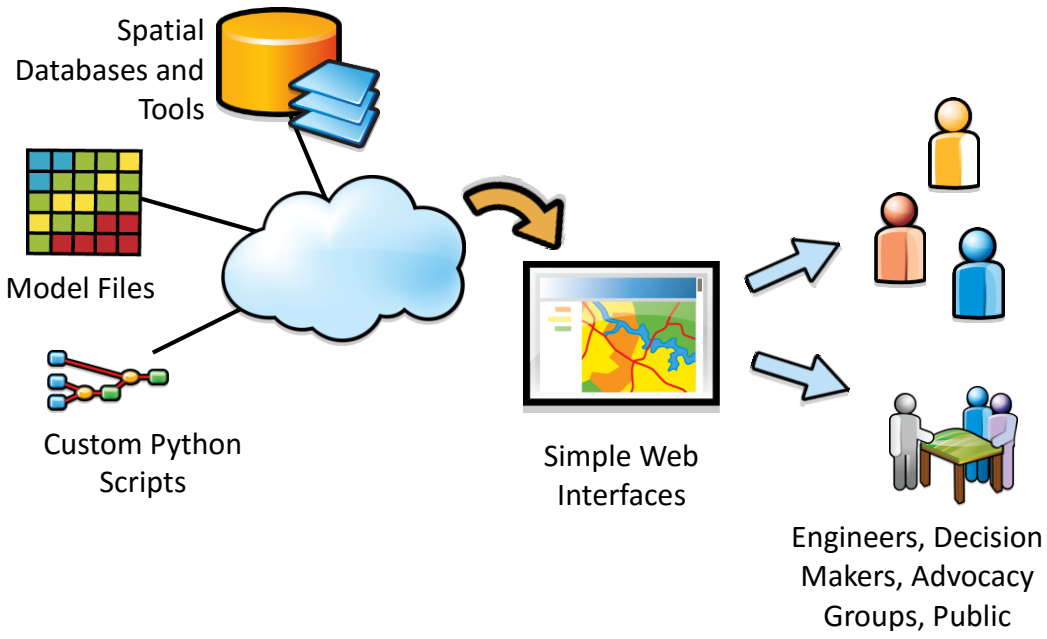
CI-WATER project

In 2011, Dr. Norm Jones and Dr. Jim Nelson were successful in a proposal to NSF's Experimental Program to Stimulate Competitive Research (EPSCoR) Track II program. The NSF awarded a grant to develop cyber-infrastructure for water resources modeling (CI-WATER for short). The goal was to develop cloud-based computing and visualization tools that would lower the barrier for water resources engineers to use for modeling applications. The CI-WATER project was done in collaboration with researchers from the University of Utah, Utah State University, and the University of Wyoming.

In 2012, students at BYU joined this project and started developing a data model for superficial water. They were mostly involved with the Access to Data & Computational Intensive Modeling Team within CI-WATER, which developed the Data & Modeling Services component.



The CI-WATER vision of creating tools came together in an open source set of tools named Tethys, which is a platform that facilitates the creation and deployment of water resources modeling and visualization applications. Several applications have been created so far with Tethys, including a new high-resolution national stream flow prediction model, a global snow prospector, two-dimensional Hydrologic Modeling GSSHA Editor/Display, Wasatch Front water availability management, pre-computed two-dimensional hydrologic modeling Canned GSSHA, and others.

Stream Flow Prediction Tool

In the last 34 years[1], floods around the world have been responsible for the loss of over 226 thousand lives, the disruption of more than 3 billion people's lives, and over a trillion dollars' worth in damages[2].

In light of growing frequency and magnitude of flooding problems, it is puzzling that our forecasting ability has remained grounded in the old technologies.

Scientists and engineers have developed tools to predict floods based on the weather for a watershed; but—until recently—flood flow predictions were only available at a relatively small number of locations nationally, or only generally over very large watersheds.

What if we could provide greater detail and lead-time to prepare for impending floods?

The next few paragraphs explain the rising potential of tools developed at BYU's Civil & Environmental Engineering Department to make such improvements to flood prediction, and therefore our readiness.

It all started when Professor Jim Nelson and colleague David Maidment visited the European Center for Medium-range Weather Forecasts **(ECMWF) and** European Joint Research Center **(JRC)**[3] in Europe to learn more about their Global Flood Awareness System **(GloFAS)**; they learned of the potential of taking the **GloFAS methodologies**[4], which are limited to flood prediction on only the largest rivers and watersheds (drainage areas in excess of 10,000 km^2), and downscaling them to the US National Hydrographic Dataset NHD-Plus, that consists of nearly 2.7 million river reaches with watersheds generally on the order of 2-3 km^2.

With the activities of the **World Water Project**[5] and the **CI-WATER**[6] research, BYU researchers worked together with the University of Texas group led by Dr. Maidment to prepare the foundational tools for the **NFIE**[7]. This led to the development of the downscaled ECMWF GloFAS runoff prediction into the Tethys Streamflow Prediction App. The application now produces twice-daily forecasts for the entire 2.67 million streams of the continental US and display results for monitoring and download.

Developed for the NFIE, these tools and methodologies represent a transformative capability for flood forecasting in the US, increasing the number of forecast locations by nearly three orders of magnitude, and potentially with greater information at longer forecast times. Further, while the US has a high resolution geographic dataset which can immediately take advantage of the downscaled forecasts, the methodologies can be applied worldwide and

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[1] 1980 through 2014.
[2] Calculated from data in Münchener Rückversicherungs-Gesellschaft, Geo Risks Research, NatCatSERVICE – As at January 2015
[3] Link to "National Water Center" article.
[4] Link to "National Water Center" article.
[5] Link to "WWF/GEO" article.
[6] Link to "CI-WATER" article.
[7] Link to "National Water Center" article.

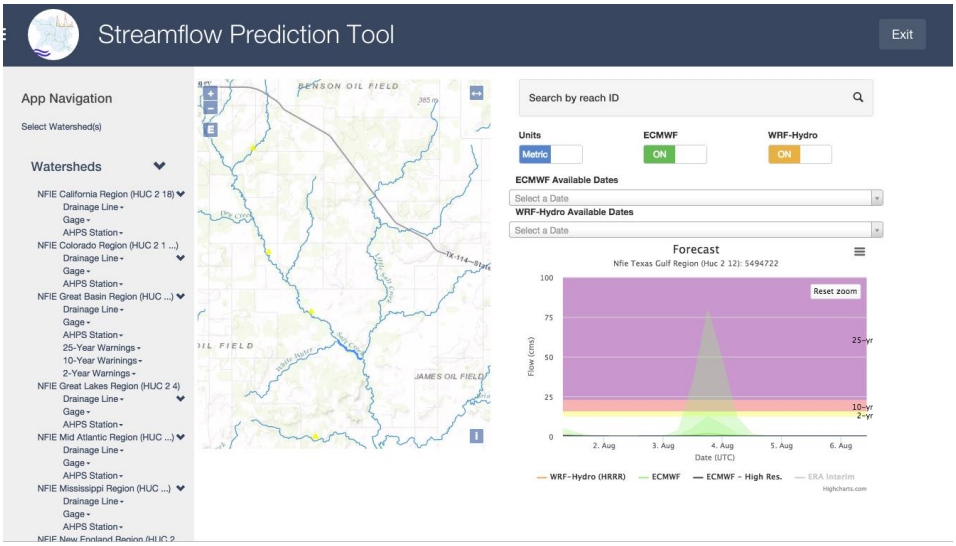
represent a very important possibility and advancement, not only for developed countries like the US, but perhaps even more so for developing countries that lack the basic tools and capacity for any kind of stream flow prediction.

This is what world experts have had to say about the Streamflow Prediction Tool:

> "What you have achieved is just completely unbelievable. It is an AMAZING leap forward … what you have demonstrated is way, way better than a conceptual slide – it's a working system that can be used at the current time to look out at the future we are currently experiencing. […] Thanks a MILLION to the BYU team and to the GloFAS and ECMWF project for making this possible for us. **This is truly transformative for flood forecasting practice in the United States**." Dr. David Maidment, University of Texas.

> "At the rate this is moving I think it's safe to assume that in a few years (definitely less than 5), having forecasted flow on every mapped stream reach in the US and Europe and other parts of the developed world will be the norm and we'll all be much further down the road trying to figure out how to densify and improve forecasts in the developing world. **Getting this solid will save thousands of lives and billions of dollars.**
> And beyond the flood and water resource applications, there are broader interests that will come to heavily rely on this, particularly in the insurance, military, and recreation industries. Great teamwork." Steve Kopp, Esri.

> "Continued collaboration with your team… will not only benefit the NFIE, but will better inform the National Water Center's scoping design and development of advanced capabilities.
> I wish BYU and the ECMWF-Tethys[8] project continued success." Ed Clark, Director of the National Water Center.



National Water Center/NFIE

[8] Tethys is a software platform developed by BYU's EMRL team

The National Water Center (NWC) is a new research center established by the National Oceanic and Atmospheric Administration (NOAA), located at the University of Alabama. With the intention to help address critical water-related issues such as droughts, and flooding, this new center will house experts from NOAA, USGS, US Army Corps of Engineers and FEMA to provide leadership in solving national water challenges.

But how did BYU get involved with it?

It all started with a connection between BYU faculty and Dr. David Maidment—a world-renowned specialist in surface water hydrology, and in particular in the application of geographic information systems to hydrology. Through the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), Dr. Maidment directed the development of the Hydrologic Information System (HIS).

Professors from the Department of Civil and Environmental Engineering at BYU have been collaborating with him for a number of years in developing standards and tools for water data sharing on the web. In January of 2014 Dr. Nelson attended a meeting of the World Meteorological Organization (WMO) at the Group on Earth Observations (GEO) annual Plenary in Geneva, Switzerland. As a result of these meetings Dr. Maidment invited Dr. Nelson and Dr. Ames to present a seminar at UNESCO's International Hydrologic Institute (IHE) in Delft, Netherlands, on the work of the BYU **World Water Project**[9], including pilot programs to Latin America that their group of researchers have led.

Dr. Nelson also arranged to visit the European Center for Medium-range Weather Forecasts (ECMWF) in London, England, and the European Joint Research Center in Ispra, Italy, to learn more about the work they were doing to create the Global Flood Awareness System (GloFAS). These visits resulted in the development of a stream flow (flood) prediction tool that is applicable globally and became the focus of developing a new high-resolution national flood forecasting capability as part of the National Flood Interoperability Experiment (NFIE). The NFIE intends to connect the National Water Center to academia, thus trying to shorten the path of "research to operations" with the latest ideas, tools, and technologies in flood warning.

The NWC started its operations in May of June 2015 and Dr. Nelson was invited to participate as a committee member of the inaugural NFIE event, in part to introduce the **Streamflow Prediction Tool**[10] as a resource from which others can build on. Because of the overall success of the application development in Tethys, the entire **CI-WATER**[11] group was invited to teach participants how to use these cloud-based computation and visualization tools to deploy other models that can enhance the National Water Center's capability in flood forecasting and water resources modeling generally.

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[9] Link to "WWF/GEO" article.
[10] Link to "Streamflow Prediction Tool" article.
[11] Link to "CI-WATER" article.

NFIE Tethys App for Probabilistic Flood Plain Mapping being presented by Caleb Buahin (USU) and Curtis Rae.

Nathan Swain discusses with another NFIE student the Tethys Applications.

Herman Dolder discusses results from inclusion of reservoirs in the national model.

World Water Project/GEO

Extending BYU's impact beyond the Provo campus and into the world takes several steps. The following paragraphs will describe a series of events that have been crucial to the EMRL's engagement in global outreach.

In 2011, **Dr. Maidment**[12] was invited to speak about current opportunities for research at a Seminar organized by the Department of Civil and Environmental Engineering at the Ira A. Fulton College.

During the seminar, Dr. Maidment mentioned that, when he was entering the campus, he read the signs with BYU's slogans—"The world is our campus" and "Enter to learn, go forth to serve". These claims caught his attention and—acknowledging that BYU's student body has proficiency in many languages and is acquainted with many cultures—he suggested that BYU's research group in Civil and Environmental Engineering was uniquely prepared to make a global impact in water data sharing efforts.

That same year, the Ira A. Fulton College of Engineering and Technology established the Weidman Center for Global Leadership, which—among other important activities—awards

[12] Link to "National Water Center" article.

professorships that promote and recognize outstanding faculty efforts and commitment in developing programs, educating students and implementing principles of Leadership or Global Agility within the college.

In 2013, the Weidman Center awarded their Professorship in Global Agility to Dr. Jim Nelson in recognition of his global outreach through study abroad programs that have provided opportunities for more than 250 students over the past 13 years.

Shortly after the Weidman Center began operations, Dr. Dan Ames joined the Civil and Environmental Engineering Faculty and brought with him experience in hydroinformatics; in particular, his work with CUAHSI, where he helped in the development of CUAHSI HIS with Dr. Maidment. Dr. Ames' role included using GIS software tools to create a desktop program—HydroDesktop—that discovers and accesses hydrologic data through web services, in the same way an internet browser accesses information on the web.

Dr. Ames and Dr. Nelson applied for a BYU Mentored Environment Grant (MEG) and—combining it with the Weidman Center Professorship of Dr. Nelson—they took up Dr. Maidment's challenge to expand water data sharing globally. They then started the BYU World Water Project.

Making water information available is crucial for managing water-related risks, but many countries don't invest in keeping this information, and some governments have the information but don't make it available.

The World Water Project (WWP) aims to bring standards and technology to water management agencies in Latin America and other developing countries, and remove the barriers to data sharing.

These objectives are achieved through ongoing initiatives, such as:

- Developing an international version of free, open-source hydrologic data sharing software tools (CUAHSI HydroServer and HydroDesktop)
- Piloting an outreach project in Central America to promote the adoption of these tools

With the new source of funding provided by the professorship and commission to capitalize on existing efforts Dr. Nelson made an important trip in March of 2013 to attend the Group on Earth Observations (GEO) kickoff meeting of the GEOSS Architecture Implementation Pilot-6 (AIP-6), in Washington DC, and thus start an important collaboration with GEO. GEO is a voluntary partnership of governments and organizations that envisions "a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information."[13] Together, the GEO community is creating a Global Earth Observation System of Systems (GEOSS) that will link

[13] https://www.earthobservations.org/wigeo.php

Earth observation resources worldwide across multiple Societal Benefit Areas—one of which is water—and make those resources available for better informed decision-making.

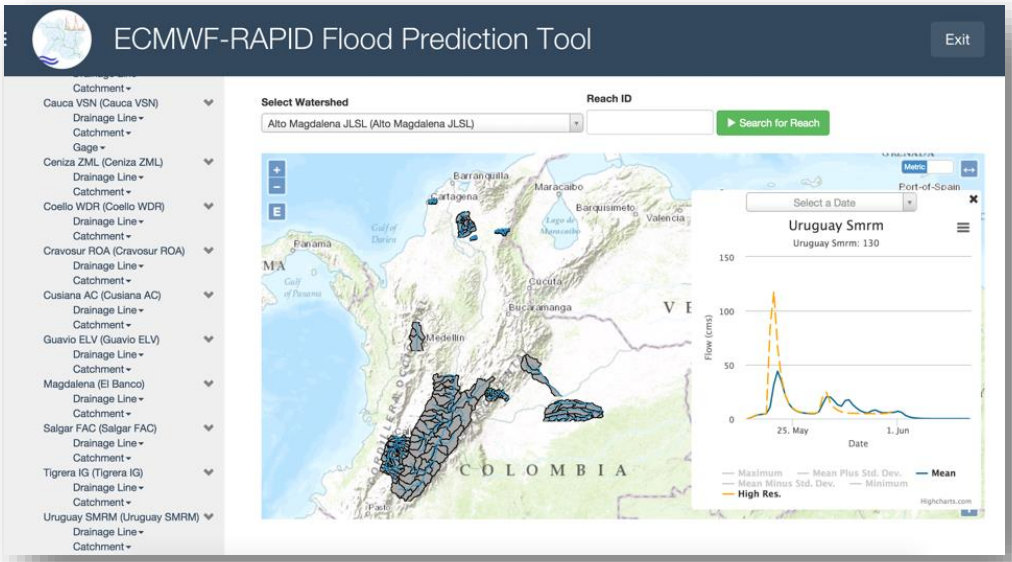
As part of the AIP-6, the World Water Project undertook the task of creating an internationalized version of HydroServer Interactive Web Client. The first step was to streamline the translation process, in order to facilitate the translation of HIS tools into any number of different languages.

Once this process was done, the first translation project was carried out to create a Spanish version of HydroServer Interactive, with the ultimate goal of deploying this translated tool internationally.

In the fall of 2013, Dr. Nelson conducted an outreach initiative to Guatemala, Honduras, and Nicaragua, to train government officials in the usage of HydroServer and promote its adoption in governmental water-management agencies.

In January of 2014, Dr. Nelson attended the GEO-X Plenary in Geneva, Switzerland. And later in October of that year, Dr. Nelson was invited to attend the GEOSS in the Americas meeting held in Bogota, Colombia. Leaders from several Latin American nations gathered to discuss common hydrologic and environmental issues and how the GEO initiatives could better serve them. Dr. Nelson made a presentation on water data sharing and was subsequently invited back to meet with the Colombian National Hydrologic Service to provide more information and training, which he did in November.

Following Dr. Nelson's previous activities in Colombia, he was invited to Cartagena to present a short course on water data sharing for Latin-American agencies. From May 19 to 22 of 2015, he trained a group of 20 representatives of water agencies, mostly from Colombia, who are piloting a more widespread activity in all of Latin-America; this activity aims to increase their capacity in water data sharing tools and the use of the downscaled Streamflow Prediction Tool.



Training session in Bogota, Colombia.