SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT AUTHORITY

THEMATIC RESEARCH PLAN

FOR

ECOHYDROLOGY

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Introduction

Ecohydrology is the study of how changes to flow patterns affect the health of aquatic ecosystems, either directly or indirectly through changes in temperature, channel morphology, or water chemistry (e.g., specific conductance). Streams, estuaries, wetlands and other aquatic environments all experience routine natural variation in the timing, magnitude, duration and frequency of flows. But human activities also can trigger significant disruptions to flow patterns that alter the structure and composition of aquatic ecosystems. California's water resources management community needs to understand the ecological consequences of these alterations, so they can make optimal decisions about how to impound, divert, recharge and otherwise manage the release of water to serve a variety of societal needs – from flood control to agricultural irrigation to water recycling. SCCWRP is working to help water resources managers take science-informed approaches to solving complex flow management issues, enabling managers to optimally protect ecological condition of receiving waters and mitigate the impacts of hydrologic alteration. By developing tools and strategies that help managers evaluate various options for offsetting current and potential future threats to ecological flows (i.e., the flows necessary to support aquatic life use and functions) and determine optimal environmental flows (i.e., the flows needed to protect the ecological health of streams while balancing human uses and other water management objectives), SCCWRP is helping to bring greater consistency, standardization and coordination to the design of environmental flow management programs across California.

Conceptual Model

SCCWRP's conceptual model for ecohydrology is centered around using the sciences of hydrology, geomorphology, ecology, and biology to more effectively protect the health of receiving waters (e.g., streams, lakes, wetlands, and estuaries) and to mitigate the impacts of anthropogenic changes to hydrological flow patterns. To build management capacity to achieve these goals, SCCWRP is pursuing research simultaneously across these disciplines, which build upon one another to ultimately inform management decisions regarding hydrological flows.

SCCWRP's ecohydrology research is driven by three major objectives: (1) Understand and predict **changes in hydrology** in response to natural and anthropogenic drivers (e.g., land use, climate change, water resource management), (2) develop tools, including statistical and deterministic models, to evaluate the relationship between changes in hydrology, **physical habitat** (e.g., sediment-flux and channel form) and biologically relevant **water-quality** parameters (e.g., temperature, salinity, nutrients) to **biological response** in the stream, and (3) evaluate the effectiveness of various **management actions** (e.g., best management practices; BMPs) and other efforts to reduce or mitigate the impacts of flow modification. Effectiveness assessment includes development of user-friendly decision support tools and case studies that demonstrate implementation of ecohydrology management actions.

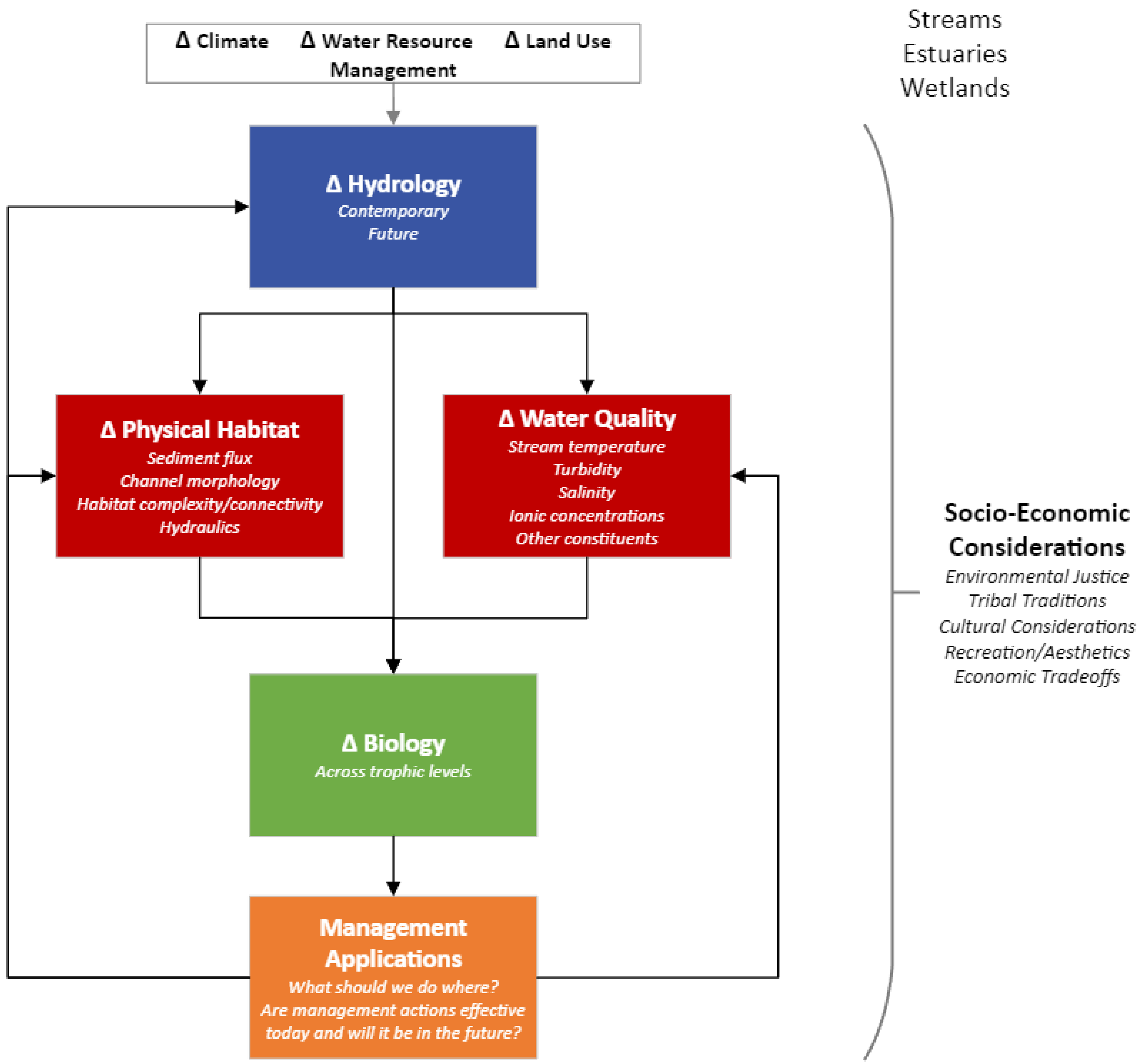

Figure 1. SCCWRP's conceptual model for ecohydrology research is divided into five main components – all designed to facilitate the development of management tools and strategies that protect ecological condition of receiving waters and mitigate the impacts of hydrologic alteration.

Δ Hydrology: Natural hydrologic patterns, including the timing, frequency, magnitude, and duration of flows, are needed to sustain healthy aquatic ecosystems. However, changes in climate (short- and long-term), water resource management (i.e., wastewater reuse, stormwater capture, water conservation, groundwater remediation), and land use have the potential to alter hydrology in ways that adversely affect aquatic life uses and functions. Thus, the goal of flow management programs is to establish and maintain hydrologic flow patterns – known as ecological flows – that protect aquatic life uses and functions. Characterizing and predicting hydrologic alteration under contemporary and future conditions in response to key drivers of change are central to understanding how hydrologic changes affect ecology and to identify effective flow management solutions. Assessing and predicting the drivers themselves is critical to understanding hydrologic change; however, research in these areas, such as projecting or predicting regional climate changes or land use patterns itself, is not part of SCCWRP's ecohydrology research and is best incorporated through strategic partnership with other researchers with expertise in these areas. Key questions addressed by this portion of the research plan are:

- What are the reference and contemporary ranges of hydrologic regimes in water body types of management concern?
- How may future changes in climate, land use, and water resource management affect hydrology?
- How can we extrapolate hydrology across broad spatial scales?

∆ **Physical Habitat:** Changes in hydrology can trigger changes in sediment dynamics, including sediment yield from hillslopes and sediment transport capacity. Synergistically, these changes can affect physical habitat structure and ecological condition. For example, because urbanized channels tend to incise or migrate laterally, channel planform, depth, and hydraulics are likely to be altered and, in response, habitat complexity and lateral/vertical connectivity are likely to be reduced. Key questions addressed by this portion of the research plan are:

- What is the current physical habitat condition?
- How do changes in hydrology impact physical habitat, hydraulics, and sediment transport?
- How can we predict contemporary and future physical habitat conditions in unmonitored locations across the region?

∆ **Water Quality:** Flow has a dominant influence on ecologically relevant water quality properties (e.g., stream temperature, concentrations of salt and nutrients), which directly (or indirectly) affects the health and survival of aquatic species. Understanding physical interactions between hydrology and water quality can facilitate flow-related solutions supportive of habitat availability and biological condition. Key questions addressed by this portion of the research plan are:

- How do changes in flow affect and interact with water quality?
- How can we improve water quality models to better understand contemporary and future conditions in unmonitored locations across the region?

∆ **Biology:** Aquatic functions and beneficial use support can be measured by the condition of species or habitats of management concern, biological communities, or populations. Flow and flow-related physical factors can directly impact biological condition and/or can affect biology indirectly through changes in physical habitat or water quality. Multiple interacting physical factors may have varying consequences on biological condition, which may be amplified through synergistic responses. To support aquatic life use, it is therefore imperative to consider these effects in the development of biological-based tools to inform decision making. Key questions addressed by this portion of the research plan are:

- How does flow alteration affect biology?
- How does flow interact with other stressors to affect biology, and what are the mediating factors of flow alteration?
- When and where is alteration impacting biology?

Management Applications: Changes in flow that have the potential to affect beneficial uses can be addressed through a variety of management approaches. Managers need tools to explore potential management solutions, assess the efficacy of management actions, inform adaptive management, and communicate outcomes of their investigations to the public. Ultimately, these investments will support decisions that identify and evaluate management actions and assess them under current and future conditions. Key questions addressed by this portion of the research plan are:

- What actions should be done where?
- Are management actions effective today and will they be in the future?

Socio-Economic Considerations: Management decisions ultimately must consider factors such as economics, potential effects on communities, tribal traditions, cultural considerations, and public safety. A robust decision-making framework must allow for consideration of all these factors and the ability to evaluate tradeoffs in a technically rigorous and transparent manner. This work is particularly relevant when decisions may affect traditionally disadvantaged communities. SCCWRP will partner with relevant social scientists, economists and others to incorporate these elements into its ecohydrology research.

Research Directions

Δ Hydrology

Accomplishments

SCCWRP has built a robust research program in the area of environmental flows that has influenced flow management programs statewide (Stein et al. 2021). SCCWRP and its partners have developed a functional flows approach that focuses on managing key flow metrics to sustain ecological, geomorphic, and biogeochemical functions needed to support native species (Yarnell et al. 2020). Additionally, statewide models that predict the natural range of functional flow metrics serve as first-tier flow targets for every stream reach in the state (Grantham et al. 2022). SCCWRP has also developed technical tools to inform regional flow management decisions, including mapping systems to classify streams based on hydrologic flow patterns (Lane et al. 2018; Pyne et al. 2017) and hydrologic models to extrapolate hydrologic changes in ungauged reaches across southern California (Sengupta et al. 2018). SCCWRP has also developed assessment methods to determine stream flow duration (Fritz et al. 2020; Mazor et al. 2021) and flow perenniality, or persistence of water within a stream (Beck et al. 2017). Finally, multiple projects have explored how future changes in climate (J. Rogers et al. 2021) and wastewater reuse impact stream hydrology and environmental flows (Wolfand et al. 2022; Taniguchi-Quan et al. 2022). SCCWRP has also extended research to consider how changing flow patterns impact estuaries, including El Niño effects (Harvey et al. 2020) and research gaps for managing environmental flows in estuaries (Stein et al. 2021).

Ongoing Research

Projects in this area are focused on better characterizing and predicting hydrologic conditions across ungauged stream reaches in the region. Such research helps understand the variability in hydrologic conditions across space and time in data-limited areas and helps minimize uncertainty in predicting hydrologic conditions.

Ongoing priority projects are focused on improving ways to estimate-low flow conditions and predicting future flow changes:

> ***Project*: Evaluating how functional flows may change under future conditions**
> Changes in climate, including rapid swings of extremely wet to extremely dry conditions, will alter hydrology and aquatic ecosystems. Management actions that do not consider changing climatic patterns may be less effective in the future. SCCWRP and its partners are working to use hydrologic models to evaluate a range of future climate scenarios, including sequences of drought conditions and extreme floods, in a sensitivity analysis to predict how functional flows may change across a range of future conditions. This study will develop characteristic drought-flood time sequences of flow that can be used to analyze the effectiveness of management actions under various climatic conditions.
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> ***Project*: Quantifying low-flow conditions during dry weather**
> Low-flow conditions during the dry season (summer baseflow), are difficult to measure and model. However, many management decisions and policies are being made based on how much water should be in the streams during the dry season and during times of drought. SCCWRP is working to develop scientific consensus on how to improve existing field measurements and modeling tools to quantify low flows. The study goal is to reduce uncertainty in observed and predicted low-flow conditions by developing and testing new field methods and modeling techniques across a range of study reaches, which range from flashy-ephemeral streams to rain- and groundwater-driven streams.

Priorities for Future Research

Future priority projects are focused on informing the location of new gauges, improving our ability to account for the influence of groundwater, and assessing effects in water bodies with limited contact recreation designations.

> ***Future focus area*: Gage gap analysis to ensure sufficient stream flow data**
> Hydrologic models are dependent on sufficient stream flow data. However, the majority of streams in the state are ungauged. California Senate Bill 361 (SB 361) was passed to reactivate, upgrade, and install new stream gages by 2030 based on the 2022 California Stream Gaging Prioritization Plan. This study will conduct a gage gap analysis to identify specific stream reaches, within the previously identified high-priority watersheds, that will improve understanding of low-flow conditions, groundwater-surface water interactions, and stream temperature, and that are of ecological significance. This study will ensure that there is sufficient

stream gaging in Southern California and underrepresented hydrologic stream classes in the state.

***Future focus area*: Understanding the influence of groundwater in stream flow management**

Many managers are required to leave water in the stream and to manage stream temperature – requirements that are typically derived from hydrologic models. However, most conventional models are missing the contribution of shallow, cool groundwater into streams. This study will use remote sensing and machine learning models to predict the likely range of shallow groundwater contributions across stream reaches in the region for different water year types (wet, dry, and moderate). Flow requirements may be adjusted based on this missing element of the water budget. Outputs from this study can also be used to improve the prediction of low flows and stream temperature across the region. This modeling work will also help inform water resource management strategies involving groundwater extraction, wastewater reuse, and dry weather diversions.

***Future focus area*: Understanding the relationship between limited water contact recreation (LREC-1), aquatic life uses, and hydrology**

Reductions in stream flow may lead to social and ecological tradeoffs, especially in urbanized watersheds where access to green space and recreational opportunities may be limited. SCCWRP will investigate how reductions in stream flow are related to limited ability to achieve water contact recreation (LREC-1) and aquatic life beneficial uses. This study will use paired hydrologic-hydraulic models to evaluate how future flow management, water resource management, and/or climate scenarios may affect LREC-1 and access to recreation, as well as aquatic life beneficial uses. This study will produce a suite of sensitivity curves that relate future scenarios and changing flow conditions to the likelihood of limited water contact recreation and support of various species, communities, and/or habitats that are indicative of aquatic life beneficial uses that can be used in a tradeoff analysis.

Δ Physical Habitat

Accomplishments

SCCWRP has done extensive work focused on the effects of hydromodification on physical habitat degradation, which has influenced statewide stormwater management strategies (Stein et al. 2012). For example, SCCWRP has produced mapping and classification systems for streams based on their susceptibility to the effects of hydromodification (Bledsoe et al. 2012). These mapping and classification systems have helped managers prioritize streams for protection and management, as well as design protocols for ongoing monitoring that are carefully designed to assess the effects of hydromodification and the effectiveness of management actions (Stein & Bledsoe 2013a, 2013b). SCCWRP has also developed channel evolution models that help managers anticipate how channels may respond to hydromodification to inform future management decisions (Hawley et al. 2012; Sengupta et al. 2012). Finally, SCCWRP has developed modeling tools to understand how changes in hydrology affect sediment flux and delivery to the coast. This includes the development of sediment flux curves to evaluate the cumulative effects of changing flows on sediment yield (Biggs et al. 2022) and the effects of estuarine sedimentation under sea level rise (Brand et al. 2021, 2022).

Priorities for Future Research

Projects in this area are focused on developing tools and methodologies to better understand and predict how changes in hydrology may affect sediment flux and physical habitat structure in areas that lack sediment and stream monitoring data.

Although there are no ongoing projects in this area, future project priorities will be focused on advancing the ability to assess and account for sediment flux and physical habitat condition and change on environmental flows.

> ***Future focus area*: Sediment flux and transport analysis to fill data gaps**
> Millions of dollars are spent annually on dredging sediment for channel maintenance and flood control. Yet, there is limited information across the region on the relationship between changes in hydrology and sediment flux, and where that sediment ultimately ends up. This study will work to fill key data gaps on sediment flux across a range of representative watersheds in the region. Sediment data will be used to develop regional models that predict sediment flux based on changes in hydrology and other watershed characteristics in unmonitored stream reaches. These models could be used to evaluate the effect of future changes in climate, water resource management, and land use on sediment flux and the effectiveness of sediment management practices in the future.

> ***Future focus area*: Understanding the relationship between physical habitat and stream channel form**
> Together with flow, physical habitat provides the stream conditions necessary for native species to survive, grow, migrate, and reproduce. However, changes to the channel form can alter the relationship between flow and ecology in ways that could mean more or less water is needed in streams. For example, a highly incised stream may need more water to inundate the floodplain compared to a shallower stream. In contrast, if an over-widened stream is narrowed, for example, less environmental flows may be needed to support fish migration. This study will explore adjusting flow-ecology relationships based on channel form. Models of synthetic stream channels will be developed to evaluate the relationship between flow and channel form in unmonitored stream reaches. Such tools can allow managers to adjust flow criteria based on channel modification and explore stream channel restoration scenarios that could provide suitable habitat under a drier flow regime.

Δ Water Quality

Accomplishments

SCCWRP has made promising progress building foundation understanding of the effects of flow alteration on water quality across southern California. For example, in the Los Angeles River basin, SCCWRP has investigated the impacts of effluent discharge reduction on total suspended solids, total dissolved solids, copper and zinc concentrations in the river (Wolfand et al. 2022) as well as contaminants of emerging concern (Wolfand et al. in review). These studies are helping to inform decision-making regarding the challenges of balancing water quality and water supply needs as southern California implements new conservation measures and water resource management decisions. In addition, SCCWRP has modelled changes to flow and stream temperature in response to future climate change (J. Rogers et al. 2021) and stream restoration scenarios i.e., substrate and shading (Abdi et al. 2021). This work includes the impact of these water quality changes on aquatic habitat and beneficial use support that will help direct conservation and restoration efforts as well as support future urban water policy. Finally, SCCWRP has developed statewide tools to predict natural levels of salinization in streams and identify thresholds where increases beyond these levels are likely to harm aquatic life (Walker et al. 2023).

Ongoing Research

SCCWRP is focused on developing and improving tools to assess and predict how changes in hydrology will impact ecologically relevant water quality properties, such as stream temperature, ionic concentrations and nutrients, and adapting these tools for application into lakes and estuaries.

SCCWRP's ongoing projects are focused on improving models of the effects of stream temperature and ionic concentrations and their interactions with flow changes.

***Project*: Understanding the relationship between flow and stream temperature**

Stream temperature is one of the most important drivers of aquatic life success and is highly influenced by hydrology and other factors (e.g., climate change, channel modification, storm and wastewater effluent discharges and riparian shading). SCCWRP has previously developed models that estimate temperature and hydrology independently; however, there is limited understanding of how changes in hydrology impact stream temperature across the region. With this information, managers will be able to determine the proportional influence of temperature on aquatic life use, as well as understand how elevated temperature can be mitigated through flow management and channel restoration. Thus, this study will develop regional temperature models that evaluate the interactive relationship between flow and temperature while also estimating temperature in unmonitored or ungauged reaches. These tools will explore management scenarios (e.g., adjusting flows, increasing shading or modifying the channel geometry) that inform decision-making associated with aquatic life use support.

***Project*: Quantifying ionic concentrations and the effects of increased stream salinity**

Maintaining natural levels of ionic balance is essential to the survival of aquatic life. However, freshwater salinization (i.e., increased ionic concentrations) is increasing due to human activities such as water withdrawals, irrigation, agricultural and urban runoff and industrial wastewater discharges. Hydrology and temperature have substantial direct and indirect impacts on ionic concentrations. For example, increased temperatures can directly increase salinization through increased evapotranspiration. Furthermore, it can affect an aquatic organism's sensitivity to toxic contaminants by disrupting physiological processes. This project will build on previously developed statewide models to predict ionic concentrations in unmonitored stream segments and to consider the interactive effects of flow and temperature on salinity in freshwater systems. This tool will allow managers to prioritize areas affected by increased salinity, while also understanding the extent to which the issue can be controlled through flow and temperature management.

Priorities for Future Research

Future ecohydrology research will include evaluating the interacting effects of flow changes and excessive nutrient concentrations, which can lead to eutrophication. SCCWRP also will prioritize extending ecohydrology research to estuaries.

***Future focus area*: Incorporating nutrients into low-flow hydrologic modeling**

Excess nutrient concentrations in streams (e.g., nitrogen and phosphorus) are a consequence of human activities, including irrigation and agricultural runoff, urbanization, and wastewater effluent discharge. Excessive nutrients can lead to dense algal blooms that harm water quality, resulting in eutrophication. Such complications cause substantial changes to aquatic habitat, impeding aquatic life use. Flow modifications have the potential to exacerbate or improve eutrophic effects. Amplification of eutrophication effects is especially true in periods of drought and low flow, during which in-stream nutrient concentrations can increase dramatically. Understanding the relationship between flow and nutrient concentrations is vital when making decisions regarding regional or statewide eutrophication (or biostimulatory) targets and management actions. Combining research from SCCWRP's Eutrophication research theme with the Ecohydrology research theme, SCCWRP will link nutrient loading and concentrations in low-flow hydrological models. This tool will provide understanding of how low flows and drought conditions, common in southern California, will impact nutrient loads in region, and inform nutrient management decisions. It can also help improve understanding of how flow modifications might be used to help mitigate effects of eutrophication.

***Future focus area*: Extending hydrologic modeling to estuaries**

Any hydrological-related change imposed upstream will have an influence on receiving waters downstream. For example, changes in stream flow can affect salinity patterns, stratification, and frequency of mouth opening in estuaries. However, little is understood about the extent to which flow management, water resource management, and climate change are impacting biotic and abiotic processes in estuaries. This project will develop hydrological models that estimate the impact of altered flow, temperature, salinity and sediment flux on estuarine habitats. The tool will allow managers to consider impacts to estuarine aquatic life beneficial use (EST) in future flow management projects, as well as inform prioritization of estuaries for protection, monitoring and restoration projects.

Δ Biology

Accomplishments

SCCWRP has completed substantial work to understand the relationship between flow alteration and biological response using a variety of ecological endpoints. For example, critical flow ranges have been developed for several species of management concern in the Los Angeles River (Steelhead, Santa Ana Sucker, Least Bell's Vireo) and South Orange County (Arroyo Chub, Least Bell's Vireo) to ascertain protective levels of wastewater reuse (Stein et al. 2021) and nuisance dry weather flows (Taniguchi-Quan et al. 2022), respectively. These flow targets help inform flow management within the basin, and the associated models provide a framework to assess future stormwater or wastewater discharge or restoration projects that may impact aquatic life use. In addition, SCCWRP has developed models to predict the vulnerability of several species of management concern (Steelhead/Rainbow trout, Arroyo Chub, Santa Ana Sucker, Arroyo Toad, Least Bell's Vireo, Southwestern Pond turtle) in response to climate (Rogers et al. 2020) and hydrological change. These tools allow managers to prioritize areas for protection, restoration or conservation efforts as well as identify specific aspects of climate and hydrological regime that need to be monitored or, where applicable, addressed. In addition to vertebrates, SCCWRP has developed predictive models for benthic macroinvertebrates and algae communities (California Stream Condition Index, Algal Stream Condition Index) as beneficial-use indicators that can be used to assess the extent of alteration and inform development of biologically relevant flow targets (Irving et al. 2022) in south Orange and San Diego counties. This includes a broadscale analysis to understand statewide linkages between benthic communities and flow alteration (Peek et al. 2022). Finally, SCCWRP has begun to investigate the relationship between stream biota and water temperature. For example, thermal suitability for steelhead migration in LA River has been assessed (Abdi et al. 2022), and models have been developed to understand the relationship with the benthic community as it relates to temperature limits on effluent discharge in San Gabriel River.

Ongoing Research

SCCWRP's work is focused on developing models for additional species and stream functions, such as floodplain inundation and scour, and integrating multiple interactive stressors, such as flow, temperature and ionic concentrations, to assess the impact the varied biological response. These models will be adapted for use in protective and causal assessment.

SCCWRP's current work is focused on advancing ecohydrology models to account for effects on multiple species and biological functions.

> ***Project*: Relating multiple species and biological functions to hydrology**
> Information that describes the occurrence, abundance, functional traits and life history of species together in relation to physical factors (hydrology, temperature, hydraulics, etc.) is the backbone of ecohydrology model development. Collating data for a diverse array of species, over extended geographical space, will provide the necessary information to develop models that inform management actions. For example, data that describes species populations and life history will help understand long-term effects of management actions, whereas geographical occurrence of species will help to prioritize areas for protection, monitoring and

restoration within a region. In addition, understanding the linkages between seasonal hydrological events and species functional traits will provide additional perspective on the impacts of altered flow (and other stressors) on stream function, and hence support of aquatic life use. Having multiple lines of evidence will inform flow-based decision-making by, for example, questioning whether information for environmental flows should be based on fish species, such as anadromous salmon, in cases where sensitive amphibian species may be a more robust driver of flow criteria. Through previous work, SCCWRP has collated information on several species; however, the data tend to be project- and location-specific. Therefore, this project will collate and map species and associated physical stressor data for inclusion in a readily available database. In addition, through testing and comparison, SCCWRP will develop an approach for prioritizing species and stream function, dependent on management problem and location.

Priorities for Future Research

Priority areas that SCCWRP intends to pursue are focused on development of integrated hydrologic-physical-biological response models and expansion of causal and protective assessment tools to account for flow, temperature and ionic effects.

***Future focus area*: Building integrated biological response models**
Hydrology is interrelated with multiple physical factors that influence biological condition. Not only do these stressors interact physically, but stream biota may show amplified or synergistic responses under the burden of simultaneous pressures for example, elevated temperature affects the physiology of migrating fish such as Steelhead, which impacts their ability to swim against faster currents. However, little is understood about how multiple interacting stressors will affect biological populations and communities in distinct locations and over various time frames (i.e., months, years, decades). This project will build from SCCWRP's previously developed single stressor models to predict the response of varied biological endpoints (individuals, populations, communities) to multiple interacting stressors (i.e., flow, temperature, salinity). These tools will provide a more comprehensive understanding of aquatic life use support that guides managers to the root cause of habitat availability as well as inform prioritization of specific stressors.

***Future focus area*: Protective/causal assessment modules for flow, temperature and ionic concentrations**
Rapid Screening Causal Assessment (RSCA) is a diagnostic tool that identifies likely causes of degradation to water body condition, complemented by protective assessment that identifies likely causes of good water body condition. Both assessments work by assessing broad classes of stressors, i.e., stressor modules, known to impact southern California streams. Stressor modules comprise conductivity, eutrophication, altered habitat and altered temperature. Measures of altered flow or ionic concentration are missing within the current framework. Although altered temperature is included, the temperature indicators collected (i.e., spot temperature measurements and canopy cover) are limited in their ability

to quantify the temporal variability vital to aquatic life support. This project will adapt SCCWRP's previously developed flow, temperature and ionic concentration models to improve the altered temperature module and include flow and ionic concentrations stressor modules in future assessments. These additions will enhance RSCA and enable managers to consider further causes of biological degradation.

Management Applications

Accomplishments

SCCWRP has developed a suite of tools that help managers use the outcomes of assessments and models to prioritize actions, investigate potential solutions, and evaluate effectiveness of those solutions through pilot applications and case studies. One of the earliest of these products is a framework for developing hydromodification management programs aimed at reducing the effects of enhanced flows on stream erosion and prioritizing areas for protection or restoration (Stein & Bledsoe, 2013a). This framework has subsequently been used in many stormwater programs across the state and was used to inform development of regional flow targets to protect beneficial uses (Mazor et al. 2018). Application of these flow targets was piloted in the San Diego River Watershed via a training program that allowed local managers to use the tools developed by SCCWRP (Stein et al. 2017). SCCWRP was a key member of the research team that developed the California Environmental Flows Framework (CEFF), which provides a consistent and unified approach for developing flow targets that is now being used by both the State Water Resources Control Board and the California Department of Fish and Wildlife (Stein et al. 2021). CEFF has been piloted to help prioritize stream restoration and flow management in south Orange County (Taniguchi-Quan et al. 2022, https://sccwrp.shinyapps.io/socfess_shinyapp) and to develop diversion limits for groundwater-influenced streams (Yarnell et al. 2022). Finally, CEFF was used to support deliberations around wastewater change petitions in the Los Angeles River that aim to balance wastewater reuse with protecting aquatic life uses in the river (Stein et al. 2021). The L.A. River project was supported by development of a web-based decision support tool and framework that has the potential to be adapted for other regions (Stein et al. 2021; https://sccwrp.shinyapps.io/lar_eflows_shinyapp/).

Ongoing Research

SCCWRP is focused on developing tools to assess a range of management solutions, evaluate tradeoffs, inform adaptive management, and assess the effectiveness of solutions. Ultimately, this set of tools can facilitate dialogue among stakeholders to produce balanced and defensible solutions.

SCCWRP's ongoing projects are focused on improving trade-off analysis tools and supporting transfer of tools to end-user communities.

***Project*: Tradeoff analysis to support balanced flow management solutions**
Flow management decisions must balance the need to protect aquatic life use with potentially competing demands, such as protection of life and property, economics, and providing recreational opportunities and other community benefits. Such decisions require tools and decision-making frameworks that are

transparent, easily applied and effectively communicated. This project will build on preliminary work completed during the development of CEFF to provide tools and approaches for assessing the relative economic and non-economic benefits and costs of various flow management solutions. The outcome will be a series of user-friendly tools that can be readily applied by resource managers and regulatory agency staff.

***Project*: Technical transfer of ecohydrology tools to support management use**
To apply products of flow-ecology analysis, managers need the ability to easily manipulate and visualize data in ways that allow them to explore alternative scenarios and communicate the potential outcomes to affected stakeholders and funders. Development of these tools must be accompanied by training and support materials that are accessible to a broad spectrum of end-users. Finally, case studies and pilot demonstration projects make application of tools tangible, allow evaluation and refinement of newly developed tools, and ultimately provide templates or roadmaps for broader adoption.

Priorities for Future Research

SCCWRP's future priorities include developing frameworks for adaptive management planning and for assessing the effectiveness of flow management actions.

***Future focus area*: Developing adaptive management frameworks**
Initial implementation of newly developed management approaches is seldom fully successful. These partial successes are valuable learning experiences and allow tools and approaches to be adapted and improved over time. Although adaptive management is an often-cited objective, there is a lack of structured approaches for developing adaptive management programs, selecting targets to trigger remedial action, and gauging success. The goal of this project is to develop template or prototype adaptive management frameworks. These frameworks will support ongoing decision-making, including adjusting operations and maintenance of BMPs and determining when a retrofit is needed and what it should entail.

***Future focus area*: Effectiveness of management actions on aquatic life**
Individual BMPs and other flow management interventions are intended to collectively improve aquatic life use beneficial uses. However, such evaluations are difficult to complete, must be done over extended periods of time, and are oftentimes difficult to scale up to the watershed level. This project will help develop the tools and capacity to assess the individual and cumulative effects of BMPs, stream restoration, flow management, and other interventions on aquatic life use primarily at the watershed or regional scale. By using the same indicators used to develop the management solutions, this effectiveness assessment will ultimately lead to improvement in future management solutions.

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