Scoping Climate Science and Decision-Support Needs for Floodplain Management in Puget Sound

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Overview

The purpose of this document is to begin defining an agenda for the science and engagement efforts needed to support the integration of climate change in multi-objective floodplain management. To do this, we propose a 3-tiered approach involving work at the regional, watershed, and project scales (Table 1). At each level, efforts to advance the science will be accompanied by stakeholder engagement aimed at defining science priorities and advancing the capacity to incorporate climate impacts in decision-making.

In the sections below we have summarized a number of actions, with their associated outcomes, assuming that the geographic scope is limited to the Puget Sound catchment. In writing the descriptions below, specific watersheds and projects have intentionally been omitted from the descriptions. Over the course of this project, it became clear that the discussions needed to identify the specific science and data needs of each stakeholder or project would require much more than was scoped for the current effort. Instead, we have distilled the results of these conversations into a set of research gaps that would address a wide range of planning and project needs, as well as a number of actions that would serve to further elucidate the science needed to support multi-objective floodplain management in the region.

Both feasibility and cost for this work will depend on the exact combination of efforts, priorities, and funding that is available for leverage. Moreover, these efforts can be undertaken by any number of entities in the region, depending on suitability and expertise. Nearly all of the efforts would require some degree of collaboration; potential partners include the many agencies, non-profits, and other institutions in the region.

Finally, it is important to emphasize that the tasks outlined in this document are intended to be a starting point for discussion. For instance, the research outlined here is focused on characterizing the physical changes that are of relevance to habitat, agriculture, and people – other research may be needed to quantify the specific impacts of interest in each sector. We view this as a living document: it is intended to provide a helpful framing for discussion, but is likely to change significantly over time based on input from researchers and stakeholders with varying points of view.

Table 1. Climate Architecture for Developing a Research Approach and Climate Work Plan for Floodplains by Design.

	Risk and Opportunity Assessment/Education	**Policy and Planning**	**Implementation**
	Working with stakeholders to identify key interests and concerns, and developing science and data products that are tailored to decision needs.	*Institutionalizing climate in regional funding, permitting, and policy decisions*	*Where to place projects to address specific climate risk, and how high to build your new levee.*
Project/Reach Scale	The Lower XX river reach is at increased risk due to sea level rise, increased sedimentation and increased flood frequency and magnitude (all could be quantified). Tributary flows, engineered protections, agriculture and habitat considerations, or other specific issues are incorporated when focusing in on the project scale.	Updates to CFHMP, Salmon plans, and other plans include watershed-specific climate information, providing a basis for evaluating project ideas and prioritizing them relative to one another.	Lower XX and XX Creek suite of projects identified and designed to be resilient to climate change.
Watershed	Peak and low flows, reservoir operations, stream temperature, sediment transport, and hydrodynamic modeling necessary to make reach scale conclusions.		Projects are implemented in the headwaters to retain sediment and flood waters while parallel acquisition efforts retain opportunity in the floodplains.
Regional	Every major floodplain in Puget Sound will experience increases in 100-year flood events ranging from an increase of 18-55%, on average, however floodplain vulnerabilities extend beyond flooding, including sediment, water temperatures, sea level rise. Regional resources are targeted and sequenced as informed by climate risk/opportunity.	Ecology and PSP budgets and research plans; Legislative support; State and federal guidance documents.	Funding is driven towards research (analysis, modeling and data collection), monitoring, and implementation of projects that are deemed necessary in the face of climate change.

Regional Efforts

The regional-scale efforts identified in this section were selected for one of two reasons: (1) To provide survey-level information for use in regional-scale risk assessment and prioritization, or (2) There is a significant economy of scale to applying the same analysis across the region.

Climate and Floodplains Resource, Learning Network

This task would create a set of resources that describe existing climate impacts datasets, science, and other resources. These could be incorporated in the Salish Sea Wiki, or developed as a set of fact sheets, an interactive data viewer, an FAQ page, or some other set of resources.

In addition, this task would coordinate a network of interested scientists and stakeholders, providing a forum for scientists to learn more about practical concerns and constraints while also sharing information about existing climate impacts science and data.

This effort would be focused on (1) curating decision-relevant science, and (2) cultivating a network aimed at increasing literacy among both scientists and stakeholders. This would complement and be coordinated with existing efforts – by TNC, PSP, and others – to support planning and project implementation.

> *Outcome:* Centralized resources for climate resilient floodplain management, new forum for shared learning among scientists and stakeholders.

Sea Level Rise, Waves, Surge

Managers report that current information on sea level rise is not useful for developing resilience strategies. Existing research (a) does not provide sub-regional specificity in impacts, (b) does not quantify the combined impacts of sea level, surge, and waves, and (c) has not been effectively synthesized for use by managers. This task would involve developing updated community-scale coastal hazards projections for Puget Sound, incorporating local variations in vertical land motion, and the additive risks associated with storm surge, sea level variability, and wave impacts.

Some of this work is already funded via a grant from NOAA NOS (project lead: WA Sea Grant). Additional work could expand the scope of the assessment at the regional scale (as described in NTA proposal #2016-0089) or involve additional work to localize the projections and impacts at the project scale (for example, to assess risks to shellfish beds in Hood canal).

As currently scoped, this work would produce new estimates of extreme high water levels. Additional modeling would be needed to estimate the resulting changes in the extent and depth of coastal flooding.

> *Outcome:* Community-scale projections of sea level rise, surge, and waves, coupled with maps and data summarizing changes in coastal hazards across Puget Sound. Could include project-specific assessments of risk.

Precipitation extremes

Changes in the intensity, duration, and frequency of heavy precipitation events may negatively affect stormwater facilities, exacerbate landslide and urban flood risk, and lead to other public safety and water quality concerns.

Existing projections – including results cited in the recent Puget Sound State of Knowledge report (Mauger et al. 2015) – are based on statistically-downscaled climate projections.[1] Recent work has shown that a physically-based approach – dynamical downscaling – is needed to capture the effects of climate change on extreme precipitation (Salathé et al. 2014). Modeling is currently underway to quantify changes in precipitation extremes across the Pacific Northwest region, but these are too small in number to fully quantify the range among projections.

This task involves three possible components: (1) Additional regional climate model simulations needed to characterize changes in extreme precipitation, (2) Develop visualizations and data providing general information on projected changes in extreme precipitation across the region, allowing users to assess and compare risk from one location to another, and (3) Tailored data products for specific weather stations, selected based on stakeholder interest/need, bias-corrected to match the observed statistics at those sites. Such projections could be used in hydrologic and hydraulic modeling to assess changes in flood risk. Options (2) and (3) could be based on existing simulations, then updated as new data become available.

> *Outcomes:* (1) Additional regional model projections permit a more robust estimate of changes in extreme precipitation, (2) Summary maps and data summarizing changes in extreme precipitation, (3) Tailored site-specific projections of changing precipitation

Reservoirs: Survey-level maps and data

Existing projections of changing streamflow, with the exception of one study on the Skagit River (Lee et al. 2016), do not account for the effects of reservoir operations. In watersheds with major reservoirs, this could mean that existing projections overestimate the change in flood risk.

In order to provide an initial look at the potential impacts of reservoirs on future flows, this task would include a survey of existing dams for all rivers in Puget Sound. Specifically, we would inventory dams and develop a set of summary products that illustrate the potential for flow modification at each location (e.g., maps showing the percent of the upstream catchment that is captured by reservoirs).

> *Outcomes:* Maps and data summarizing existing reservoirs and their potential for influencing flows.

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[1] Since global climate model projections are coarse in spatial scale, "downscaling" approaches are needed to translate projections to local scale changes in climate. Approaches generally fall into one of two categories: (1) statistical downscaling – which uses observations to estimate local scale changes in climate – and (2) dynamical downscaling, which uses a regional climate model to simulate the physical processes associated with climate change at the local scale.

Sediment loading: Preliminary Estimates

Sediment loading in rivers affects water quality, habitat, and flooding. Climate change will exacerbate sediment issues by increasing the supply of sediment from the uplands while, via sea level rise, impeding the transport of sediment out of the estuaries and into Puget Sound.

Recent reports have quantified the *current* rates of sediment transport in Puget Sound rivers, but to date only one study has quantified the change in sediment loading, focused on the Skagit River (Lee et al. 2016).

This task would leverage the streamflow modeling described above, combining these projections with existing sediment rating curves to provide a first estimate of *changes* in sediment transport within other Puget Sound watersheds. Sediment rating curves are not available for all watersheds, but could be applied where available. These could be used to assess the relative risk posed by sediment changes across the region.

This task would also include a literature review of existing approaches to quantifying climate change impacts on sediment transport.

> *Outcome:* Preliminary estimates of changing sediment loading for Puget Sound watersheds.

Groundwater: Survey-level maps and data

Groundwater is a key resource for both farmers and fish, affecting water quality and supply as well as drainage. This effort would provide survey-level information that may help identify areas where changes in groundwater supply and quality may be of greatest importance. A set of simple maps and data products would be produced, highlighting information such as the location and depth of wells (both permitted and exempt), soil depth and porosity, known areas of recharge and discharge, etc.

Some simple modeling may also be feasible, which could be used to identify areas at greatest risk of change. USGS has previously developed models for much of Puget Sound, including models for the Kitsap Peninsula, Bainbridge Island, the Skagit basin, Jefferson County, and Olympia. These could potentially be extended to cover the entire Puget Sound catchment.

> *Outcome:* Projected changes in groundwater height and amount, and associated impacts on hyporheic exchange, drainage, and saltwater intrusion.

Changing Area and Depth of Flooding: Unified Hydrodynamic Modeling

Recent geospatial assessments of floodplains (Konrad 2015) have proven difficult to use in regional restoration planning, in part because of the need for greater accuracy at local scales. Ultimately, models are needed to represent the fluid dynamics that determine the depth and extent of flooding (e.g., to define the FEMA 100-year floodplain).

Existing hydrodynamic modeling is frequently undertaken separately for specific reaches and sub-basins. As a result, “off-the-shelf” calibrated hydrodynamic models are often created at different times with varying approaches, sophistication, and baseline data.

Not only does this limit apples-to-apples comparisons across the region, it is an impediment to scalability: each model must be obtained and applied in a piecemeal fashion. This task would expand the domain of existing hydrodynamic models so that they can be used to simulate changes in inundation for all of the lower floodplains in Puget Sound.

Proof of concepts already exist for this approach. Preliminary estimates of changing inundation can be obtained using the simplified methods of Paul Bates and colleagues (Sampson et al. 2015) – they are currently working with Kris Johnson at TNC to evaluate flood risk in the upper Mississippi river basin.

A more refined approach has also been tested, in which PNNL's Salish Sea Model was used to model the Skagit River floodplain up to Concrete (Yang et al. 2012). This same model could also be used to evaluate changes in water quality, temperature, and sediment processes. USGS is currently developing another model with similar capabilities – although currently focused on coastal flooding, this model could also be extended to inland floodplains.

> *Outcome:* Consistent estimates of current and future flood risk – depth and area of inundation – for all mid- and low-elevation floodplains in Puget Sound.

Watershed-scale Efforts

The watershed-scale efforts identified in this section were selected for one of two reasons: (1) Because the science is not sufficiently mature for expansion to the entire region, or (2) because the regional-scale analysis provides insufficient detail for watershed-scale planning (i.e.: although appropriate for regional use, a more refined analysis is needed for local planning).

Engagement

Our work with stakeholders in the Stillaguamish and Puyallup has clarified two basic issues regarding climate-resilient watershed planning: (1) Many key stakeholders remain largely unaware of existing climate science that could help inform their planning, and (2) there is a need to "level the playing field": some stakeholders are currently much more informed than others.

In this task, we would engage with watershed-scale planning discussions (e.g., LIOs, WRIAs) with the goal of raising awareness about climate change impacts, while also providing a resource for initial discussions around climate-resilient planning. The work would primarily involve time for participation in meetings and responding to inquiries. In addition, a short watershed summary document would be created, to serve as a quick reference for stakeholders. The effort could be scaled to include training, a workshop, or additional interviews with a selection of stakeholders.

Feedback from project proponents indicates that this effort would be most effective if funding is also provided to local stakeholders to support their participation. This funding could even be provided via a competitive process, in which individuals or entities are selected based on criteria such as need, interest, or potential.

> *Outcomes:* Watershed "climate impacts fact sheet", stakeholders have increased awareness of climate impacts resources, researchers have a better understanding of stakeholder needs, and project proponents receive support for climate impacts incorporation.

Changing Streamflow

Existing projections of changing streamflow do not account for projected increases in the intensity of heavy rains, leading to an underestimate of changing flood risk. Recent research has shown that regional climate modeling is needed to accurately estimate changes in flood risk (Salathé et al. 2014).[1]

This task would build on existing hydrologic models for Puget Sound, using new regional climate model projections to develop estimates of changing streamflow for the watershed of interest. Results would be synthesized into a set of maps and user-friendly data products that summarize the expected changes in peak flows, low flows, and streamflow timing for specific streamflow sites of interest.

This task would leverage existing modeling efforts by UW and PNNL.

Outcomes: Maps and data summarizing changes in streamflow at specific sites across the watershed.

Reservoirs: Modeling the Effects of Operations

Existing streamflow projections do not account for the effects of reservoir operations, potentially leading to an overestimate of flood risk in watersheds with major reservoirs. The survey-level information on reservoirs – described above under the regional priorities – would identify areas where reservoir management, and possible changes in operations, could have an important effect on downstream flows. However, that analysis could not be used to quantify reservoir impacts on changing streamflow.

This task would involve modeling the effect of all reservoirs within a watershed on downstream flows. The work could include two separate, scalable efforts: (1) develop models to represent reservoir operations, in consultation with dam operations professionals at each site, and (2) evaluate opportunities for optimizing operations. New reservoir models would be combined with existing streamflow projections, such as those described above, to estimate projected changes in managed flows within a watershed.

This effort would leverage existing work to model reservoirs in the Skagit, Snohomish, Green, and White watersheds. Economies of scale are likely if expanding the effort to cover all reservoirs in Puget Sound.

Outcome: (1) Projected changes in streamflow with current reservoir operations, (2) Potential for altered reservoir operations to reduce climate change impacts.

Land cover change and flood risk: Pilot study

Changes in land use and land cover can have a significant impact on flood risk. Many of the issues related to land use and land cover involve considerations that differ from one watershed to another (e.g., specific planning jurisdictions, land ownership, the distribution of impaired or vulnerable lands, etc.). As a result, a watershed-scale approach is needed to both capture these local details and also incorporate realistic scenarios of changing land use. Although a project-scale focus could allow for a more detailed assessment, an analysis that is too localized might overlook important watershed-scale drivers of risk.

Building on recent studies (e.g., Cuo et al. 2009, Cuo et al. 2011), this task would combine hydrologic modeling with land use and land cover change projections (e.g., due to wildfire, development, forest practices, etc.) to evaluate the impacts on flood risk. Stakeholders and planners at various levels would be engaged to develop a range of land use scenarios based on specific planning and policy choices. Using existing hydrologic models, we would evaluate the implications of each land use scenario for flood risk, with a particular emphasis on the potential for each to mitigate the effects of climate change.

This work could be implemented at the watershed or the regional scale.

Outcomes: (1) Simulations identify areas that are most susceptible to climate change vs. various changes in land use and land cover. (2) Future projections quantify impact of both on changing flood risk.

Sediment loading: Scoping

Sediment loading in rivers affects water quality, habitat, and flooding. The preliminary estimates – described above under the regional science needs – will be useful for prioritizing efforts across the region. Although substantial research is already underway by USGS and UW researchers, many watersheds will require a much larger effort to accurately evaluate the implications for habitat and flooding.

Focused on one or several key watersheds, this task would (1) synthesize existing research and data, and (2) convene experts and stakeholders to develop a research agenda focused on characterizing the sediment processes of relevance to watershed scale planning and management. This would include a review of existing literature, data, and modeling approaches that could be used to estimate changes in sediment supply, transport, and deposition.

Outcome: (1) Synthesis of existing science and data of relevance to sediment supply and deposition, and (2) A research agenda, developed with stakeholder input, aimed at characterizing sediment processes of relevance to planning.

Groundwater: Watershed-scale modeling

Groundwater models have previously been developed for some parts of Puget Sound, although coverage is sparse, few are adequately calibrated, and models are of varying sophistication. Because each watershed is unique – both in terms of its geology and surface water – groundwater models have typically been developed separately for specific watersheds or areas within the region.

This task would involve creating and calibrating a groundwater model for a specific Puget Sound watershed, and using that model to evaluate changes that may be of relevance to habitat and agriculture (e.g., height of the water table, hyporheic exchange, groundwater ponding, saltwater intrusion, etc.).

As with the land cover modeling above, the details of each watershed affect the scope of the work needed to properly assess the impacts of climate change. Simpler models can often be inexpensively developed by consulting firms, whereas more complex analyses involving integration with other issues/models (e.g., surface water, saltwater, hyporheic exchange), will require a greater investment of time and resources.

Although this work is currently listed under the watershed-scale priorities, there is some potential to develop a complete set of groundwater models for the entire Puget Sound catchment: USGS has previously developed models for much of Puget Sound, including models for the Kitsap Peninsula, Bainbridge Island, the Skagit basin, Jefferson County, and Olympia.

Outcome: Projected changes in groundwater height and amount, and associated impacts on hyporheic exchange, drainage, and saltwater intrusion.

Stream temperature modeling

The NorWeST stream temperature dataset (Isaak et al. 2011), already packaged into simple GIS products and maps, includes current and future stream temperature assessments for the entire Pacific Northwest. Although very useful, there are two primary limitations to this product: (1) results only include average water temperatures for the month of August, and (2) these are statistically-based estimates of stream temperature, derived by interpolating between available measurements. This means that differences in physical processes from one reach to the next are not captured by the NorWeST approach.

This task would take a complementary approach by producing physical model simulations of current and future stream temperature. This would allow for a more refined analysis of changing stream temperature, including thermal refugia, hyporheic flow, day/night temperature changes, maximum weekly temperatures, and so on. New sensors would be deployed on a temporary basis for model validation.

Leveraging existing efforts in the region (e.g., Cao et al. 2016, Steel et al. 2012), modeling could be used to document project effectiveness, and serve as a means of identifying opportunities for monitoring. The model could also be used to prioritize conservation efforts by identifying important cold pools or areas that are highly sensitive to warming.

This effort could be expanded to the full Puget Sound region.

> *Outcome:* Projected changes in water temperature, cold water patches, and other key habitat metrics related to water temperature.

Plan Evaluation

State and local planning processes – e.g., Salmon plans, Comprehensive Flood Hazard Management Plans (CFHMPs) – may not adequately account for the impact of climate change. In this task, researchers would collaborate with local planners and stakeholders to review an existing plan, identifying new or exacerbated risks resulting from climate change, and summarize these for integration in a plan update. Researchers could also evaluate potential response options for effectiveness and prioritization within the plan.

> *Outcome:* A report summarizing projected changes in risk, for inclusion in a new or updated Salmon plan, CFHMP, or other relevant plan.

Project-level Efforts

Engagement and scoping

Project-level engagement is needed to scope out potential impacts of climate change and evaluate options for altering existing plans. The purpose of this effort would be to (1) increase the capacity of project proponents to identify and assess potential climate change impacts, and (2) identify science and data that is needed to assess impacts. This task would involve engaging with project proponents to understand the specific considerations affecting project design, along with the feasibility of adaptive measures. Project leads would be provided with relevant science and data from existing sources. If additional work is needed, researchers would develop a scope of work for accomplishing these efforts. Table 1 lists the types of analysis that may be needed in different project phases.

As above, feedback from project proponents indicates that this effort would be most effective if funding is also provided to local stakeholders to support their participation, possibly via a competitive process.

> *Outcomes:* (1) Improved climate literacy among project proponents. (2) Project-level evaluation of impacts, with summaries of relevant data and science. Scoped research effort needed to address gaps in the science and data.

Monitoring Strategy

Planned monitoring efforts may not adequately emphasize key climate change sensitivities, and monitoring for project effectiveness may require a different approach in light of climate change. Working with project proponents (e.g., Puyallup monitoring working group), this task would identify metrics of relevance to planning. Based on these metrics, researchers would use existing datasets to identify areas where changes are likely to be most pronounced.

> *Outcome:* Suggested monitoring locations based on climate change vulnerability.

Hydraulic modeling: Project-scale changes in flood risk

Changes in streamflow and sea level may not provide sufficient information for planning. In these cases, hydraulic or hydrodynamic modeling is needed to evaluate changes in the depth and area of flooding. In addition, these models can often be used to evaluate changes in the potential for sediment deposition and erosion via changes in the erosive capacity of flood flows.

In many areas, models have already been developed to do this – either for FEMA flood studies or some other purpose. For example, NHC has recently developed a calibrated hydraulic model for much of the lower Puyallup. Similarly, FEMA is currently developing coastal inundation models in several Washington communities as part of its RiskMap process. In addition to these, the PNNL and USGS models mentioned above could be used for project-level impacts assessments. Where such models exist, these could be used to simulate changes in flood risk by simply adjusting the model inputs to reflect the simulated changes in streamflow and sea level rise. These models could also be altered to evaluate the impact of restoration actions.

> *Outcome:* Projected changes in the depth and area of inundation at select project sites. Some models can also be used to evaluate the erosive potential of flood flows.

Table 2. Examples of floodplain management projects and climate science that can be incorporated into different project phases to help ensure the project will be robust to future climate changes. Examples of climate science are provided for consideration only; each project is different and may not require any/all of analyses listed.

PROJECT PHASES	CLIMATE SCIENCE
Prioritization of acquisition projects (including easements)	***Hydrologic modeling*** can identify areas with the greatest impact on downstream flows (including upland forest areas, agricultural areas at risk of development, and setback levees).
	Sediment modeling can evaluate changes in sediment source areas and river locations with potential for storage.
	Hydrodynamic modeling can identify where future flood inundation is likely due to climate change.
	Groundwater modeling can identify river reaches where groundwater exchange is important as well as upland areas that may be important for recharge.
	Water temperature modeling can evaluate opportunities for cold water refugia and priority areas for riparian vegetation.
Feasibility and design of floodplain reconnection projects	***Hydrologic modeling*** can evaluate streamflow changes as well as the effect of project design on peak and low flows.
	Sediment modeling can estimate future changes in channel capacity and evaluate design effects on sediment transport and storage.
	Hydrodynamic modeling can evaluate changes in flow velocity (scour, avulsion risk, etc.) and inundation due to climate change and evaluate the effect of the design on flood risk.
	Groundwater modeling can evaluate the effect of proposed projects on hyporheic exchange.
Feasibility and design of estuary/nearshore restoration projects	***Sea level rise projections*** can help ensure that project designs will be robust to future storms.
	Groundwater modeling can assess drainage on adjacent agricultural lands and the potential for saltwater intrusion.
	Hydrodynamic modeling can evaluate the extent and depth of coastal inundation and the effect of design on flood risk.
	Sediment modeling can estimate future changes in sediment deposition and the implications for nearshore habitat.
Best management practices on working lands	***Hydrologic modeling*** can identify drainage issues in winter and the extent of water conservation needed in summer.
	Sediment modeling can evaluate the impacts of management practices on sediment supply.
	Groundwater modeling can identify areas at risk of saltwater intrusion and the impact of best practices on hyporheic exchange.
	Crop system modeling can evaluate climate effects on crops as well as the effect of management practices on production, nutrient runoff, soil water, erosion, and many other factors.

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