A white paper for the Palouse Basin Aquifer Committee:

A physically based decision-making support tool for the upper Palouse Basin aquifer: Reviving the only groundwater flow model ever built for the Palouse

Nick Engdahl[1] and Julie Padowski[2, 3]

[1] Department of Civil and Environmental Engineering, Washington State University, Pullman WA, 99164
[2] Center for Environmental Research, Education, and Outreach, Washington State University, Pullman WA, 99164
[3] State of Washington Water Research Center, Washington State University, Pullman WA, 99164

1. Problem statement

The upper Palouse Basin of eastern Washington contains the towns of Moscow, ID, Pullman, WA, and many other small towns that all rely on groundwater as their primary and often sole water source. The trends observed within the Moscow-Pullman corridor are representative of the entire system, which has been in a gradual decline since at least 1935 because of overdraft [PBAC 2009; 2014]. Despite a reasonable amount of hydrogeologic characterization, there are no reliable estimates regarding the total volume of the greater Palouse aquifer system and no conclusive evidence regarding the location of the recharge zones, so it is not possible to estimate the lifespan of the aquifer. This is a critical information gap because the continual declines imply that eventually users will exhaust the groundwater resources if efforts to the recharge the system are not pursued. Recycling and reinjection of nontraditional surface water sources may help further slow the water level declines but this cannot replenish all of the extracted water. It is likely that eventually water will have to be imported but, regardless of how this is done, it poses a question of storage. The most logical storage location is the existing aquifer but it is unclear how rapidly water can be injected, if the volumes that have been extracted can be replenished, and whether or not this water will be accessible to and usable by communities in the future.

Fundamentally, there are three knowledge barriers that limit planning for, and achieving, long-term sustainability of the Palouse aquifer: 1) lack of knowledge on the recharge zones and mean annual recharge, 2) unknown total aquifer volumes, and 3) insufficient tools for evaluating the physical effects of different mitigation strategies. Data collection can be used to form initial hypotheses regarding each of these gaps but without costly field testing, or risky and expensive pilot projects, but there is currently no way to evaluate these hypotheses about the flow system or to test options to further slow or reverse the long-term declines.

2. Proposed action

The primary objective of this proposal is to produce a working flow model based on the previous research activities to reduce the knowledge barriers and better understand how the UPB may be used for long-term, sustainable water storage. In doing so, these efforts would also archive existing work in formats accessible for future research, while significantly reducing the costs of developing a model from scratch.

The primary descriptive and predictive tools used throughout the United States for groundwater flow issues are numerical simulations. Several other nearby locations in Washington have already adopted geologically based numerical models to assess long-term changes in groundwater including the Yakima Basin [Ely et al., 2014] and the greater Columbia Plateau Regional Aquifer system (CPRAS) [Ely et al., 2014]. Both of these modeling efforts were recently completed by the US Geological Survey and the complete model packages are publicly available and the latter includes most of the Palouse Basin at coarse resolution. Beyond this, only one model has ever been constructed specifically for the Palouse Basin as detailed by Lum et al.

[1990]. However, due to its age and a lack of robust archiving practices, the Palouse Basin model files are not available in any format that can be used today.

Our proposed action is to reconstruct and revive the numerical simulation platform for the Upper Palouse Basin (UPB) based on the existing CPRAS model [Ely et al., 2011] and the Lum et al. [1990] model to evaluate groundwater availability. The information needed to re-create the Lum et al. [1990] model can be found in the report and this can be updated with the improved geological characterizations provided by the USGS CPRAS model. The model domain and scale will be revised so that it can be used more effectively as a predictive tool in the Moscow-Pullman corridor and it will be updated to include groundwater withdrawals since the Lum et al. simulation. The observed surface recharge and pumping rates will be based on observation data, which will eliminate a significant source of uncertainty and allow future efforts to focus on improving the structural representation and parametric values used in the model to improve its calibrated performance. The 3-D groundwater flow model that we expect to produce will be relatively simple as it is a first step but its development will enable a broad spectrum of future research activities. The simulation period will span from 1890-2017 at monthly time steps using the same historic recharge and pumping estimates from Lum et al. up to 1985 (the end of its simulation period) and the same methodology will be used to add the data up to the present day.

3. <u>Project deliverables</u>

The main result of this project will be a fully functioning, modern groundwater model of the UPB, focused on the Moscow-Pullman corridor, though this study area can be expanded if necessary. The model package will be built around the MODFLOW-NWT numerical platform [Niswonger et al., 2011] and the complete set of required inputs along with detailed documentation and metadata will be provided directly to PBAC along with a report detailing the construction and calibration process. Drawdown maps for the various aquifer units will be produced as well as time series estimates of the total aquifer volume, recharge volumes, and we expect to provide the improved estimates of the lifespan of the aquifer. When possible, time series animations of these maps will also be produced to facilitate PBAC outreach activities. We also expect to publish the 3-D conceptual hydrogeological model and the results of the numerical simulations in peer-reviewed journals. Lastly, the model framework will be freely and openly shared on the HydroShare.org project. The goal of the HydroShare project is to make hydrologic data and models more easily discoverable to the public, improve transparency, and ensure the preservation of simulation files and results into the future.

4. <u>Project tasks</u>

The primary task of the project is creating a functioning model from the previous descriptions of the Lum et al. [1990] model to create a functional planning tool for the Palouse area. This requires several subtasks briefly outlined here:

4.1. *Compilation of hydrogeological information:* The previous Palouse Basin model [Lum et al., 1990], the CPRAS model [Ely et al., 2014], and existing geological characterizations [e.g. Burns et al., 2011; 2012] will serve as the primary data used in building the updated groundwater model. This will produce a 3-D hydrogeologic model of the UPB model domain.

4.2. *Assembly of input datasets:* The inputs for the model will be guided by the previous modeling efforts and their data sources [Lum et al., 1990; Kahle et al. 2011; Ely et al., 2014]. This mainly requires spatially distributed input files describing the location and magnitude of recharge and the timing and volumes of water extracted from the aquifer(s).

4.3. *Calibration of the model:* This project will assume that the existing hydrogeologic characterization is structurally accurate and the calibration will focus on identifying the effective hydraulic conductivity of each hydrogeologic unit. The initial values will be provided from the previous models and these will be optimized to reproduce the observed water levels. This task will also quantify the sensitivity of the model to potential errors in the inputs, including recharge rates and locations.

4.4. *Analysis:* The completed model will be used to formulate and evaluate fundamental hypotheses about flow within the UPB. This includes generating drawdown maps for different geological and pumping scenarios, comparisons of the model outputs and observed data, estimates of recharge locations, among others. The main goal is to provide a simulation framework that can be used to address PBAC's specific questions in the future so minimal analysis is included here, but a full presentation of the operation, functioning, and output of the model will be provided to PBAC though at least two example applications (Sections 4.4.1 and 4.5.1).

4.4.1. *Example application - Identifying the necessary water supply to achieve sustainability:* This example would focus on the deceptively simple question of how much water must be added to the Palouse aquifer system to halt the declines. The model allows precise calculation of the volumes extracted and the flow rates within the system, which highlights the optimal locations and depths for supplying recharge, either naturally or artificially. This information is unavailable from the limited network of observation wells because they are not laterally extensive enough to completely characterize the system. More importantly, wells cannot predict the response of the system to the previously unseen change of adding water instead of just extracting it.

4.5. *Cooperative scenario development:* During the model development, the project team also will work directly with PBAC to develop future groundwater use and replenishment scenarios of interest to the Committee. We anticipate that these scenarios would focus around applied questions the Committee may have related to potential available storage, timing and availability of water, and water quality considerations under different source water, demand, and climate scenarios. Regular updates on model progress and capabilities would inform scenario development discussions as the model is being completed. The resulting scenarios would serve as the basis for future work with the proposed model framework to develop a sustainable management model for the Palouse.

4.5.1. *Example scenario - Potential recharge afforded by winter flows:* Winter flows often have fewer regulatory constraints than other seasons and could provide a source of recharge water. This scenario would explore the overall effect of diverting a portion of the winter flows in Paradise Creek into an artificial recharge system. This complements example 4.4.1 by showing how much of the necessary demand could be met with existing flows before resorting to costly imports, which would likely also have to be stored in the subsurface.

5. Anticipated timeline and budget

We anticipate a project period of 1-year. This includes a 6-month period to re-construct the previous model and reproduce its results. A second 6-month period will update the model and simulate up to the present day. The purpose of this project is to develop a simulation framework that can be used for a wide range of future studies including, but not limited to, artificial recharge and storage, residence time, geochemistry and water quality, and alternative management strategies. The anticipated budget covers the cost for one graduate student and one undergraduate assistant to update the models along with a minimal amount of salary support for the PIs to directly assist the students in performing Tasks 4.1-5. The total costs are estimated at approximately $65k. Facilities and administration (overhead) charges will be exempted.

References:

Burns, E.R., Morgan, D.S., Peavler, R.S., and Kahle, S.C., 2011, Three-dimensional model of the geologic framework for the Columbia Plateau Regional Aquifer System, Idaho, Oregon, and Washington: U.S. Geological Survey Scientific Investigations Report 2010-5246, 44 p.

Burns, E.R, Snyder, D.T, Haynes, J.V., and Waibel, M.S., 2012, Groundwater status and trends for the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho: U.S. Geological Survey Scientific Investigations Report 2012–5261, 52 p.

Ely, D.M., Bachmann, M.P., and Vaccaro, J.J., 2011, Numerical simulation of groundwater flow for the Yakima River basin aquifer system, Washington: U.S. Geological Survey Scientific Investigations Report 2011-5155, 90 p.

Ely, D.M., Burns, E.R., Morgan, D.S., and Vaccaro, J.J., 2014, Numerical simulation of groundwater flow in the Columbia Plateau Regional Aquifer System, Idaho, Oregon, and Washington (ver. 1.1, January 2015): U.S. Geological Survey Scientific Investigations Report 2014–5127, 90 p.

Kahle, S.C., Morgan, D.S., Welch, W.B., Ely, D.M., Hinkle, S.R., Vaccaro, J.J., and Orzol, L.L., 2011, Hydrogeologic framework and hydrologic budget components of the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho: U.S. Geological Survey Scientific Investigations Report 2011–5124, 66 p.

Lum W E, Smoot J L and Ralston D R 1990, *Geohydrology and Numerical Model Analysis of Ground-Water Flow in the Pullman-Moscow Area, Washington and Idaho* (US Geological Survey)

Niswonger, R.G., Panday, Sorab, and Ibaraki, Motomu, 2011, MODFLOW-NWT, A Newton formulation for MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6–A37, 44 p.

PBAC 2009 2006-2009 Municipal Pumping and Water-Level Records

PBAC 2014 Palouse ground water basin water use 2013, Palouse Basin Aquifer Committee.