SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT AUTHORITY

THEMATIC RESEARCH PLAN

FOR

ECOHYDROLOGY

Last Revised May 2016

Table of Contents

Introduction

Ecohydrology is the study of how changes in the frequency, magnitude and duration of hydrological flows affect the structure and composition of aquatic ecosystems. Because hydrology influences nearly all other components of aquatic ecosystems – ranging from physical habitat to water chemistry – hydrology is often considered the *master driver* determining ecological condition of waterbodies. In arid and semi-arid regions such as Southern California, ecological and hydrological relationships are tightly coupled, with waterbody condition vulnerable to seemingly inconsequential changes in flow patterns. As compliance monitoring for aquatic ecosystems increasingly relies on biological endpoints to assess condition, there is a growing need to develop and improve tools and strategies that elucidate ecological-hydrological relationships and how these relationships are impacted by management actions (e.g., flood control, stormwater capture and water reuse practices), by natural climatic patterns (e.g., droughts) and by long-term climate change. Through improved understanding of ecosystem properties, dynamics, functions and biotic-abiotic interactions across multiple spatial and temporal scales, SCCWRP's goals are to model the ecohydrological effects of flow alterations, inform management decisions to reduce and mitigate the impacts of hydrological alterations, and help managers evaluate the tradeoffs that are intrinsic to water resources management.

Conceptual Model

SCCWRP's conceptual model for ecohydrology research is centered around using the sciences of geomorphology, hydrology, ecology and biology to more effectively protect the health of receiving waters 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 three tiers, which build upon one another to ultimately inform management decisions regarding hydrological flows.

Tier I is comprised of research aimed at better understanding the three main **drivers** of hydrological alterations (**Δ land uses**, **Δ climate**, and **Δ water uses**).

Tier II is comprised of research aimed at understanding the **effects** that these drivers have on hydrological alterations (**Δ hydrology**) and associated changes in sediment loading (**Δ sediment**), which collectively lead to changes in habitat structure (**Δ physical habitat**), which, in turn, leads to changes in biological communities (**Δ ecological condition**).

Tier III is comprised of research that applies the findings of earlier research to the development and application of strategies and tools (**Management actions**) aimed at protecting ecological condition and mitigating hydrological impacts. These strategies and tools are both **site-specific** (i.e., solutions that involve **best management practices** and **low-impact developments**) and **regional** (i.e., solutions that involve **source control** and **offsets**). Finally, all of these management strategies and tools must be placed into a decision framework from which managers can evaluate options and make the most effective decisions.

Once management actions are taken, they trigger impacts of their own, creating a need to cycle back to understand these effects as well.

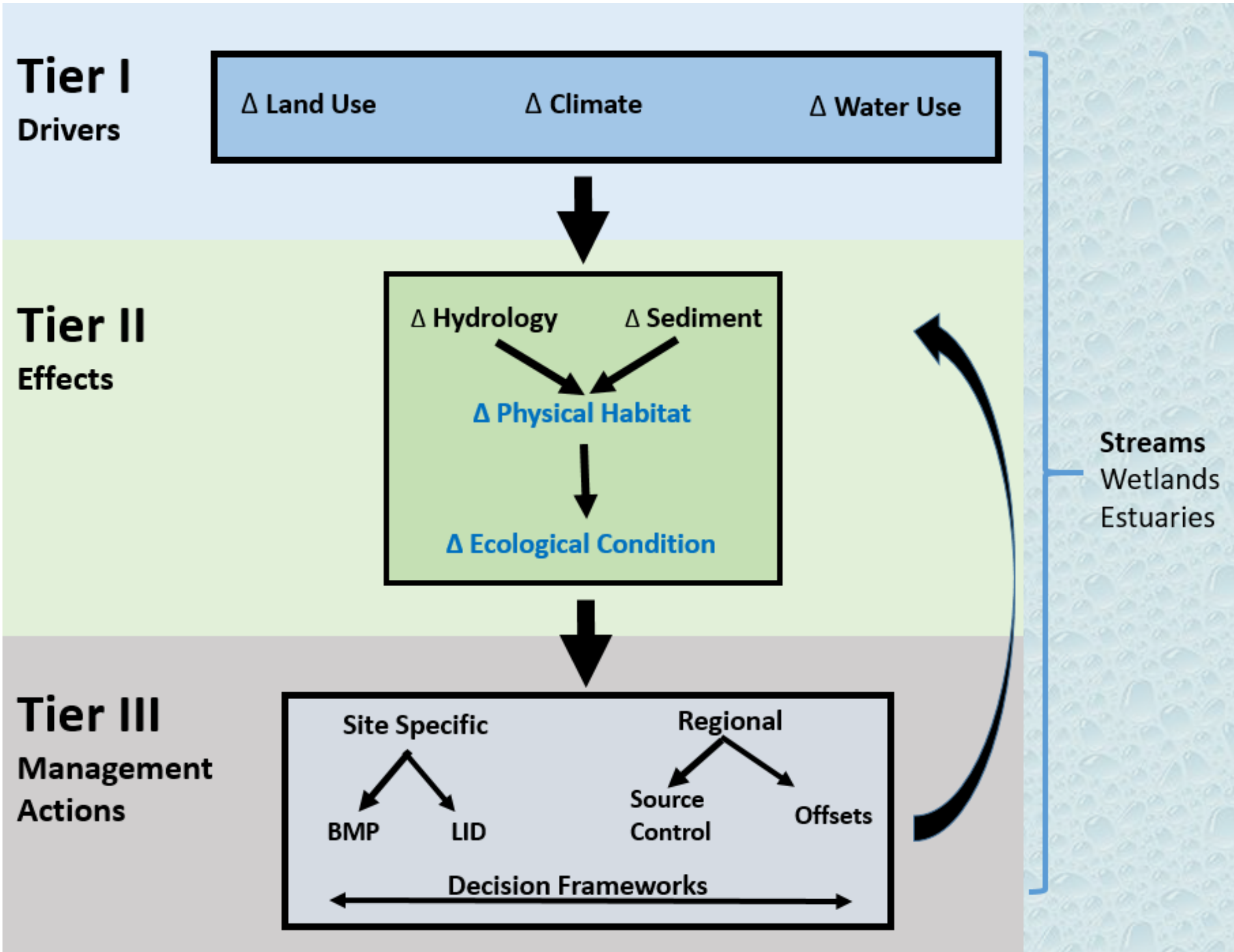

Figure 1. SCCWRP's conceptual model for ecohydrology research is divided into three main research tiers – all designed to facilitate the development of management tools and strategies that protect ecological condition of receiving waters and mitigate the impacts of hydrological alterations. Although this conceptual model was developed for streams, the basic framework applies to wetlands and estuaries as well.

Tier I. Drivers

Changes in land use, changes in climate patterns (both short- and long-term), and changes in water uses all have the potential to alter the frequency, magnitude and duration of hydrological flows and associated runoff patterns.

- **Δ Land Use**: Changes in land use are primarily driven by population growth and economic development, resulting in urbanization of historically agricultural and rural lands. Although the net area that requires irrigation tends to decrease in response to urbanization, the size of this decrease depends on land-use planning strategies. Meanwhile, net impervious surface, increases with urbanization, leading to accelerating runoff velocities and increases in base hydrological flows. Not only does these changes in stormwater runoff patterns increase demand for improved flood control protections, but there also is a net increase in developed lands that will require these protections.
- **Δ Climate**: Changes in climate encompass both short-term changes, such as seasonal or annual variability that can lead to conditions such as drought, and long-term changes that are being triggered by global climate change. Climate change in California will impact hydrological patterns. Preliminary studies of downscaled models indicate an increase in overall temperature in Southern California, a shift from less snow to more rain, and an increased frequency of extreme drought and storms. Under these conditions, the magnitude and duration of hydrological flows will accelerate runoff velocities and alter base flows. This, in turn, has profound implications for aquatic biology. For example, cold-water-dependent fish and invertebrates may be increasingly restricted to high-elevation refugia, and estuaries may shift from brackish to saline environments on a more frequent basis.
- **Δ Water Uses**: As drought-prone Southern California increasingly focuses on development of sustainable water supplies that promote conservation, water-use efficiency, conjunctive use, wastewater recycling, groundwater remediation, and desalination, managers will need to understand the implications of these actions. Specifically, these actions have the potential to affect groundwater-surface water interactions and, subsequently, base and peak flows. Furthermore, as water resource agencies increasingly focus on projects with multi-benefits, such as stormwater capture and reuse of runoff and wastewater discharge (as well as flood plain reconnection and increased groundwater and surface storage), there will be an increased need to understand the ecological implications of these decisions across Southern California, where a large number of aquatic systems during dry weather are dominated by artificial water sources.

Tier II. Effects

Changes in land use, climate and water use trigger alterations both to hydrology and to sediment loading. These interrelated changes trigger changes to physical habitat, and physical habitat changes, in turn, ultimately lead to changes in ecological condition.

- **Δ Hydrology and Δ Sediment**: Hydrological alteration associated with changes in runoff triggers a number of impacts, including modifications to soil moisture, groundwater recharge, and timing and magnitude of runoff and baseflow. When combined with local and regional environmental factors, such as geology and climate, these hydrological alterations trigger changes in sediment production and transport that lead to both altered hillslope sediment yields and subsequent changes in transport capacity. Synergistically, changes in hydrology and sediment yield affect stream channel morphology and ultimately habitat and ecological condition.

- **Δ Physical Habitat**: Changes in hydrology and sediment yield affect nearly all components of aquatic ecosystems, but particularly physical habitat. For example, because urbanized channels tend to incise or migrate laterally, channel planform and depth are likely to be altered and, in response, habitat complexity is likely to be reduced. Similarly, increased summer stagnation can increase solute or pollutant concentrations and deplete dissolved oxygen in ways that fundamentally modify the water chemistry of a physical habitat.
- **Δ Ecological Condition**: Changes in patterns of flow and sediment discharge, mediated by chemistry and habitat changes, can affect the biology of aquatic ecosystems. For example, an increase in stagnant conditions may eliminate benthic macroinvertebrate species that breathe through gills, while favoring species with life history adaptions to hypoxic conditions (e.g., respiratory pigments, or air-breathing structures). These changes can be monitored and quantified through bioassessment, which can reveal the impacts of the many disparate mechanisms by which hydrologic alteration affects aquatic ecosystems. Because organisms are able to integrate the full range of environmental conditions to which they are exposed, bioassessment-based biotic indices are extremely valuable in assessing changes in ecologic condition associated with change hydrology, and other stressors.

Tier III. Management Action

Improved understanding of the drivers and effects of hydrological alterations serves as the foundation for science-informed management actions that minimize the impacts of hydrological alterations and maximize the beneficial uses of aquatic systems. Management actions fall into two main categories based on spatial scale: Site-specific and regional. To evaluate the benefits of various scenarios, managers need all possible solutions to fit into a decision framework.

- **Site-specific management actions**: In many instances, the most effective solution to combat hydrological alteration (or the threat of alteration) is to take site-specific action. These actions typically consist of implementing one or more best management practices (BMPs), such as construction of a stormwater retention basin, or implementing one or more low-impact development (LID) strategies, such as installation of pavement permeable to water.
- **Regional management actions**: More often than not, the most effective management actions to combat hydrological alteration are whole-watershed or regional scale strategies. For example, once the relationship between modified hydrology and biological condition are understood, numeric targets that protect aquatic life across an entire watershed can be set, and tools can be developed to help managers achieve these targets. These numeric targets may vary widely, with desired endpoints that differ based on regulatory requirements, agency mandates and competing demands for use.
- **Decision frameworks**: Armed with all viable management options at their disposal, managers also need adaptive system-based frameworks that can help them optimize possible solutions to achieve multiple endpoints and that help them systematically evaluate the net benefit of different scenarios. A major component of developing these decision frameworks is to conduct case studies; case studies also have the added benefit

of promoting acceptance and ownership of the framework among the key stakeholders who will be affected by it, including regulatory agencies, advocacy groups, and municipalities who are the principle implementers of management actions. .

Research Directions

The field of ecohydrology is becoming increasingly important as modern water management strategies demand rigorous, thorough evaluation of morphological, biological and ecological impacts. SCCWRP's goal is to play a leading role in helping to meet the challenges associated with management of instream flows and the effect on aquatic resources to help balance a set of often competing priorities that encompasses water-supply issues, water-quality goals and ecosystems protection.

Tier I. Drivers

Accomplishments

SCCWRP has provided watershed-based modeling frameworks for multiple water-quality programs across southern California, including support of development of Total Maximum Daily Loads (TMDLs). SCCWRP has developed tools that address variability and confidence of land use and imperviousness relationships at a regional scale (Ackerman and Stein 2008), as well as identified background concentrations from natural catchments that serve as the foundation for multiple modeling efforts in the region (Stein and Yoon 2008, Yoon and Stein 2008). SCCWRP also has chronicled stormwater contaminant loading patterns from Southern California catchments following wildfires (Stein et al. 2012). Finally, SCCWRP has used Ballona Creek as a case study for assessing the impact of development on local water supplies and for assessing opportunities to direct native water to environmental restoration efforts (Liu et al. 2011).

Ongoing Research

***Project*: Using hydrologic models to discern long-term climatic signals**
SCCWRP and its partners are working to discern climatic signals by applying statistical and modeling tools to long-term regional data for water flow, temperature, and quality. The study spans several drought and wet periods, and will serve to develop characteristic drought-flood time sequences of flow that can be used to parameterize watershed models and analyze potential effectiveness of management actions under different climatic conditions.

***Project*: Assessing feasibility of harvesting stormwater runoff to supplement water supplies**
SCCWRP is working on a multi-scale analysis of the capacity for stormwater capture in coastal Southern California, both across time and space (regional, county, and by land use type). The goal is to determine the economic feasibility of harvesting stormwater runoff to supplement existing supplies. The project relies on 20-year plans for the installation of best management practices (BMPs) in Southern California and imposes decadal precipitation variations as boundary conditions on stormwater harvesting. Economic optimization is based on the

volumes harvested vs. the associated costs, such as construction, operation and maintenance.

***Project*: Evaluating impact of sea level rise on coastal wetlands**
SCCWRP is using a combination of coastal flooding models, including the Coastal Storm Modeling Systems (CosMos) projections for estuaries and embayments, and wetland response models, including the Marsh Equilibrium Model (MEM) and Sea-Level Affecting Marshes Model (SLAMM), to evaluate potential effects of sea level rise on coastal wetlands. Sea levels along the California coast are estimated to rise by approximately 1 m to 1.4 m by the year 2100, according to the Pacific Institute. This increase not only puts coastal populations at risk due to flooding, but it also impacts vast areas of wetlands and other natural ecosystems in the vicinity. Results of these analyses will be used to rank relative vulnerability and help inform adaptive management practices.

Priorities for Future Research

***Future focus area*: Downscaling climate change models to aid in water resource planning**
SCCWRP is interested in developing downscaled climate model scenarios for coastal Southern California at a resolution that can be used in watershed scenario analyses. The goal is to understand the long- and short-term impacts of climate change, as these climate predictions are essential for the success of water resource planning. Short-term climate impacts will be generated with existing historical and current precipitation, flow and water-quality data to discern the effects of anomalous weather extremes on water resources. Statistical and non-linear methods will be used to explore factors, such as evapotranspiration, temperature, and vegetation in impacting the observed flows.

***Future focus area*: Quantifying ecological impacts of flow alterations in response to changing water-use practices**
SCCWRP is interested in developing modeling-based frameworks that allow managers to evaluate the ecological impacts of increased capture and reuse of dry and wet weather discharges. Water-use practices are changing as Southern Californians increasingly focus on water reuse and improving the reliability of local water supplies; there is heightened interest in maximizing the potential for stormwater capture and reclamation of treated wastewater. However, these practices have the potential to dramatically impact stream flow patterns. For example, during dry months, treated effluent is the primary source of flow for many Southern California aquatic systems; this means that reclaiming effluent during high-demand dry months for other uses would directly impact the flows in those systems. Thus, as part of this modeling work, SCCWRP will factor in conditions such as magnitude and seasonality.

***Future focus area*: Improving accuracy of estimates of effective impervious area (EIA)**
SCCWRP intends to improve the accuracy of determining effective impervious area (EIA) within a catchment, including developing regionally relevant, robust

relationships between EIA and total impervious area (TIA). EIA in a catchment is the area that is directly connected to receiving waters, while TIA is the total area of the catchment (and is thus simpler to calculate). Studies have shown that EIA is a better predictor of ecosystem alterations in urban streams and that stormwater management strategies developed around EIA – as opposed to TIA – have a significant effect on improving water quality in the receiving waters. However, there is a dearth of localized, validated relationships between the TIA and EIA in the region, with most programs in Southern California relying on a Maryland-based study. Given differences in climate and geomorphology, these TIA-EIA relationships are not always transferable to Southern California; thus, for greater accuracy of the models and for appropriate BMP sizing, regionalized relationships are needed. SCCWRP intends to develop these relationships using a combination of field assessments and modeling efforts.

***Future focus area*: Updating land use-runoff coefficient relationships**
SCCWRP intends to expand an existing database of land use runoff coefficients that was developed for the Los Angeles region from 2002 to 2005 and may or may not transfer well to represent other geographies in the region or contemporary land use practices. This database of runoff coefficients serves as the foundation for local models and planning exercises (e.g., Region 9 stormwater BMP equivalency plan). It is clear that changing land uses and proliferation of low-impact developments have significantly impacted runoff patterns. Updates would be achieved by collecting data from watersheds representative of all of Southern California land uses and hydrology. New remote sensing methods could be used to produce high-quality land-use maps that are linked to discharge locations; regression-based models could be used to develop land-use coefficients for various use categories. As land-use patterns continue to change over time, these coefficients could be updated through ongoing monitoring.

***Future focus area*: Developing watershed modeling frameworks to understand cumulative hydrological and sediment impacts**
SCCWRP prioritizes developing watershed-based modeling frameworks that allow managers to evaluate management scenarios based on cumulative impacts of changes to hydrology and sediment loading. While the independent effects of the drivers on the hydrology and sediment transport have been studied, it also is essential for planning purposes to account for the cumulative impacts of these drivers. In certain cases, they might be synergistic; for example, efforts to capture stormwater might mitigate the flashy runoff predicted in some climate scenarios. In other cases, the effect might be incremental; for example, urbanizing land and flashy precipitation might acerbate the sediment erosion in streams and change runoff patterns.

Tier II. Effects

Δ Hydrology

Accomplishments

SCCWRP has built a robust research program in the area of hydromodification that has influenced statewide stormwater management strategies (Stein et al. 2012). Multiple projects have explored the effects of hydromodification on the degradation of streams and associated loss of beneficial uses, such as habitat for fish and wildlife, stock watering, fire protection, and recreation (Hawley et al. 2012, Bledsoe et al. 2012). SCCWRP has produced mapping and classification systems for streams based on their susceptibility to the effects of hydromodification. 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 and Bledsoe 2013a, Stein and Bledsoe 2013b). Finally, SCCWRP has developed modeling tools that couple hydrologic simulations, physical process models, and risk-based modeling to assess the effects of hydromodification on stream condition, including characterizing changes in runoff associated with changing land-use patterns (Stein and Bledsoe 2013a, Bledsoe et al. 2012).

Ongoing Research

***Project*: Modeling hydrologic flows at ungauged stream sites across Southern California**

SCCWRP and its partners are assessing environmental flow requirements at more than 850 ungauged bioassessment stream sites across Southern California using the Ecological Limits of Hydrologic Alteration (ELOHA) framework, a scientific framework developed to support comprehensive regional flow management (Poff et al. 2010). This project seeks to link changes in hydrology to changes in biological condition, allowing for development of estimates of the hydrological conditions necessary to support in-stream biological communities. There are two stages to this project: hydrologic classification and prediction of hydrologic change. First, streams are classified by grouping them based on similarity in hydrologic patterns, which allows for control of sources of natural variability. This classification effort also helps support initial evaluation of how a stream's natural characteristics and setting influence the relationship between flow and biology, which, in turn, estimates the likelihood that a stream flow has been modified/altered by anthropogenic activities. Second, predictive modeling allows for development of relationships between flow metrics (based on flow alteration between natural and current conditions) and the biological responses. To estimate continuous flow data for current and natural conditions, SCCWRP is using an ensemble approach that involves developing and calibrating a series of regionally representative models. New sites of interest are assigned to one of the ensemble models based on similarity of catchment properties. These rainfall-runoff models are being used to predict the flows at sites of interest. Once developed, the models can be used to estimate potential hydrologic changes associated with future water resource management decisions.

Priorities for Future Research

SCCWRP is interested in improving upon existing predictive tools to provide better estimates of hydrology, sediment, and hydraulic (i.e. channel morphology) changes, including changes in response to potential management actions. SCCWRP also is interested in establishing baseline or natural conditions against which these changes can be evaluated.

***Future focus area*: Establishing baseline/reference conditions through watershed modeling**

To provide context for evaluating current and potential future hydrologic conditions, SCCWRP is interested in using watershed modeling to establish baseline conditions against which future management actions can be evaluated. Baseline conditions could be determined by developing a simulation of natural or unaltered states, or a simulation of an alternative, desired baseline that assumes some impacts from human activities. The baseline will allow for contextualization of future management actions and development of regulatory and monitoring targets.

***Future focus area*: Modeling changes in stream hydraulics in response to changing hydrological conditions**

Because in-stream biological communities change in direct response to changes in the physical/hydraulic properties of a stream, SCCWRP is interested in modeling stream hydraulics. Hydraulic properties can be represented by aggregate hydraulic measures, such as Reynolds number, shear stress, and stream power. Advanced measurement methods (including remote sensing) and stream-flow hydraulic models can be used to map areas of past hydraulic change and to predict future hydraulic changes that have the potential to affect biological communities.

***Future focus area*: Identifying opportunities to protect sediment yield areas**

SCCWRP is interested in developing tools and approaches to identify sediment source areas with high potential for coarse sediment yield that could be used to provide protection to adjacent stream environments. The magnitudes of the sediment loads transported by streams have important implications for the functioning of the system; for example, in-stream habitat quality is affected by material fluxes, geochemical cycling, channel morphology, and erosion and deposition patterns. SCCWRP intends to use GIS analysis, statistical relationships, mechanistic modeling, and Bayesian and machine learning methods to understand how best to assess sediment loading potential as a means to protect and remediate streams.

***Future focus area*: Linking surface water and groundwater models to understand impacts on stream flows**

As management decisions are made regarding the rates at which groundwater and surface water are extracted and used for other purposes, it is important to understand how base flows in streams are impacted by such activities. SCCWRP is interested in developing linked surface water-groundwater models that can evaluate how stream flows are impacted combinations of groundwater extraction and redirecting of surface water runoff and effluent discharge. This modeling work will become more important over time in helping to inform water resource management strategies, especially regarding adaptation to future climate change.

Δ Physical Habitat

Accomplishment

SCCWRP has conducted extensive historical ecologic analyses that have established a framework for understanding the historical extent and function of Southern California's wetland and riparian resources, including how they have changed before and after urbanization (Stein et al. 2010). These studies have yielded historical maps of major wetland types, including riparian forests and tidal marshes, based on sources such as the U.S. Coast and Geodetic Survey of the mid-19th century and aerial imagery from the early 1900s. These maps have been used to assess changes in stream and wetland coverage and to set restoration targets (Stein et al. 2007b, Grossinger et al. 2011, Stein et al. 2014). SCCWRP has also developed and contributed to protocols for assessing physical habitat in streams (Fetscher et al. 2009, Ode et al. 2016) and depressional wetlands (Fetscher et al. 2015). SCCWRP also has created metrics to assess habitat data (plus supporting calculators); developed a training, auditing, and QA program used by major stream surveys statewide; and published several studies on the relationships between these habitat endpoints and biological condition indicators (e.g., Mazor et al. 2014, Mazor 2015).

Ongoing Research

***Project*: Modeling physical habitat changes induced by hydrologic alteration**
SCCWRP and its partners are developing models that predict how hydrologic alterations impact stream physical habitats, a key assessment endpoint for quantifying hydrologic alteration because degradation of stream habitats is a leading cause of stream impairment. Following an approach similar to the one used in the development of the California Stream Condition Index, these models will predict habitat conditions at a site based on natural factors, paving the way to assess the degree to which a site has degraded from natural conditions. This work includes development of regionally relevant flow ecology relationships that predict how changes in hydrology, hydraulics and sediment yield/transport alter physical habitats. Ultimately, these models could be used to create an index of physical habitat integrity in streams, or to set management numeric targets for physical habitat metrics that support aquatic life.

Priorities for Future Research

***Future focus area*: Updating and expanding detailed habitat maps to support physical habitat assessments**
To improve the quality of baseline habitat assessments that managers use to make decisions, SCCWRP intends to continue to produce detailed maps that elucidate habitat structure, land cover, and priority biological endpoints (i.e., target taxa). This work encompasses updates to existing habitat databases, as well as an integrative GIS model that can delineate habitat suitability for key species. These habitat maps can serve a wide range of applications, including for local landscape planning, zoning, delineation of protection zones, landscape framework planning, design of habitat connection corridors or biotope linkage systems and environmental impact assessment. As these maps are developed, SCCWRP also

will look to incorporate unmanned aerial vehicles and other emerging technologies into established technologies and approaches.

***Future focus area*: Understanding historical flow permanence through hindcasting**

SCCWRP intends to use hindcasting to understand how physical habitat characteristics of a stream site influence and help determine the permanency of flow. Flow permanence has tremendous influence on the habitat structure, as it can constrain macroinvertebrate community structure and biological traits. For example, clear distinction is observed between communities in perennial, intermittent springs vs. the main stem of a river. SCCWRP will use simple quantitative indices to determine how substratum and flow help shape habitat permanency, as well as use modeling methods to determine the historical or natural state of flow permanence at different sites and how these conditions are expected to change under future climate scenarios.

***Future focus area*: Developing integrated, multimeric indicators for physical habitat condition**

SCCWRP intends to develop integrated indices or risk assessment calculators that synthesize multiple physical habitat metrics into a single multimeric indicator of physical habitat condition. These condition indices will be able to assess how physical habitats have been altered from those that would be expected under natural conditions.

Δ Ecological Condition – Fixing Past Problems

Accomplishments

SCCWRP has developed several biological indices to assess the ecological condition of streams that provide the foundation for assessing the ecological impacts of hydrologic alteration (e.g., Fetscher et al. 2014, Mazor et al. 2016, California Wetlands Monitoring Workgroup 2013).

Ongoing Research

***Project*: Establishing flow ecology relationships for stream benthic invertebrates**

SCCWRP is developing flow-ecology relationships for the California Stream Condition Index that will allow managers to understand in-stream flow requirements necessary to meet ecological benchmarks. Via various modeling tools, SCCWRP is working to relate data from previously identified metrics of stream flow and hydraulics to statewide taxonomic and function-based benthic invertebrate data. Eventually, flow-ecology relationships will be developed for algal data as well.

***Project*: Incorporating hydrologic alteration considerations into causal assessments**

SCCWRP is developing and refining causal assessment tools that appropriately weigh hydrologic alteration as a possible cause of impairment. This critical area of ecohydrological research will build capacity for managers to be able to use causal assessment methods such as the EPA's CADDIS (Causal

Analysis/Diagnosis Decision Information System) method to understand how hydrologic alteration impacts stream condition. The goal is to help resource managers identify waterbodies where flow management is likely to succeed vs. fail to improve conditions.

Priorities for Future Research

***Future focus area*: Expanding biological indicators used in flow-ecology analyses**

Although SCCWRP has historically focused on developing flow-ecology response relationships for benthic invertebrate communities, SCCWRP is interested in developing analogous relationships using stream algae, estuarine indicators such as benthic infauna, and possibly fish. The overall goal of this work is to be able to relate changes in flow to changes in biological condition for several biological indices in order to improve diagnostic ability and to take advantage of a multiple lines of evidence approach in assessing effects.

***Future focus area*: Creating early detection biological indicators to the effects of changes in flow and habitat structure**

SCCWRP intends to develop diagnostic tools that are able to detect early biological responses to flow and habitat structure changes; thereby providing a screening level tool that can more readily separate hydrologic effects from those due to other stressors. This project will involve identifying the key metrics or integrated indices that are the early and/or best responders to these stressors, then using them in the development of biological indicators specific to these stressors.

Δ Ecological Condition – Preventing Future Problems

Priorities for Future Research

***Future focus area*: Forecasting ecological responses to future management scenarios**

SCCWRP intends to apply watershed modeling tools to predict the impacts of various possible hydrologic management scenarios on flow, sediment and habitat. These predictions can be generated based on existing flow-ecology relationship data and existing thresholds for ecological impact. These models can then be used to inform future management decisions.

***Future focus area*: Identifying streams that are resilient vs. sensitive to hydrologic changes**

Given that preliminary research indicates that some streams respond more strongly to hydrologic alteration or changes in hydrologic drivers than others, SCCWRP is interested in exploring the factors that confer resilience to hydrology-related changes. Factors that appear to contribute to resilience include catchment-scale factors (e.g., large changes in land use that do not significantly change discharge), reach-scale factors (e.g., local geology that constrains the ability of a stream to incise in response to increased flow), and biological factors (e.g., taxa that normally occur at a site that are resilient to hydrologic change). SCCWRP will develop a process for creating maps to identify streams with various levels of resiliency, with a goal of using this information to inform future hydrologic management plans.

***Future focus area*: Evaluating the environmental sustainability of minimum-flow management decisions**

SCCWRP is interested in documenting the environmental sustainability implications for specific biota of interest (such as the Southern California steelhead fish *Oncorhynchus mykiss*) as minimum-flow decisions get made. The goal is to understand how various ecological and social/political factors influence decisions regarding flow targets, and the implications of these decisions in terms of their ability to support environmentally sustainable communities. These issues are important to understand because competing uses for water can inadvertently imperil important biological resources that depend on minimum flows at critical points in their lifecycles. In the case of anadromous fish like the Southern California steelhead, adequate flows are needed to support upstream migration of adults in early spring, to support spawning and juvenile rearing habitat in the summer, and to support downstream migration in the fall.

Tier III. Management Action

Accomplishments

SCCWRP has conducted multiple BMP evaluation studies aimed at better informing hydrological management planning, including modeling analysis following implementation of BMPs in Ballona Creek at the watershed scale (Brown et al. 2013, Stein and Tiefenthaler 2004), multiple BMP/LID evaluation projects in conjunction with the Southern California Stormwater Monitoring Coalition, and an exploration of how BMPs can be used effectively to improve water quality of urban runoff (i.e., through reducing the toxicity and concentrations of metals and organic pollutants) (Ackerman and Stein 2008). SCCWRP also subsequently facilitated implementation of next-generation hydromodification management tools and approaches across Southern California and beyond.

Ongoing Research

***Project*: Optimizing water resource management in a pilot watershed**

SCCWRP is working with an international team to improve water resource management in an Australian watershed by creating a decision support tool to optimize BMP implementation. The modeling study involves developing tools that optimize the density, type and placement of BMP mitigation measures, so they can serve as environmental offsets that improve flow, water quality, and invertebrate and vertebrate habitats. The case study has widespread applicability across Southern California, and provides a roadmap for developing optimized local equivalency plans that support hydrological and biological endpoints. This study also focuses on understanding barriers to this approach to watershed management, and will recommend changes in governance to support more transparent stakeholder engagement processes.

Future Research

As SCCWRP works toward better informing management actions at both the site-specific and regional scales, and integrating this knowledge into a decision framework, SCCWRP's priorities will be to focus on research that spans three main areas: appropriate hydrological and biological endpoints and targets for management, effective BMP implementation strategies to achieve these endpoints, and optimization of the effectiveness of these management strategies.

First, SCCWRP will focus on optimizing the approaches and tools used to determine appropriate management endpoints and targets.

***Future focus area*: Identifying hydrological and biological endpoints linked to management needs**

SCCWRP is interested in identifying endpoints and thresholds associated with various management needs –from bugs and algae and habitat to erosion control and volume capture. The goal is to optimize hydrologic management strategies to achieve multiple management endpoints. This is challenging because while numerous programs have a stated goal of watershed protection, their actual desired endpoints tend to differ based on regulatory requirements, agency mandates and competing demands for water use. For example, the MS4 program uses water quality and bioassessment endpoints to protect watersheds. Meanwhile, various sediment management programs rely on mitigating stream erosion and estuarine siltation, and ensuring coarse sand delivery to the coast, as strategies for restoring sediment balance and improving watershed health. Furthermore, optimizing management strategies becomes more challenging as water-use practices evolve over time and consumption habits for both potable or non-potable sources change. SCCWRP intends to tackle these challenges by engaging stakeholders to identify areas of common interest regarding setting desirable endpoints and thresholds. Once the areas of common interest are identified, SCCWRP will work to reach consensus on the endpoints, and then define the flow-based thresholds for each endpoint using a combination of existing flow ecology relationships and literature – or, when existing information is inadequate, by developing new relationships.

***Future focus area*: Developing a framework to prioritize hydrologic management options**

SCCWRP is committed to developing a decision-support framework that helps managers prioritize possible hydrologic management action. This framework is necessary to evaluate the compatibility of various objectives and to have a process in place to evaluate tradeoffs. SCCWRP intends to hold stakeholder workshops to discuss the hydrologic implications of different management priorities. Then, SCCWRP will use analytical tools such as HEC-RPT to investigate the conflicts and compatibilities of environmental flow regimes associated with various management needs. These management needs might include species protection, water supply, and erosion control.

***Future focus area*: Setting thresholds to measure effectiveness of management actions**

Similar to setting thresholds to assess physical habitat condition, SCCWRP will develop comparable thresholds for measuring the impact or efficacy of hydrologic management plans. Thresholds and/or targets will be developed based on the relationships between shifts in biology – both single metrics as well as integrated indices based on both changes in flow and habitat.

Second, SCCWRP will focus on developing effective BMP implementation strategies for watershed management, and ensuring these strategies are optimized to meet diverse management needs and priorities.

Future focus area**: Optimizing BMPs for hydromodification and flow management**
SCCWRP is interested in assessing individual BMPs and sets of BMPs being used to manage stormwater flows and to mitigate hydromodification risk. These BMPs will be assessed according to three main metrics: (1) performance, which refers to how well the BMPs meet the desired goals for the stormwater that flows through, (2) effectiveness, which refers to how well the BMP system is meeting goals for all stormwater reaching the BMP site, including bypass, and (3) efficiency, which refers to how well an individual BMP or a BMP system removes pollutants, controls erosion or helps meet flow targets. Optimizing BMPs requires careful consideration of each of these metrics. SCCWRP intends to collaborate with managers in the region to implement standardized BMP monitoring protocols (for example, SMC CLEAN), and to evaluate BMP design and maintenance protocols optimized for pollutant removal to determine their efficacy for managing hydrology.

Future focus area**: Quantifying benefits of floodplain and stream restoration**
SCCRWP intends to help the incorporation of floodplain and stream restoration into water quality improvement plans through a two-step process. First, we plan to assess the effectiveness of floodplain and stream restoration by ranking existing floodplains and stream reaches based on the magnitude and severity of their impairment and their net contribution to overall watershed degradation. The goal is to identify the greatest potential environmental benefits that could be gained from moving forward with restoration projects. Second, we will use directed field studies to quantify the benefits of floodplain restoration, both in terms of reversing hydrologic alteration and improving water quality. Sustainable floodplain management practices consist of restoring floodplain areas to their natural condition, and/or increasing retentiveness of water, matter, and sediment to ensure healthy functioning of the ecosystem in a catchment. Quantifying floodplain restoration benefits of will make it possible to use restoration projects as a hydrologic management measure, in both stand-alone and equivalency programs.

Future focus area**: Analyzing watershed vulnerabilities to future hydrologic change**
SCCWRP is interested in developing watershed vulnerability indices that can quantify the impacts of future hydrologic changes in vulnerable areas. Ongoing efforts to protect the highest-quality streams are dependent on being able to assess

not just present vulnerabilities, but also vulnerabilities to future impacts. SCCWRP intends to use landscape assessments to identify areas that support critical processes, such as proving sediment yield to streams or providing connectivity. Through modeling and the results of previous flow-ecology analyses, it will then be possible to evaluate the sensitivity of areas to shifting land-use changes that may trigger altered runoff patterns.

***Future focus area*: Predicting BMP effectiveness along the trajectory of compliance**

SCCWRP is committed to developing tools that help quantify the anticipated level of effort required to implement various BMPs, especially regarding the costs associated with BMP implementation as permittees move incrementally along the trajectory toward full compliance. This research is significant because while the consensus view in the ecological science community is that natural flow regimes are necessary to sustain the ecological integrity of aquatic systems, this objective may not be realistically attainable – and thus managers would benefit from improved clarity before they implement BMPs. For example, if flow regimes have been altered for many centuries, and/or if flow regimes are anticipated to change in lockstep future climate change, the effectiveness of BMP actions could be compromised.

***Future focus area*: Developing offset equivalency currencies for hydrologic management endpoints**

SCCWRP intends to aid its member agencies in developing equivalency/offset currencies for various hydrologic management endpoints, including flow, hydromodification, and water quality. This work is essential as the latest generation of stormwater permits provides the option of offsetting impacts at a site through mitigation measures in other portions of the watershed. These offset measures might include regional detention or retention facilities, stream and floodplain restoration, and low-impact development measures. SCCWRP will develop tools that can quantify the relative value (in terms of hydrologic or biologic endpoints) of these offsets relative to the impacts they are intended to mitigate. In collaboration with member agencies, SCCWRP also will identify test watersheds that will be used to quantify how offsite equivalency measures can mitigate hydrologic change and protect downstream reaches.

Third, SCCWRP will focus on providing ongoing implementation support to ensure the smooth transfer of tools and strategies to end users.

***Future focus area*: Infusing automation into ecohydrology scoring and assessment tools**

Because ecohydrology assessments require the use of models and other scoring tools that may involve processing large data sets and conducting detailed and complex analyses, SCCWRP is committed to developing automated scoring and assessment tools that can facilitate interpretation of scores by non-technical experts. These tools will ensure managers can take advantage of automations to analyze ecohydrology data in a consistent, streamlined and unbiased manner. SCCWRP will focus on developing a variety of user-friendly protocols to support these tools, including user manuals, training programs, quality assurance procedures, automated scoring tools (i.e., calculators), and data management infrastructure.

***Future focus area*: Coordinating integrated monitoring approaches to improve hydrologic management outcomes**
SCCWRP intends to help develop and demonstrate integrated monitoring approaches for assessing effectiveness of hydrologic management strategies, including alternative compliance measures, and overall watershed health. The goal of these coordinated monitoring approaches will be to optimize the ability to manage hydrology to protect biological endpoints. With these integrated monitoring approaches, the efficacy of new management strategies can be evaluated, and ecohydrology monitoring can be connected to existing monitoring programs, with strategies leveraged with existing efforts to allow information sharing across programs.

***Future focus area*: Test-driving flow-habitat-ecosystem relationships through case studies**
SCCWRP intends to develop case studies with willing partners to demonstrate application of new ecohydrology assessment tools and management approaches. Case studies provide a mechanism to demonstrate how new assessment tools and management strategies can be implemented to inform resource management decisions. Case studies also provide a process for figuring out the details of how new programs may be implemented in a controlled and limited setting, as well as provide powerful examples that can be emulated by future adopters.

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