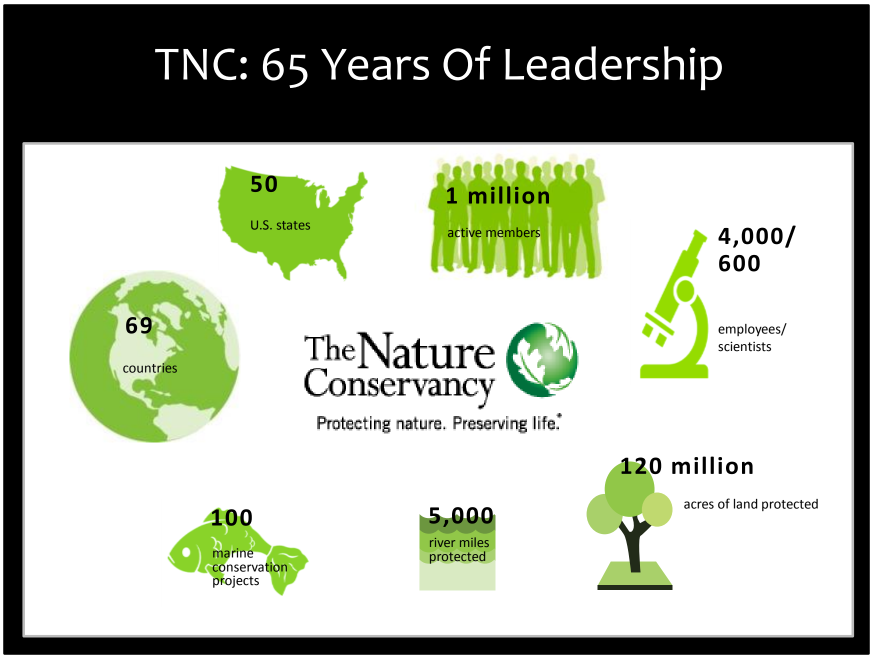


- The Nature Conservancy is a conservation NGO with 4,000 employees and 1 million members in all 50 US states and 69 countries.
- Our mission is to conserve the lands and waters on which all life depends.
- With 600 scientists on staff, we are strongly science-based.
- We bring new, scientific approaches to pragmatic, collaborative problem solving. Rather than oppose development, we work directly with local communities, businesses, governments, and financial institutions to find smart development paths that achieve economic and social goals while minimizing environmental impacts.
- USGS is one of our most important partners: > 124 co-authored publications since 2000, many more project collaborations

National water resource challenges over the next 25 years

- Water scarcity and allocation – sustain water for people and the environment
- Water quality – support designated uses of our nation's water bodies
- Risks to freshwater biodiversity – restore species at risk and protect native species and assemblages
- Non-stationarity – design water resource and infrastructure decisions to account for changing hydrology and other conditions

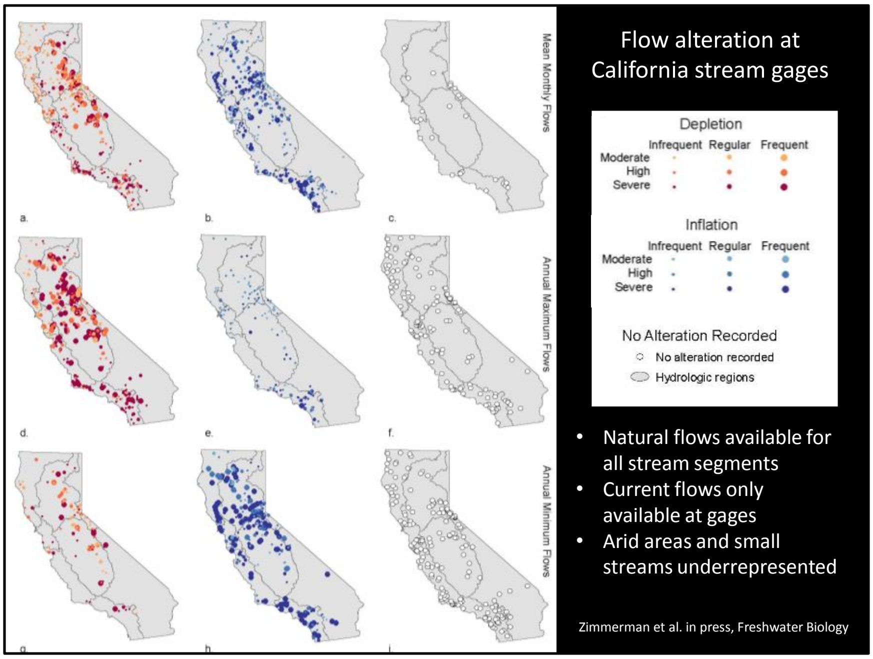
- TNC's perspective on water resource challenges over the next 25 years
- 4 categories:
    - Providing sufficient water for people and nature
    - Supporting designated uses by managing water quality, including temperature
    - Restoration and protection of native species
    - Managing for a "new normal" under changing hydrology, temperature, sediment regimes, species assemblages, other factors

Water scarcity

Provide adequate water to meet social, economic, and environmental needs

- Articulate full sets of value-based objectives for water resources (all uses)
- Support decision making through trade-off analyses and stakeholder engagement
  - Create models to evaluate trade-offs among competing objectives under management scenarios
  - Synthesize data to support decision making
    - Natural flows, lake & groundwater storage
    - Current flows & groundwater/aquifer storage
    - Predicted conditions under changing demands and climate
    - Groundwater-surface water interactions

- Many watersheds are currently fully or over-allocated
- We expect competing objectives for water allocation: human demands are likely to increase and we have or will have insufficient environmental allocations without protections for ecological outcomes
- We need to fully articulate value-based objectives for water needs and develop tools and data to support trade-offs analyses and decision making

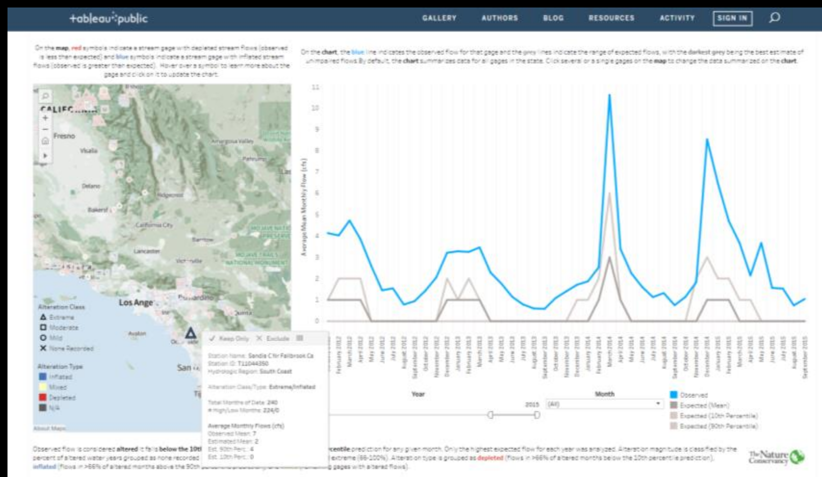


- We utilized machine learning statistical models to predict natural monthly flows (natural stream flows without the influence of water management or anthropogenic land use) in California from 1950 to 2015, using time-dependent and fixed watershed variables from reference stream gages. These models were then used to make estimates of mean, maximum, and minimum monthly flows in all streams in the state.
- We compared observed flows measured at 540 stream gages across the state with expected natural flows at the same locations,to quantify the type, frequency, and magnitude of flow alteration over the past 20 years (1996-2015). A gage was considered altered if an observed flow metric (monthly mean, annual maximum, annual minimum) fell outside the 80% prediction interval of the modeled flow estimate.
- We found that 95% of the 540 stream gages in California had at least one month of altered flows over the past 20 years, and 11% of gages were frequently altered (over ⅔ of the months recorded had evidence of altered flows). The type of alteration varied across the state with flows being either depleted, inflated, or a mix of both at different times of the year. Most altered gages (68%) exhibited both depletion and inflation in monthly flows over the time period. Inflation of monthly mean flows was most prevalent during the summer months while depletion of

monthly flows was evident throughout the year.

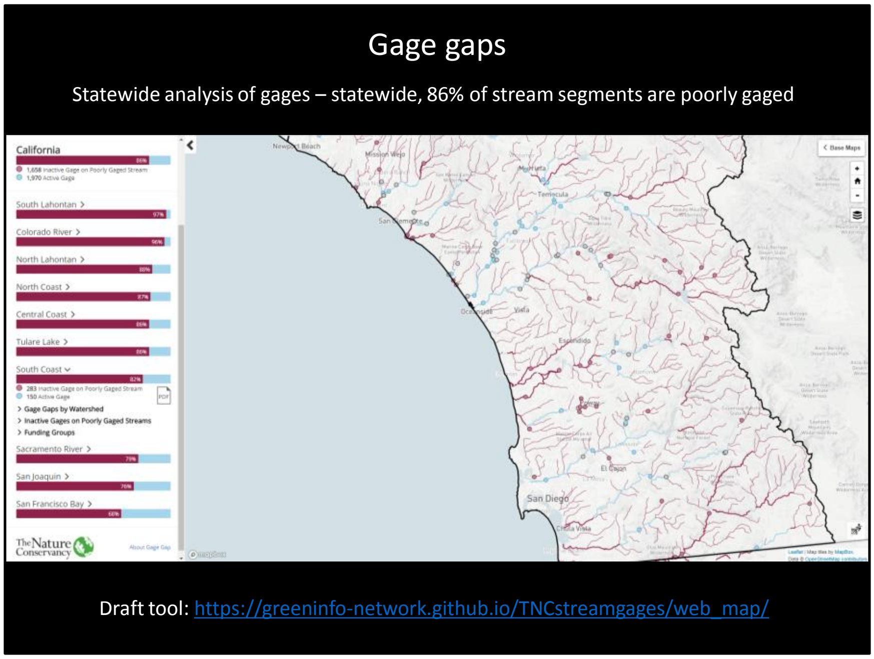
- There were notable differences in patterns of flow alteration among regions, which correspond to distinct climate conditions and water-use pressures.
- Streamflows can be altered in subtle and distinct ways. Streams found in close proximity can display dramatically different patterns in flow alteration and individual streams may be altered in some years and not in others. Furthermore, the type, timing, and magnitude of alteration can vary substantially within a year at a single stream.
- As the quality and resolution of geospatial data increases, model performance could be expected to improve. Model performance is also highly dependent on the number, spatial distribution, and period-of-record of reference quality gages

Flow alteration at California stream gages: visualization tools for gages



https://public.tableau.com/profile/kklausmeyer#!/vizhome/California_Stream_Flow_Alteration/mean
https://public.tableau.com/profile/kklausmeyer#!/vizhome/California_Stream_Timing_Alteration/minmax
API for natural flow data: https://rivers.codefornature.org/

- In addition to statewide analyses, we are using the natural flows database to visualize predicted and observed flows and individual gages
- This gage in San Diego county helps illustrate the complicated picture of hydrologic alteration in California, where water is moved from wet to dry areas and from wet seasons to dry seasons
- Streams in southern California are often naturally intermittent. However, runoff from urban use and wastewater treatment often creates perennial streams and support novel ecosystems
- We can only visualize these patterns for gaged streams and need synthesized current flow datasets to get a complete picture of flow alteration at ungaged sites



- A statewide analysis by TNC found that 86% of stream segments statewide are poorly gaged.
- Small streams and arid areas are particularly underrepresented.
- Without a complete gaging network, we need to develop other methods for developing a hydrologic foundation and water budgets

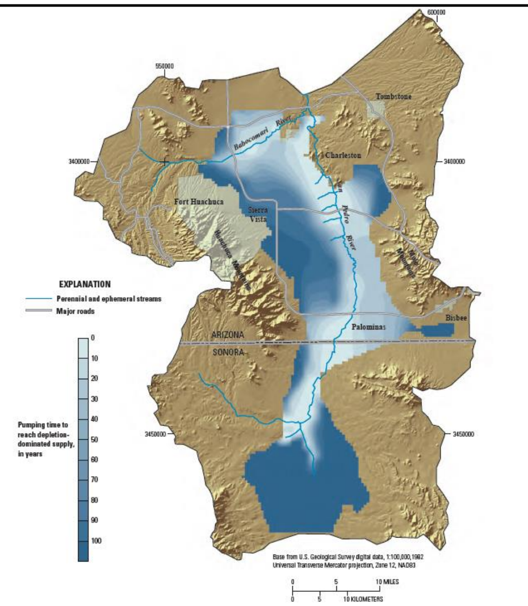
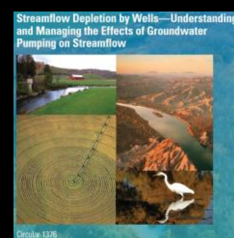


Figure 48. Computed time to reach a depletion-dominated supply of pumped water for the lower basin-fill aquifer in the Upper San Pedro Basin, Arizona, when streamflow depletion exceeds half of the pumping rate.

San Pedro basin

- Modeling of streamflow response to groundwater pumping
- Interactions between aquifer recharge and streamflow depletion
- Basin-wide analyses to estimate and manage depletion
- Identify sites for artificial recharge



https://pubs.usgs.gov/circ/1376/pdf/circ1376_barlow_report_508.pdf

TNC used the model to identify locations for artificially recharging urban stormwater in order to have the water discharge to the depleted San Pedro River when and where it was most needed.

Minute 319

- Agreement between US and Mexico on allocating Colorado River water
- Binational science team, including USGS
- Detailed monitoring plan included USGS implementation of piezometers and temporary streamflow gaging stations
- No specified monitoring budget for USGS – critical elements of monitoring plan were not implemented
- Succeeded by minute 323 with specified monitoring budget, implications not yet clear

Reference notes:

Minute 319, an historical agreement between the United States and Mexico, changed the way the two countries share Colorado River water during times of surplus and drought. Among its provisions was an allocation of funding and water to restore degraded ecosystems in the Colorado River delta and the creation of an Environmental Workgroup for stakeholders to oversee these activities and monitor and evaluate the hydrologic and ecological impacts of the environmental water deliveries. The Environmental Workgroup convened a binational science team, which includes federal agencies, universities, and NGOs (including TNC) to develop and recommend plans for water delivery and monitoring.

In 2013-14, the Minute 319 science team, which includes USGS, developed a binational monitoring plan for environmental activities. Thereafter, implementation of the plan was conducted by institutions represented on the science team. Minute 319 did not specify a monitoring budget, and the U.S. Bureau of Reclamation emerged as the principal funder of monitoring activities. However, USGS funded its own activities. USGS implemented elements of the monitoring plan, including installing and monitoring 7 piezometers (while Mexico installed and monitored nearly

100) and several temporary streamflow gaging stations. Although USGS was expected to monitor these sites through 2017 (the term of Minute 319), in fact they ended data collection after a few months. Thankfully, the Yuma USGS office conducted field training with their Mexican counterparts, ensuring consistency in data collection methods. USGS also conducted QA/QC for Mexican water data obtained as part of Minute 319, although they only evaluated a subset of the data; to this day, most of the hydrogeologic data has not been properly checked. Notably, because USGS funded its activities independently, the scope of its activities went beyond those identified in the monitoring plan, while critical elements of the monitoring plan were not implemented due to lack of available funding.

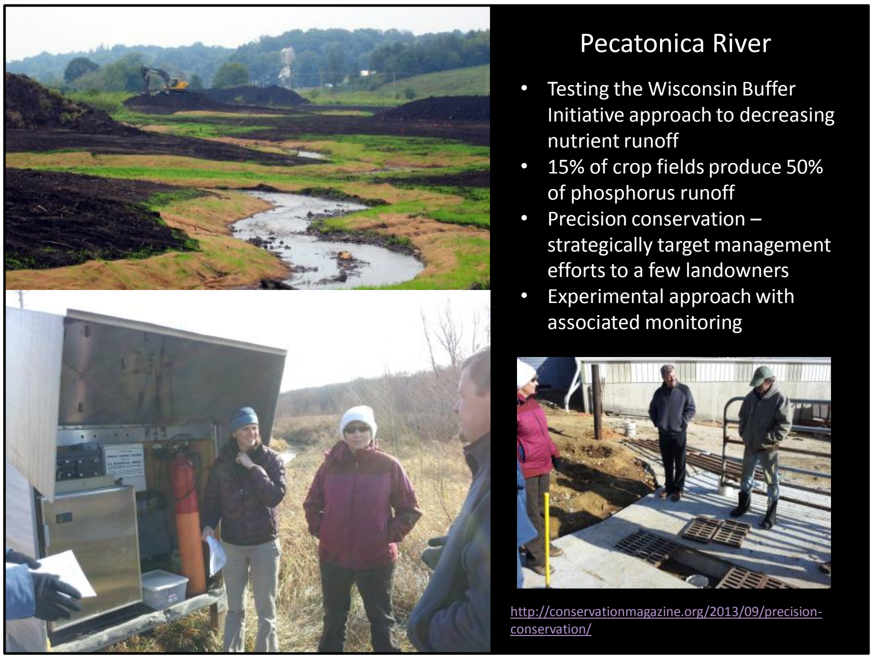
Minute 323, in force 2017-2026, succeeds Minute 319. Minute 323 specifically identifies a science and monitoring budget of $9 million, to be contributed in equal shares by the federal governments of the US and Mexico as well as a consortium of NGOs. Again, a monitoring plan will be developed by the science team and recommended to the Environmental Work Group, and again we expect a host of institutions to collaborate in implementing plan elements. We understand that USGS volunteered $2.6M for monitoring, again in-kind, thus comprising the vast majority of the US commitment. We are hopeful that in spending their funds, USGS will adhere closely to the monitoring plan, and that USGS would be willing to pass funds to other institutions if they can implement monitoring activities more readily or cost-effectively. This kind of cooperation will be essential to ensure that available funds are optimized to support as much of the Minute 323 monitoring plan as possible.

Water quality

Ensure our nation's waters can support designated uses for agriculture, water supply, recreation, aquatic life

- Meet nutrient criteria through cost-effective management practices
  - Monitor nutrient loads at the mouths of sub-watersheds to test hypotheses about management practices on downstream nitrogen and phosphorus, nutrient trading, other practices
- Manage temperature to mitigate streamflow alteration and climate change
  - Develop additional temperature modeling approaches and large-scale datasets

Develop management practices to meet water quality objectives, including temperature. Build models and synthesize or collect data to test hypothesizes about management practices to ensure actions are achieving conservation outcomes

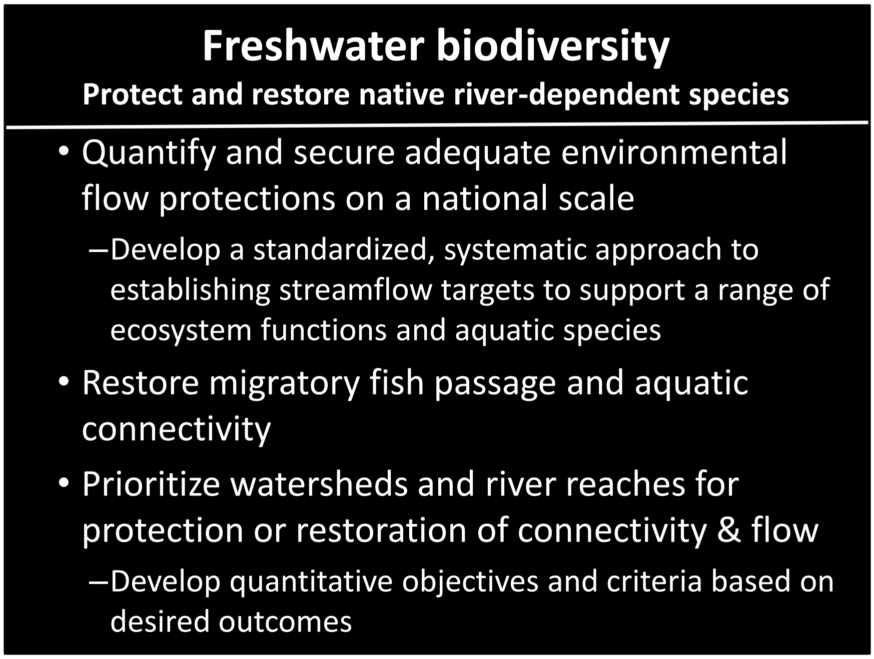


- Pecatonica is a major tributary to the Mississippi River and the site of a collaborative project to test effectiveness of precision conservation
- The Wisconsin Buffer Initiative (WBI) is a state-wide coalition of researchers, farmers and conservation practitioners who are working together to find more effective ways to improve water quality in streams
- We found that 15% of the crop fields and pastures (or only ten fields on ten farms) within this watershed was contributing 50% of the phosphorus. We are successfully working with eight of them to implement land management practices that support conservation. Our goal with these landowners is to identify conservation practices that are compatible with their farm's current cropping and livestock system and, where possible, increase or don't significantly reduce profitability.
- To measure the health of the stream, we are gathering data on water quality and fish and invertebrate populations in a control watershed, where no conservation action is taking place, as well as the test watershed where we are working with the eight farms
- An estimate, based on a software program called SNAP-Plus that calculates soil loss and phosphorus run-off from any given field, is that we will reduce the levels of phosphorus delivered to the streams within the test watershed from cropland

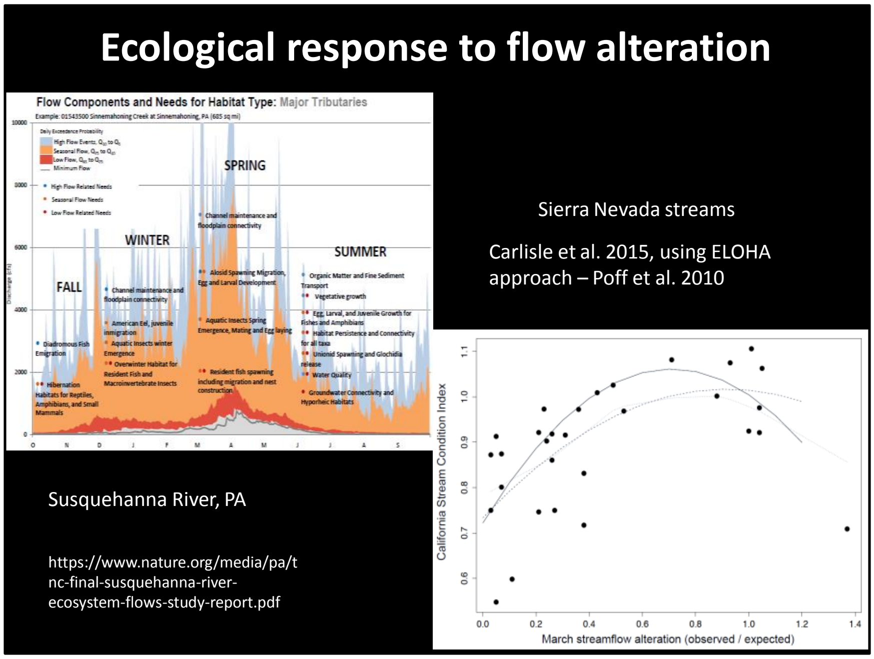
and pastures by 20-30% and will reduce stream bank contribution of phosphorus and sediments to the stream from eroding stream segments, primarily by reducing cattle access

- Right now, there are 15 additional watershed projects beginning to implement similar practices in Wisconsin

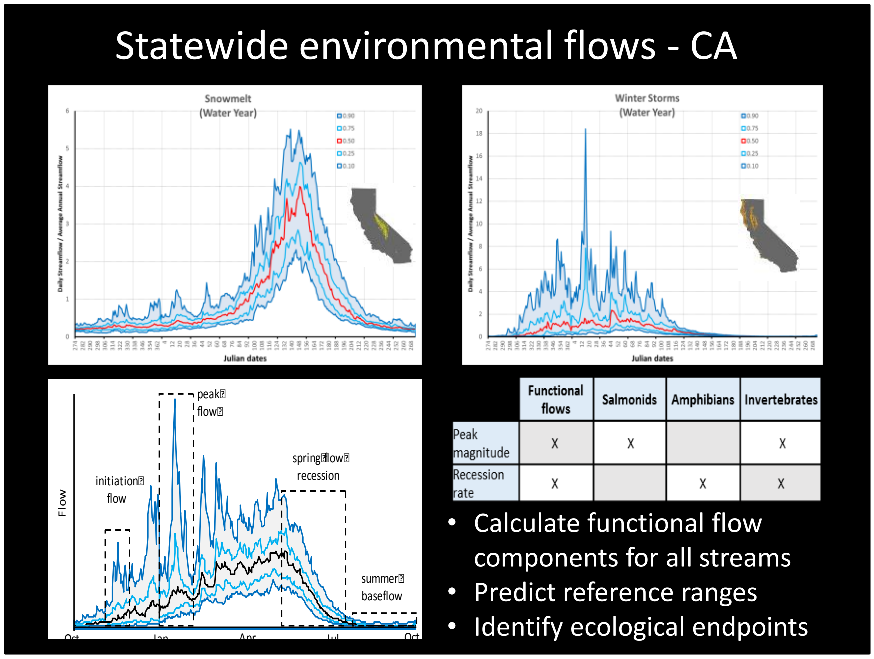
- Need to explore novel and creative solutions for addressing water quality and other related problems on a global scale
- Nature-based solutions, such as source water protection, have the potential to provide water quality and quantity benefits for cities as well as other ecosystem services
- Protection and management of source watersheds can provide clean and abundant water supplies, climate adaptation, fire risk management, and recreational opportunities, among other benefits
- Can be supported by financing tools such as water funds that enable downstream water users to jointly invest in upstream land conservation and restoration to secure improved water quality and regulate water supply. Over the past 15 years, the Conservancy has helped established 29 water funds worldwide and currently has another 30 in development.
- The water fund model was first applied in Quito, Ecuador in 2000, in response to the degradation of the natural landscape where water sources are located.



- Develop a standardized, systematic approach to establishing streamflow targets to support a range of ecosystem functions and aquatic species.
- Currently, efforts are largely fragmented and narrowly focused on local, species-specific needs.
- Promote consistency and coordination in establishing, maintaining, and monitoring instream flow requirements



- Most studies that document ecological responses to altered flow focus on discrete metrics rather than flow regimes, making it difficult to fully characterize hydrologic alteration and relate it to specific changes in species or communities
- Most streamflow studies are still applied at the reach scale (e.g., IFIM), although there is a body of work supporting regional approaches (e.g., ELOHA)
- Studies that characterize flow regimes (e.g., Susquehanna) rely on hypothesized links between flow and ecological response based on species traits or seasonal life history needs/events
- Studies that quantify ecological response to flow alteration measure change as a response to individual metrics
- Develop approaches that can characterize dynamic hydrology and characterize potentially complicated patterns of alteration (reduce the use of individual metrics) and have predictive links to ecological outcomes (Poff 2017, Freshwater Biology)
- Also need to incorporate non-flow variables – temperature, sediment, water quality, habitat, etc.



- A current California project has the goal of supporting various regulatory and management agencies in developing and implementing local, regional, and statewide in-stream flow targets to benefit fish and wildlife by providing a coarse resolution set of environmental flow recommendations for all streams in the state and guidance on refining those recommendations with local or regional data.
- The outcomes from the project will provide a statewide assessment of environmental flow conditions that can be used to prioritize the need for more intensive investigations into stressors and mitigation measures and to assess the efficacy of those mitigation/management measures over time.
- Coarse resolution environmental flow recommendations are based on the concept of functional flows (Yarnell et al. 2010, Bioscience) calculated from reference hydrology (historical flows at reference gages)

Non-stationarity

Design water resource and infrastructure decisions to account for changing hydrology and other conditions

- Manage for increasing frequency and magnitude of floods and droughts
  - Quantify predicted hydrologic change
  - Analyze risks to current infrastructure
- Inform investments in adaptation strategies
  - Develop tools to guide implementation and assessment of natural infrastructure, such as floodplain and wetland restoration
  - Assess the potential for source water protection to contribute to carbon sequestration

- Changes in hydrology, temperature, sediment regimes, non-native species, and other factors mean that we can no longer depend on historical reference conditions fully informing future decisions
- Restoration to reference conditions is no longer possible in many places
- Current infrastructure may be designed to manage scenarios that are obsolete or not informative of future risks
- Managing for non-stationarity and shifting baselines includes:
  - Synthesizing future data (hydrology, consumptive use, temperature, land use, species extent, etc.)
  - Analyzing risk to current infrastructure
  - Evaluating alternative management strategies and infrastructure that maximize adaptation to changing conditions and contribute to carbon sequestration

Reference notes:

INCORPORATING CLIMATE CHANGE INTO TODAY'S DECISIONS & ACCELERATING ADAPTATION. Provide clear methods and data to account for hydrologic conditions under a changing climate in a way that can inform water allocation & infrastructure investment decisions (gray and green). This includes clear methods to estimate both the magnitude of the problem (floods and droughts), an empirical understanding of interactions of climate change and land-use change and subsequent hydrological changes and providing science-based support for the effectiveness of solutions.

Understanding the scale of the problem.

Using GCM's, USGS, perhaps in concert with NOAA/National Weather Service could develop regionally downscaled data (HUC 8's?) to estimate changes to seasonal and interannual water availability and stream temperatures. Sub-seasonal forecasts will be especially useful in real-time water management decision-making, per the USBR 'Sub-seasonal Climate Forecast Rodeo'.

Investigate the magnitude of expected climate change on our water systems as compared to the ability of various water management strategies to address related challenges. Will our strategies be effective given climate change or will climate change make our strategies irrelevant?

Inform investments in adaptation strategies.

Grey infrastructure. Have a significant existing problem of aging and obsolete water infrastructure. None of it was constructed to handle changing climate conditions. Opportunity to develop regional plans to decide where to modernize and where to remove to meet broad sustainability objectives. Opportunity to develop data to support the development of these types of comprehensive basin management plans.

Catalog current infrastructure risks and risk under a changing climate. Continue to support the USGS Powell Center for Dam Removal Science in collating monitoring data on the risks and benefits (public safety and ecosystem) of hundreds of dam removal projects.

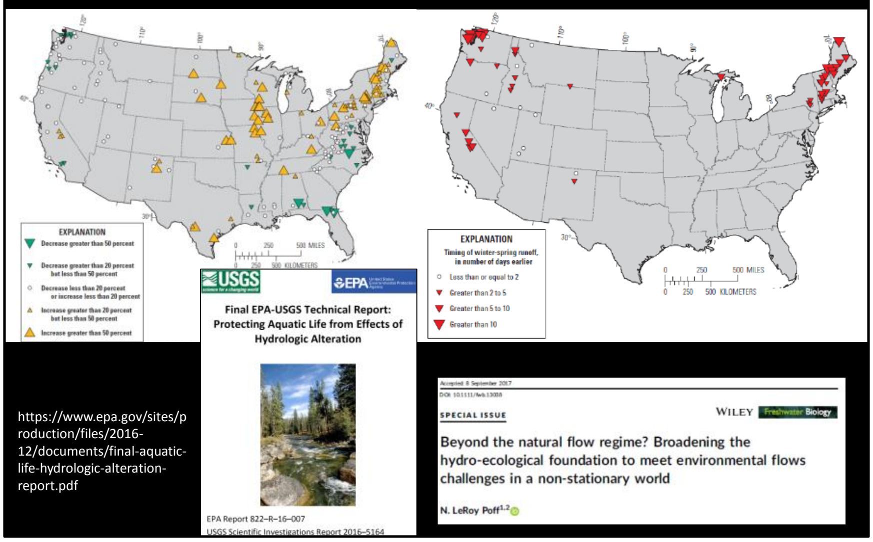
Nature-based solutions. Provide science-based guidance on where nature-based solutions could be most useful in adapting to climate risks (floods, droughts, fire, water quality, etc.), accounting for the relative benefit of nature-based solutions (conservation & restoration) in meeting water management challenges in a way that can clearly guide future investments;

- Monitor the hydrologic and water quality impacts of restoring floodplain functions. Use the data to estimate the areal extent of floodplain restoration needed to meet flood management and nutrient reduction goals.
- Monitor the impacts of source water protection on water quality, quantity and in sequestering carbon, as appropriate
- Quantify the hydrologic and water quality impacts of forest management to reduce

wildfire intensity (e.g., thinning trees). We may have watershed-scale applications to monitor and compare to control watersheds.

- Join with us to build the case that aligns the health, development, and environmental sectors around a shared evidence base linking our common problems and solutions?
- Committing to long-term monitoring (>20years) in critical basins to understand the true hydrologic nature of the basins and how this may be shifting over time.
- Ensuring monitoring is occurring at varying spatial scales to improve our understanding of the micro and macro hydrologic processes across the landscape.

Trends in the magnitude of 7-day low streamflows in the United States, 1940-2009



- Non-stationarity is an emerging challenge for environmental flows science (Poff 2017) as well as infrastructure development and water resources planning
- Needs: 1) ecological foundation at broader spatial scales (at least regional), 2) mechanistic understandings of hydrology and flow-dependent outcomes, 3) analysis of non-flow factors, 4) special attention on extreme events (magnitude, duration, frequency)

- Possible solutions include managing for resilience – infrastructure, communities, etc. that are able to function, persist, and thrive under changing conditions
- Research needs include predictive relationships between anticipated changes and desired outcomes; tools that can help visualize managing for resiliency

Emerging themes: research needs

- Decision analysis: articulate value-based objectives and evaluate trade-offs
- Applied tool development: models, tools, monitoring to directly support decision making
- Water budgets: quantify unimpaired, current, and future conditions nationwide for streams and major aquifers
- Integrated water management: model interactions between groundwater and surface water to characterize supply
- New approaches to management: Implement and monitor creative tools and nature-based solutions

Reference notes:

Decision analysis:

Involve stakeholders to articulate quantitative objectives for all water needs. Develop models that can predict trade-offs among competing objectives under different management scenarios. Implement monitoring in an adaptive management context to test predictions and adjust actions in response.

Applied tool development:

Continue building partnerships with innovative technology developers to address some of the technical challenges that could help us improve management of water systems, such as with cheaper, more accurate monitoring equipment, artificial intelligence, improvement of real-time and remote-sensing data and automated data collection and analysis systems. Bringing together experts in water management and high-tech innovators could help us leap forward in addressing some of our science challenges.

Water budgets:

Characterizing surface water supply. Developing a nationwide hydrologic foundation that includes (1) unimpaired flows, (2) current flows, and (3) projected future flows under changing conditions (climate, land use, water demand.

Declining aquifers & groundwater supplies.
Continue to improve our knowledge of the changing state of our groundwater aquifers to help us better address growing challenges in groundwater water quantity and quality. Quantifying groundwater availability in the major aquifers nation-wide, and quantifying limits to withdrawal that prevent these resources from being mined to a point where they will no longer support nature, communities, and irrigated agriculture. Build and calibrate priority groundwater models at appropriate scales to guide specific projects. Some examples:

- Regional groundwater model of the Mexicali Valley/sustainability of Minute 323 in light of regional groundwater pumping and irrigation efficiency projects.
- Groundwater models that can be used to make decisions about where irrigation efficiency, water rights retirement, or other practices will benefit water tables as well as stream baseflow and spring discharge. An example of this is the current groundwater modelling project in the Harney Basin in eastern Oregon.

Integrated water management:

Understanding of the connections between surface water and groundwater, including related to water quality, to help support expansion of conjunctive management of water resources.

- Evaluate groundwater-surface water interactions to support implementation of groundwater regulations (e.g., SGMA) and development of environmental flow recommendations that incorporate groundwater dynamics.

New approaches to management:

- Water Funds as mechanisms to support source water protection and carbon sequestration; floodplain restoration to decrease flood risk