Coupling Hydrologic Models with Data Services in an Interoperable Modeling Framework

CDI FY19 Full Proposal

Lead PI Information

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Plain Language Summary

Computational models of flood inundation, precipitation-runoff, and groundwater have been traditionally developed within the scientific niche of each of these fields. Increasingly there is a need and desire to couple these models together into integrated systems to solve complex problems. For example, the timing and impact of a flooding event in a watershed could be simulated by linking a precipitation-runoff model to flood-inundation model. In this project, computer models developed at the USGS and elsewhere will be added to a system developed at the University of Colorado that facilitates model-coupling and provides a comprehensive suite of tools including web-based data access to drive these coupled models. The open-source python accessible system provides an easy collaboration platform for developing and prototyping complex integrated models. Several tutorials with examples of model coupling will be made available to document the use of the system.

Financial Information

Total Requested Funds: 46117
In-Kind Matching Funds: 19642

Project Information

Project Description: This project investigates a Python-based technical framework for integrated modeling. Several existing USGS hydrologic and hydraulic models will be incorporated into the framework, coupled into integrated models, and driven by web-based data services through the framework's Python interface.

List of Anticipated Deliverables: We will create plug-and-play components for four USGS models the in CSDMS Python based Modeling Framework (CMF). A new component in the CMF to consume data services will be created. Example model coupling tutorials will be developed. All will be made freely available under an open source license.
SSF Element 1: Communities of Practice
SSF Element 2: Applications
SSF Element 3: Analysis

Collaborators

	Name	City	State	Organization
Co-PI	Steve Markstrom	Denver	CO	Water Mission Area - Model Support and Coordination Branch
Collaborator	Mark Piper	Boulder	CO	University of Colorado
Collaborator	Eric Hutton	Boulder	CO	University of Colorado

Coupling Hydrologic Models with Data Services in an Interoperable Modeling Framework

USGS Lead PIs: Steven Markstrom and Richard McDonald

1. Scope

Integrated modeling is an important component of the U.S Geological Survey's (USGS) Water Science Strategy (Evenson and others, 2013). Integrated modeling was identified as a priority challenge for the USGS by the National Academies of Sciences (2018). The Integrated Modeling and Prediction Division (IMPD) of the USGS Water Mission Area has been assigned goals from the Water Science Strategy in its 5-year plan including: "Develop and apply models to predict the potential effects of changes in population, land-use, climate, and management practices upon future water availability considering human and ecological needs". This goal, in part, has been articulated in an expected outcome of the IMPD 5-year plan to "develop and deliver a Modeling and Prediction Collaborative Environment ("sandbox") that can be used to couple hydrology and other environmental simulation models with data and analyses". The deliverables of this proposal will provide, in part, a proof-of-concept sandbox that tests model integration for several currently available USGS models.

Software frameworks for model integration are in extensive development and use (e.g., Laniak et al., 2013; Peckham et al, 2013; Jiang et al., 2017). While the details of these frameworks vary, many have settled on component-based approaches where individual models are transformed into reusable software components with standard interfaces. Additionally, these interfaces have a set of common methods that include: *initialize*, *run*, *finalize*, and *set*/*get* to transfer parameters and variables between model components. Importantly, in choosing a framework today, the risk of investing effort in a single framework, that could potentially become obsolete, lose funding and become orphaned is lowered as these maturing frameworks converge on a common set of methods for model integration. In other words, the basic first step of simply componentizing a set of models within a common interface provides the basic set of functionality to begin coupling models.

The Community Surface Dynamics Modeling System (CSDMS) is an NSF-funded program that seeks to transform the science and practice of earth-surface dynamics modeling. CSDMS strives to expand the use of quantitative modeling techniques, promotes best practices in software development, and advocates for the use of open-source software. CSDMS was founded in 2007 and now includes over 1700 members worldwide. To facilitate the conversion of a model written in C, C++, Fortran, Python, or Java into a reusable, plug-and-play component, CSDMS has developed the Basic Model Interface (BMI; Peckham et al., 2013). A BMI is a set of functions with prescribed names, arguments, and returns, that are used to interact with and control a model. BMI functions are generic enough that they can be used in a variety of modeling frameworks, including the CSDMS Modeling Framework (CMF; Syvitski et al., 2014). The CMF includes grid mappers, time interpolators, data exchange tools, support for open-source interfaces (e.g., UGRID, SGRID, EarthCube Geosemantics), a plug-in framework for adding new models, and a Python front-end, the Python Modeling Toolkit (PyMT; Hutton, 2019). Allowing researchers to run components interactively through Python, either programmatically or interactively with IPython or Jupyter Notebook, is a key advantage of the CMF. With PyMT, a researcher can drive components with a great deal of control; e.g., they can advance a model in time, pause to plot output, change variables, and perform analyses using the abundant scientific libraries present in Python. Further, Python tools for pre- and post-processing USGS models such as MODFLOW, GSFLOW, and PRMS are now commonplace (Bakker et al., 2016, Gardner et al., 2018, Volk and Turner, 2019). Finally, graphical user interface (GUI) like capabilities are on the cusp of viability within Jupyter Notebook, and many components of a modeling workflow will become more standardized within the open-source tools—potentially eliminating the need to develop and maintain customized GUIs (See for example, PyViz (PyViz authors, 2018) and

EarthSim (EarthSim authors, 2018). These tools can be easily leveraged within the CMF and PyMT for individual model initialization and setup.

The proposed activities will have a direct impact for the USGS, in that USGS researchers will be able to run and couple multiple USGS models in an easy-to-use, Python-based integrated modeling framework. Additionally, integrating these USGS models into the CMF will expose them to the CSDMS community, which may lead to broader impacts, such as a collaboration with USGS scientists in a model-coupling experiment, or even the serendipitous discovery and use of these models by a researcher who had no previous knowledge of them.

2. Technical Approach

We propose two work packages that integrate USGS and CSDMS technologies.

Work Package 1

We propose to add BMIs to two USGS models and a model from the iRIC application (Nelson et al., 2014):

1. FaSTMECH (USGS, steady surface water flow and sediment transport),
2. Nays2DFlood (iRIC, unsteady surface water flow and sediment transport), and
3. PRMS6 (USGS, precipitation-runoff).

Further, as a stretch goal, we will add a BMI to a fourth model, MODFLOW6 (USGS, groundwater flow). This is a formidable task, so here we will focus narrowly on wrapping MODFLOW6 to provide access to its UZF unsaturated-zone flow package.

Each of these models, written in Fortran, will then be integrated into the CMF as components, thereby making them accessible in Python through PyMT. CSDMS has developed a process for integrating Fortran models into PyMT. A sketch of this process is depicted in Figure 1.

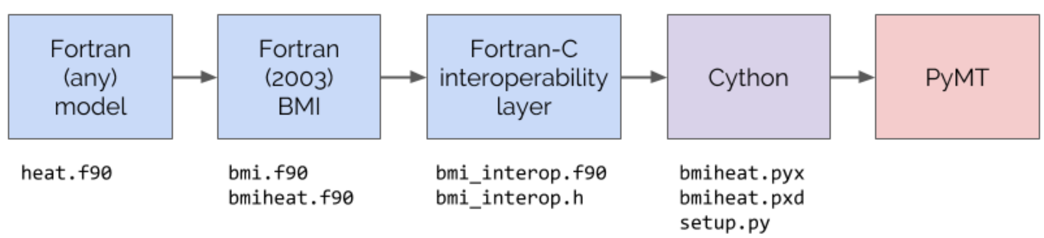

Figure 1. A depiction of the process for bringing a Fortran model (here, the "heat" example from the Fortran BMI) into Python and PyMT.

A model equipped with a Fortran BMI (Piper, 2018) is wrapped with a C interoperability layer. This interoperability layer uses the ISO_C_BINDING module, introduced in Fortran 2003, that allows Fortran code to be compiled and linked into a C library. Each function in the BMI is wrapped with an equivalent function that uses C types from the this module. The C library created from the interoperability layer can be called from Cython (Bradshaw, 2019), which provides an extension language for accessing C libraries from Python. Cythonized code can be called directly from Python, and therefore from PyMT. This process has been templatized and automated, so that once a model with a BMI is provided to CSDMS, it can be quickly added to the CMF and called from PyMT. A side effect of this process is that a user running the model in PyMT has no indication that the model is written in Fortran; the model is controlled solely through calls in the Python language.

The addition of a Python interface to these models will make them easier to use, especially for researchers lacking experience in compiling and linking Fortran code. Furthermore, by exposing these models to the broader CSDMS community, other researchers can perform experiments with them beyond what we've planned in this proposal.

Once these models are integrated into the CMF, we will investigate the following use cases. Our primary focus is on the first two use cases, anticipating the third as a stretch goal for the project. The use cases are:

1. **Coupling of flow models to themselves to extend model domain (FaSTMECH)**. When used on a High Performance Computing (HPC) system, a set of coupled models could run simultaneously, sequentially updating the boundary conditions in an upwind direction. This could expand the possible model domain when it is too big for a single CPU to manage
2. **Coupling a precipitation-runoff model of a watershed (PRMS) with a two-dimensional flood-inundation model (Nays2DFlood) where PRMS provides discharge boundary conditions to ungaged tributaries**. Detailed two-dimensional simulations of river flow are generally limited to reaches with measured discharge. When a reach has one or more ungaged tributaries contributing to the accumulated discharge, the contribution from each ungaged tributary must be estimated. Using PRMS to estimate both timing and magnitude of tributary discharges would improve simulations where tributaries added a significant increase to the overall flow.
3. **Coupling a flood-inundation model (Nays2DFlood) with a groundwater model (MODFLOW) to investigate the attenuation of a flood hydrograph due to infiltration**. The initial spread of a floodwave onto a floodplain often occurs over a dry permeable substrate. Or in arid regions, floods often propagate over a dry riverbed. The loss of water due to infiltration can have a dramatic effect on both the timing and magnitude of the flood as it moves downstream. These important processes are often overlooked or treated in overly simplistic ways, such as an estimated fixed infiltration rate. Directly coupling a flood inundation model to a groundwater model could improve the predictions of the simulated propagation of the floodwave.

Exploring the full functionality of each these four models is not necessary for the scope of this proof-of-concept project. Given the time constraints, only the functionality required for the intended coupling will be made available through the BMI. We anticipate with the success of this project, work will continue to expose the full functionality of each model. These use cases address needs in existing USGS studies, utilize currently existing models, and provide an experimental platform to understand potential issues when coupling models, in general, across varied spatial and temporal scales. The proposed model domains for each use case are: (1) bankfull flow on the Kootenai River, near Bonners Ferry, ID, (2) the Kootenai River basin, ID, and (3) the lower Colorado River through the US/Mexico border. For each use case, a Jupyter Notebook will be developed to allow others to see, and attempt to reproduce, the numerical experiment.

Work Package 2

We propose to build a BMI wrapper for data services and integrate it into the CMF as a component. The data services component would allow users of the CMF to access data just as they would a model. For example, the BMI *initialize* function sets the initial conditions for a model; here, it would open a connection to a data service, accessing either a local or a remote file. Likewise, the *get_value* function, which retrieves the current value of a model variable, would be used to pull data from an open file through the data service. The BMI *update* method, which advances the model state by one time step, would be used to step forward in time through a file; e.g., using slices in a NetCDF file. Finally, the *finalize* method, which shuts down a model, would close the file.

With this new technology, we can more tightly couple data and models in a common plug-and-play environment. In the context of this Work Package, we would consume web data services, such as climate predictions, weather forecasts, and USGS gage data, and use them to drive the coupled models from Work Package 1. In addition, when the National Water Model output is available as a web service it could be used to drive detailed models of specific areas of interest. Each of the three use cases outlined in Work Package 1 above will be driven where possible by existing data services, either in a forecasting mode or in hindcasting for model calibration.

Software Engineering Plan

For the proposed activities, we will use best practices in software development derived from our experience in CSDMS, as well as guidelines such as those from Wilson et al. (2014) and Boettiger et al. (2015). Because of the small size of our team, we will use a traditional waterfall development process (McConnell, 2004), with some features from Agile, such as the morning stand-up meeting. The waterfall model emphasizes a "design up-front" process, which is appropriate for augmenting the existing CSDMS cyberinfrastructure. All CSDMS code is hosted on public repositories on GitHub. Users are encouraged to submit issues to report bugs or add feature requests. We also encourage community members and other developers to fork our software and send us pull requests with their modifications. All code that enters a CSDMS repository on GitHub does so through pull requests, which allow the CSDMS software engineers to discuss, review, and approve code. CSDMS software products are released through GitHub, and follow the semantic versioning specification (Preston-Werner, 2013). Major releases are stamped with a digital object identifier (DOI) for persistent, long-term identification. All software produced by CSDMS is freely available under the MIT open source license. Unit tests are written concurrently with code. We use Travis CI (macOS, Linux) and AppVeyor (Windows) continuous integration services to test software as revisions are merged into a GitHub repository. Code coverage within a project is tested with the Coveralls service. We use the lint-like Landscape service to check Python code for errors, poor style, and bad code smells. Thorough testing builds a base for a sustainable software framework, eases the process of accepting community contributions, and ensures robust and portable code.

3. Project Experience and Collaboration

PI Steven Markstrom is a hydrologist with the USGS. He is the chief of the Modeling Support and Coordination Branch in the Integrated Modeling Division of the Water Mission Area. Past experience includes being co-developer of the USGS Precipitation Runoff Modeling System (PRMS) and the GSFLOW (tight coupling of PRMS and MODFLOW models). He also has significant experience developing the (now retired) Modular Modeling System, a modeling framework used in the decades of the 1990s through the 2000s.

PI Richard McDonald is a hydrologist with the USGS. He is a developer of graphical user interfaces (GUI) to bring research computational models of flow and sediment-transport in rivers to operations including the Multidimensional Surface Water Modeling System (MD_SWMS) and the International River Interface Cooperative (iRIC). He as been involved in research and applied applications of these models including river restoration design analysis, habitat analysis, larval drift modeling, and sediment-transport. He has used his applied experience to developed tutorials covering a wide range of applications as a guide to using these generic GUIs and taught them to other federal agencies and universities.

Eric Hutton is the Chief Research Software Engineer at CSDMS. Dr. Hutton was the coauthor of the Basic Model Interface (BMI) specification for model-to-model and model-to-data coupling and is the architect of the CSDMS Modeling Framework (CMF). He has over 20 years of software development experience that includes development of Earth-process models, model coupling, as well as development of model-coupling tools.

Mark Piper is a Research Software Engineer at CSDMS. His duties include developing software tools, converting models into components, integrating components into the CMF, and training users on CSDMS cyberinfrastructure tools such as BMI and PyMT. Dr. Piper has a range of experience in software development in commercial and in research settings, having worked in professional services, training, technical marketing, product management, and software engineering over his 20-year career. He has proven experience in developing software products at CSDMS, including Dakotathon, a Python wrapper for the Dakota systems analysis toolkit, the Fortran BMI bindings, and the Web Modeling Tool client.

4. Sustainability, Outreach, and Communication

In general, CSDMS addresses software sustainability through design, dependencies, and documentation. For example, by design, the BMI builds on a core set of interface functions that are considered elemental for coupling models. Models that expose this interface are not tied to any particular framework; they can be included in the CMF, or in similar present or future frameworks. We use software tools and languages that have large user bases, are mature, and are open-source. Such software includes Python for building PyMT and the CMF; Python, C, C++, Fortran, and Java for wrapping models; git for version control; GitHub for software configuration management and issue tracking; NetCDF for model output; and SQLite for database storage. Software products we develop are accompanied by developer and user documentation.

Through CSDMS best practices, each deliverable for this project has a built-in sustainability plan, described below.

- *Model BMIs*. The source code for each model's BMI (FaSTMECH, Nay2DFlood, PRMS, MODFLOW) will be hosted on the USGS code repository, https://code.usgs.gov, and mirrored to the CSDMS-Contrib GitHub repository, https://github.com/csdms-contrib. The source code will be released under the permissive open source MIT License and made available to the public. Note that the source code for the models themselves will remain with their owners.
- *Model components*. The source code for each model component will have its own GitHub repository in the PyMT-Lab organization, https://github.com/pymt-lab. The source code will be released under the MIT License and made available to the public. Each component will be integrated into the CMF and be subject to CSDMS testing practices. Each component will also be listed in the CSDMS Model Repository (Piper et al., 2018).
- *Data services component*. The source code for the new data services component will be housed in a GitHub repository in the CSDMS organization, https://github.com/csdms, and made available to the public with an MIT Licence.
- *Jupyter Notebooks*. A Notebook will be created for each model coupling experiment described in Section 2. The Notebooks will be 1) listed alongside other examples of using PyMT at https://pymt.readthedocs.io/en/latest/examples.html, and 2) included in the CSDMS EKT Repository, https://csdms.colorado.edu/wiki/Labs_portal.

Because the USGS models will be listed in the CSDMS Model Repository, with examples in the CSDMS EKT Repository, and included in the CMF, they'll gain exposure outside of USGS to the broader CSDMS community of scientists. The project work will be highlighted in a CSDMS quarterly newsletter, and also announced on the CSDMS Twitter feed.

This project represents an interesting collaboration between USGS and CSDMS, between government and academic institutions, and, in terms of sustainability and outreach, if it's even partially successful, it will generate discussion and open many possibilities for future collaboration.

5. Budget Justification

PI Richard McDonald will contribute $13836 of his USGS salary to provide the 30 percent in-kind match for this project. No funding is requested for PI Steven Markstrom.

Collaborator Eric Hutton (CSDMS) is requesting 1.0 months FTE support to develop and test the data services wrapper that will allow data to be ingested into the CSDMS Modeling Framework (CMF). Collaborator Mark Piper (CSDMS) is requesting 1.5 months FTE support to integrate the numerical models developed at USGS into the CMF, allowing them to be called from Python and coupled with other models in the framework. Hutton and Piper are research faculty at the University of Colorado Boulder. They are fully funded by grants; they receive no other institutional support. Other INSTAAR project assistants include an accounting tech for account management (0.0154 FTE) and a systems administrator for handling workstation networking and software (0.0045 FTE). The fringe benefit rate of 36.6 percent is calculated on requested salary per the University's federally negotiated rate agreement with the Department of Health and Human Services. Facilities and administration costs are charged at a rate of 54 percent on all direct salaries and wages, applicable fringe benefits, materials and supplies, services, and travel, according to the University's federally negotiated rate agreement.

No funding is requested for computational resources. Software development and testing for Hutton and Piper will be performed on workstations purchased through CSDMS funds, and on compute nodes purchased by CSDMS on the University of Colorado's Summit supercomputer.

No travel funds are requested to attend the CDI Workshop in June 2019, since all project personnel reside in the Denver-Boulder metropolitan area.

6. Timeline

The project timeline is displayed in Table 1 below. The timeline assumes an award date of 2019 May 31 and a project completion date of 2019 September 30. The week preceding the project completion date is left open in case of overflow on any of the project tasks.

Note that the timeline for tasks related to FaSTMECH is shorter because some preliminary prototyping work has already been performed.

Table 1. Timeline for proposed work. Elements of the Work Packages and Outreach Plan described above have been resolved into specific tasks, listing responsible personnel, start date, end date, and duration.

Task	Personnel	Start date (MM/DD/19)	End date (MM/DD/19)	Duration (weeks)
Add BMI to FaSTMECH	RM	5/31	6/7	1
Add BMI to Nays2DFlood	RM	6/10	6/21	2
Add BMI to PRMS6	RM	6/24	7/5	2
Add BMI to MODFLOW6	RM	7/8	7/19	2

Componentize FaSTMECH, integrate into CMF, test	MP	6/10	6/14	1
Componentize Nays2DFlood, integrate into CMF, test	MP	6/17	6/28	2
Componentize PRMS6, integrate into CMF, test	MP	7/1	7/12	2
Componentize MODFLOW6, integrate into CMF, and test	MP	7/15	7/26	2
Develop data services component, integrate into CMF, test	EH	5/31	7/12	6
Science use case 1	RM, SM	7/15	8/2	3
Science use case 2	RM, SM	8/5	8/23	3
Science use case 3	RM, SM	8/26	9/13	3
Jupyter Notebook tutorial for use case 1	RM, MP	7/29	8/2	1
Jupyter Notebook tutorial for use case 2	RM, MP	8/19	8/23	1
Jupyter Notebook tutorial for use case 3	RM, MP	9/9	9/13	1
Outreach	MP	9/2	9/13	2
Prepare manuscript for publication	All	9/30	12/31	--

References

Bakker, M., V. Post, C.D. Langevin, J.D. Hughes, J.T. White, J.J. Starn, and M.N. Fienen (2016), Scripting MODFLOW Model Development Using Python and FloPy. *Groundwater* 54, no. 5: 733–739

Boettiger, C., S. Chamberlain, E. Hart, and K. Ram (2015), Building software, building community: Lessons from the rOpenSci project, *Journal of Open Research Software*, 3(1).

Bradshaw, R., Behnel, S., Seljebotn, D. S., Ewing, G., et al. (2019), The Cython compiler, http://cython.org, accessed 2019-02-19.

EarthSim authors (2018), EarthSim, https://earthsim.pyviz.org/, accessed 2019-02-19.

Evenson, E.J., Orndorff, R.C., Blome, C.D., Böhlke, J.K., Hershberger, P.K., Langenheim, V.E., McCabe, G.J., Morlock, S.E., Reeves, H.W., Verdin, J.P., Weyers, H.S., and Wood, T.M. (2013), U.S. Geological Survey water science strategy—Observing, understanding, predicting, and delivering water science to the Nation, *U.S. Geological Survey Circular* 1383–G, 49 p.

Gardner, M.A., C.G. Morton, J.L. Huntington, R.G. Niswonger, W.R. Henson (2018), Input data processing tools for the integrated hydrologic model GSFLOW, *Environmental Modelling and Software*, 109, pp. 41-53, 10.1016/J.ENVSOFT.2018.07.020.

Hutton, E.W.H. (2019), The Python Modeling Toolkit (v1.0), https://pymt.readthedocs.io, accessed 2019-02-19.

Jiang, P., M. Elag, P. Kumar, S.D. Peckham, L. Marini, and L. Rui (2017), A service-oriented architecture for coupling web service models using the Basic Model Interface (BMI), *Environ. Model. Software*, 92, pp. 107-118.

Laniak, G.F. , G. Olchin, J. Goodall, A. Voinov, M. Hill, P. Glynn, G. Whelan, G. Geller, N.Quinn, M. Blind, S. Peckham, S. Reaney, N. Gaber, R. Kennedy, A. Hughes (2013), Integrated environmental modeling: a vision and roadmap for the future, *Environmental Modelling and Software*, 39, 3-23.

McConnell, S. (2004), Code Complete, Second Edition, Microsoft Press, Redmond, WA, USA.

National Academies of Sciences, Engineering, and Medicine (2018), Future Water Priorities for the Nation: Directions for the U.S. Geological Survey Water Mission Area. Washington, DC: The National Academies Press. https://doi.org/10.17226/25134.

Nelson, J.M., Shimizu, Y., Abe, T., Asahi, K., Gamou, M., Inoue, T., Iwasaki, T., Kakinuma,T., Kawamura, S., Kimura, I., Kyuka, T., McDonald, R.R., Nabi, M., Nakatsugawa, M., Simões, F.R., Takebayashi, H., Watanabe, Y. (2016). The international river interface cooperative: Public domain flow and morphodynamics software for education and applications. *Adv. Water Resour*. 93, 62–74.

Peckham, S. P., E. Hutton, and B. Norris (2013), A component-based approach to integrated modeling in the geosciences: the design of CSDMS, *Computers & Geosciences*, 53, 3–12.

Piper, M. (2018), Fortran bindings for the Basic Model Interface, https://github.com/csdms/bmi-fortran, accessed 2019-02-19.

Piper, M., G. Tucker, I. Overeem, A. Kettner, E. Hutton, and L. McCready (2018), The CSDMS model repository, in *AGU Fall Meeting Abstracts*.

Preston-Werner, T. (2013), Semantic Versioning 2.0.0, https://semver.org, accessed 2019-02-05.

PyViz authors (2018), PyViz, http://pyviz.org/, accessed 2019-02-19.

Syvitski, J.P.M., E.W.H. Hutton, M.D. Piper, I. Overeem, A.J. Kettner, and S.D. Peckham (2014), Plug and Play Component Modeling—The CSDMS 2.0 Approach. International Environmental Modelling and Software Society (iEMSs) 7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA, Daniel P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.).

Volk, J. M. and M. A. Turner (2019), PRMS-Python: A Python framework for programmatic PRMS modeling and access to its data structures, *Environmental Modelling and Software*, Volume 114, Pages 152-165, ISSN 1364-8152.

Wilson, G., D. A. Aruliah, C. T. Brown, N. P. Chue Hong, M. Davis, R. T. Guy, S. H. D. Haddock, K. D. Huff, I. M. Mitchell, M. D. Plumbley, B. Waugh, E. P. White, and P. Wilson (2014), Best practices for scientific computing, *PLOS Biology*, 12(1), 1–7, doi:10.1371/journal. Pbio.1001745.

Appendix A. CVs of Project Personnel

Steven Markstrom

U.S. Geological Survey
Denver Federal Center

Education

MS in Civil, Environmental, and Architectural Engineering, University of Colorado Boulder
BS in Civil, Environmental, and Architectural Engineering, University of Colorado Boulder

Experience

- Supervisory Research Hydrologist, U.S. Geological Survey (Lakewood, CO) 2017 to present
- Research Hydrologist, U.S. Geological Survey (Lakewood, CO) 2011 to 2017
- Hydrologist, U.S. Geological Survey (Lakewood, CO) 1993 to 2011
- Hydraulic Engineer, U.S. Bureau of Reclamation (Lakewood, CO) 1992 to 1993
- Engineer, Waterloopkundig Laboratorium (Delft Hydraulics) (Delft, The Netherlands) 1991 to 1992
- Professional Research Assistant, University of Colorado (Boulder, CO) 1990 to 1991
- Research Asst, International Institute for Applied Systems Analysis (Laxenburg, Austria), 1989 to 1990

Selected Publications

Markstrom, S. L., Hay, L. E., and Clark, M. P., 2016, Towards simplification of hydrologic modeling: identification of dominant processes. Hydrol. Earth Syst. Sci., 20, p. 4655–4671.

Markstrom, S. L., Regan, R. S., Hay, L. E., Viger, R. J., Webb, R. M. T., Payn, R. A., and LaFontaine, J. H., 2015, PRMS-IV, the precipitation-runoff modeling system, version 4, book 6, chap. B7, U.S. Geological Survey Techniques and Methods, U.S. Geological Survey, Reston, Virgina, 158 p., doi:10.3133/tm6B7.

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW—Coupled ground-water and surface-water flow model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods 6–D1, 240 p.

Markstrom, S.L., and Koczot, K.M., 2008, User's manual for the Object User Interface (OUI)—An environmental resource modeling framework: U.S. Geological Survey Open-File Report 2008–1120, 39 p.

Markstrom, S. L., Hay, L. E., Ward-Garrison, C. D., Risley, J. C., Battaglin, W. A., Bjerklie, D. M., Chase, K. J., Christiansen, D. E. Dudley, R. W., Hunt, R. J., Koczot, K. M., Mastin, M. C., Regan, R. S., Viger, R. J., Vining, K. C., and Walker, J. F, 2012, Integrated watershed scale response to climate change for selected basins across the United States, U.S. Geological Survey Scientific Investigations Report 2011-5077, US Geological Survey, Reston, Virginia, 1–143.

Markstrom, S.L., 2012, P2S--Coupled simulation with the Precipitation-Runoff Modeling System (PRMS) and the Stream Temperature Network (SNTemp) Models, U.S. Geological Survey Open File Report 2012-1116, U.S. Geological Survey, Reston, Virginia, 19 p.

Koczot, K. M., Markstrom, S. L., and Hay, L. E., 2011, Effects of baseline conditions on the simulated hydrologic response to projected climate change, Earth Interact., 15, 23 p.

Richard R. McDonald

Hydrologist
U.S. Geological Survey
Denver Federal Center

Mr. McDonald is a hydrologist with 25 years of experience working on general water resources, flow and sediment transport dynamics and the emerging field of eco-hydrology. He has extensive experience performing field, laboratory and computational research on river flow and sediment transport associated with regulated and unregulated rivers related to instream flow requirements, physical habitat, and evaluation of channel restoration designs. He is the principal developer of the U.S. Geological Survey's Multi-Dimensional Surface Water Modeling System (MD_SWMS) and co-developer of the iRIC modeling system (www.i-ric.org).

Education

University of California, Santa Cruz, Earth Science, M.S. 1993
University of California, Santa Cruz, Earth Science, B.S. 1990

Professional Experience

- U.S. Geological Survey, National Research Program, Denver, CO, 1997-present.
- Exponent, engineering and scientific consulting, Boulder, CO, 1995-1997
- U.S. Geological Survey, National Research Program, Boulder, CO, 1993-1995.

Relevant Publications

Nustad, R.A., A.J. Benthem, K.J. Skalak, R.R. McDonald, E.R. Schenk, and J.M. Galloway. 2018. "Streamflow, Sediment Transport, and Geomorphic Change during the 2011 Flood on the Missouri River Near Bismarck–Mandan, ND." Journal of the American Water Resources Association 54 (5): 1151–1167.

Cohen, S., G.R. Brakenridge, A. Kettner, B. Bates, J. Nelson, R. McDonald, Y.-F. Huang, D. Munasinghe, and J. Zhang. 2017. Estimating Floodwater Depths from Flood Inundation Maps and Topography. Journal of the American Water Resources Association 54 (4): 847–58.

MT Wyman, MJ Thomas, RR McDonald, AR Hearn, RD Battleson, 2017, Fine-scale habitat selection of green sturgeon (Acipenser medirostris) within three spawning locations in the Sacramento River, California, Canadian Journal of Fisheries and Aquatic Sciences 75 (5), 779-791

McDonald, R.R., Nelson, J.M., Fosness, R., and Nelson, P.A., 2016, Field scale test of multi-dimensional flow and morphodynamic simulations used for restoration design analysis, in: RiverFlow 2016, Constantinescu, Garcia, and Hanes, eds, Taylor and Francis, London, ISBN 978-1-128-02913-2, 1390-1398.

Nelson, J.M., R.R. McDonald, Y. Shimizu, I. Kimura, M. Nabi, and K. Asahi. 2016. "Flow and Sediment-Transport Modeling." In Tools in Fluvial Geomorphology (Second Edition), edited by G.M. Kondolf and H. Piegay, 412–41. Chichester, United Kingdom: John Wiley & Sons, Ltd.

Nelson, P.A., McDonald, R.R., Nelson, J.M., and Dietrich, W.E., 2015, Coevolution of bed surface patchiness and channel morphology: 2. Numerical experiments, J. Geophys Res. Earth Surface, 120

Nelson, P.A., McDonald, R.R., Nelson, J.M., and Dietrich, W.E., 2015, Coevolution of bed surface patchiness and channel morphology: 1. Mechanisms of forced-patch formation, J. Geophys Res. Earth Surface, 120

Nelson, J.M., Shimizu, Y., Abe, T., Asahi, K., Gamou, M., Inoue, T., Iwasaki, T., Kakinuma,T., Kawamura, S., Kimura, I., Kyuka, T., McDonald, R.R., Nabi, M., Nakatsugawa, M., Simões, F.R., Takebayashi, H., Watanabe, Y., 2016. The international river interface cooperative: Public domain flow and morphodynamics software for education and applications. Adv. Water Resour. 93, 62–74.

Stogner, Robert W., Sr.; Nelson, Jonathan M.; McDonald, Richard R.; Kinzel, Paul J.; Mau, David P., 2013. Prediction of suspended-sediment concentrations at selected sites in the Fountain Creek watershed, Colorado, 2008-09. U.S. Geological Survey Scientific Investigations Report 2012-5102, vii, 36 p.

Legleiter, C.J., Kyriakidis, P.C., McDonald, R.R., and Nelson, J.M., 2011, Effects of uncertain topographic input data on two-dimensional flow modeling in a gravel-bed river: Water Resources Research, v. 47, W03518.

Topping, D.J., Rubin, D.M., Grams, P.E., Griffiths, R.E., Sabol, T.A., Voichick, N., Tusso, R.B., Vanaman, K.M., and McDonald, R.R., 2010, Sediment transport during three controlled-flood experiments on the Colorado River downstream from Glen Canyon Dam, with implications for eddy-sandbar deposition in Grand Canyon National Park: U.S. Geological Survey Open-File Report 2010-1128, 111 p.

McDonald, R., Nelson, J., Paragamian, V., and Barton, G., 2010, Modeling the effect of flow and sediment transport on white sturgeon spawning habitat in the Kootenai River, Idaho: Journal of Hydraulic Engineering, v. 136 no. 12, p. 1077-1092.

Paragamian, V.L., McDonald, R.R., Nelson, J.M., Barton, G, 2009, Kootenai River velocities, depth, and white sturgeon spawning site selection – a mystery unraveled?, Journal of Applied Icthyology, v. 25, pp //640-646

Barton, G.J., McDonald, R.R., Nelson, J.M., and Dinehart, R.L., 2005, Simulation of flow and sediment mobility using a multidimensional flow model for the white sturgeon critical-habitat reach, Kootenai River near Bonners Ferry, Idaho: U.S. Geological Survey Scientific Investigations Report 2005-5230, 54 p.

McDonald, R.R. and Anderson, R.S., 1996, Constraints on eolian grain flow dynamics through laboratory experiments on sand slopes, Journal of Sedimentary Research, Vol. 66, No. 3, pp. 642-653

Rubin, D.M., and McDonald, R.R., 1995, Nonperiodic eddy pulsations: Water Resources Research, v. 31, p. 1595-1605.

McDonald, R.R. and Anderson, R.S., 1995, Experimental verification of aeolian saltation and lee side deposition models. Sedimentology, 42, pp. 39-56.

Eric W. H. Hutton

Professional Preparation

- University of British Columbia, Vancouver, British Columbia. B.A.Sc., Engineering Physics (Geophysics option), 1997
- University of Colorado, Boulder, Colorado. Ph.D., Geophysics (Graduate Certificate in Oceanography; Graduate Certificate in Hydrology), 2007

Appointments

2007 - present: INSTAAR, University of Colorado: Research Scientist
2007 - present: CSDMS, University of Colorado: Chief Software Engineer
1997 - 2007: INSTAAR, University of Colorado: Professional Research Assistant

Products

1. A. D. Ashton, E. W. Hutton, A. J. Kettner, F. Xing, J. Kallumadikal, J. Nienhuis, and L. Giosan. 2013. Progress in coupling models of coastline and fluvial dynamics. Computers & Geosciences, 53(0):21 – 29. Modeling for Environmental Change. doi:10.1016/j.cageo.2012.04.004.
2. E. W. Hutton and J. P. Syvitski. 2008. Sedflux 2.0: An advanced process-response model that generates three-dimensional stratigraphy. Computers & Geosciences, 34(10):1319 – 1337. Predictive Modeling in Sediment Transport and Stratigraphy. doi:10.1016/j.cageo.2008.02.013.
3. E. W. H. Hutton. CSDMS Model Coupling Framework (Version 0.9). CSDMS, Boulder, Colorado, 2008-2014. [Computer Software]. URL: https://github.com/csdms/coupling.
4. S. D. Peckham, E. W. Hutton, and B. Norris. 2013. A component-based approach to integrated modeling in the geosciences: The design of CSDMS. Computers & Geosciences, 53(0):3 – 12. Modeling for Environmental Change. doi:10.1016/j.cageo.2012.04.002.
5. Hobley, D.E., Adams, J.M., Nudurupati, S.S., Hutton, E.W., Gasparini, N.M., Istanbulluoglu, E. and Tucker, G.E., 2017. Creative computing with Landlab: an open-source toolkit for building, coupling, and exploring two-dimensional numerical models of Earth-surface dynamics. Earth Surface Dynamics, 5(1), p.21.

Other Products

1. E. Hutton, J. Syvitski, and A. Watts. 2013. Isostatic flexure of a finite slope due to sea-level rise and fall. Computers & Geosciences, 53(0):58-68. Modeling for Environmental Change. doi:10.1016/j.cageo.2012.03.020.
2. E. W. H. Hutton. sedflux (Version 2.1). Boulder, Colorado, 2001-2012. [Computer Software]. doi:10.1594/IEDA/100161.
3. I. Overeem, J. P. M. Syvitski, and E. W. H. Hutton. 2005. River Deltas - Concepts, Models, and Examples, chapter Three-dimensional numerical modeling of deltas, pages 13–30.
4. J. P. M. Syvitski, E. W. H. Hutton, S. D. Peckham, and R. L. Slingerland. 2011. CSDMS: A modeling system to aid sedimentary research. The Sedimentary Record, 9(1):4–9.
5. J. P. M. Syvitski, A. J. Kettner, M. T. Hannon, E. W. H. Hutton, I. Overeem, G. R. Brakenridge, J. Day, C. Vörösmarty, Y. Saito, L. Giosan, and R. J. Nicholls. 2009. Sinking deltas due to human activity. Nature Geoscience, 2(10):681 – 686. doi:10.1038/ngeo629.

Synergistic Activities

Community Standards for Model Coupling

- BMI: A Basic Modeling Interface Standard, Version 0.9. The Community Surface Dynamics Modeling System, http://csdms.colorado.edu/wiki/BMI_Description.
- CSDMS Standard Names: A Model Variable Naming Standard, Version 0.9. The Community Surface Dynamics Modeling System, http://csdms.colorado.edu/wiki/CSDMS_Standard_Names.

Model-Coupling Education Through Short Courses and Conference Sessions

- Plug-and-play Modeling with the Web Modeling Tool. Two-hour short-course. CSDMS Conference 2014, Boulder, Colorado, USA.
- Modeling coupled processes with sedflux. Two-hour short-course. CSDMS Conference 2011, Boulder, Colorado, USA.
- Earth-Surface Dynamics Modeling: Model Coupling. Two-hour short-course. RCEM Conference 2009, Santa Fe, Argentina.

Mark Piper

Professional Preparation

University of Wisconsin	Madison, WI	Mathematics	BS, 1992
Penn State University	University Park, PA	Meteorology	MS, 1994
University of Colorado	Boulder, CO	Atmospheric Sciences	PhD, 2001

Appointments

Research Associate. INSTAAR, University of Colorado, Boulder, CO (2013-present)
Product Manager. Harris Geospatial Solutions, Boulder, CO (2012-2013)
Solutions Engineer. Harris Geospatial Solutions, Boulder, CO (2010-2012)
Professional Services Engineer. Harris Geospatial Solutions, Boulder, CO (1999-2010)

Products

1. M. Piper, The Permafrost Benchmark System (v1.0). CSDMS, Boulder, CO, 2018. [Computer Software]. URL: https://permamodel.github.io/pbs.
2. M. Piper, Fortran Bindings for the Basic Model Interface (v1.0). CSDMS, Boulder, CO, 2018. [Computer Software]. URL: https://github.com/csdms/bmi-fortran.
3. M. Piper, CSDMS Dakota Interface (v0.4.1). CSDMS, Boulder, CO, 2017. [Computer Software]. URL: https://github.com/csdms/dakota.
4. M. Piper, CSDMS Web Modeling Tool Client (v1.1). CSDMS, Boulder, CO, 2016. [Computer Software]. URL: https://github.com/csdms/wmt-client.
5. J. P. Syvitski, E. Hutton, M. Piper, I. Overeem, A. Kettner, and S. Peckham, 2014. Plug and Play Component Modeling—The CSDMS2.0 Approach. In: Ames, D.P., Quinn, N.W.T., Rizzoli, A.E. (Eds.), *Proceedings of the 7th International Congress on Environmental Modelling and Software*, June 15-19, San Diego, CA. ISBN: 978-88-9035-744-2.

Other Products

1. M. Piper, A Basic Model Interface for the ILAMB benchmarking toolkit (v0.1.3). CSDMS, Boulder, CO, 2017. [Computer Software]. URL: https://github.com/permamodel/bmi-ilamb.
2. M. Piper, E. Hutton, and J.P. Syvitski, 2016. A Python Interface for the Dakota Iterative Systems Analysis Toolkit, AGU Fall Meeting Abstracts, H34E-06, URL: http://adsabs.harvard.edu/abs/2016AGUFM.H34E..06P.
3. M. Piper, E. Hutton, I. Overeem, and J.P. Syvitski, 2015. WMT: The CSDMS Web Modeling Tool, AGU Fall Meeting Abstracts, IN13B-1841, URL: http://adsabs.harvard.edu/abs/2015AGUFMIN13B1841P.
4. M. Piper and T. Bahr, 2015. A Rapid Cloud Mask Algorithm for Suomi NPP VIIRS Imagery EDRs. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* XL-7/W3, 237-242, doi:10.5194/isprsarchives-XL-7-W3-237-2015.
5. M. Piper and J.K. Lundquist, 2004. Surface-layer turbulence measurements during a frontal passage, *J. Atmos. Sci*., 61, 1768-1780.

Synergistic Activities

1. With M. Perignon, developed and taught CSDMS Software Carpentry Bootcamp, a one-day training course on using shell, Python, and version control, all with an earth science theme. Held at the CSDMS Annual Meeting, Boulder, CO, 2016, 2017, and 2018.

2. With E. Hutton, developed and taught BMI Live, a two-hour short-course on implementing a Basic Model Interface (BMI) for a numerical model. Held at the CSDMS Annual Meeting, Boulder, CO, 206, 2017, and 2018. URL: https://github.com/csdms/bmi-live-2018.
3. NSF CISE/OAC panel review, 2018.
4. Reviewer for *Computers & Geosciences*, *Basin Research*, and *Journal of Open Source Software*.
5. Developed and taught ATOC IDL Seminar, a three-hour short course for the Department of Atmospheric and Oceanic Sciences at the University of Colorado Boulder, 2015. URL: http://mdpiper.github.io/ATOC-IDL-seminar.

Appendix B. Letters of Support

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Menlo Park, California 94025

February 26, 2019

Support for Coupling Hydrologic Models with Data Services in an Interoperable Modeling Framework

To Whom It May Concern:

I am expressing my enthusiastic support for this proposal. Adding USGS codes to The Community Surface Dynamics Modeling System (CSDMS) will expand the user-base of USGS software by generating awareness through the popular CSDMS, and this work will be an important first step toward integrating hydrodynamic models, such as the Nays2DFlood to regional scale hydrologic models such as PRMS6 and MOODFLOW6. As described in this proposal, integration of river-scale hydrodynamic modeling with regional-scale hydrology simulation is a rapidly growing research focus because of the need to incorporate regional inflows to hydrodynamic models and to represent complex hydrodynamic simulation for ecological and flooding studies in regional-scale water resources investigations. Coupling these models through a generalized community-based modeling system is an important step forward because it promotes a standardized coupling approach that will be more easily accessible to a broader range of developers and users of these codes. I also have had the opportunity to work with principal investigator (PI) Steve Markstrom on several modeling projects, and I know him as a highly productive scientist with great talents for software development. Although I have had less time working with PI Richard McDonald, I am familiar with his excellent work and know him to be a great team leader and highly productive scientist. For these reasons, I am supportive of this proposal and confident that this work will be successful and lead to highly valuable tools for the water resources community and society in general.

Sincerely yours,

Dr. Richard Niswonger
Research Hydrologist
USGS Water Resources Mission Area
Email: rniswon@usgs.gov
Phone: 775-297-1392
345 Middlefield Road Menlo Park, CA
94025

United States Department of the Interior
U.S. GEOLOGICAL SURVEY
Water Mission Area
Reston, VA 20192

March 1, 2019

To Whom It May Concern,

I am pleased to offer this letter of support for the work proposed in "Coupling Hydrologic Models with Data Services in an Interoperable Modeling Framework" and am willing to provide the USGS staffing resources (Rich McDonald and Steve Markstrom) as outlined in the proposal. I believe the proposed work is well-conceived and I anticipate the results being very valuable.

Coupling of Earth Science models, particularly hydrologic and related models, is a high, and rapidly increasing, priority for the USGS Water Mission Area (WMA) and for the Integrated Modeling and Prediction Division within the WMA. Internally, we have many models that we are looking to couple. Additionally, we are actively pursuing numerous possibilities of coupling our models with models from other Federal agencies. Connecting models with a large inherent variety of languages, techniques and scientific foci represents a daunting challenge that we must address immediately if we are to make progress. Understanding an array of coupling strategies, including CSDMS, is an essential component of our decision-making process as we pursue a modeling framework strategy.

Should you wish to discuss the proposal and USGS's commitment to the work, please feel free to contact me.

Respectfully,

Harry L. Jenter, Ph.D.
Director, Integrated Modeling and Prediction Division
12201 Sunrise Valley Drive
415 National Center
Reston, Virginia 20192
(703) 648-5916
hjenter@usgs.gov

Community for Data Integration (CDI)
Data Management Plan for Full Proposals

Instructions: Fill out all relevant fields of the following tables to help your team plan for your project's data management and product communication needs. For more guidance on data management plans, see the *USGS Data Management Website*, specifically the *Data Management checklist*. All products resulting from CDI projects must comply with the *Office of Science Quality and Integrity Instructional Memoranda* on data management.

Data Inputs	
Title	**Source/URL**
Model: Fastmech	https://code.usgs.gov/Fastmech/Fastmech-BMI
Model: Nays2DFlood	https://code.usgs.gov/Fastmech/nays2dflood-BMI
Model: PRMS6	https://code.usgs.gov/rmcd/prms6-bmi
Model: MODFLOW6	https://water.usgs.gov/ogw/modflow/MODFLOW.html

Data Processing	
Access and Sharing	USGS code written in FORTRAN and adapted to the Community Surface Dynamics Modeling System (CSDMS) Basic Model Interface (BMI) will be stored in the U.S. Geological Survey's GitLab repository https://code.usgs.gov. All downstream software products created by CSDMS will be stored on GitHub, as described in the sections below.

Proposed Products: Work Package 1A	
Title	Model BMIs
Product Type	Software
Description	BMI-wrapped versions of four USGS models: FaSTMECH, Nays2DFlood, PRMS6, MODFLOW6
Format	Fortran source code
Data Volume Estimate	100 MB
Backup & Storage	N/A
Metadata	N/A
Repository for Product	USGS GitLab at https://code.usgs.gov
Communication Plan	For each model, an entry will be created in the CSDMS Model Repository, and an announcement will be made in the CSDMS quarterly newsletter.

Proposed Products: Work Package 1B	
Title	Model Components
Product Type	Software
Description	Componentized versions of USGS models: FaSTMECH, Nays2DFlood, PRMS6, MODFLOW6, integrated into the CSDMS Modeling Framework
Format	Fortran and Python source code

Data Volume Estimate	100 MB
Backup & Storage	N/A
Metadata	N/A
Repository for Product	The source code for each component will be stored in a repository under the PyMT-Lab GitHub organization, https://github.com/pymt-lab
Communication Plan	Each wrapped component will be announced on the CSDMS Twitter feed, and be listed as a new PyMT component in the CSDMS quarterly newsletter.

Proposed Products: Work Package 1C	
Title	Jupyter Notebook Tutorials
Product Type	Software
Description	Jupyter Notebooks demonstrating use of the componentized versions of USGS models: FaSTMECH, Nays2DFlood, PRMS6, MODFLOW6
Format	Jupyter Notebook
Data Volume Estimate	10 MB
Backup & Storage	N/A
Metadata	N/A
Repository for Product	The source for each Notebook will be stored in the repository for the model component in the PyMT-Lab GitHub organization. The Notebooks will also be listed in the CSDMS EKT Repository.
Communication Plan	Each Notebook will be announced on the CSDMS Twitter feed. On project completion, the Notebooks will receive a write-up in the CSDMS quarterly newsletter.

Proposed Products: Work Package 2	
Title	Data Services Component
Product Type	Software
Description	A component in the CSDMS Modeling Framework that exposes a BMI for accessing data
Format	Python source code
Data Volume Estimate	10 MB
Backup & Storage	N/A
Metadata	N/A
Repository for Product	The source code for the data services component will be stored in a repository under the CSDMS GitHub organization, https://github.com/csdms.
Communication Plan	On completion, the data services component will be announced on the CSDMS Twitter feed and receive a write-up in the CSDMS quarterly newsletter.

CDI Product Type Vocabulary

Data Release: A formal USGS data release that will go through FSP review and approval
Mobile Application: Interactive application built specifically for a mobile device
Presentation: Slides, video, or other presentation media

Publication: Peer-reviewed publication (USGS or external journal publication)
Software: Executable or compiled code that can be downloaded
Source Code: A code repository for the project's source code
Web Application: Interactive application that runs on a web browser
Web Link: Project webpage, wiki page, white paper, or online resources that do not fit other categories
Web Service: A service endpoint URL where your service can be accessed by a client application

Community For Data Integration (CDI) RFP BUDGET FORM

Budget Category	Federal Funding "Requested"	Matching Funds "Proposed"
GRAND TOTAL:	$46,117	$19,642
Do not edit the rows above this line.		
1. PERSONNEL (SALARIES including benefits):		
Personnel:		
Steven Markstrom, 0 hrs at $0/hr	$	0
Richard McDonald, 360 hrs at $54.56	$	$19,642
Contract Personnel (includes 36.6% benefit rate for University of Colorado):		
Eric Hutton, 160 hrs at $54.83125/hr	11,984	$
Mark Piper, 240 hrs at $49.625/hr	16,269	$
Accounting Specialist, 29.58 hrs at $28.0257/hr	1,132	$
System Administrator, 8.65 hrs at $47.5145/hr	561	$
Total Salaries:	$29,946	$19,642
2. TRAVEL EXPENSES:		
Trip 1 (CDI Workshop, June 2019, 2 local participants)		
Per Diem:	0	0
Transportation (Airfare + Mileage/Shuttle):	0	0
Other expenses (e.g. registration fees):	0	0
Trip 2 (description, # days, # travelers)		
Per Diem:	$	$
Transportation (Airfare + Mileage/Shuttle):	$	$
Other expenses (e.g. registration fees):	$	$
Total Travel Expenses:	$0	$0
3. OTHER DIRECT COSTS: (itemize)		
Equipment (inc. software, hardware, purchases/rentals):	0	0
Publication Costs:	0	0
Office supplies:	0	0
Training:	0	0
Other expenses (specify):	0	0
Total Other Direct Costs:	$0	$0
Total Direct Costs:	$29,946	$19,642
Indirect Cost:	$16,171	$0