assessments regarding flow complexity, variability, and habitat suitability at low and medium flows. The Los Angeles River was chosen as a pilot site for future research because of the extreme urbanization of the channel and watershed, and the interest and momentum that is being generated towards improving the ecosystem and aesthetic qualities of the river. There is a large group of federal, city, and local partners committed to improving the urban river corridor. This report summarizes meetings that were held with many of the partners, in addition to observations from a site visit to the river.

An initial list of ideas was developed during the scoping research to enhance ecosystem function or aesthetics without increasing flood stage. Concepts may include a sinusoidal meandering low-flow channel, roughness elements, topographic changes, flow deflectors, and grade control structures to create pools and riffles. Continuing research is proposed to further develop and analyze the initial list of ecosystem features. A two-dimensional hydraulic model would be utilized for preliminary assessments, followed by physical modeling of the most promising alternatives.

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Introduction

This report summarizes key outcomes from the Fiscal Year (FY) 2016 scoping research funded by Reclamation's Science and Technology (S&T) Program. The research topic is to investigate low flow ecosystem features that can be implemented in urban channels without raising the flood stage. Scoping research goals include identifying and evaluating relevant previous studies, developing partnerships, and refining the research strategy for a multi-year proposal submitted to the S&T Program. An important component of the scoping effort was a series of stakeholder meetings and site visits that occurred in Los Angeles (LA), CA on April 20th and 21st, 2016. The trip to Los Angeles was funded by Reclamation's Southern California Area Office (SCAO) and was a valuable addition to the literature review.

The Los Angeles River provides an excellent pilot site for the research because of the extreme urbanization of the channel and watershed, and the interest and momentum that is being generated towards improving the ecosystem and aesthetic qualities of the river (e.g., Los Angeles River Revitalization Master Plan (LARRMP 2007), Los Angeles River Ecosystem Restoration Project Integrated Feasibility Report 2015). There is a 2 mile reach starting at 1st Street and continuing downstream to the LA city limit at Washington Blvd that may provide a good pilot area to use for the low-flow ecosystem features research. The proposed research area is downstream of a planned large-scale restoration effort by several partners including the Corps of Engineers and the City of Los Angeles.

A primary consideration for S&T proposal awards is developing effective partnerships through collaborative research. In addition to strengthening S&T proposals, partnerships provide benefits such as increasing the usefulness and relevancy of the research products. Therefore, the objectives for the trip to Los Angeles were to:

- Identify potential partners and inform them about our research ideas
- Identify potential roles for the partners and opportunities for collaboration
- Identify in-kind data and potential funding opportunities from partners
- Learn more about technical and non-technical considerations that should be incorporated into the research
- Visit river sites in the field to better visualize the challenges and opportunities for restoring urban streams

The groups we met with were very enthusiastic about the research ideas and provided several helpful suggestions, which are discussed in more detail below. They mentioned that it would be helpful to have scientific, data-driven studies to give more credibility to their ideas about improving habitat on the LA River.

Literature Review

The literature review identified the important considerations, challenges, and benefits for restoring urban streams (Findlay and Taylor 2006, Bernhardt and Palmer 2007), as well as a framework for diagnosing urban streams and selecting restoration targets (Booth and Fischenich 2015, Bain et al. 2014, Hegberg et al. 2001). Recycled water was noted as an important resource that can be used to improve urban streams by providing reliable flow augmentation (Bischel et al. 2013). This is one of the factors that makes the Los Angeles River an effective pilot site for the study, because there is a reliable base flow throughout the year. Several documents were reviewed that describe the Corps of Engineers' (COE) proposed $1.4 billion Los Angeles River Ecosystem Restoration Project. The Locally Preferred Plan (LPP, Alternative 20) proposes riparian corridor restoration for 11 miles of river. The COE project focuses on arroyo confluences, stream daylighting of minor tributaries, establishment of side channels, and channel and floodplain widening by re-purposing industrial areas. The COE typical cross section drawings and study reports do not show any riverbed modifications or features that would be active at low to medium flows. Riverbed topography appears to remain flat and uniform in the COE project.

In addition to the LA River, several other cities were identified that have implemented urban river restoration projects:

-San Antonio River Walk (San Antonio, TX)
-Historic Arkansas River Walk (Pueblo, CO)
-Guadalupe Riverfront (San Jose, CA)
-New River Walk (Fort Lauderdale, FL)
-Tennessee Riverpark (Chattanooga, TN)
-Downtown Creek Front, Cherry Creek (Denver, CO)
-South Platte River (Denver, CO)

It appears that most of the large scale urban stream restoration projects have only been evaluated with a one-dimensional hydraulics model. There is minimal predictive or monitoring performance data on these projects regarding flow complexity, variability, and habitat suitability at low to medium flows. Conversely, a small number of studies (Lange et al. 2015, Schwartz et al. 2015, Im and Kang 2011) used multi-dimensional numerical modeling to assess habitat structures or habitat suitability. However, these studies did not evaluate the change in flood stage at high flows due to the proposed design.

The proposed future research will build off the results of previous work while adding an integrated approach between ecosystem design, 2D numerical modeling, physical modeling, and ecological function.

Outreach Meetings

Two outreach meetings were held on Wednesday, April 20. The first meeting occurred at the Council for Watershed Health office at the Metropolitan Water District Building. The second meeting was at the Nature Conservancy office on South Figueroa Street. Table 1 lists the attendees at the first meeting and Table 2 lists the attendees at the second meeting. An informal presentation was given at each meeting to provide background information about Reclamation, the scope and context of the research, and preliminary plans for moving forward. Each group had an opportunity to ask questions, provide input, and discuss their projects and research efforts. There is currently a significant amount of monitoring and data collection being conducted that could increase opportunities for collaboration.

Table 1. Attendees at first outreach meeting at the Council for Watershed Health.

Name	***Organization***	***Title***
Pauline Louie	Council for Watershed Health	Urban Waters Los Angeles River Watershed Ambassador
Chris Solek	Council for Watershed Health	Programs Director/Sr. Scientist
Wendy Ramallo	Council for Watershed Health	Executive Director
Mark Hanna	Geosyntec Consultants (consultant for River LA)	Senior Principal Water Resources Engineer
Al Preston	Geosyntec Consultants (consultant for River LA)	Senior Engineer
Peter Arnold	Arid Lands Institute	Director of Research
William Preston Bowling	Friends of the Los Angeles River	Special Projects Manager
Nathan Holste	Bureau of Reclamation	Hydraulic Engineer
Jennifer Bountry	Bureau of Reclamation	Hydraulic Engineer
Doug McPherson	Bureau of Reclamation	Environmental Protection Specialist

Table 2. Attendees at second outreach meeting at the Nature Conservancy District.

Name	***Organization***	***Title***
Shona Ganguly	The Nature Conservancy	External Affairs Manager
Sophie Parker	The Nature Conservancy	Senior Scientist
Stephen Mejia	Friends of the Los Angeles River	Community Programs Manager
Jennifer Mongolo	Resource Conservation District of the Santa Monica Mountains (RCDSMM)	Environmental Scientist
Nathan Holste	Bureau of Reclamation	Hydraulic Engineer
Jennifer Bountry	Bureau of Reclamation	Hydraulic Engineer
Doug McPherson	Bureau of Reclamation	Env. Protection Specialist

Meeting with the stakeholder groups provided additional insight into some of the technical aspects that should be considered for the research. One important piece of information was consideration of the groundwater level beneath the concrete-lined channel. The “soft bottom” section of the channel was never lined with concrete because of a high water table that would have risked failure of a constructed concrete bed. This may be due to shallow bedrock that drives groundwater up in this reach. Even in concrete-lined river sections, there is a series of manholes to serve as relief valves for high groundwater levels. Geosyntec Consultants reported that core samples were collected in October 2013 (a dry period) by drilling through the concrete bed. At one location where the concrete core was removed it was observed that the groundwater was within inches of the channel bed. Although a more detailed groundwater study would be required, this highlights a potential consideration of allowing connectivity between the groundwater and the channel to assist with ecosystem feature establishment. Groundwater connectivity with the channel may also provide opportunities for improved water quality and increased base flows.

Another important topic was the design flow for the proposed ecosystem features. One concept discussed was that low flow features do not necessarily have to be able to withstand the 50-yr or the 100-yr flow event. An example is the existing vegetation in soft-bottom reaches, which has been washed away or damaged during high flows but has been observed to quickly recover and grow back. Rather than designing large structures that would be completely stable at high flows, a better approach may be to design features that could easily be maintained or reconstructed. One concern raised was to ensure that any habitat elements did not wash out and pose a risk to damaging or increasing flood stage at downstream bridges. There is also a concern about raising the flood stage at high flows, but discussion highlighted that this could potentially be addressed by widening the channel bottom and creating steeper side slopes. The increased channel capacity could allow for increased roughness and diversity in the low flow channel.

A key objective discussed by the group was incorporating ecosystem features that would be functional over a range of low to medium flows. A better characterization of these flows would be helpful for the design. The low flow discharge is subject to change in the future and has been a topic of discussion among the various local stakeholders. A substantial portion of the low flows comes from recycled water discharge, which provides perennial flow to the river. This recycled water baseflow will be reduced when the East Valley Water Reclamation Project becomes fully operational. Reclamation’s Title XVI program provided $13,371,664.82 for the East Valley Water Reclamation Project, 25% of the design and construction expenditures. The Los Angeles Department of Water and Power ("DWP" - the Title XVI grant recipient) has agreed to leave a portion of the recycled water in the river to support biological values. There will be a reliable perennial flow for the long term, sufficient to maintain ecological resources.

The topic of access to the river by the public and maintenance crews was discussed with regards to potential design constraints and opportunities for multi-purpose benefits. There is a proposal to extend and enhance bike trails along the river, including in the potential study reach of the 1st Street Bridge south to the Los Angeles city limit. The bike trail can serve a dual purpose as public access and a path for maintenance crews to drive on. Geosyntec Consultants is working on developing an early warning system for high flashy flows to alert people near the river when there are safety concerns. Current maintenance practices within the channel are a difficult subject, with some groups believing that maintenance guidelines are outdated. In order to improve habitat conditions, more flexibility to allow some vegetation growth within the channel may be needed.

Data needs and availability were also discussed. The Frank Gehry team has been commissioned by River LA to conduct a data-driven study of the water and uses of the river. Trimble has collected elevation and location data along the entire 51-mile length of the river and a 3D computer model surface is currently being developed. Another important piece of data is water temperature. RCDSMM is currently studying temperature ranges for fish survival and has installed 18 data loggers to collect temperature and dissolved oxygen information along the river. The Southern Steelhead is more temperature and water quality tolerant than most species, but may be unable to tolerate the current high temperatures in the river. A potential research component discussed is the effect of increasing groundwater connectivity to mitigate warm temperatures during low-flow periods.

Table 3 summarizes potential collaboration opportunities between the partner organizations and the Reclamation research proposal. The conducting research proposal was provided to the groups to solidify commitment levels.

Table 3. Potential partner roles for S&T research proposal.

Organization	***Role/Contribution***
Council for Watershed Health	Has a watershed monitoring program. Has developed a rapid habitat assessment method and the staff/contracts to conduct habitat monitoring. In-kind services via data sharing. Particularly interested in project implementation phase and providing assessments using their current tools and indicators.
Geosyntec Consultants (consultant for River LA)	Could serve as an independent peer reviewer or provide technical input for concept design. May be able to provide or assist in obtaining surface topography and groundwater data.
Arid Lands Institute	Primary research focus has been on sub-watershed conditions and stormwater runoff. Looking at how urban landscape can be changed to reduce peak flows. Could potentially contribute in-kind services such as reports/data on flow and sediment entering the

Organization	*Role/Contribution*
	river. Has partnered with university students before, so may be able to assist with data collection for a pilot project.
Friends of the Los Angeles River	Could provide support through community outreach, volunteers, and habitat studies.
The Nature Conservancy	Has developed a few concepts for non-earth moving restoration techniques such as invasive weed control and planting native vegetation. Could contribute results from their habitat study where they conducted various surveys for animals, reptiles, etc.
Resource Conservation District of the Santa Monica Mountains (RCDSMM)	Could provide in-kind data and services through temperature and water quality studies.

Site Visit

The site visit occurred on Thursday, April 21st and was hosted by Michael Affeldt and Carol Armstrong with the City of Los Angeles. Matt Kondolf, a professor from UC Berkeley, and a group of his associates also participated in the tour. Their primary focus was on the social aspects of urban restoration and revitalization. The groups met at the Los Angeles River Center and Gardens at 570 W Ave 26, Los Angeles, CA. After initial introductions and discussion, four sites along the river were visited. Figure 1 shows the location of the sites relative to the greater Los Angeles area. The sites covered a range of about 9 miles along the river out of the total 51 miles of river length. Site 1 was near the LA Zoo and Site 4 was near downtown Los Angeles. For reference on the location map, the LA River flows south into the Pacific Ocean near Long Beach. The observed sites included a range of channel widths, side slopes, and substrate materials (concrete or gravel/cobble).

Figure 2, Figure 3, and Figure 4 provide a map and photos of Site 1, which is about 600 feet downstream of the Verdugo Wash confluence. This is the widest section of channel that was observed on the site visit and was likely designed to accommodate peak stormflow events entering the river from Verdugo Wash, a tributary entering on river left (looking downstream). The channel cross section was rectangular at this site, with vertical side walls and a top width of about 400 feet. Upstream and downstream of the site the channel transitions to a trapezoidal cross section with sloping side walls and a top width of about 300 feet. During the site visit flow depth was very shallow due to the wide, flat-bottom channel. Algae were growing near the channel edges and ducks and other waterfowl were observed in the channel. A few cyclists were using the bike path along the top of the right bank, but a closure due to maintenance forced them to turn around or take a detour. About 2,000 feet downstream of the site there was a transition from the concrete bed to a native material “soft-bottom” bed that allowed for vegetation growth along the channel edges.

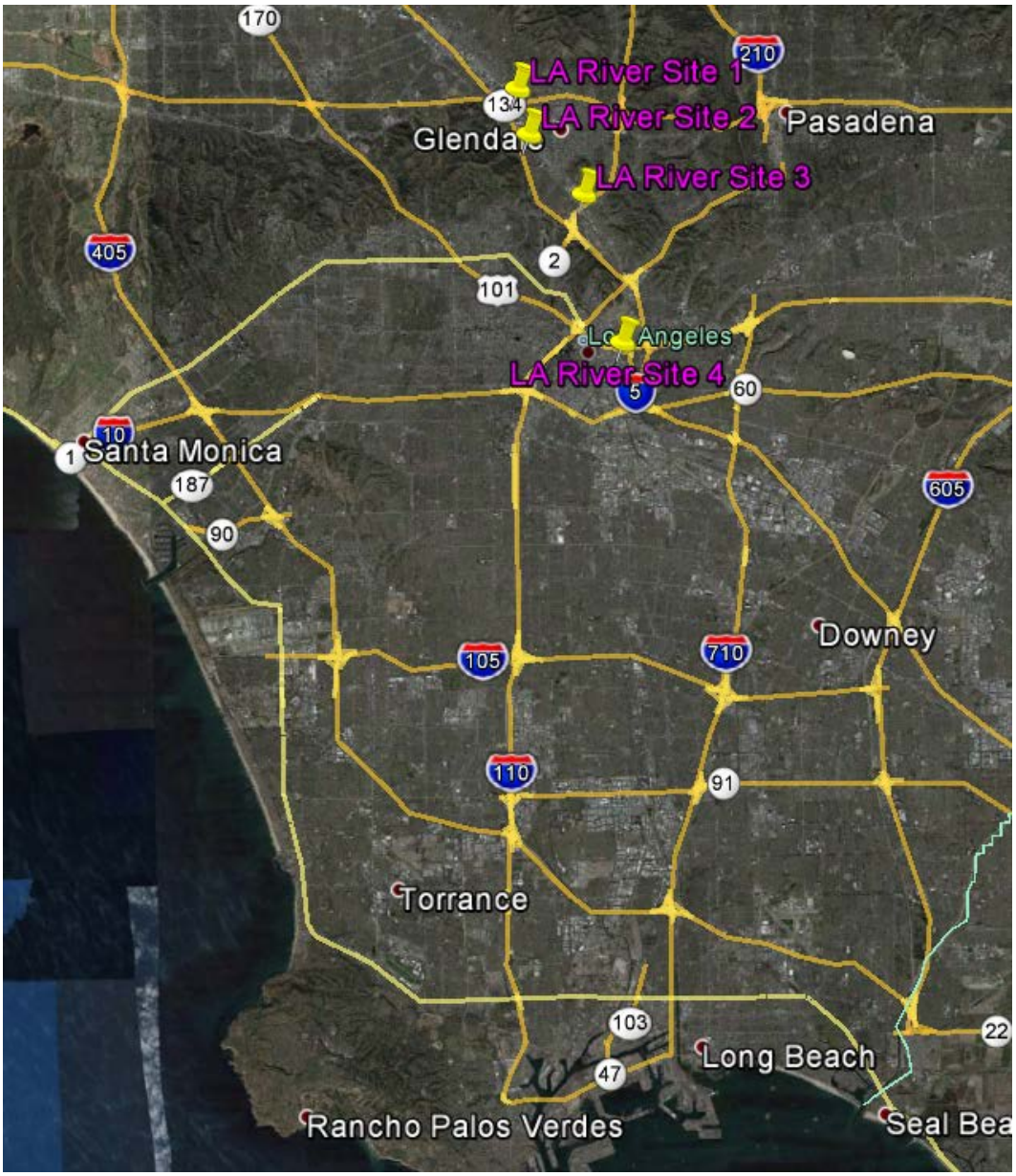

Figure 1. Overview site map of locations visited during LA River tour.

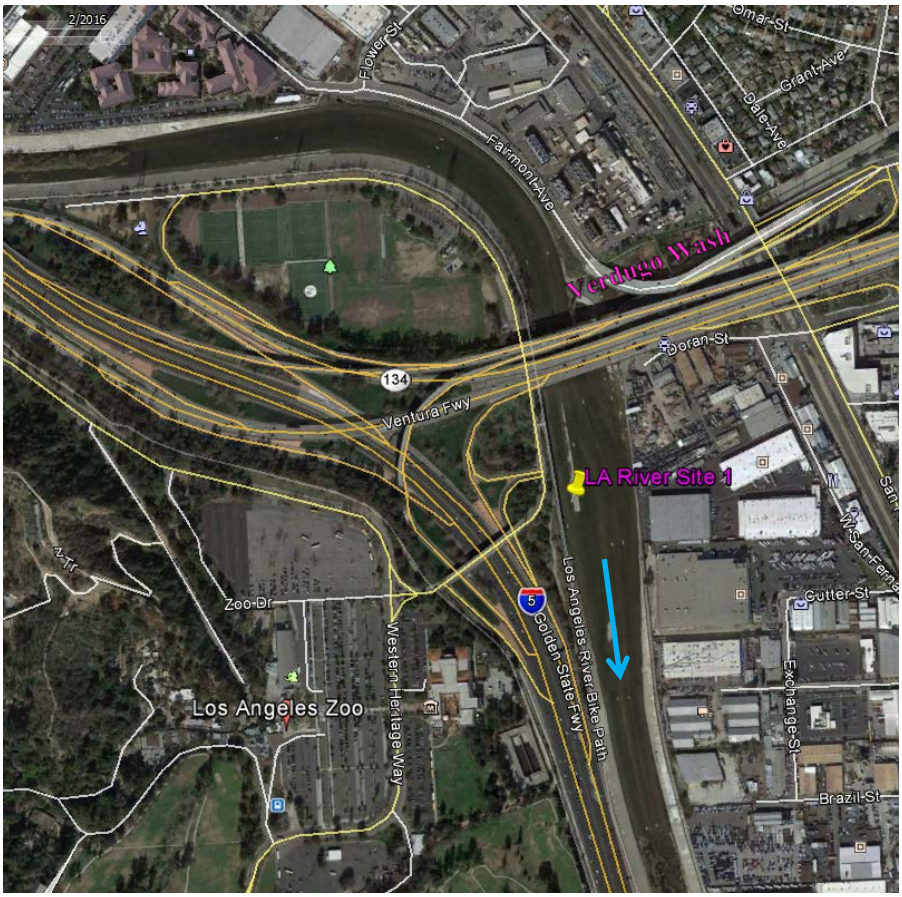

Figure 2. Overview map of Site 1 location (Verdugo Wash/LA Zoo).

Figure 3. Site 1 looking across channel from right bank. Note the algae growth, ducks, and manhole pedestals in the channel. Photograph taken by Jennifer Bountry (April 21, 2016).

Figure 4. Bike path closure at Site 1. Photograph taken by Jennifer Bountry (April 21, 2016).

Figure 5 and Figure 6 provide a map and photo of Site 2, which is at North Atwater Park and about 1.3 miles downstream of Site 1. This site is located within the "soft bottom" section of the LA River, which extends for about 6 miles without a concrete-lined bed. A notable feature of the park was a redesigned stormwater channel that is meant to improve water quality before entering the LA River. The sandy bed material and vegetation along the stormwater channel was designed to trap and remove pollutants from the 60-acre drainage prior to flowing into the river as surface water or groundwater. The vegetation (willows, mulefat, and shrubs) appeared quite lush and healthy even though it was relatively new. This site was the most scenic and natural looking portion of the LA River that was observed during the tour. The toe of the right bank was well vegetated with grasses, willows, and trees. There were also small "islands" of vegetation along the left bank. The cobble bed material was interesting because the reaches upstream and downstream are lined with concrete and have no sediment on the bed. Developing a better understanding of sediment sources along the LA River and the potential for bed material transport may be helpful for evaluating restoration ideas in downstream river sections.

Figure 7, Figure 8, and Figure 9 show a map and photos of Site 3 at Marsh Park. This site was about 2.5 miles downstream from Site 2 and also had an unlined "soft-bottom" bed. Vegetation growth was only along the toe of the left bank and the water surface width was narrower than at Site 2. The right side slope appeared to be constructed of a grouted riprap type of material rather than smooth concrete as in most other sections of river.

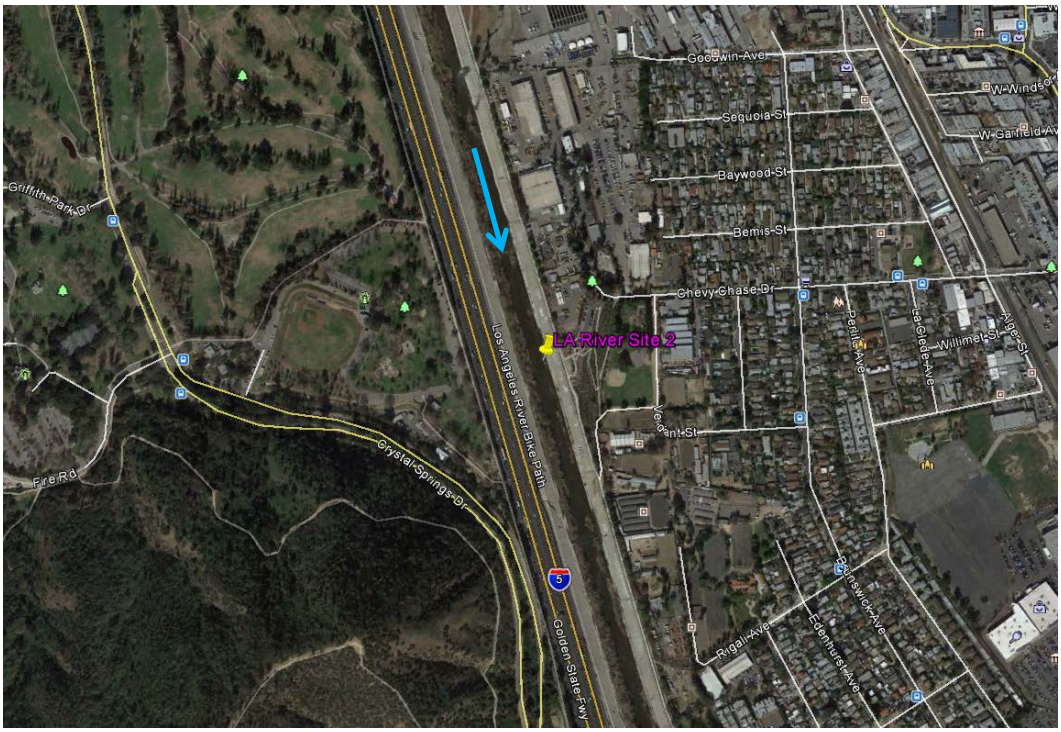

Figure 5. Overview map of Site 2 location (North Atwater Park).

Figure 6. Site 2 looking upstream from the left bank. Note the large cobble sized bed material and vegetation growth near the channel. Sand filled barriers have been temporarily installed along the left bank to raise the bank height due to flooding concerns prior to the El Niño season. Photograph taken by Nathan Holste (April 21, 2016).

Figure 7. Overview map of Site 3 location (Marsh Park).

Figure 8. Site 3 looking downstream from the right bank. Note the vegetation growth along the left bank and grouted riprap along the right bank. Photograph taken by Jennifer Bountry (April 21, 2016).

Figure 9. Posted sign at Site 3 that notes recreation uses and the endangered species habitat supported by riverbed vegetation. Photograph taken by Jennifer Bountry (April 21, 2016).

Figure 10 and Figure 11 provide a map and photo of Site 4, which is at 1st Street Bridge and about 4.8 miles downstream of Site 3. The channel bed in this section is not flat, but has a low flow notch (~20 feet wide) that contained most of the flow during the site visit. This site is in an industrial area near downtown Los Angeles and has train tracks on both sides of the channel. Site 4 is at the downstream boundary of the Corps of Engineers' proposed 1.4 billion dollar ARBOR (Area with Restoration Benefits and Opportunities for Revitalization) Project. Site 4 provided a good contrast to the cobble bed sections at Sites 2 and 3. Sites 2 and 3 had some variability in flow depths and velocity due to the natural bed and vegetation, whereas Site 4 had no hydraulic variability unless water spilled out of the low flow notch. There were no signs of sediment deposition or vegetation growth, except for a small amount of vegetation that was growing through a crack in the concrete near the toe of the left bank.

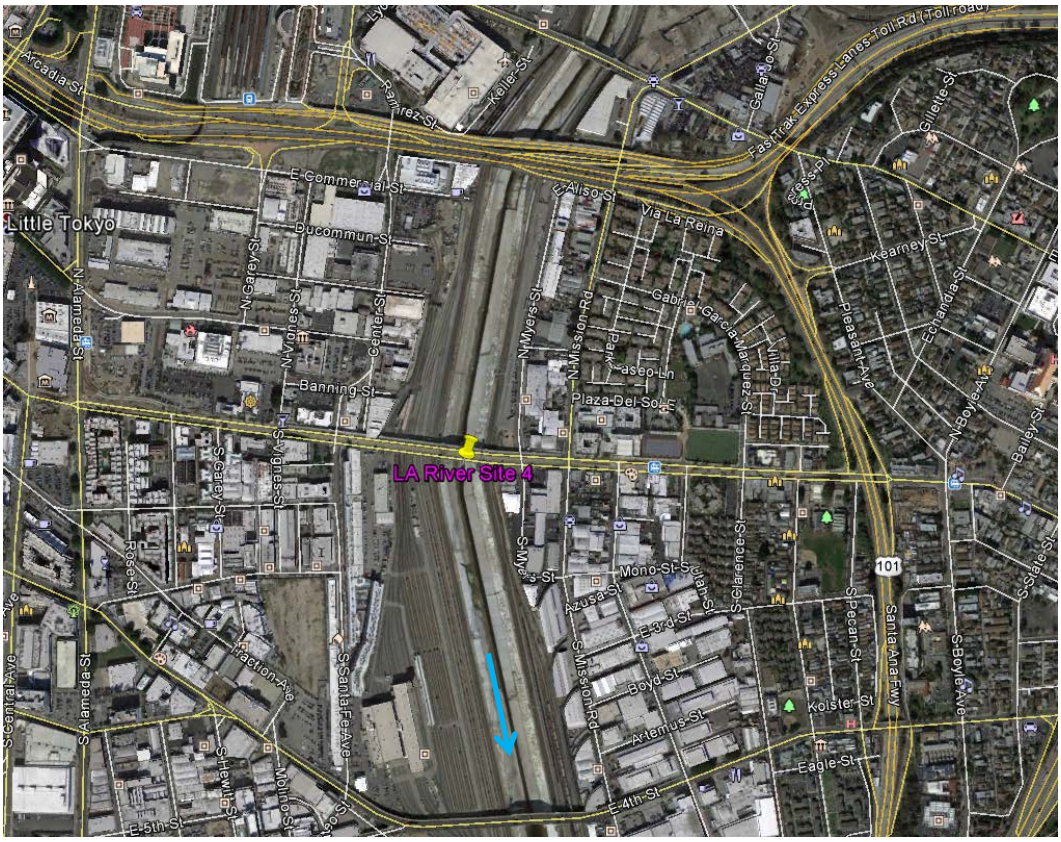

Figure 10. Overview map of Site 4 location (1st Street Bridge).

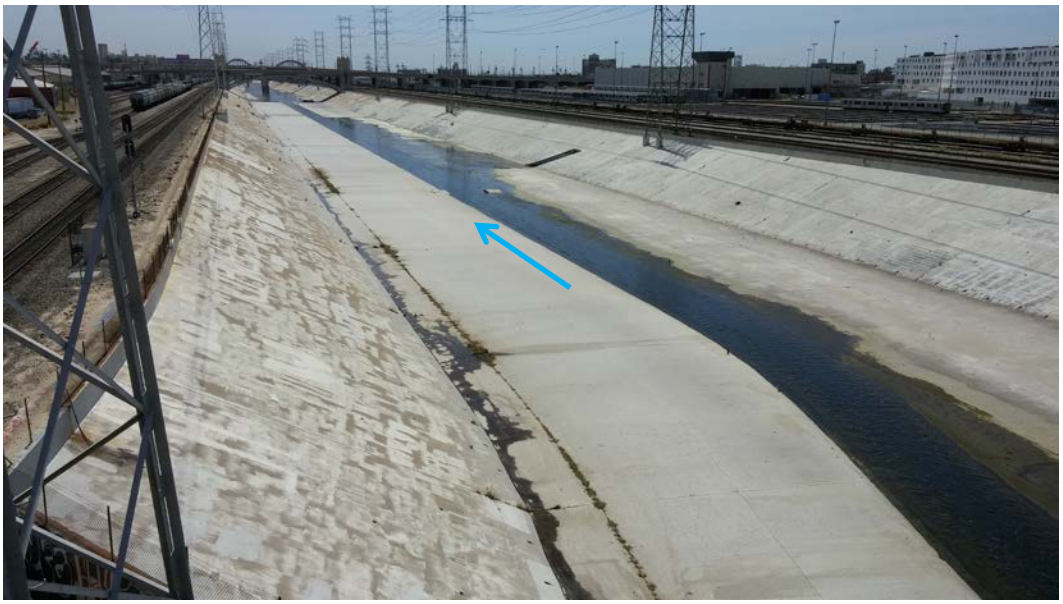

Figure 11. Site 4 looking downstream from 1st Street Bridge. Note that flow is mostly contained by the low flow notch, but spills out in a few areas. Photograph taken by Nathan Holste (April 21, 2016).

Discussion

The two primary outcomes from the trip to Los Angeles were interacting with the local stakeholders and better defining the scope of the research proposal. Observing the “soft bottom” sections that were adjacent to concrete-lined reaches provided ideas for different types of ecosystem features that could be implemented within a confined urban channel. A fluvial gravel or cobble substrate will likely provide the most opportunities for habitat development, but may not always be feasible. One outcome of the research may be a comparison of restoration alternatives with a concrete bed to methods that utilize a natural bed. Figure 12 shows a conceptual drawing of what channel restoration could look like by reworking the channel bottom. Localized, site-specific areas of concrete lining (i.e., near bridges) may be necessary as long as they do not impair connection between upstream and downstream reaches. The LARRMP (2007) emphasizes that a continuous path from the ocean to the headwaters with pools, riffles, and runs is the most important factor for successful recolonization of the steelhead and other native aquatic species. Cover and shade from riparian vegetation and improved water quality and temperature conditions are other important habitat needs.

Important considerations for urban stream restoration include reducing flow velocity, maintaining channel capacity, and naturalizing the bank edges. Increasing channel capacity by reshaping the side slopes could prevent the increased roughness of natural features from raising the flood stage. It is also possible that select vegetation along the channel edge would only increase channel roughness at low to medium flows, but may not appreciably increase the roughness at high flows. Excessive scour of the channel bed during high flows may be a concern if the concrete is removed. An idea for mitigating scour is to install a semi-rigid feature, such as a geocell cellular confinement system or an articulated concrete block mattress, and then covering it with native bed material. The installed features would act as a type of bedrock while allowing exchanges between groundwater and surface water.

It is useful to consider the different functions provided by the river at a variety of flows. At low to medium flows, the river is a multi-use system that can provide habitat, recreation, and water quality benefits. At high flows the river is a single use system with flood control being the primary concern. The goal of the S&T research is to develop and evaluate concepts for ecosystem improvements at low to medium flows while maintaining channel capacity at high flows. Key metrics will be water surface elevation, depth, and velocity at a variety of discharges from low to high. Integrating conceptual design, numerical modeling, physical modeling, and a pilot field site (if possible) during the research will provide valuable information to decision makers who are considering urban stream restoration. Table 4 outlines the preliminary research schedule, and the bullet list below presents some of the ecosystem feature concepts that are being considered.

Existing: Looking north along the existing channel section above 1st Street in Downtown Los Angeles. (2006)

Future: The channel bottom with a restored riparian corridor with native plants.

Figure 12. Artist's rendering of potential channel restoration scheme upstream of 1st Street (from LARRMP 2007), Site 4.

Table 4. Preliminary schedule for S&T research proposal (FY2017 – 2019).

Fiscal Year (Oct 1 – Sep 30)	*Technical Service Center Research Tasks*
2017	• Development and conceptual design of urban channel restoration concepts • 2D numerical modeling of concepts
2018	• Physical modeling of concepts (model flume will be approximately 8 ft wide by 80 ft long)
2019	• Synthesis and analysis of results • Report and/or journal article • Workshop with partners and/or planning for field site pilot project implementation*

*A small pilot site in the field would have tremendous value. However, the feasibility is currently uncertain and the scope is beyond the S&T budget. Only local agencies would have the authority and means to construct a pilot project.

- Roughening the low-flow channel bottom and side slopes to create diverse hydraulics with small boulders, topographic low and high points, etc.
- Construction of a sinuous low-flow channel within the larger trapezoidal channel or varying the low-flow channel width.
- Construction of small side channels to the low-flow channel that would further enhance ecological benefit and opportunity for diversity.
- Excavation of small relatively flat areas within the concrete channel side slopes to create riparian planting areas.
    - Construction of steeper side slopes to provide additional capacity and opportunities for vegetation growth on terraces.
- Excavation of a portion of the concrete bottom and underlying soil to allow for development of a low-flow channel and possibly small side channels and riparian areas. The excavation would increase conveyance and offset the increased roughness due to vegetation. If necessary, the excavated bed could be stabilized by a variety of means including:
    - Placing a cellular confinement system or articulated concrete block mattress beneath the channel bed and covering with layers of gravel/cobble bed material.
    - Placing grade control or bed sill structures across the channel bed to create pools and riffles.
    - Installing transverse features to create eddies and redirect flow, thereby initiating local areas of sediment deposition and scour.

- Inclusion of bike paths adjacent to or alongside the canal side slopes.
- Increase in public access to channel.
- Floodplain widening? This is likely not feasible at many locations, but may be necessary to have truly sustainable ecosystem features for some alternatives. Improved stormwater detention would also increase sustainability, but is beyond the research scope.

As mentioned, the current plan is to use the 2 mile reach from 1st Street (Site 4) to the LA city limit at Washington Blvd as a pilot area for the low-flow ecosystem features research. The alternatives developed should not only be applicable to other sites on the LA River, but also to other similar urban flood control channels across the United States. Alternatives will be developed by Reclamation's SRH Group with input from Doug McPherson and other partners. Several different alternatives will be initially tested with a 2D hydraulic model to quickly assess performance. The most promising alternatives (approximately 3) will be tested with a physical model. Results from the numerical and physical models will be analyzed to provide a better understanding of the benefits and risks associated with the ecosystem features.

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