United States Department of the Interior

U.S. GEOLOGICAL SURVEY

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Exhibit 1 Work Tasks for Study:

Assessment of Columbia and Willamette River Flood Stage at Portland, OR in a Future Climate on the Columbia Corridor Levee Systems

The following is the scope of work to provide the Columbia Corridor Drainage Districts Joint Contracting Authority (JCA) with an assessment of the flood stage of the Columbia and Willamette Rivers on areas protected by the Columbia Corridor levee systems during high-flow and extreme events in the future. The Columbia Corridor levee systems are managed by four drainage districts and stretches 27 miles from Smith Lake to the Sandy River. The JCA has been delegated contracting authority and financial management for the four drainage districts (Peninsula Drainage District No. 1 (PEN 1), Peninsula Drainage District No. 2 (PEN 2), Multnomah County Drainage District No. 1 (MCDD), and Sandy Drainage Improvement Company (SDIC)) for multi-district projects, such as this project. The JCA assumes MCDD's duties and responsibilities, however project management and staffing services are still housed at MCDD.

Objectives of the Study:

To provide JCA with an estimate of the Columbia and Willamette River flood stage on the Columbia Corridor Drainage Districts levees that reduce flooding risk during extreme high-flow events in the future, using:

- State-of-the-art hydraulic models,
- Boundary condition hydrographs based on the best available science, describing a future climate at the warmer and wetter extreme of the range in future climate scenarios as described by Intergovernmental Panel on Climate Change Coupled Model Intercomparison Project Phase 3 (IPCC CMIP-3) experiments (out to the year 2060),
- Sea level change scenarios based on the best available science, describing intermediate and high scenarios of sea level rise (out to the year 2100), based on a range from moderate to maximum ice sheet loss, and
- Two different hydraulic models to provide some assessment of the uncertainty inherent in hydraulic model selection.

Problem Statement and Background:

When levee certification in parts on the Columbia Corridor expired in August 2013, a group of stakeholders seized the opportunity to identify collaborative solutions for property owners and interested parties within the affected area. Since then, Levee Ready Columbia (LRC) emerged and over twenty stakeholder agencies and organizations have worked together to expand the geographic scope of the project and work in partnership toward either obtaining or renewing certification and remaining accredited. The work behind LRC has not only benefited the Portland metropolitan area but has provided funding for levee certification in other communities across Oregon. As the partners engage in risk-informed discussions, the project is shifting toward long-term considerations of tolerable risk, accounting for future conditions like climate change in order to build resilient and informed communities.

The LRC partnership is working with five levee systems that are managed by five drainage districts: PEN 1, PEN 2, MCDD, SDIC, and Sauvie Island Drainage Improvement Company (SIDIC). This study will only address the levee systems and associated climate change projections for the systems within the Columbia Corridor (PEN 1, PEN 2, MCDD, and SDIC).

These Columbia Corridor levee systems reduce the risk of flooding on the Columbia and Willamette Rivers. These levee systems span the southern shore of the Columbia River between Smith and Bybee Lakes and the Sandy River, approximately river miles 105.5 to 120.5. The LRC partnership, represented in this project by the JCA, has requested assistance in determining design criteria that incorporate the effects of a changing climate on the river hydrographs upstream of Portland and on sea level downstream at the mouth of the Columbia River (MCR). The US Geological Survey (USGS) and US Army Corps of Engineers (USACE) propose to provide this assistance in the form of hydraulic model simulations of the lower Columbia River (LCR) that incorporate the best available knowledge regarding peak flows in the Columbia and Willamette Rivers in a future climate, and projected sea level change (SLC) at the MCR, both of which affect river stage at Portland.

Peak flow statistics derived from the current period of record at The Dalles (the nearest upstream streamflow gage on the Columbia) or the Willamette gage at Portland or Oregon City (the nearest upstream gages on the Willamette) is not adequate for this study because the frequency distribution of streamflows is expected to be different in future decades than it has been during the period of record. Climate change projections predict that, in general, river basins of the Pacific Northwest will experience a decline in spring snowpack and reduced snowfall to annual precipitation ratios, earlier snowmelt, and earlier peaking hydrographs. This is particularly true of those basins (like many in the Cascade Range) that are currently classified as mixed-rain-and-snow type. Some basins may experience higher peaks as well. The Willamette River basin and other sub-basins of the Columbia River are expected to share these trends.

Climate change projections are based on the output of planetary scale atmospheric models called general circulation models (GCMs), and assumptions made about the rate of increase of the greenhouse gases that warm the earth's surface. Many institutions and government agencies around the world run their own unique GCM, and many of these have formed a collaborative arrangement to develop standardized approaches to simulating future climate scenarios. The umbrella term for the collaborative arrangement is the Coupled Model Intercomparison Project (CMIP) under the World Climate Research Programme. CMIP products inform the assessments of the Intergovernmental Panel on Climate Change (IPCC). The IPCC fifth assessment is in progress, and the experimental design that the GCMs will use to inform that assessment is CMIP-5. However, because it takes many years between the development of the experimental protocol and the availability of products useful to regional studies, we propose to use CMIP-3 products in this study.

The Climate Impacts Group (CIG) at the University of Washington has made available downscaled versions of the climate forcing functions and streamflow output of the CMIP-3 experiments. “Downscaled” means that the data from the GCMs, which has a resolution of perhaps 50 km (31 mi), has been refined either statistically or with regional-scale models to provide information at the scale useful to regional studies (1/16 the degree or about square 6 km (3.7 mi) grid resolution). The CIG used these downscaled data to provide forcing functions for a hydrologic model (the Variable Infiltration Capacity, or VIC model) that converts meteorological variables such as precipitation, soil moisture, and air temperature into daily values of streamflow. The hydrologic model simulations cover three time periods of 30 years: 2020s (between 2010 and 2039), 2040s (between 2030 and 2059) and 2080s (2070 to 2099). Each simulation is further identified by the assumption regarding the greenhouse gas emissions scenario that went into the GCMs. For example, the A1B scenario is one in which it is assumed that the world experiences rapid economic growth and future energy sources are assumed to be balanced between fossil intensive and non-fossil sources. The B1 scenario is one in which it is assumed that the world experiences the same rapid economic growth as in A1B, but with far more reliance on clean and resource-efficient technologies. The A1B scenario is therefore a more extreme scenario of future emissions than the B1 scenario.

An example is useful to understand these products. Figure 1 shows the monthly mean hydrograph (expressed as inches of runoff plus base flow over the entire contributing basin) of the Willamette River at Portland, and the Columbia River at Bonneville, respectively, based on the historical record (in blue) and on 10 GCMs (shown as a pink range, with the average shown as a red line). Results from the two emissions scenarios A1B and B1 are shown. It is apparent in Figure 1 that most GCMs predict higher runoff in the late winter months as captured at the Willamette River at Portland, particularly for the A1B scenario. It can be seen in Figure 1 that most GCMs predict higher and slightly earlier runoff in the spring in the Columbia River at Bonneville, for both emissions scenarios. Higher monthly runoff translates to higher peak flows on event time scales, and higher peak flows associated with given recurrence intervals, which is the basis for the interest in incorporating climate change into design criteria for flood-protection levees in Portland. The daily streamflows on which these monthly mean hydrographs are based are referred to as “naturalized,” that is to say unregulated, flows.

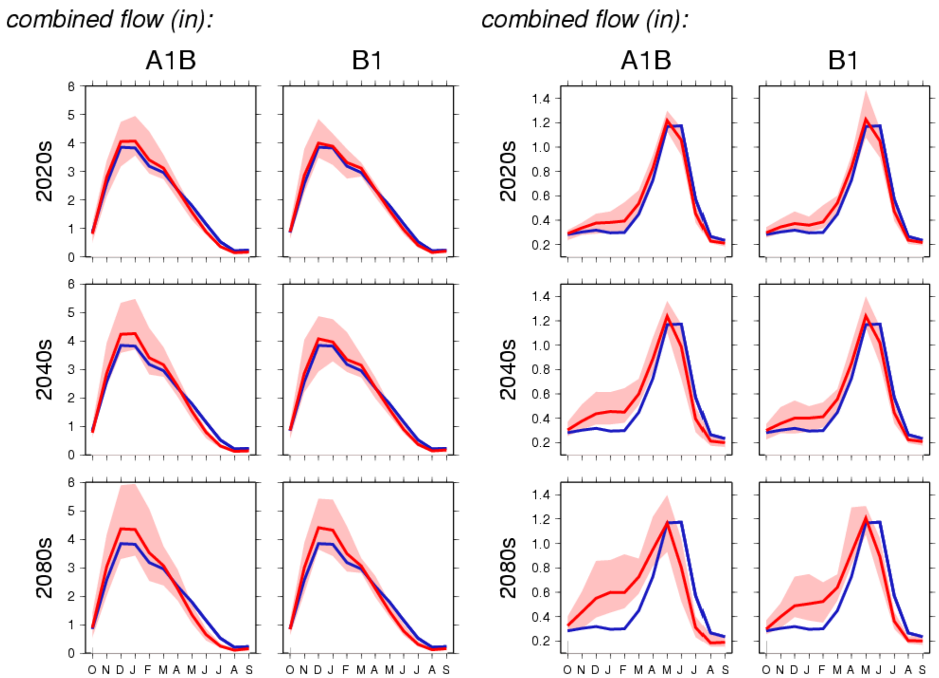

Figure 1. Monthly mean hydrographs (not adjusted for bias) for the Willamette River at Portland (left) and the Columbia River at Bonneville (right). Blue lines show the average historical values (1916-2006). A1B and B1 refer to emissions scenarios. Pink bands show the range of climate change scenarios from 10 (for A1B) or 9 (for B1) GCMs. Dark red lines are the average of the climate change scenarios. These figures were downloaded from the CIG website: http://warm.atmos.washington.edu/2860/products/sites/.

The hydrographs shown in Figure 1 are based on unregulated flows (no dams) because the hydrologic model (VIC) that generated them incorporates the physics and chemistry of precipitation, infiltration, snowmelt, runoff and baseflow, but not the effects of man-made restrictions on streamflow. In order to incorporate the effects of the dams in the Columbia River system, the streamflows developed by the CIG (daily values) are used as inflows to the reservoirs, and the operating rules of the USACE and Bonneville Power Authority (BPA) are applied with the use of the USACE Reservoir System Simulation model developed by the Hydrologic Engineering Center (ResSim). In practice, there is an additional step, in which the VIC streamflows determined from the downscaled climate data need to be further bias-corrected by a comparison with measured data at a specific location before using them as input to ResSim. The USACE is currently in the process of putting the bias-corrected CMIP-3 streamflows developed by the CIG for the 2040s through a next-generation version of ResSim. This produces a daily hydrograph of regulated flows, based on future climate scenarios as modified by passage through the reservoirs in the basin, under the assumption that the reservoirs are operated under present-day, or known future, rules, at selected gage sites throughout the Columbia River basin. To supply boundary conditions for model scenarios, the sites of interest are the Columbia River at Bonneville and the Willamette River below Willamette Falls. These daily streamflows are the regulated upstream flows referred to in Task 3 below.

River stage in the Columbia at Portland is influenced by Pacific Ocean tides, and any study of worst- case scenario flooding in Portland has to take this into account. Tides have strong natural cycles at monthly time scales. High stage events in Portland that take place over days and weeks will be influenced by how the timing of the event interacts with astronomically driven tidal cycles. In addition, strong winds associated with weather systems over the coastal ocean can push water toward shore, causing high water. Superimposed on each of these is the effect of climate change, which is expected to cause a rise in mean sea level over time. The projected rise in sea level depends on the assumptions made regarding the rate of warming of the earth and associated melt of land ice sheets, and therefore will be represented by a range of values in the model simulations. The total influence of the Pacific Ocean on river stage in Portland is dependent on the combination of all three of these.

We propose to use two existing 2-dimensional hydraulic models of the LCR to simulate stage in the river reach of interest (Columbia RM 105.5 to 120.5), and compare the output of the two models as an additional constraint on the precision of the results. Starting with existing models is a big advantage, because the model domain already extends out to the ocean, facilitating the inclusion of the tidal effect and sea level change at the ocean boundary into the analysis. Comparison of these two models is instructive because, while each solves the same underlying equations governing fluid flow, there are distinct differences between them. Perhaps the most important difference is the underlying grid used to apply the numerical methods. Delft3D employs a static curvilinear grid, whereas AdH employs an unstructured grid that adapts to the flow conditions as the simulation progresses

The first model is a Delft3D model of the LCR that was originally developed by the USGS in collaboration with USACE to inform sediment management at the mouth of the river. Delft3D is an open-source code developed by Deltares in the Netherlands, with a long record of documented applications to many river and estuarine systems around the world. The second is the USACE Adaptive Hydraulics (AdH) model of the LCR. The USACE used the AdH model to estimate sea level change in accordance with USACE guidance on incorporating sea-level change considerations into infrastructure planning (Circular EC-1165-2-211). Both models require boundary conditions at Bonneville on the Columbia, at Willamette Falls on the Willamette, and at the Pacific Ocean boundary.

Project Team

The United States Geological Survey (USGS) team will be led by Tamara Wood, who will help coordinate project partners to complete this study. If the project lead changes, USGS will inform the JCA and a new lead will be proposed by the USGS, but must be approved by the JCA in writing before work is authorized to continue.

The USACE must work in close collaboration with USGS on this study. USACE's team will be Keith Duffy and Hans Moritz. The USACE team will provide statistical downscaling of climate data and multi-dimensional hydraulic models. If this team or the level of their contribution were to change, JCA may need to revise the scope and budget of this contract.

Scope of Services

The work tasks to be completed for this project were submitted, reviewed, and approved by the Levee Ready Columbia Technical Advisory Subcommittee (TASC) in 2015.

Task 1 – Model Development

Because the study team is starting with existing models, limited hydrodynamic model development is required. However, because the emphasis of the application of the Delft3D model has been on sediment transport and deposition at the mouth of the estuary, the model grid was not originally developed with the level of detail in the Portland area that is required to address the question of water levels on the Columbia Corridor levees. Therefore, included among the tasks of this study is the enhancement of the model grid to incorporate the higher level of detail required in the Columbia Corridor utilizing existing LiDAR and bathymetric data, and subsequent re-calibration of the model. The USACE acquired topographic LiDAR data for the Columbia River, including complete coverage of the floodplains and surge plains from December 2009 through February 2010 (data were collected by Watershed Sciences, Inc.). Comprehensive multibeam bathymetric data were collected by David Evans and Associates for the National Oceanic and Atmospheric Administration (NOAA) (Columbia RM 30 to 110) as part of the agency's updates to existing nautical charts. Both of these data sources produced 0.5-meter-resolution gridded data sets. A merged digital terrain model of the area of interest including the land topography and river channel bathymetry, based on best available data with 1-meter horizontal resolution was developed by the USGS' Oregon Water Science Center (ORWSC).

- Task 1.1. Enhancement of the existing Delft3D and AdH model grids, as needed, in order to achieve the necessary refinement of the model in the area around the North Portland peninsula. The most recent LiDAR data will be considered, with regard to enhancements.
- Task 1.2. Baseline model runs with the two models, using agreed-on historical flows and sea level, for inter-comparison.
- Task 1.3. Provide a short memo to JCA documenting completion of the task and providing a basic summary of the results of the model comparison.
- Task 1.4. Present findings to TASC.

Task 2 – Development of Boundary Conditions to Represent Future Climate Conditions

The development of boundary conditions in the form of hydrographs at the upstream boundary and tidal elevations at the ocean boundary that are appropriate to address the question being posed is a critical part of this study. Inflow boundaries for the first hydraulic model simulations (see Task 3 below) will use observed flows utilizing USGS streamflow gages 14207740 Willamette River Above Falls at Oregon City, OR and 14128870 Columbia River below Bonneville Dam, OR. The 1 and 0.2 annual exceedance probability flood hydrographs would be used as inflow boundaries for these first model runs.

For the future projection time frame of the 2040s, this study builds on work already done by USACE to support Columbia River Treaty (CRT) deliberations for the upstream hydrographs. For the time frame of the 2080s, however, the study cannot rely on work already done. Several time-consuming steps need to be repeated, in particular the bias-correction of the naturalized flows from the VIC model, the routing of the bias-corrected flows with the ResSim model, and the smoothing of the output from the ResSim model. Therefore, the development of upstream boundary conditions for the 2040s is relatively straightforward.

The CRT Climate Change Workgroup focused on two “bookend” scenarios from the 2040s CIG dataset (2030-2059), which represented the most reasonable range of possible climate change outcomes in the Basin using CMIP-3 products. These were:

> 1. LW/D: A Less Warming/Driest scenario. This scenario derived from the ECHO_G GCM, assuming a modest carbon dioxide emission scenario (scenario B1). This scenario resulted in an average annual temperature increase of 1.8°C in the Columbia basin, and an aggregated precipitation decrease of 7.9 percent, compared to the 1971-2000 average temperature and precipitation.
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> 2. MW/W: A More Warming/Wettest scenario. This scenario derived from the MIROC 3.2 Global Climate Model (ref), assuming an aggressive carbon dioxide emission scenario (scenario A1B). This scenario resulted in an average annual temperature increase of 2.8°C in the Columbia basin, and an aggregated precipitation increase of 14.2 percent, compared to the 1971-2000 averages.

Because the focus of this study is on high flows and possible “worst-case” scenarios, the LW/D scenario is of limited interest, and it is proposed to use the unregulated, bias-corrected streamflows that the CRT workgroup developed based on simulations of the MIROC 3.2 GCM for the 2040s, under the A1B emissions scenario. These streamflows will be routed through an updated version of the ResSim model of the Columbia River basin. The updated ResSim will include updated year round water management rule sets for flood, power and biological operations. This will provide 30 years of streamflow data at our sites of interest; we propose to extract the year representing the 99th percentile peak flow (evaluated individually for the Columbia and the Willamette) from those years for running the hydrodynamic models.

As with streamflows, the projections of SLC depend on the assumptions made about greenhouse gas emissions in the future and the rate of warming of the climate. We propose to follow the projections provided by NOAA as modified by USACE guidance. The range of NOAA projections can be summarized as follows:

> 1. A “lowest” scenario. SLC is extrapolated from the historical rate derived from tide gages. At the MCR, this projection is slightly negative because the land surface elevation at the MCR has been rising very slowly over the historical record.
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> 2. An “intermediate-low” scenario. SLC is projected to be 0.5 m (1.6 ft) by 2100. The projections are based on climate models using the B1 emissions scenarios (a more moderate scenario). This scenario focuses its projection primarily on thermal expansion of the oceans.
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> 3. An “intermediate-high” scenario. SLC is projected to be 1.2 m (3.9 ft) by 2100. The projections are based on statistical relations between observed global sea level change, air temperature, and ice sheet loss. This scenario focuses its projection on a limited loss of ice sheets.

4. A “highest” scenario. SLC is projected to be 2.0 m (6.6 ft) by 2100. SLC is based on thermal expansion of the oceans, and a calculation of maximum possible glacier and ice sheet loss by the end of the century.

Because the focus of this study is on possible “worst-case” scenarios, the “lowest” scenario is not of interest. The USACE guidance uses a modification of NOAA projections, applied to specific coastal locations. We propose to use the USACE “intermediate” and “high” scenario to bookend projections. SLC is not linear through time; therefore, the consideration of a projection applicable to the 2040s will be interpolated appropriately.

- Task 2.1. Construct daily hydrographs at the upstream boundaries (Columbia at Bonneville and Willamette at Willamette Falls) for future modeling of Intermediate and High Scenarios.
- Task 2.2. Construct time series of tidal elevations at the mouth of the Columbia River- Pacific Ocean boundary.
- Task 2.3. Provide a short memo to JCA documenting completion of the task and providing a basic summary of the results of the development of boundary conditions.
- Task 2.4. Present findings to TASC.

Task 3 – Hydraulic Model Simulations

It has been noted that there is a relatively straightforward method for projecting SLC at the ocean boundary into the future as far as 2100, and that obtaining an upstream hydrograph for the 2040s (2030 and 2059). In order to provide useful, citable results within the time frame required by stakeholders, we propose a three-phased approach. By doing the work in phases we will be able to assess the sensitivity of peak flood stage in Portland to SLC at the MCR through 2100, relative to future climate changes to the hydrographs upstream, through the 2040s, within about a year.

Upstream boundary conditions will be based on events from hydrographs observed at USGS streamflow gages on the Columbia River at Bonneville (site 14207740) and on the Willamette at Oregon City (site 14128870). The boundary condition at the MCR will be based on observations at the Astoria gage, in combination with the “intermediate-high” and “highest” SLC projections for the 2040s (SLC-2040). This provides a baseline for the relative effects of SLC in combination with high flows under current conditions, for comparison to the simulations in the remaining tasks.

Upstream boundary conditions will be based on projected flows from a future climate, utilizing the work done by the CRT workgroup to determine regulated flows in the 2040s timeframe (FF-2040). The boundary condition at the MCR will be based on high tides in combination with the “intermediate-high” and “highest” SLC projections for the 2040s (SLC-2040).

- Task 3.1. Run Intermediate and High models with historical flows (HF) and sea level change (SLC); compare to HF and historical sea level (HSL) from the first task, and to the extent possible, observations.
- Task 3.2. Run both models with future-climate regulated flows from the 2040s and SLC projections for the 2040s (SLC-2040), the 2080s (SLC-2080), and 2100 (SLC-2100).

- Task 3.3. Provide a short memo to JCA documenting completion of the task and providing a basic summary of the results of the task.
- Task 3.4. Present findings to TASC.

Task 4 – Analysis and Draft Reporting

- Task 4.1. Detailed analysis of results; comprehensive interpretation of findings; comparison of model results between USGS, USACE, and project partners.
- Task 4.2. Prepare draft final report.
- Task 4.3. Provide preview of final report for the TASC to review.
- Task 4.4. Present findings to TASC.
- Task 4.5. Present findings to Levee Ready Columbia Project Team

Task 5 – Report Publication

- Task 5.1. Submit draft report for peer review.
- Task 5.2. Prepare public-friendly fact sheet; submit for peer review.
- Task 5.3. Respond to peer reviews; prepare revised report for USGS approval.
- Task 5.4. Technical editing and layout.
- Task 5.5. The final deliverables will be a peer-reviewed USGS series report and a short public-friendly USGS series fact-sheet. The results of Delft3D and AdH model simulations, specifically the river stage at requested levee locations, will be provided in electronic form.

Cost Estimate and Schedule

The budget and personnel requirements shown here reflect the work to be done by the USGS on each of the tasks above, in cooperation with the JCA. The USGS will share costs by providing 35% of the total project costs; JCA will provide 65%. A breakdown of the project expenses and cost-share is provided in the table below.

It is assumed USACE will contribute to this study through its Planning Assistance to State (PAS) Agreement; those costs and personnel requirements are not included herein. Without this contribution, JCA will need to stop all work until a revised scope and budget are agreed to and match appropriations.

USGS will invoice the JCA monthly. The invoice will include a description of the work performed and the price for the work. The JCA shall have 90 days upon receipt of invoice to make payments.

Expense	Estimated Cost

Salaries and Benefits:	
Task 1 – Model Development	$ 17,760
Task 2 – Boundary Conditions	$ 17,760
Task 3 – Hydraulic Model Runs	$ 29,960
Task 4 – Analysis and Draft Reporting	$ 54,980
Task 5 – Report Publication	$ 17,720
Publication Costs	$ 8,700
Other Expenses	$ 8,700
Total Estimated Cost -	$ 155,580
USGS Cost Share -	$ 54,450
Cost to JCA -	$ 101,130

Schedule based on federal fiscal years (October 2 to September 30)

Timeline:	**FY2016**				**FY2017**			
Task 1. Model Development				x				
Task 2. Boundary Conditions				x	x			
Task 3. Model Simulations					x	x		
Task 4. Analysis/Reporting						x	x	x
Task 5. Report Publication							x	x